Chapter 9

GROUNDWATER CHEMISTRY FROM PREVIOUSLY MINED AREAS AS A MINE DRAINAGE QUALITY PREDICTION TOOL

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Introduction

The groundwater quality emanating from adjacent abandoned or reclaimed mine sites has proven a very useful tool for predicting water quality characteristics of proposed mine sites. The assumption is that if the same coal and overburden are being mined and the mining conditions are similar, hydrogeologic conditions will be sufficiently alike so that the groundwater quality from the proposed mine will approximate that of the previously mined area. Frequently, this is the case. Groundwater chemistry from previous mining, when available and used properly, is the best prediction tool in the tool kit. In fact, there are times when the requirement for acid-base accounting is waived because water quality from previous mining has affirmatively demonstrated that mining can occur without pollution. Groundwater chemistry from previously mined areas has the advantage of providing concentrations of water quality parameters that resulted from actual mining. Interpretation, however, requires an understanding of the limitations of this method.

Water quality from prior mining has been used as a prediction tool since at least the early part of the twentieth century. The deleterious effects of previous mining were used in the early 1900's as an argument by the Pennsylvania Railroad while trying to prevent additional mining within the Indian Creek watershed in Fayette County (Crichton, 1923; Collins, 1923). The Pennsylvania Railroad and public water supply companies were using a reservoir that was in danger of being degraded by additional deep mining. The Crichton and Collins studies showed that most deep mines in Pennsylvania were producing acid mine drainage. During these investigations, Leitch et al. (1932) found that the water from the "Thick Freeport Coal" deep mines in an area northeast of Pittsburgh was alkaline; so it has been long recognized that not all mines and coal seams produce the same quality water.

A publication entitled "Factors Involved in estimating Quality and Quantity of Mine Drainage" (PA Department of Health, 1966) pointed out that "nearby abandoned and operating coal mines can yield significant information about the quality and quantity of mine drainage to be expected from new mining operations." This publication also points to several things pertinent to interpreting adjacent mine information, such as whether mining was to the dip or rise, the size of area mined, the type of mining, and the "completion" practices (i.e., reclamation). In January, 1975 a surface mine permit application from Harmon Coal Company was denied because of the potential pollution of the stream which served as Brookville's water supply. This denial, perhaps the earliest for environmental reasons, used previous mining within the area of the proposed mine site as a mine drainage quality prediction tool.

Brady and Hornberger (1990) discussed the use of postmining water quality as a prediction tool for surface mines. They listed limitations to this method as:

> "(1) stratigraphic or chemical changes occur between sites (i.e., overburden on adjacent site may not be similar to the proposed site, or differing depths of mining are responsible for the chemical and stratigraphic changes), (2) mining practices, such as disposal of high sulfur coal refuse, may have adversely affected water quality, (3) multiple seam mining has occurred on adjacent sites and the observed water quality cannot necessarily be tied to any one particular coal seam and overburden, and (4) hydrologic complications make it difficult to relate water quality to previous mining (such as the absence of discharges, dilution of discharges by water unaffected by mining, interference from other pollution sources, neutralization from unaffected strata, and so forth)."

The examination of mine drainage from previously mined lands is the best predictor of mine drainage quality, when adequate data is available and interpretation of that data is done properly. The major advantage of looking at the quality of preexisting mine

drainage is that it is the result of a full-scale weathering (leaching) test, which has incorporated into it climatic, mining, and other variables. Climatic variables include: site specific precipitation, and field temperatures, including any seasonal variations. Field conditions also include infiltration and runoff factors. The mining variables include the strata (lithologies) encountered by mining, including its variability within the site, and the redistribution of these rocks in the spoil. Other variables include spoil pore gas chemistry, including vertical variations, and real world scale (i.e., rock particle size, ratios of rock volume to water volume). These are factors that are only approximately simulated, if at all, in laboratory leaching tests. Studies of previous mining also provide information on actual concentrations of mine drainage constituents, including pH, alkalinity, acidity, iron, manganese, aluminum, and sulfate. Previous mining water quality is, with some limitations, "the proof of the pudding." As with any prediction technique, interpretations must be considered in the light of information provided by other prediction tools.

Factors to Consider

Four factors must be considered when interpreting water quality from previously mined areas. Each of these, if not properly taken into account can lead to improper predictions of water quality for the proposed mine. These factors are: the proposed mining is on different coals and overburden, mining on same seam(s) but with significant differences in stratigraphy or in amount of area disturbed, hydrologic complications, and differences in mining practices.

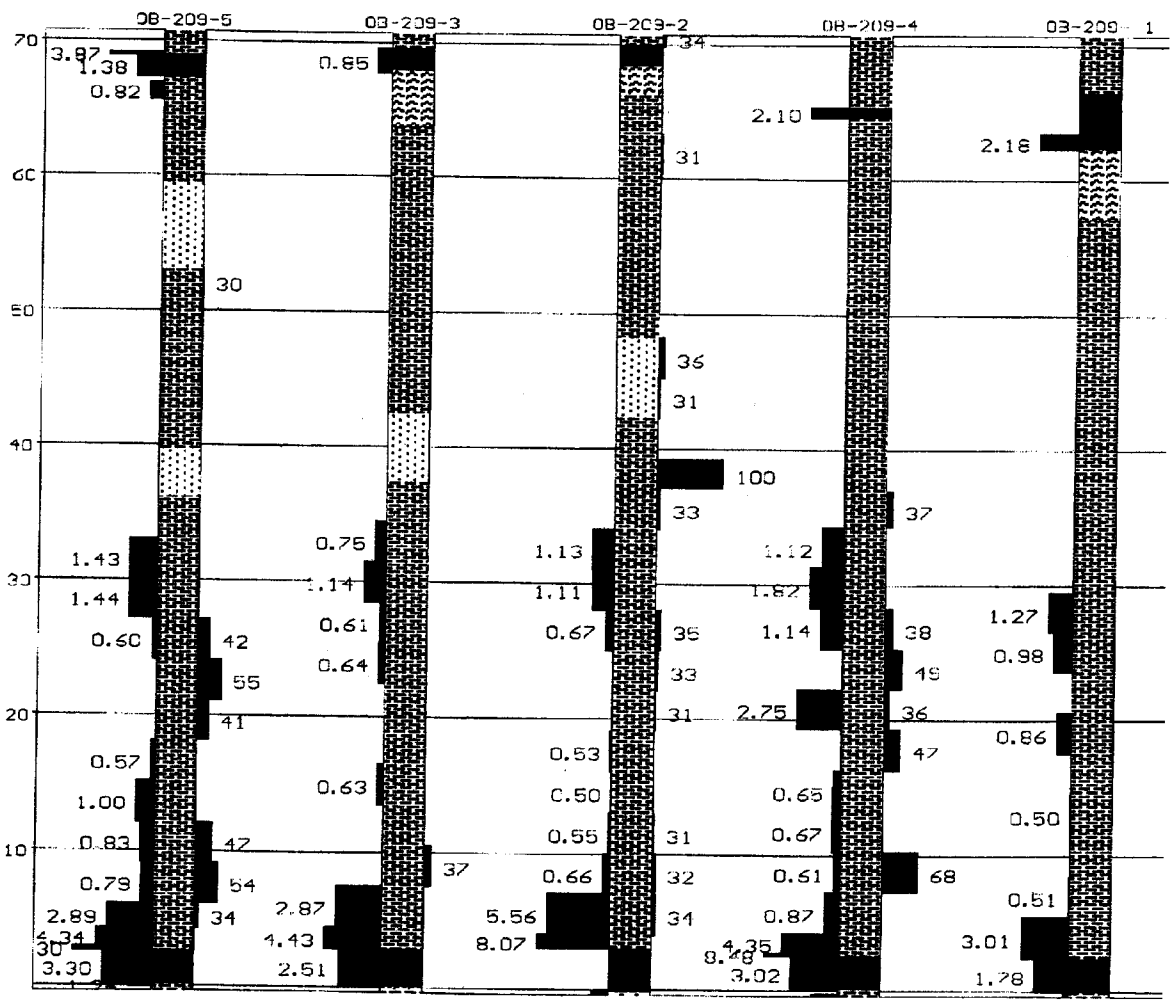


Figure 9.1 Overburden from the lower Kittanning coal to just above the middle Kittanning coal showing percent sulfur (left of columns) and neutralization potential (NP) (right of columns). The site is located in Redbank Township, Clarion County. Only sulfur values greater than 0.5% and NP greater than 30 ppt $CaCO_3$ are shown.

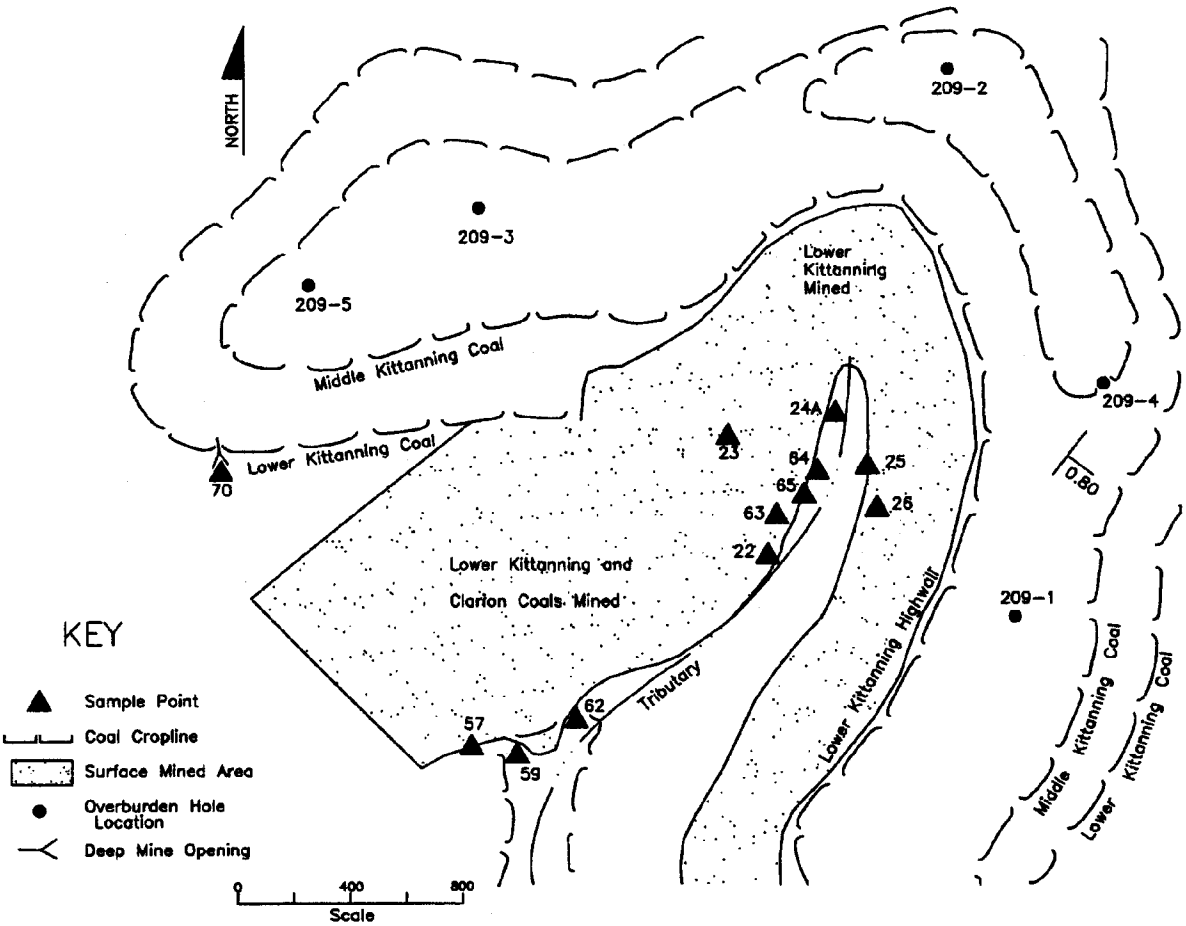


Figure 9.2 Site map showing mined areas, coal outcrops, water sample points and location of overburden drill holes. The drill logs are shown in Figure 9.1. Net alkalinity of water is shown next to water sample points (diamonds). The site is located in Redbank Township, Clarion County.

The Proposed Mining is on Different Coals and Overburden

Obviously, if no mining has occurred on a particular coal seam in the area of interest, previous mining's water quality cannot be used as a predictive tool, because it does not exist. Also, predictions of water quality can only be made if the same coal seam(s) and strata are being considered. Accurate geologic maps, showing coal croplines and structure are an extremely helpful aid in assuring correct correlations of coal seams. Numerous excellent studies by the Pennsylvania Geological Survey, in particular since the early 1970s, have helped resolve stratigraphic correlation problems around the state. Local geologic reports should be consulted for stratigraphic correlations, locations of coal outcrops, and structure. Site specific and nearby permit drilling information should also be consulted to confirm correlations.

Some examples will illustrate the importance of knowing which coal seams were mined. The first example involves the Clarion and lower Kittanning coals in Redbank Township, Clarion County, PA. Water quality associated with the lower Kittanning is typically acidic, which is consistent with results of acid-base accounting, which shows up to 30 ft (10 m) of strata with percent sulfur frequently being 0.5 to 7.5 percent (Figure 9.1). Neutralization potentials (NP) within this same stratigraphic interval are generally less than 40 ppt $CaCO_3$. Drill holes 1, 2, and 3 were analyzed by a different laboratory than holes 4 and 5. It is interesting to note that only holes 4 and 5 show NP's greater than 40. Differences between laboratories for NP's in this range have been frequently noted when siderite is the dominant carbonate. Siderite is not an effective acid neutralizer.

The marine Vanport limestone occurs stratigraphically between the Clarion and the lower Kittanning coals. Although no acid-base accounting was performed on the Vanport in this vicinity, it typically has greater than 80% calcium carbonate (see Chapter 8). In the area of the mine site the limestone is about 6 ft (2 m) thick. The Figure 9.2 map shows areas where the Clarion and lower Kittanning coals were mined, and the associated mine discharges. Table 9.1 shows the associated water quality. Where the spoil is predominately Clarion coal overburden, the drainage is net-alkaline (e.g., sample points 57, 59, 62). Discharges associated with mining that was predominantly on the lower Kittanning coal are net-acidic (e.g., 23, 24A, 25, and 26). Discharges that are a mixture of Clarion and lower Kittanning spoil range from net-alkaline (e.g., 63) to net-acidic (e.g., 22, 64, 65). The mixed spoil, even when acidic, is less acidic than water from areas where just the lower Kittanning coal was mined. Thus, the overburden from the two coals produces different water qualities.

Table 9.1 Median water quality values for sample points shown in Figure 9.2. LK indicates water associated with the lower Kittanning coal, CL identifies water associated with the Clarion coal, and "mix" is water from both seams.

Sample Point	Coal Seam	N	pH	Conductance (µS/cm)	Net Alkalinity (mg/L)	Fe (mg/L)	Mn (mg/L)	Sulfate (mg/L)
23	LK	5	4.8	1557	-38	1.96	40.0	1050
24A	LK	3	5.8	2110	-84	0.32	60.2	1690
25	LK	2	3.5	1570	-99	3.39	39.2	1185
26	LK	3	4.3	1663	-52	0.08	35.0	1220
70*	LK	1	4.7	130	-13	1.35	0.3	35
22	MIX	2	4.2	1398	-19	0.21	27.1	1047
57	CL	2	6.6	1181	+42	3.48	24.6	760
59	CL	2	7.8	1462	+83	2.90	12.8	931
62	CL	1	8.1	1369	+121	1.32	6.4	832
63	MIX	3	8.0	948	+189	0.28	0.0	272
64	MIX	3	6.8	1657	-10	0.05	47.5	1070
65	MIX	1	5.7	1798	-39	2.28	51.9	1375

*Sample point 70 is from a small "country bank" mine. All other samples are surface mine discharges.

The importance of knowing which coals were mined in an area is also illustrated by a study near Luthersburg in Clearfield County, PA (David Bisko, DEP hydrogeologist, personal communication, 1991). The lower Kittanning through upper Kittanning coals were mined. The lower Kittanning and middle Kittanning coals, if surface mined by themselves, produce acidic drainage. If these coals are mined in conjunction with sufficient calcareous strata associated with the upper Kittanning coal, the water quality is usually alkaline. Most mines in the area did multiple seam mining, although the combination of seams mined varied from site to site. Figure 9.3 is a map of the area showing

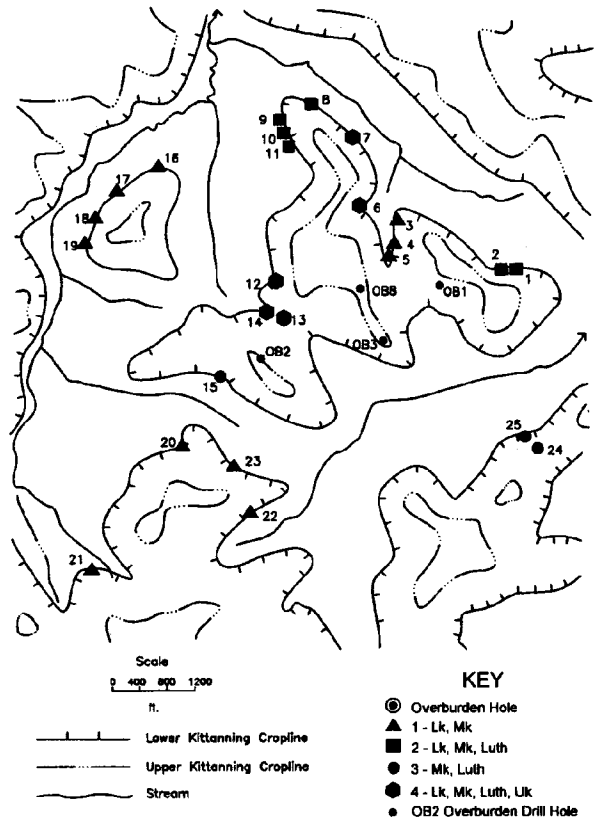


Figure 9.3 Map of an area within the Luthersburg Quadrangle, Clearfield County. Map shows coal croplines and mine discharge sample point locations discussed in text and shown in Table 9.2. The different symbols used at water sample locations indicate which coal seams and associated overburden were mined upgradient from the discharge point.

locations of water samples and overburden drill holes. Figure 9.4 shows representative examples of overburden percent sulfur and neutralization potential for intervals from the lower Kittanning coal through the upper Kittanning coal overburden. Note that overburden above the lower and middle Kittanning coals is high in sulfur (up to 2.7%), but low in NP (< 40 ppt CaCO3). The highest NP's (as high as 327 ppt CaCO3) are associated with the "Johnstown limestone" which occurs below the upper Kittanning coal.

Table 9.2 shows water quality analyses for the discharge points shown on the Figure 9.3 map. Boxplots comparing pH and net alkalinity for various combinations of coal seams mined are shown in Figure 9.5. It is clear from the pH and net alkalinity values that the coal overburden combinations of the lower Kittanning and middle Kittanning, and the LK, MK and Lutherburg result in water that is acidic. Mining of the MK

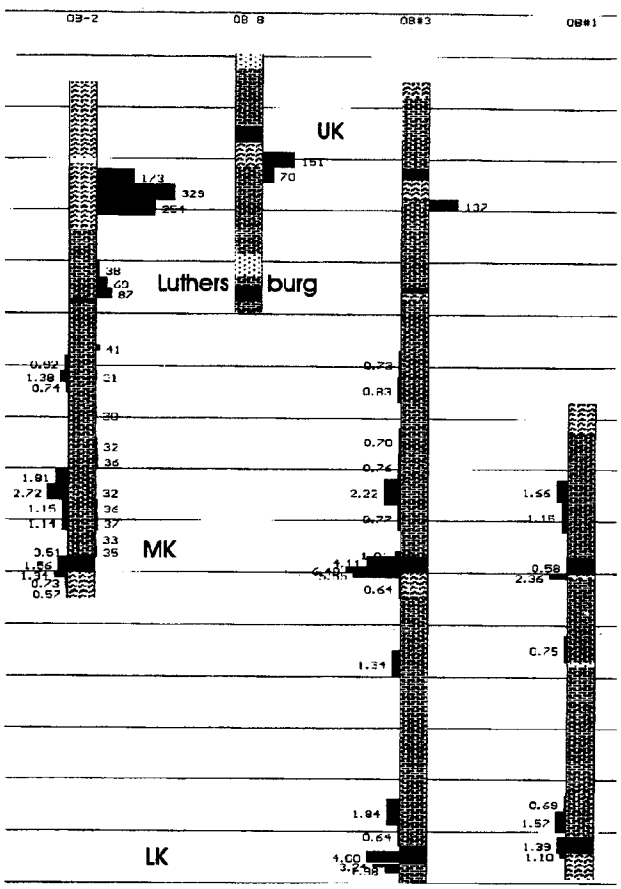


Figure 9.4 Overburden chemistry of the interval from the lower Kittanning through the upper Kittanning coals. The location of the drill holes is shown on Figure 9.3. Total percent sulfur values are displayed to the left and NP to the right of the drill log. Only sulfur values greater than 0.5% and neutralization potential values greater than 30 ppt $CaCO_3$ are shown. Gridlines are at 10 ft (3m) intervals.

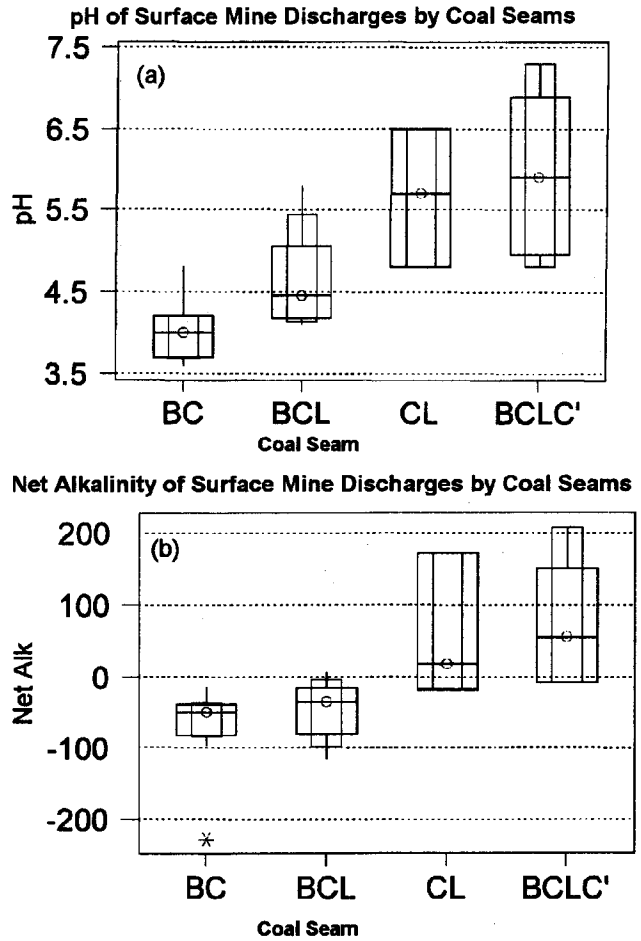


Figure 9.5 a and b Boxplots showing the distribution of (a) pH and (b) net alkalinity for discharges representing different combinations of coal seams that were surface mined. Wide "box" shows interquartile range (i.e., contains 50% of data). Horizontal line with circle is the median. Narrow box shows the 95% confidence interval around the median. Letters on x-axis indicate the coal seams that were mined. BC = lower Kittanning and middle Kittanning coals; BCL = lower Kittanning, middle Kittanning, and Luthersburg coals; CL = middle Kittanning and Luthersburg coals; BCLC' = lower Kittanning, middle Kittanning, Luthersburg, and upper Kittanning coals. The letters used are those that are frequently used in Pennsylvania's bituminous coal fields to indicate the designated coal seam (with the exception of the Luthersburg coal, which is rare in other areas of the coal field). Water quality data is from Table 9.2.

and Luthersburg coals, and the LK, MK, Lutherburg, and upper Kittanning coals typically results in net-alkaline drainage. (The Luthersburg coal occurs between the MK and UK coals, and occurs in minable thickness in the area of Luthersburg, Clearfield County.) The differences in pH and net alkalinity of mines that disturbed only the overburden of the stratigraphically lower coals (LK and MK coals), compared to mines that disturbed higher strata (LK through UK overburden), are statistically significantly different. The mines that encountered the higher strata, in particular sufficient amounts of Johnstown limestone, produced alkaline drainage. The mines that encountered only the lower strata produced acidic drainage.

The point of the above examples is that apples must be compared to apples. Mines having similar geology can be compared with meaningful results. However, mines involving different coal seams or different sections of strata should not be compared. Water quality

prediction requires knowing the stratigraphic relationships of the coal seams that were mined.

Table 9.2 Water quality data for sample points shown on Figure 9.3. Distributions for pH and net alkalinity are shown on Figure 9.5 for the four groups of coal overburden. LK is lower Kittanning, MK is middle Kittanning, Luth is Luthersburg, and UK is upper Kittanning.

Sample No.	Coal Seam Mined	pH	Net Alkalinity (mg/L)	Mn (mg/L)	Sulfate (mg/L)
1	LK, MK, Luth	4.1	-116	57.9	1807
2	LK, MK, Luth	4.6	-68	45.9	1330
3	LK, MK	4.8	-14	5.8	738
4	LK, MK	4.1	-47	16.3	678
5	LK, MK	4.0	-68	15.7	588
6	LK, MK, Luth, UK	4.8	-6	4.2	780
7	LK, MK, Luth, UK	5.1	-8	1.4	654
8	LK, MK, Luth	5.8	+6	23.5	1578
9	LK, MK, Luth	4.3	-22	14.1	1500
10	LK, MK, Luth	4.8	-38	9.5	414
11	LK, MK, Luth	4.2	-32	15.6	768
12	LK, MK, Luth, UK	6.5	+94	12.0	852
13	LK, MK, Luth, UK	5.9	+56	13.6	1680
14	LK, MK, Luth, UK	7.3	+208	.4	1710
15	MK, Luth	6.5	+172	18.2	572
16	LK, MK	3.9	-98	36.7	1428
17	LK, MK	4.3	-23	14.2	732
18	LK, MK	4.1	-82	52.0	1692
19	LK, MK	3.7	-42	16.4	462
20	LK, MK	4.2	-38	4.6	850
21	LK, MK	3.6	-50	36.7	937
22	LK, MK	3.6	-74	8.5	294
23	LK, MK	3.7	-228	18.6	978
24	MK, Luth	5.7	+18	37.2	1470
25	MK, Luth	4.8	-18	21.5	792

As a rule of thumb, the closer the previously mined area is to the proposed mine site, the better it can serve as a prediction tool. At what distance a mine fails to serve as an accurate prediction tool will vary depending on the similarity of the geology between the area previously mined and the proposed mine site. Where significant facies changes occur over short distances, immediately adjacent mines may not be representative. This limitation is discussed below in more detail.

Mining on Same Seam(s) but with Significant Differences in Stratigraphy or in Amount of Area Disturbed

Mining may be proposed on the same seam, but if there are significant stratigraphic changes between the previously mined area and the proposed area, comparisons may be inappropriate. The two most common factors related to stratigraphic changes are geologic facies differences from one mine to the next, and the mining of differing amounts of cover. Higher cover will encounter additional strata. An additional factor that will be discussed is the role that differing amounts of disturbed area can have on water chemistry.

Facies Relationships - An example of the role of facies changes can be illustrated by five mines studied in the Stony Fork watershed in Fayette County (Brady et al., 1988). All mines in this area extracted the upper Kittanning coal seam. The mines with predominately sandstone overburden are producing acidic drainage, whereas mines with calcareous shales and limestones are producing alkaline drainage. The mine sites (A through F) are shown in relation to the depositional environment interpreted from strata at 25 ft. (7.6 m) and 50 ft (15.2 m) above the coal (Figures 9.6 a and b). Since the time of the Brady et al. study, several additional mine permit applications have been received for this watershed, and consequently more data have been obtained. Since publication of the Brady et al. (1988) paper, two permit applications have been received for the area between mine sites A and B. Both mine sites occur in the area having calcareous shales and limestones. One of these has been mined and reclaimed and is producing alkaline drainage (site F, Figures 9.6 a) and b)). Another application was received for the area just north of site D. Its overburden was essentially identical to site D (i.e., predominantly sandstone overburden), and the permit was denied.

The mines developed in the area interpreted to have been deposited in a high energy depositional environment, have sandstone and siltstone overburden. Mine sites A, D, and E occur within this depositional environment. The area interpreted as a lower energy depositional environment contains mines B, C, and F. The sandstone and siltstone units are not calcareous, whereas the low energy deposits contain calcareous shale and freshwater limestones. Mining in the area containing the calcareous strata results in alkaline drainage. Table 9.3 shows water quality chemistry for the six reclaimed mine sites.

Paleoenvironmental maps, such as those constructed for the Stony Fork drainage basin, may help predict the distribution of facies, however, studies of this type are rare. Even if good paleoenvironmental maps exist, facies changes can be abrupt, and detailed drilling is typically necessary in areas of facies transition. Paleoenvironmental maps probably are best used as a tool for designing an overburden sampling plan. In the Fayette County study, mine site A is both within the high energy and low energy depositional environments. Inspection of the active highwall revealed an

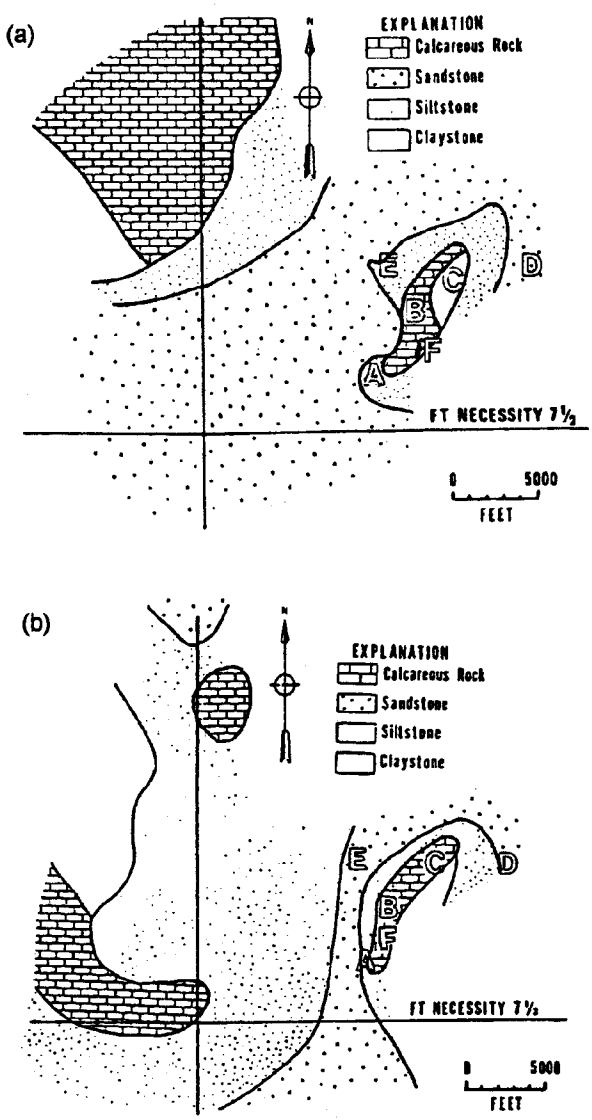


Figure 9.6 a) Facies map of lithologies at 25 feet above the upper Kittanning coal in the vicinity of the Stony Fork watershed, Fayette County, PA. b) Facies map of lithologies at 50 feet above the upper Kittanning coal in the vicinity of the Stony Fork watershed, Fayette County. Figures from Brady et al. (1988). The letters show the locations of mine sites discussed in the text and correspond with water quality data shown in Table 9.3.

area where the limestone was eroded and replaced by a channel deposit. All the overburden drill holes were located within the low energy portion of the mine, thus overestimating the calcareous nature of this site. This permit was issued prior to an understanding of the lateral distribution of depositional facies. If the true nature of the site had been known, either the permit would have been denied or the mining plan would have been modified to compensate for the acid potential. Sandstone overburden within the Allegheny group, as illustrated in the above example, can be acid producing. This subject is dealt with in detail in Chapter 8.

Table 9.3 Median postmining water quality for mine sites in Stony Fork watershed.

Mine Site	pH	Net Alkalinity (mg/L)	Fe (mg/L)	Mn (mg/L)	SO_4 (mg/L)
A	3.2	-185	25	22	1434
B	5.6	+6	0	0	<43
C	7.6	+382	5	5	744
D	2.9	-814	51	29	981
E	3.1	-361	52	31	432
F	7.4	+237	0	1	32

Amount of Cover - Different amounts of cover mined on the same coal seam can result in different water quality. Because of mining equipment limitations, old pre-act mining from the 1940s and 1950s seldom exceeded 40 ft (12 m) of cover. Improvements in mining technology have allowed many of these sites to be remined to greater cover heights. Mining of additional cover can have both positive and negative influences. Figure 9.7 illustrates a situation where low cover mining ~40 ft (12 m) or less would encounter high sulfur strata, but no appreciable calcareous strata. A mine would not encounter calcareous strata until a highwall height of 40 ft (12 m) or more is mined. The reason for this is a combination of the stratigraphic position of the calcareous strata and the dissolution of carbonates by surface weathering, at shallow <20 ft (6 m) cover.

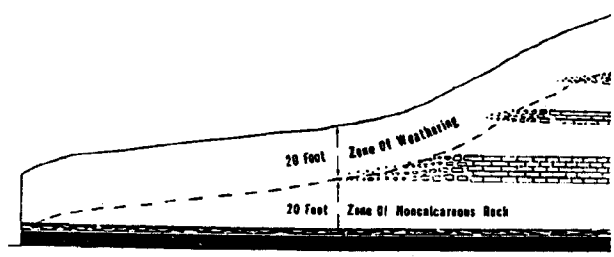


Figure 9.7 Schematic cross-section showing relative positions of high-sulfur strata and calcareous strata (brick pattern). In this example 40 ft (12 m) or more cover must be mined in order to encounter the alkaline material.

Shallow mining <40 ft (12 m) would probably result in acidic drainage, whereas mining to a cover height of 85 ft (26 m) should encounter enough calcareous rock to result in alkaline drainage.

An example of water quality differences between old mining, that encountered shallow cover and occurred over a limited area, compared with more extensive and deeper mining is illustrated by a mine site in Cambria County. The original shallow-cover <30 ft (10 m) mining occurred in the 1950s, and only a few tens of acres were affected. No water quality data is available from this early period. The earliest water quality data available is from 1978, over 20 years later (Figure 9.8). In the intervening years some natural amelioration may have taken place. It is doubtful, however, that the mining in the 1950s ever had a significant impact on the water quality, because the overburden was mostly weathered shallow-cover material and the area of disturbance was small. Modern mining methods were first used at this site in November 1980.

Figure 9.8 shows plots of various water quality parameters at a spring down-gradient from the mine in Cambria County. The initial water quality in 1978 through 1981 represents conditions from pre-modern mining methods. The water had low concentrations of sulfate, acidity, manganese, and aluminum, and little variation in their concentrations. Specific conductance was also low (~100 µS/cm). Figure 9.8 shows water quality through time for acidity, manganese, and sulfate. The mining that occurred from November, 1980 through September, 1985 took a maximum of 80 ft (24 m) of overburden and affected approximately 175 acres (71 hectares). Mining-related increases in acidity, manganese and sulfate are apparent from Figure 9.8. Other parameters that increased are aluminum and specific conductivity.

Figure 9.9 shows the acid-base accounting data for the coal and overburden from three drill holes at the Cambria County mine site. The coal and overlying strata have the potential to produce acid (% S > 0.5%), and have little, if any, neutralization potential. Thus, additional mining exposed unweathered rock that had acid potential, but no neutralization potential.

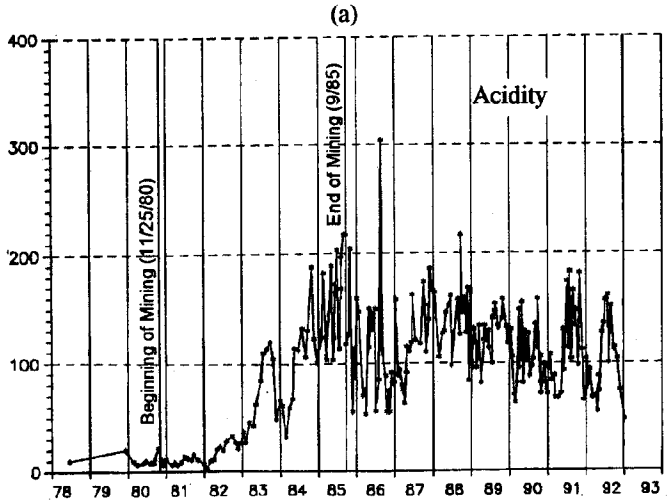
Water from the previously mined area of the 1950s did not reflect the water quality that was produced by the mining conditions in the 1980s. Mining on this site was concurrent, done according to permit plans, and is now reclaimed with lush vegetation. Mining in accordance with permit conditions does not assure successful water quality on a site that has acid-producing potential and lacks calcareous strata.

Increased Area of Disturbance - The affect of an increased area of disturbance and the mining of additional cover is illustrated in Figure 9.10. This is the same Cambria County site that is discussed in the above paragraphs. Two conservative water quality parameters, sulfate and manganese, show increases in concentration that are directly related to the amount of area affected. Sulfate compared to acres mined is shown in Figure 9.10. When mining was progressing quickly, as in early 1982, there was a sharp increase in manganese and sulfate a year later. When mining was progressing more slowly, as during the second half of 1982 through the middle of 1983, there was a corresponding leveling off of water quality from the middle of 1983 to the middle of 1984. The larger the area affected by mining, the higher the concentration of water quality parameters.

Figure 9.10 suggests that discharge quality can be a function of the area disturbed. In this case, the stopping of mining in mid-course would have reduced the amount of acid and metal formation. Alternatively, monitoring results could have been heeded and mine drainage prevention methods could have been incorporated into the mine plan. As can be seen from Figure 9.10, the downgradient discharge point that was being monitored showed delayed effects from mining of about one year. There are two factors that could account for this delay, one being the rate of acid formation and the other being the rate of transport (flow rate) of acid weathering products. If the delay was due to flow rate, the length of time it took for water from the mine site to discharge at the surface water monitoring point, a quicker monitoring warning system might have been achieved by installing monitoring wells in the spoil.

Hydrologic Complications

There are several hydrologic complications that can affect the use of water quality from adjacent mines as a prediction tool. The most obvious of these is the situation where there is no water discharging from the previously mined area; the old adage "it's a dry site." This can be falsely assumed to mean mining "success", because there are no "pollutional discharges." There is no such thing as a "dry site" in Pennsylvania. The absence of discharges does not mean that there is no water associated with or flowing from the mined area. Pennsylvania has a humid climate, where precipitation exceeds evapotranspiration on a yearly basis. Thus, there is groundwater recharge, and this groundwater recharging through the mine spoil is flowing somewhere. It may not discharge as seeps or springs, but may be entering



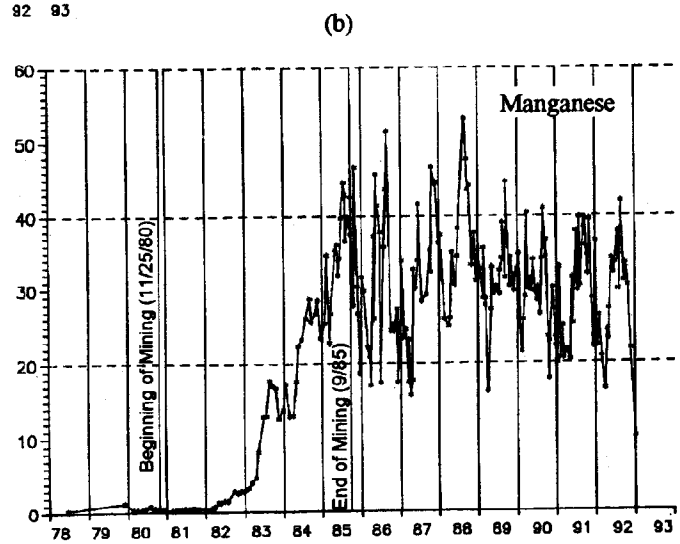
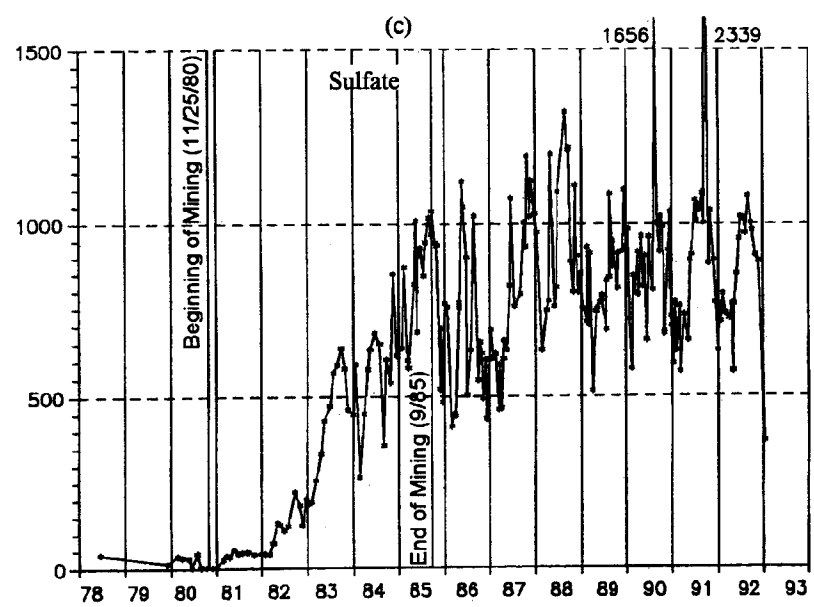


Figure 9.8 Graphs of (a) acidity, (b) manganese and (c) sulfate through time for a mine site in northeastern Cambria County. Y-axis unit is mg/L. Conditions prior to impact by modern mining are represented by data from 1978 through 1981. Postmining conditions are those samples collected after the end of mining in September 1985.



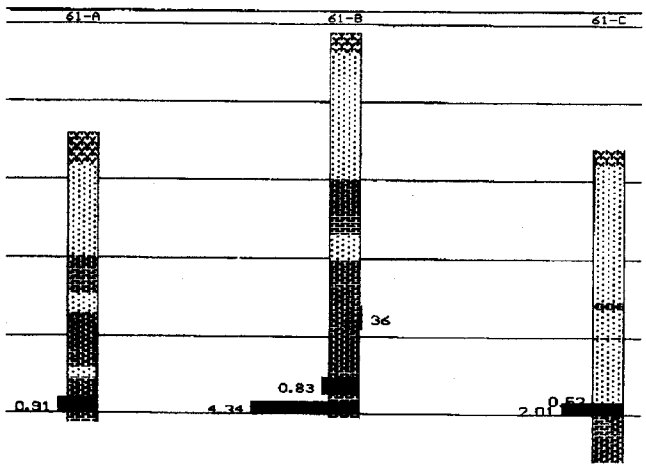


Figure 9.9 Overburden data for drill holes from the same mine as the water sample data shown in Figure 9.9. Total percent sulfur is shown to the left of the drill logs and NP is shown to the right. Only sulfur values greater than 0.5% and neutralization potential values greater than 30 ppt $CaCO_3$ are shown. Gridlines are spaced at 10 ft (3m).

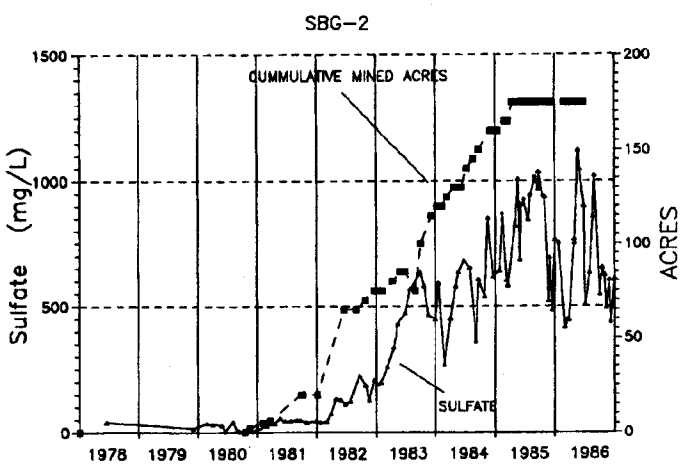


Figure 9.10 Graph showing the relationships between acres mined and water quality changes for sulfate. All acreages are estimates by one mine inspector, with the exception of the one "decrease" in acreage (late 1983), which was an estimate by a different mine inspector.

a deeper groundwater flow system which will ultimately discharge as base flow to a stream or as a discharge from a lower stratigraphic interval. Groundwater and surface water will be discussed separately because of the many different factors that influence their chemistry.

Groundwater - Adjacent mining as a prediction tool only works where there is representative groundwater (from springs or wells) that can be sampled and analyzed. If existing groundwater sample points are inadequate, monitoring wells or piezometers can often be installed into previously mined spoil, or into an underlying aquifer, to ascertain the postmining water quality. Groundwater chemistry is rarely uniform through time or through space. The discussion that follows will illustrate water quality variability.

Climatic influences on discharge quality. When using water quality data as a prediction tool, it must be kept in mind that water quality, even at the same sample point, is not normally a constant, but will vary for a variety of climatic reasons such as seasonal influences and precipitation/infiltration events. In some instances, not only water quality, but also water quantity must be considered. Flow can affect concentration. Concentration times flow is "load," which has units of mass (or weight) per period of time. Load is significant if determining the amount of reagent necessary to treat a mine drainage problem, and load is used to determine water quality changes, pre- and post-remining, on remining sites (see Chapter 17).

Flow can be greatly influenced by infiltration, which is dependent on various processes, such as rainfall, runoff, evapotranspiration, and snow-melt. Not all mines respond similarly. Smith (1988), in discussing flow, concentration, and load, points to three types of discharges. A forth type of discharge is also discussed below based on observations of the author and other sources. The four types of discharges are:

1. High flow - low concentration / low flow - high concentration response, where the flow rate varies inversely with concentration and variability is generally very great;
2. Steady or damped response discharges which exhibit relatively minor or delayed response in flow rate with minor changes in chemical characteristics;
3. "Slugger" response, whereby dramatic increases in discharge are accompanied by little change in concentrations, resulting in large increases in loading; and
4. "Slammer" response, whereby dramatic increases in discharge are accompanied by increases in concentration. This will result in significant increases in loading during these "slammer" events.

Figure 9.11 illustrates an example of a Type 1 discharge at the Arnot No. 1 deep mine in Tioga County. This figure shows the relationships between flow,

acidity concentration, and acidity load. The data represents the averaging of approximately four years of monthly data. Figure 9.11 shows an inverse relationship between flow and concentration and the seasonal influences on both. During the spring months (March, April and May) flow is high and concentrations are low due to dilution. Load is most influenced by flow. Smith (1988) concludes that "the majority of preexisting discharges fall into this category. This usually occurs with non-point surface mine discharges where the capacity for ground water storage is relatively small and groundwater flow paths are short." Type 4 discharges are probably the second most common from surface mines.

The Type 2 discharge "shows no systematic trend in acidity concentration with increasing discharge, presumably due to the large ground water storage reservoir and its ability to dampen changes in water quality" (Smith, 1988). The example given in Smith is a discharge from a large anthracite deep mine with a huge mine pool. The Type 3 discharge described by Smith is represented by a discharge from a coal refuse pile in Indiana County. "This type of discharge exhibits large variations in discharge rate with relatively minor, if any, change in acidity concentrations. Consequently, rapid increases in flow result in similarly large increases in acid loading rates or acid "slugs." Types 2 and 3 are probably less common with surface mine discharges.

Type 4 discharges often have a dramatic increase in acidity (and other mine drainage parameters) following substantial rainfall and infiltration. Brady et al. (1990) observed a surface mine discharge (Mine Site 10) in Venango County that had net alkalinity ranging from -225 mg/L to +225 mg/L $CaCO_3$ and pH from 4.5 to 6.8. The acid conditions followed precipitation events. This site had an abundance of both calcareous and pyritic strata. McCommons and Shaw (1986), DEP hy-

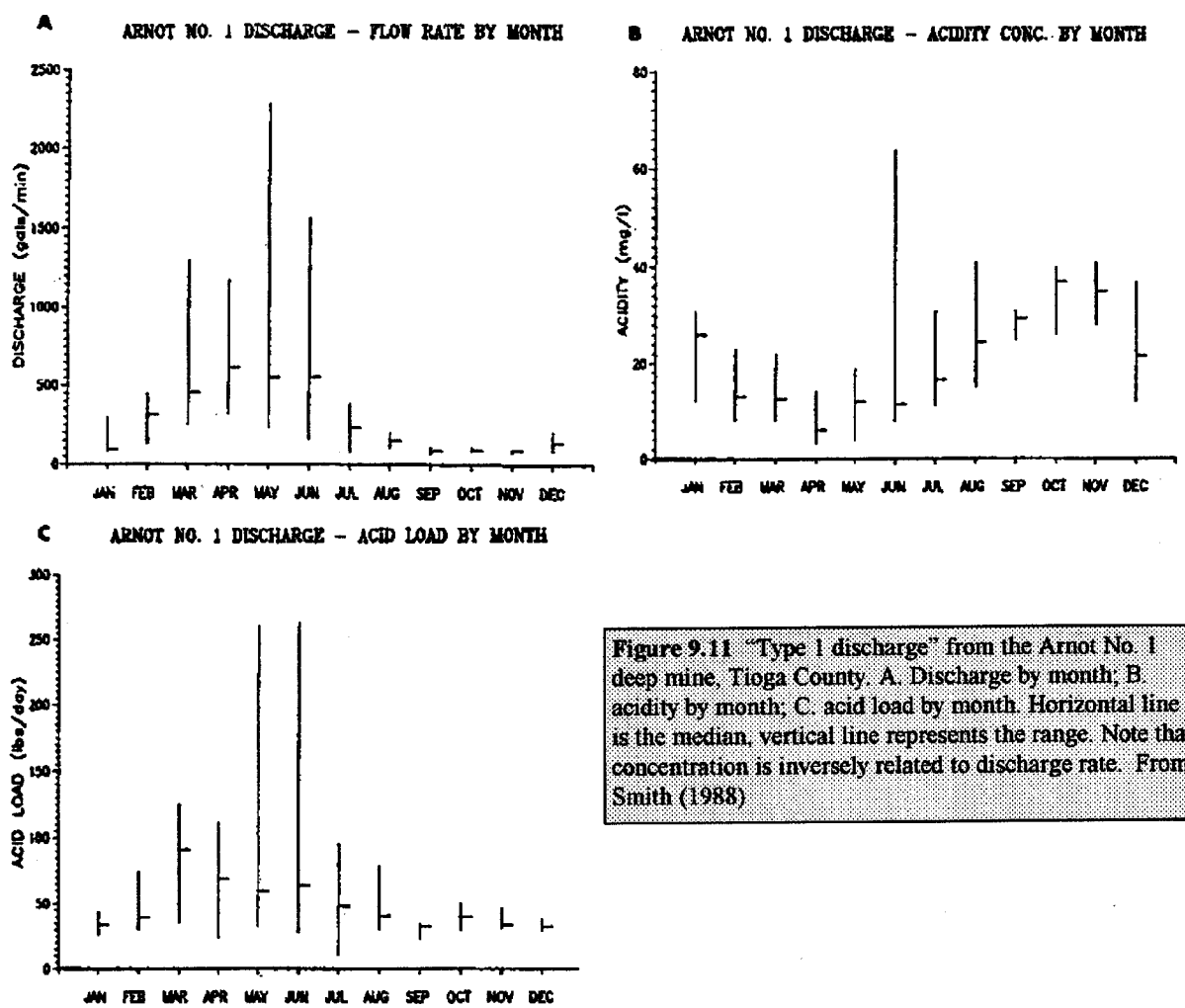


Figure 9.11 "Type 1 discharge" from the Arnot No. 1 deep mine, Tioga County. A. Discharge by month; B. acidity by month; C. acid load by month. Horizontal line is the median, vertical line represents the range. Note that concentration is inversely related to discharge rate. From Smith (1988)

drogeologist and aquatic biologist respectively, observed increased sulfate following significant rain events at a deep mine discharge in northern Cambria County. This discharge had been impacted by surface mining of overlying coal seams. McCommons and Shaw compared fluctuations in sulfate concentration with the occurrence of rainfall events. Table 9.4 summarizes significant precipitation events that preceded peak sulfate concentrations (>1000 mg/L). "In each case, observed rainfall for the 15 days prior to the sample date exceeded expected accumulations for that time interval. Each sulfate peak, resulting from a precipitation event, was followed by a considerable drop in sulfate concentration as the hydrologic system returned to near base flow conditions. The rainfall observed during the 15 days preceding these low readings was less than or near normal accumulations."

The "slams" of sulfate and acid following rain events is apparently due to several processes. First, during dry periods, there is a buildup of pyrite weathering products, soluble sulfate salts, in the unsaturated mine spoil. These salts are essentially stored mine drainage. Second, infiltrating waters from rainfall or snowmelt dissolve these salts, and flush them into the saturated groundwater zone. A third process that influences the variable water quality involves unequal rates of acid production (from pyrite oxidation and flushing of these weathering products) and dissolution of calcareous minerals.

It is obvious from the above examples and discussion that to accurately characterize mine discharge chemistry, it is necessary to have multiple samples which represent seasonal variation and variation due to various other climatic events such as rainfall and snowmelt. With only one sample it may be impossible to tell whether or not a sample is representative of seasonal and other climatic influences that affect the water chemistry.

Lateral variability in water quality within a mine site. Another complication in interpretation of mine site water quality is that water chemistry can vary within a mine, and some mines produce both alkaline and acid water. Sites with alkaline and acid water seem to be the exception rather than the rule in Pennsylvania, but these types of sites do exist (e.g., Brady et al., 1990, Mine Site 6; and examples cited below). Erickson and Hedin (1988) in their study of 32 mines in Pennsylvania, West Virginia, Maryland, Illinois, and Kentucky looked at some sites that had both alkaline and acid discharges. Which states these sites occurred in is not stated, but about half of the sites studied were in Pennsylvania.

Three mine sites with multiple sample points in mine spoil will be examined. Two of these sites also had postmining discharges. These sites were chosen to show mines with alkaline spoil water, acidic spoil water, and both alkaline and acidic spoil water. The first site (Table 9.5) represents spoil with predominantly alkaline water. The coal seam was the lower Kittanning and the depositional environment above the coal was marine. The mass-weighted net neutralization potential for the area of the wells was 2.92 ppt $CaCO_3$, with MPA being 18.67 and NP being 21.59 ppt $CaCO_3$. The three spoil wells and one bedrock well (N-1) shown in the table were drilled in an area of less than 15 acres (6 hectares). More details on this site, including locations of wells and overburden chemistry, are contained in Cravotta et al. (1994a; 1994b). This study was partially funded by the Department of Environmental Resources (DER) (now the Department of Environmental Protection (DEP)).

The second site, the John A. Thompson site in Clearfield County, illustrates water chemistry variation across a mine that has acidic water (Table 9.6). The lower Kittanning coal was mined on this site. Brackish shales overlie the coal, and fluvial sandstones overlie the brackish shales. The mass-weighted net neutralization potential for the site is 1.71 ppt $CaCO_3$ (NP = 13.59, MPA = 11.88). Most of the carbonate at this site is probably siderite. All spoil wells and discharges have acidic water. Detailed information on this site is presented in Cravotta (1998). This study was also partially funded by the DER. Another example of a mine site with acidic water is the Fran mine site in Clinton County. This mine is discussed below in the section on "Differences in Mining Practices," along with representative water quality data. The water quality at this site varies from very poor to extremely poor. The worst water quality is associated with "coal cleanings" (Schueck, 1996).

The third mine site has extremely variable spoil water quality. Figure 9.12 shows locations of wells and a mine discharge and the water quality from these sample locations. This mine is located in Springfield Township, Fayette County, and the lower Kittanning seam was mined. The information on this mine was provided by DEP hydrogeologist Richard Beam. The overburden was primarily sandstone. One overburden hole was drilled, but only percent sulfur was determined. The analyses showed the 2 ft (0.6 m) coal had

Table 9.4 Variations in sulfate concentration at a mine discharge in Cambria County as a result of precipitation and snow melt. Precipitation is reported in cm (1 cm = 0.394 inches). Climatological data from Carrolltown, approximately 5 miles (8 km) south of the discharge. Table adapted from McCommons and Shaw (1986).

Sample Date	SO_4 (mg/L)	observed[1] (cm)	expected[2] (cm)	observed - expected	Preceding Days (15 days unless otherwise indicated)[3]
2/22/84	1002	7.29 (2.0)	4.37	+2.92	2/8 to 2/22/1984
3/22/84	510	4.04 (2.0)	4.37	-0.33	3/8 to 3/22/1984
8/22/84	1320	10.26	4.95	+5.31	8/8 to 8/24/1984 (17 days)
9/27/84	822	3.18	4.37	-1.19	9/12 to 9/26/1984
2/28/85	1320	7.16 (3.8)	4.67	+2.49	1/13 to 1/28/1985 (16 days)
3/6/85	624	4.27 (3.0)	4.37	-0.10	2/22 to 3/6/1985
9/10/85	1041	8.05	4.95	+3.10	8/25 to 9/10/1985 (17 days)
10/16/85	799	3.71	4.37	-0.66	10/2 to 10/16/1985

[1]Parentheses values in this column represent proportion of the observed cm as rain equivalent of depth of snowpack that melted during observation period. It is realized that actual snow/rain ratios are variable, being dependent on environmental conditions. For this study a snow/rain ratio of 10:1 was used.
[2]Expected rainfall values represent the daily average times days of observation period. The average annual rainfall measured at Carrolltown, 106.4 cm (41.88 inches), is based on a 30 year period (1951 to 1980). The daily average = 106.4 cm / 365 = .291 cm / day (x 15) = 4.37 cm = 15 days expected accumulation. 4.37 cm = 1.72 inches.
[3]The 16 and 17 day exceptions to the preceding 15 day time interval were made to include abnormally high rainfall events commencing just before the 15 day period started.

Table 9.5 Water quality from four wells in surface mine spoil, Clarion County. Chemical analyses are from samples collected December, 1992. Data from Cravotta et al. (1994b).

Well No.	pH	Fe (mg/L)	SO_4 (mg/L)	Alkalinity (mg/L)
N1-1	6.7	0.6	570	130
N2-1	6.1	30.0	2200	120
N3-1	6.1	2.0	680	170
N4-1	5.5	3.3	1150	51

8.4 percent sulfur (% S), a one ft (0.3 m) sand stone/shale stratum above the coal had 1.12 % S, and the coal/mudstone stratum below the coal had 4.45 % S. The highest sulfur in the overlying 53 ft (16 m) of sandstone is 0.19 %. Although neutralization potential of this overburden is unknown, it would appear from some of the more alkaline spoil water that some calcareous strata were present. All surface discharges emanating from this site are acidic. As can be seen on Figure 9.12, pH ranges from 2.9 to 6.4, and net alkalinity from -504 to +100. Acid and alkaline water occurs in wells only 200 ft (60 m) apart. This is the most variable spoil water known to the author.

The overburden of the Waynesburg coal (Dunkard Group), is notorious for producing both alkaline and acidic discharges, commonly on the same permit area (D. Scott Jones, DEP hydrogeologist, personal communication, 1991). As discussed in Chapter 8, water quality from the Waynesburg seam is among the most difficult to predict.

Fortunately, from a mine drainage prediction standpoint, most mines on other coal seams produce either alkaline or acidic water, not both. The point to be made here is that a single sample point may not reflect the true character of water being produced by a mine site.

Table 9.6 Water quality from the John A. Thompson mine in Boggs Township, Clearfield County. Net alkalinity is alkalinity minus acidity. Samples collected December 1991. Data from Durlin and Schaffstall (1993).

Sample Point	pH	Fe (mg/L)	SO_4 (mg/L)	Net Alkalinity (mg/L)
Well 2	4.0	120.0	880	-173
Well 3	4.3	36.0	1000	-150
Well 4	3.7	50.0	1600	-418
Well 5	3.4	72.0	1300	-364
Well 6	3.4	120.0	4600	-1140
Well 7	3.6	8.8	1300	-1000
Well 8	3.5	84.0	2300	-2000
Well 9	4.1	52.0	860	-710
Discharge N-1	3.3	48.0	2300	-380
Discharge S-1	3.3	0.7	990	-162

Chemistry changes along flow path. Something that must be kept in mind about groundwater is that its chemistry can change along the flow path. Dissolution or precipitation of minerals can alter the original chemistry of the mine drainage. When conditions allow for oxidation of iron, spoil water within the subsurface may be high in iron, and have a higher pH, than a surface discharge from the "toe" of the spoil. Table 9.7 illustrates the differences in water quality that can result from oxidation and precipitation of iron. Spoil water from the well is compared to water quality from two downgradient seeps. The spoil well has high iron (49.7 mg/L), whereas the discharges have low iron (<1.0 mg/L). The pH in the backfill is relatively high (5.5), whereas the seeps have pH from 3.8 to 4.1. It should also be noted that all of the iron in the spoil is in the reduced form, Fe^{2+}. Under reduced conditions, high iron water can have a relatively high pH. With precipitation of the iron, as has occurred between the spoil well and the discharges, the pH is lowered. Another factor that has occurred between the spoil well and the discharges is dilution. The Mn, SO_4, Ca, and Mg are

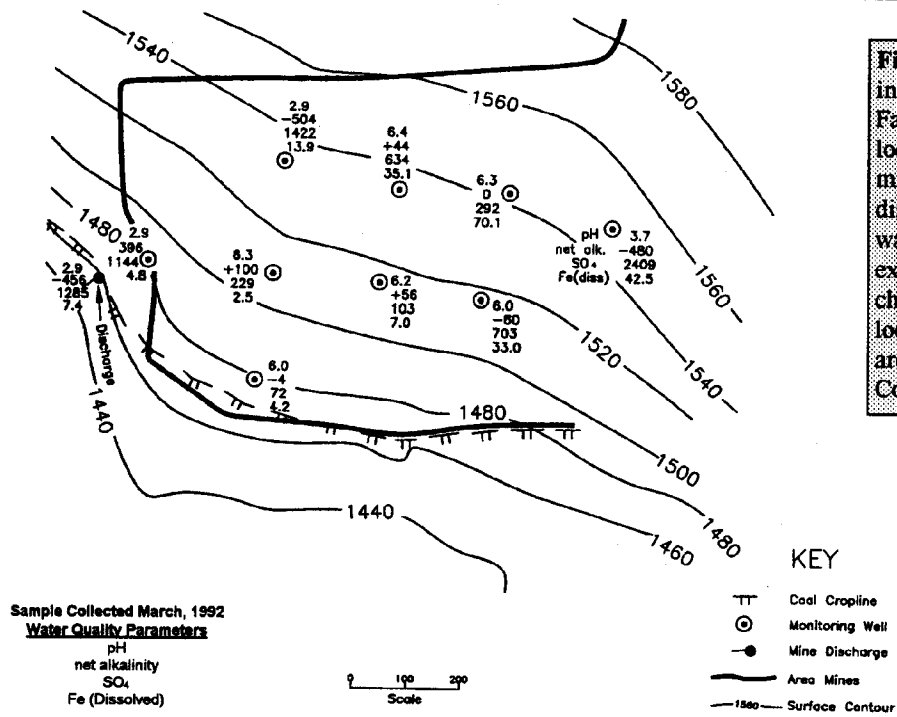


Figure 9.12 Map of mine site in Springfield Township, Fayette County, showing locations of wells drilled in mine spoil and a mine discharge, and associated water chemistry. Note the extreme variation in water chemistry among sample locations. Water quality units are mg/L, except for pH. Contours are in feet.

Table 9.7 Water quality from spoil and discharges at a mine in northern Cambria County.

Sample Point	pH	Net Alkalinity (mg/L)	Tot. Fe (mg/L)	Fe^{2+} (mg/L)
Spoil Well	5.5	-106	49.70	49.7
Discharge	4.1	-45	0.96	0.2
Discharge	3.8	-54	0.62	–

Sample Point	Mn (mg/L)	Al (mg/L)	SO_4 (mg/L)	Ca (mg/L)	Mg (mg/L)
Spoil Well	35	1	1327	192	172
Discharge	10	4	370	47	46
Discharge	8	4	277	30	32

four to five times higher in the spoil subsurface water than at the seeps.

If an acid pollution plume travels through calcareous rocks, some attenuation of the mine drainage quality should occur. Also, groundwater samples may be a mixture of water from mined and unmined (or mined on a different seam) sources.

Interference from other pollutional sources can also complicate interpretation. Mine drainage from coal mines is typically distinct enough in chemistry that other sources can be readily identified. For example, mine drainage is notorious for containing elevated sulfate, but surface mines normally have low chloride concentrations. Gas and oil well brine waters, on the other hand, have low sulfate in comparison to the high chloride concentrations. The differences between coal surface mine drainage and well brines are so distinct that they cannot be confused. Sometimes water from brines and mine drainage can commingle producing a mixed chemistry of the two waters. The interpretation of groundwater chemistry also requires an understanding of baseline water quality and the site's location within the groundwater flow system. Groundwater flow and hydrochemical zones are discussed in Chapter 2, and spoil hydrology is discussed in Chapter 3. Poth (1973) and Rose and Dresel (1990) identify three hydrochemical zones above the brine/freshwater interface (see Chapter 2). Most surface mines occur within the upper, most shallow, zone which has a Ca-HCO_3 baseline signature (see Chapter 10). Same deep mines occur in the deeper Na-HCO_3 zone (see Chapter 2).

Another factor that could possibly result in water quality differences between deep mines, especially flooded mines, and surface mines is differences in iron concentrations due to oxidation and the subsequent precipitation of iron. Iron from flooded deep mines may stay in solution as it travels from the mine to the surface discharge point. Surface mine spoil water, on the other hand, often will be oxygenated enough in the shallow subsurface such that substantial iron will have precipitated within the spoil; thus, the discharge may be low in iron.

The bottom line is that caution must be exercised when interpreting groundwater chemistry from previ-

ously mined areas. Multiple sample locations and an understanding of the groundwater hydrology is invaluable and will contribute to accurate interpretations of the data.

Surface Water - This chapter emphasizes the role of groundwater in water quality prediction, however, it is necessary to make a few comments about surface water chemistry. Surface water is much less desirable as a prediction tool than groundwater for a multitude of reasons. Interpretation of groundwater chemistry is not without its problems as discussed above. Surface water, however, is even more complicated in this regard. Hydrologic factors that can complicate the interpretation of surface water quality from previously mined areas are: dilution of mine drainage by surface runoff, mixing of waters from tributaries that are not impacted by mining, groundwater baseflow from areas unaffected by mining, flow of ground or surface waters affected by mining on a different seam of coal, and chemical alteration of the water by oxidation and precipitation of metals.

Stream water chemistry can change in the downstream direction because of the precipitation of metals, particularly iron. Figure 9.13 shows the concentrations and loads for iron, manganese, and sulfate at various points in a stream in northeastern Cambria County. Significant quantities of mine drainage enter the stream at three different points. Concentrations vary along the flow path for all parameters, but especially so for iron. Concentrations can be affected by dilution, load is not. The graph of constituent load shows that the conservative parameter sulfate is essentially cumulative along the downstream course. Manganese, for a metal, is comparatively conservative (i.e., does not precipitate readily from solution), and likewise its load increases or only slightly decreases downstream. There is some precipitation of manganese along the flow path, but it is minor compared with iron, which is not conservative. The iron load is high at locations just below mine drainage entry points, but it quickly precipitates out of solution and by the time the water reaches the mouth of the stream, the iron has been mostly removed from the water through precipitation onto the stream bed.

Stream water quality can be useful in presenting a "broad-brush" view of mining related problems over a large area. As illustrated above, it is most useful for conservative parameters. Surface water quality studies such as Wetzel and Hoffman (1983, 1989) can show broad regional trends in water quality (see Chapter 8).

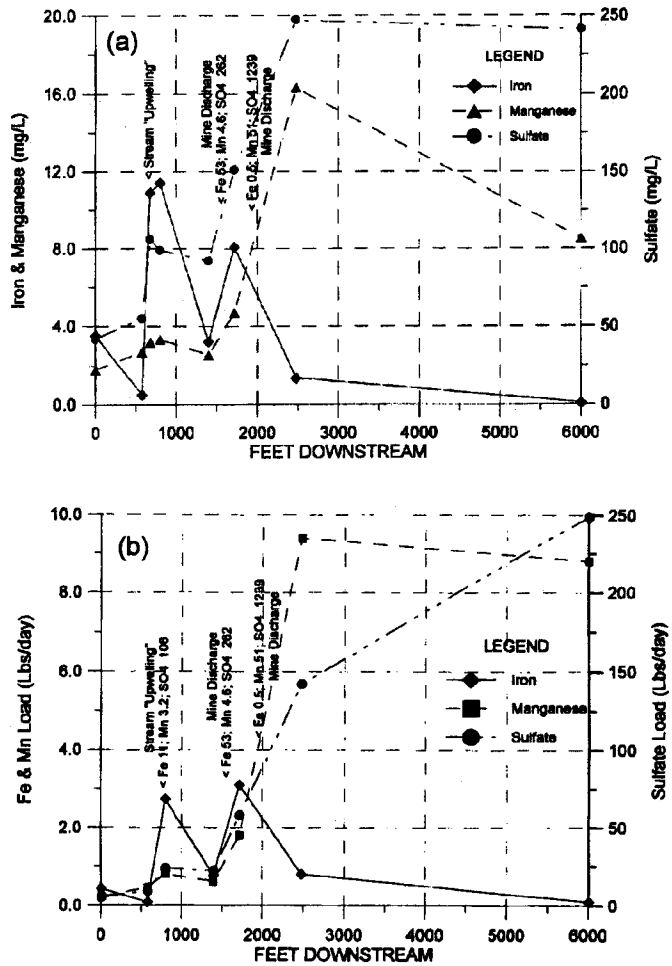


Figure 9.13 Graphs of (a) concentrations and (b) loads for iron, manganese and sulfate in a stream in northeastern Cambria Co. (a). Changes in stream concentration in response to entry of mine drainage discharges along stream reach. (b). Iron, manganese and sulfate load in response to entry of mine drainage discharges along stream reach. Unpublished data from H.S. Baker, Jr., DEP aquatic biologist.

However, unless more detailed information is available, such as what seams were mined, what percentage of the watershed was mined, and what mining practices were used (deep mining, surface mining, refuse disposal, type of reclamation practices, etc.), this information is not generally useful for the prediction of water quality for a proposed mine site.

Differences in Mining Practices

Differences in mining practices must be considered when predicting water quality from previous mining. Different mining practices can significantly influence the water quality produced from a mine. Deep mine

water quality may differ significantly from surface mine water quality on the same coal seam. There have been recent advances in surface mining practices that have the potential to favorably affect water quality. Examples are concurrent reclamation, alkaline addition, special handling, and engineering water movement through or around the backfill. Mine sites that clearly employed adverse practices may be producing water of poorer quality than what a proposed mine site would produce employing favorable mining practices. Mining practices that can adversely affect surface mine water quality include disposal of "tipple refuse" (i.e., rejected material from a coal processing plant), auger mining, improper disposal of acidic strata, and non-concurrent reclamation. Other mining practices that may influence postmining water quality are the type of mining equipment used (dragline vs. trucks and loaders vs. bulldozers), and the length of time a pit remains open and exposed to weathering.

Surface Mine vs. Deep Mine Water Quality - As a general rule of thumb, if a deep mine on a particular coal seam is making alkaline drainage, a surface mine on that same seam will also produce alkaline drainage. The inverse, however, is not necessarily true. If a deep mine is discharging poor quality water, it should not be assumed that a surface mine on the same seam will also produce poor quality water.

The following example of daylighting a deep mine by stripping is an extreme case of water quality improvements. A company named "Solar" deep mined approximately 760 acres of Pittsburgh coal in Findlay Township, Allegheny County, during the early 1900s. Water was sampled from this mine in 1974 for an Operation Scarlift report (Department of Environmental Resources, 1976). Aloe Coal Company began daylighting the deep mine in about the mid-1970s. They daylighted approximately 60 percent of the mine (John Davidson, 1996, DEP mine inspector, personal communication). Aloe mined up to 250 ft (87 m) of cover, which is not normally economical; however, this was a "cost-plus" operation (the coal buyer paid costs, plus a profit). Figure 9.14 is a general geologic column showing the stratigraphy above the Pittsburgh coal in this area. There are several freshwater limestone units that were encountered by surface mining, the thickest being the Benwood, which is frequently 50 ft (15 m) thick. Figure 9.15 illustrates the improvement in pH before deep mine daylighting (1974) and after daylighting (1995). The improvement in water quality after daylighting is dramatic and obvious. Most deep mine daylighting will not encounter as much calcareous strata as in the above example and the water quality improvements would not be as spectacular; however, when calcareous materials are encountered during daylighting operations, water quality does generally improve.

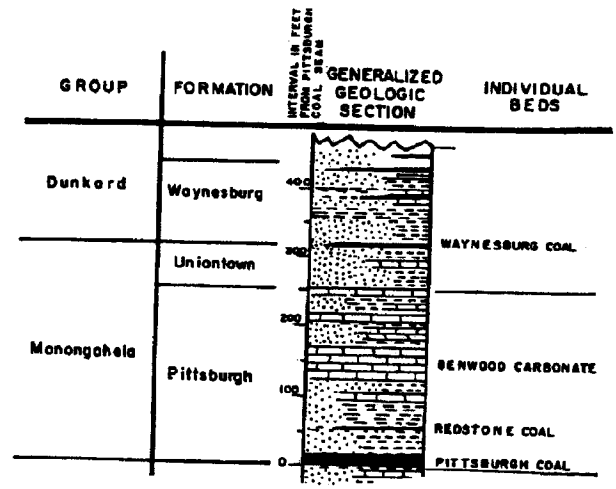


Figure 9.14 Generalized geologic section of the stratigraphy in the vicinity of the Solar/Aloe site. Note the thick Benwood Limestone and other thinner limestones.

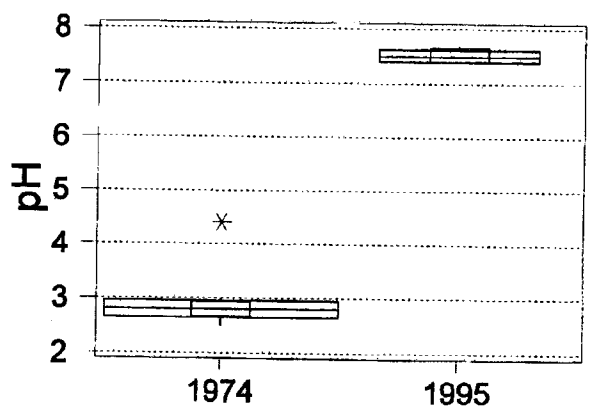


Figure 9.15 Boxplots showing the distribution of pH before (1974) and after (1995) daylighting of the Pittsburgh deep mine.

The reason for poorer water quality from deep mines relative to surface mines is that the strata with the maximum disturbance and exposure to weathering is the coal, roof rock and floor rock. This rock frequently has the greatest amount of pyrite in the overburden. Postmining caving and rubblization of the mine roof and crushing of coal pillars increases the surface area of these pyritic rocks. Water and air flowing through the mine will cause pyrite in the rock to oxidize. A second factor that can contribute to better

water quality being produced from surface mines than from deep mines is that surface mines can disturb and utilize stratigraphically higher overburden rock. If this rock is calcareous, alkalinity generated by this rock can neutralize acid and inhibit pyrite oxidation. Thus, postmining water quality from a surface mine can be alkaline, whereas that from a nearby deep mine on the same coal seam is acidic. These factors are illustrated in the example below.

Discharges from surface and deep mines on the same coal seam (middle Kittanning) in Saltlick Township, Fayette County, show marked differences in water quality (Lighty et al., 1995; and personal communication, 1997). Table 9.8 compares discharge water quality from three surface mines and three deep mine discharges. Figure 9.16 shows the distribution of net alkalinity for each of the mine discharges. The deep mine water is markedly poorer quality than the surface mine water. Figure 9.17 shows acid-base accounting data for three drill holes from one of the surface mines. When the middle Kittanning coal is surface mined, the thick interval of high NP strata below the upper Kittanning coal is encountered and incorporated into the backfill. Water in the deep mine, however, is primarily influenced by the chemistry of the roof rock, coal pillars, floor rock, and any coal waste that was left in the mine. Some of this material, especially the floor rock, has high sulfur content. The rock 10 ft. (3 m) above the mine roof has NP's in the 15 to 60 ppt $CaCO_3$ range. Low NP's at this stratigraphic position (i.e., immediately above the middle Kittanning coal), and the lack of alkalinity in the deep mine water suggest that the NP is from siderite rather than a calcareous carbonate.

Mining Practices - Mining practices that can positively affect water quality are addressed in several other chapters. These practices include special handling, alkaline addition, and water management. A site that includes these pollution prevention measures may produce different quality water from sites that did not include these measures. Examples are given in each of those chapters illustrating the effectiveness of these methods.

An example of poor special handling practices that resulted in extremely poor water quality can be illustrated by the Fran site studied by DEP hydrogeologist Joe Schueck (e.g., Schueck et al., 1996). This site had fairly shallow overburden (average around 30 ft (10 m)) with high sulfur content and little to no neutralization potential. Mining occurred in the 1970s. The operator "special handled" the coal cleanings by placing them in piles. In addition, the operator returned several loads of tipple refuse to the site which was also placed in piles. However, the operator failed to insure that these high-sulfur materials were placed in piles, failed to insure that these materials were placed well above the pit floor, and no attempt was made to cover these materials with an impervious cap.

Table 9.8 Comparison of median water quality from middle Kittanning surface and deep mines in Saltlick Township, Fayette County. Net alkalinity is alkalinity minus acidity. Sample points S 1 through S 3 are from surface mines and D 1 through D 3 are from deep mines. All units, with the exception of pH are mg/L. Data from Lighty (1997, personal communication).

Sample No.	S 1	S 2	S 3	D 1	D 2	D 3
No. of Samples	15	6	5	6	17	7
pH	6.3	6.5	7.2	3.2	3.2	3.1
Net Alkalinity	92	163	194	-235	-284	-216
Fe	13.7	2.2	0.2	52.4	65.9	66.8
Mn	3.3	2.3	0.5	2.5	2.3	2.4
Al	0.2	0.1	0.2	14.0	12.7	5.2
SO_4	180	156	356	529	570	418

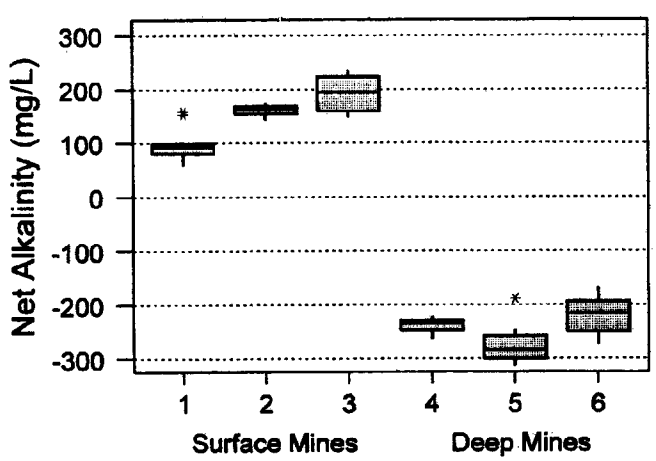
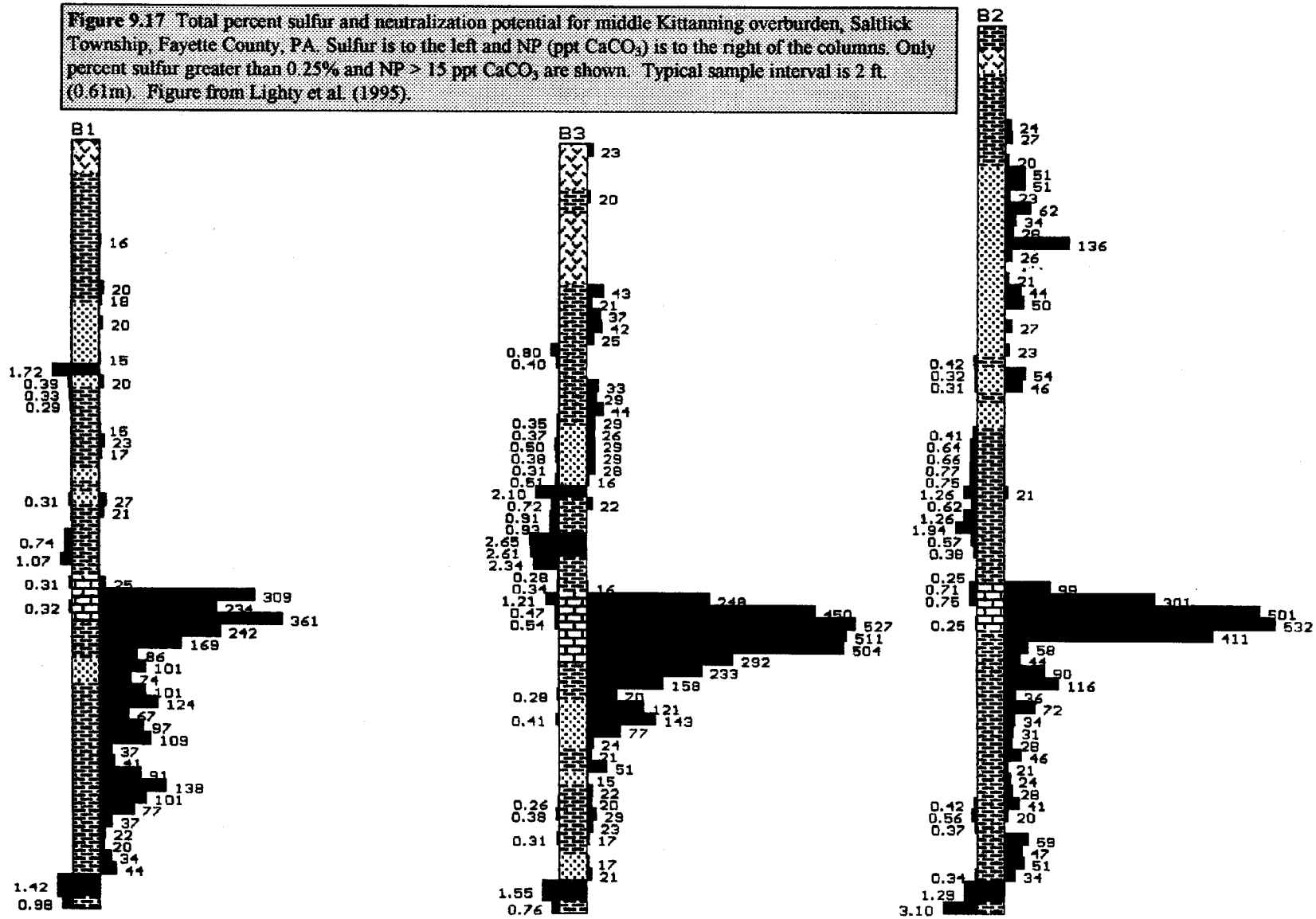


Figure 9.16 Distribution of net alkalinity for three surface and three deep mine discharges from the middle Kittanning coal seam, Saltlick Township, Fayette County, PA.

Table 9.9 shows representative water quality from selected monitoring wells located on the site which clearly demonstrate the impact that tipple refuse and coal cleanings can have on water quality when not properly handled. Well L44 represents the poor water quality resulting from the overburden alone. This well is not influenced by the piles of coal cleanings and tipple refuse on the site. Well K23 is located in a pile of improperly handled, buried tipple refuse. Both infiltrating precipitation and water migrating along the pit floor contacts this acid forming material. Concentrations of the mine drainage parameters in this "acid

Figure 9.17 Total percent sulfur and neutralization potential for middle Kittanning overburden, Saltlick Township, Fayette County, PA. Sulfur is to the left and NP (ppt $CaCO_3$) is to the right of the columns. Only percent sulfur greater than 0.25% and NP > 15 ppt $CaCO_3$ are shown. Typical sample interval is 2 ft. (0.61m). Figure from Lighty et al. (1995).



factory" are more than 5 times higher than in well L44. As the mine drainage migrates from this location toward the discharge points, it becomes diluted by the poor quality AMD generated elsewhere on the site. The resulting water quality is represented by well X48, located downgradient from the K23 well. The quality of the water which ultimately discharges from the site is shown in well FF62. This well taps a perched aquifer located below the coal seam which was mined. The water discharging from this portion of the site migrates to the regional water table and discharges into the receiving stream as base flow, some 250 ft (76 m) lower in elevation (Schueck, personal communication, 1997).

Department experience has shown that long-term cessations on mine sites with low NP overburden can result in poor postmining water quality. During the cessation the acidic spoil is left exposed to the elements to weather and form acid products. When comparing mines on the same coal seam that were mined concurrently with mines that had long-term cessations, the area mined with the cessation frequently had poorer water quality.

Table 9.9 Representative water quality from a mine in Clinton County, PA. Values are means. Data from Schueck (1996).

No. of Samples	pH	Acidity (mg/L)	Fe (mg/L)	Al (mg/L)	Mn (mg/L)	Sulfate (mg/L)	Sample ID & Description of Sample Point
16	2.5	2995	321	268	48.3	2571	D3, toe-of-spoil seep
15	2.3	4088	876	256	39.2	3477	FF62, spoil well
21	2.5	3828	747	236	48.1	2958	L44, spoil well
13	2.1	21315	5437	1515	60.5	15639	K23, spoil well
14	2.4	7470	1707	492	72.8	6991	X48, spoil well

Discussion

When the geology, hydrology, mining practices, and reclamation practices are similar between a previously mined area and a proposed mining area, and this tool is used properly, no other single prediction tool is better or more useful than the examination of water quality from a previously mined area. Previously mined sites can demonstrate water chemistry generated by rock weathering under actual mining and field (hydrologic, climatic) conditions. Important mining conditions include: the strata encountered by mining, including its variability within the site; the distribution of these rocks within the spoil; weathering of the rocks at the actual scale (rock sizes) that were produced by mining; and influences from various mining methods. Important field conditions include: site specific precipitation, infiltration and runoff; field temperatures, including seasonal variations; pore gas chemistry, including vertical variations; and real world scale of rock to water ratios. These are factors that are only approximately simulated, if at all, in laboratory tests. The examination of water quality from areas previously mined also provides information on actual concentrations of mine drainage constituents, including pH, alkalinity, acidity, iron, manganese, aluminum and sulfate. Previous mining water quality is "the proof of the pudding."

The most confident predictions of postmining water quality will always be those made using a variety of prediction tools, especially if each tool points toward the same conclusion. Much more often than not (although there are exceptions) if postmining water quality is good the acid-base accounting will likewise show calcareous overburden and premining water quality will be alkaline. If postmining water quality is good, but the acid-base accounting data suggest that acid will be produced, a couple of possibilities exist (in addition to the various factors discussed above). First, sampling may not be representative. Additional sampling may reveal calcareous strata that was missed in the initial sampling. Second, the carbonate mineralogy of the overburden may need to be better defined (e.g., siderite masquerading as neutralization potential).

Adjacent mining is often given precedence when prediction tools are conflicting. An example of this is an area where the lower Kittanning coal was mined in northeastern Armstrong County and southwestern Jefferson County. Figure 9.18 shows acid-base accounting data for two overburden drill logs from a lower Kittanning mine site in Redbank Township, Armstrong County. The overburden is clearly high sulfur. The weighted-average NP for the site is 24.08 ppt $CaCO_3$ and the MPA is 23.51 ppt. Thus, the NNP is a mere 0.57 ppt. With "thresholds" (see chapters on acid-base accounting for discussion of thresholds) the NP is 9.16 ppt and the MPA is 21.27, giving an NNP of -12.11. This site would normally be interpreted to indicate an acid-producing site. The site is actually producing alkaline drainage. The following water quality shown below is the average of ten samples from a representative postmining discharge. Values (except for pH) are in mg/L.

pH	Alkalinity	Acidity	Fe	Mn	Al	SO_4
6.7	68	0	0.23	0.25	<0.5	267

The lower Kittanning mines in this area of Armstrong and Jefferson Counties, despite having high sulfur overburden, produce alkaline drainage. Permits in this area of Armstrong and Jefferson Counties have

been issued routinely based on adjacent mining water quality.

A problem with interpreting neutralization potentials in the range shown in Figure 9.18 is not knowing what carbonate minerals are present. The common iron-carbonate mineral siderite frequently produces NPs in this range. Siderite, as discussed in other chapters, is not alkalinity generating. X-ray diffraction analyses for the Armstrong County site discussed above did not detect siderite. The NP is from calcite

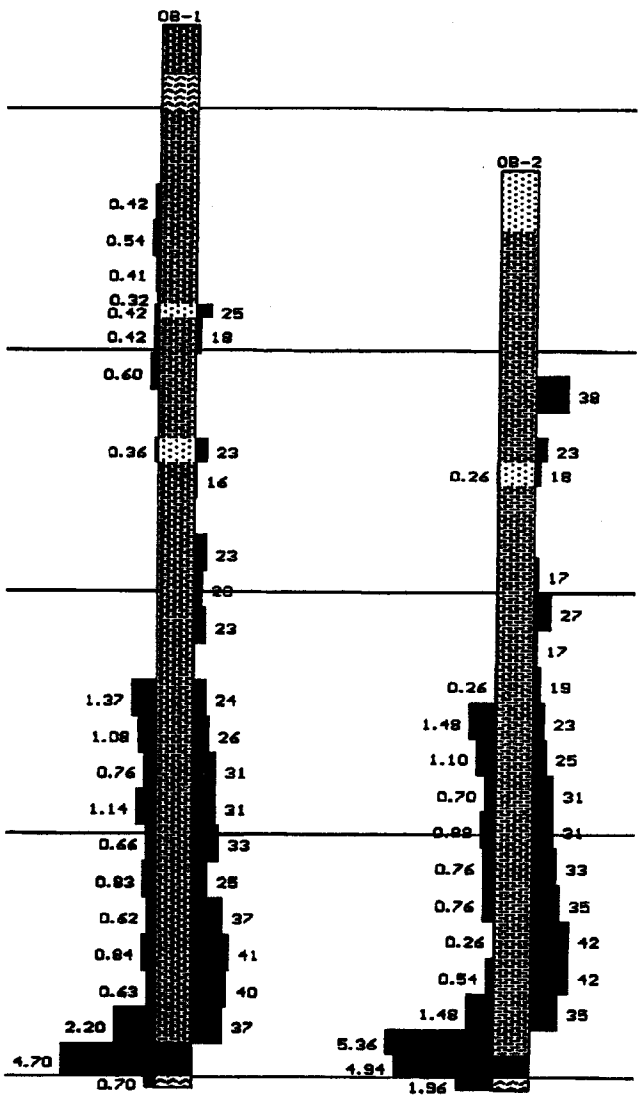


Figure 9.18 Acid-base accounting results for two drill holes penetrating down to the lower Kittanning coal seam in Redbank Township, Armstrong County. Total percent sulfur is shown on the left and neutralization potential (ppt $CaCO_3$) is shown on the right. Only percent sulfur values greater than 0.25% and NP values greater than 15 ppt $CaCO_3$ are shown. Grid lines are at 20 ft (6 m) spacing.

(R. Smith, PA Geological Survey, personal communication, 1996). The intimate association of the calcite with the pyrite may inhibit some pyrite oxidation.

Conclusions

Groundwater quality from previously mined areas, when available and if used properly, can be the best mine drainage quality prediction tool in the tool box. Accurate predictions of water quality for a proposed mine require that apples be compared with apples (i.e., mines and mining conditions be alike). It is therefore important that it can be demonstrated that the same coal seam(s) is being mined, the geology is similar, the amount of area disturbed is similar, there are no complicating factors such as mixing of water from other sources or chemical changes along flow paths, and that there are no significant differences in mining practices. When these conditions are met, adjacent mining is an accurate forecaster of postmining conditions. Previous mining provides real-world field data with actual chemical concentrations of, among other parameters, alkalinity, acidity, metals, and sulfate.

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