Chapter 18

APPLICATION OF THE PRINCIPLES OF POSTMINING WATER QUALITY PREDICTION

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Introduction

The previous chapters of this document present in detail the individual predictive tools necessary to determine if and how a site can be surface mined without an unacceptable risk of pollution. This chapter will summarize the key principles from the previous chapters and will show how those tools are synthesized into a prediction of whether pollution will occur. The process is not always straightforward nor simple.

Historically, there has been some skepticism surrounding predicting postmining water quality, especially the heavy use of overburden chemical analysis. Apparent reasons for this skepticism include:

- Any decision making which relies heavily on the professional judgment and experience level of the decision maker is typically subject to question.
- The number of factors which must be considered and the potential for those factors to sometimes contradict one another provide an opportunity for even experienced data interpreters, looking at the same data set, to reach somewhat differing conclusions.
- To interested parties not closely familiar with the geologic and chemical science behind the data interpretation, the decisions may appear virtually random. It may be completely reasonable in terms of the potential for pollution why one property may be mineable and an adjacent property may not be. However, it is easy to understand how the affected property owners and mining companies may find such a decision incomprehensible.
- The legacy of polluted streams left behind by mining operations that took place prior to modern understanding of the mechanisms of mine drainage formation has convinced much of the general public that any mining will lead to acid mine drainage pollution and that efforts to prevent it are fruitless.
- The science of predicting acid mine drainage is fairly young, and as is always the case when the experience level is low, there were notable early predictive failures.

Despite the skepticism, much progress has been made in the science of predicting postmining water quality over the past ten to twenty years, and a significant majority of the sites permitted and mined in Pennsylvania today produce acceptable postmining drainage quality. A recent informal survey (Gary Byron, PA DEP, personal communication, 1997) of surface mining permits issued in Pennsylvania between 1977 and 1992 showed that 344 permits out of a total 3710 permits issued, or 9.3% resulted in discharges which failed to meet effluent limits and which required permanent treatment. (See table 18.1 for data.) However, the average failure rate for predictions during the first 8 years of the period examined was 14.7 %, while the failure rate for the final 8 years (1985-1992) improved to 2.9%. The data in Table 18.1 should be viewed with some caveats in mind: the predictive success for sites, which due to hydrologic conditions, do not produce a discharge is really an unknown and not necessarily a success; not all the sites surveyed have been completed to date, which is one reason why data for sites permitted after 1992 were not considered here; other factors such as market conditions (the demand level for certain coal seams) and changes in inspection frequencies and sampling intensity may also have some influence on these data. A comprehensive study (Hawkins, 1995) of Pennsylvania's program (subchapter F) for remining sites with poor quality discharges revealed that the acidity and iron loads were either unchanged or declined at 21 of the 24 sites studied for an 87% success rate. Acidity rates actually declined significantly at nearly one-third of the sites. A recent survey conducted by the Department (Michael Smith, PA DEP, personal communication, 1997) revealed that, of 260 subchapter F permits issued up to

1997, only 5 have caused statistically significant long-term degradation of the pre-existing discharges; an additional 6 sites required treatment of discharges at some point during operation, but the water quality on those sites eventually returned to baseline conditions. The data from the remining studies are especially notable since such sites are generally very well-monitored.

Table 18.1 Total number of surface mining permits issued in PA per year and the number of those permits resulting in discharges requiring treatment. (Please see caveats in text regarding these data.)

Year	Total Permits Issued	Permits With a Discharge Requiring Treatment	Percentage of Permits Requiring Treatment
1977	341	54	16
1978	265	35	13
1979	212	50	24
1980	230	36	16
1981	245	51	21
1982	228	37	16
1983	185	25	14
1984	300	7	2
1985	300	13	4
1986	250	2	1
1987	260	5	2
1988	221	7	3
1989	181	8	4
1990	183	5	3
1991	167	5	3
1992	142	4	3

The importance of adequate water monitoring both during and after mining is emphasized here for two reasons. First, accurate predictions of postmining water quality depend on accurate input data, and water quality from adjacent mined sites is one of the most useful predictive tools. Second, such monitoring can serve as an early-warning system for active sites that unexpectedly develop problems. If the problems are discovered early enough, it is possible that one or more of the management tools discussed in other chapters of this document can be employed to correct the problem or lessen its severity. While traditional stream monitoring is useful, the monitoring of pit water, mine discharges, downgradient springs and monitoring wells best document water quality directly associated with a mine site. Inadequate monitoring hampers both the mining industry and regulators in making appropriate decisions about how and where to mine.

The findings in this document are based upon research and experience largely applicable to the northern Appalachian coal fields. Geochemical and climatic differences found in other regions of the country, especially in the arid West, must be understood and factored in by water quality predictors in those regions.

Complicating Factors

There are several potential complications which confront those who attempt to predict postmining water quality. In some cases information is not available on all the factors which may affect postmining water quality. Perhaps there is little pertinent mining history to evaluate, or the site's hydrogeological setting may make it difficult to discover background groundwater quality. A decision must nonetheless be made. Sometimes the predictive factors point the data interpreter in opposite directions: site-specific overburden analysis may suggest alkaline drainage will result, while adjacent sites have produced acid mine drainage. More commonly, the factors may present seemingly ambiguous results, not pointing strongly toward any one conclusion. Complicating factors exist not only between the predictive tools but within each one. Probably the most notorious is the "gray zone" in acid-base accounting results, wherein the rate of predictive failure can still be significant despite the advances in understanding which have shrunk that zone over the years. Another complicating factor is how to assess the array of possible management practices which a mine operator may suggest to counter problems with overburden quality. Will alkaline addition work and how much is enough? What are the benefits of special handling of overburden materials and what specific plan is best for the site under consideration?

Risk Assessment

The need to consider the risk level associated with a prediction that proves to be incorrect is interwoven with the complicating factors which must be weighed when predicting mine drainage quality. The reality, which applies to any type of predictive endeavor, is tied to the need to consider risk: there will always be a certain percentage of failures, although under some conditions the risk of predictive failure is extremely low. Common sense and legal and regulatory requirements affect the level of certainty acceptable for a given prediction. For a mine site proposed on a pristine stream that serves as a public water supply, the level of certainty required of the prediction is much

higher than that required for a proposed remining site (one involving abatement of existing environmental problems) on a degraded stream. In the latter case it may be acceptable to permit a site where the predictive tools provide somewhat contradictory guidance. This action may be justified because of the potential benefits of remining the site, and the possibility of less stringent effluent limits - which for some pre-existing discharges may be equal to background polluted water quality. However, for the case of the pristine stream serving a public water supply, the requirement for stricter effluent limits, tighter in-stream standards, and the need to protect public health and safety suggest that all the predictive tools must provide strong evidence of acceptable postmining water quality to support a decision to approve mining on the site.

Each proposed mine site presents a different scenario of potential risks and benefits, usually not as clear-cut as the two just described. There are also risks associated with decisions, which err on the conservative side: property owners and society as a whole suffer economically if a site which can safely be mined is not permitted because of a misperceived risk level. While there has historically been little formal discussion of risk analysis as it applies to mine-site permitting, it nevertheless has been, and will continue to be, a factor weighed by permit applicants, technical consultants and regulators, who all naturally and inevitably consider the potential consequences of their decisions.

The Best Tool

Those who must predict postmining water quality sometimes debate which of the predictive tools should weigh the heaviest. An appropriate answer to the debate is "all of them." Some critical cases may require that all the factors point solidly in the same direction. However, more frequently, they do not, nor is it usually necessary that they do.

Water quality data from adjacent completed mining operations on the same coal seams are often cited as the most reliable of the predictive tools. This may be true as a generality, because such water quality data are direct empirical evidence. However, site-specific exploratory drilling and overburden chemical data should be used to evaluate lithologic, stratigraphic, and geochemical differences between the sites being compared. If these differences are significant, predictions based solely on adjacent mining can be completely wrong. For example, a completed site on which the overburden was primarily a channel sandstone without significant neutralization potential may have produced an acidic discharge. However, data from a proposed adjacent site may show that, due to facies changes, the overburden is primarily shale that is relatively high in calcium carbonate content. In that case it may be appropriate to weigh the water quality results from the adjacent mining less heavily than some of the other factors. In situations where well-documented historical data has proven that surface mining operations on certain seams consistently produce good quality water, site-specific overburden analysis may not even be required to make a correct prediction, and the requirement for overburden analysis may be waived.

Even when data from adjacent mining and site-specific overburden analyses are in complete agreement, serious prediction errors can occur if factors such as the extent and depth of weathering and the mining plan are not considered. For example, a completed site may have been mined to a ninety-foot highwall height and produced an acceptable quality discharge; the overburden analysis may show units high in sulfur but also may include a thick, consistent high-carbonate shale unit located forty feet above the coal. However, if the proposed site mining plan is to take only fifty to sixty feet of cover, perhaps due to thinning of the coal between the sites or the existence of a deep mine under higher cover, then it is doubtful that a significant amount of the high-carbonate shale unit will be encountered in a unweatherd state. Without consideration of weathering and the mining plan, a prediction based on historical water quality and a site-specific overburden analysis, which are in complete agreement with one another, could still be wrong.

In summary, the best predictions are those that weigh all the predictive factors, and serious errors can result from predictions that fail to consider less than all of the available data. Or, in the words of two noted researchers in the field of predicting volcanic eruptions: "Predictive capability is best achieved by using a combination of data sets and methods, rather than by reliance on any single procedure," (Voight and Cornelius, 1991).

Key Principles from Previous Chapters

The correctness of any prediction is dependent on the validity of the information considered. The following key principles from the previous chapters of this document must be understood and considered by

those who attempt to predict postmining water quality. As noted earlier in this chapter, information is not available on all the predicative factors all the time, nor is that always necessary. But the best predictions make use of the largest amount of scientific data available.

1. Not all mine sites in Pennsylvania make acid. Mine drainage quality can vary widely from waters that are highly acidic to waters that are highly alkaline. The metals concentrations found in mine drainage can also vary greatly. Tables 1 and 2 of Chapter 7 show the wide range of possible water qualities from mine sites by presenting the worst-case and best-case water qualities that the Department has documented from mine sites in PA. The presence or lack of carbonates strongly affect shallow groundwater chemistry.

2. There is no such thing as a "dry" mine site in the humid East where in any year precipitation always exceeds evapotranspiration. Every mine site contributes groundwater flow to lower strata and to downgradient discharge points, although in some geologic settings, the effects of the mining may be difficult to document. Sites located in groundwater discharge areas have the potential to create much larger problems in terms of the volume of water discharged through and from the site. However, water quality problems cannot be completely avoided by selecting "water-free" sites; they do not exist in the Appalachian coal fields.

3. Groundwater flow in mine spoil occurs in a "dual-porosity" system, as defined in Chapter 3. The hydraulic properties of spoil are difficult to predict. Porosity, hydraulic conductivity and transmissivity of mine spoil are much higher than in the undisturbed surrounding rock.

4. The environmental, economic and social consequences of incorrect mine drainage predictions are considerable.

5. Obtaining representative samples for overburden chemical analysis is critical. The importance of a well-planned sampling regimen following proper protocols is imperative. No prediction can be better than the quality of the underlying data.

6. Laboratory personnel and data interpreters must be aware of aspects of the acid-base accounting (ABA) test which can affect the reliability of the results. The fizz test is subjective. Since it determines the volume and normality of acid used in the neutralization potential (NP) digestion, it affects NP results. Siderite, a common mineral in Pennsylvania coal overburdens, can interfere with NP determinations. The addition of a hydrogen peroxide step seems to reduce this interference. Presently, using total sulfur values leads to more reproducible and accurate maximum potential acidity (MPA) values than does using forms of sulfur data.

7. Kinetic tests could be a valuable tool in the mine drainage prediction toolbox, because they factor in several variables found under field conditions but not reproducible by static tests. However, the large variation in the test methods used and the lack of standardization has made interpretation of kinetic test results quite challenging. There are specific physical, chemical and biological factors which should be included in any kinetic test.

8. In a general sense water quality can be correlated to the geologic units affected by mining, so proper understanding of the geologic section and of controls, such as depositional environments, can serve as a first-cut predictive technique. However, there can also be considerable regional and local variation in water quality generated from mines in the same geologic section. Tables 1 and 2 of Chapter 8 show how variable mine drainage quality can be and how the quality relates to the stratigraphic section being disturbed. The distribution of carbonates in the geologic section is critical to predicting mine drainage quality, because without carbonates significant alkalinity will not be produced. Site geology must be thoroughly understood to ensure representative overburden sampling and to develop appropriate mining and special handling plans.

9. Water quality from adjacent mining in the same strata can be a powerful predictive tool. However, site-specific data must be carefully analyzed to ensure that lithologic, geologic, geochemical, and hydrogeologic differences between sites do not negate the validity of the comparisons being made.

10. If the groundwater flow systems are properly understood, background water quality data from a proposed mining site can help confirm overburden analysis data and the presence of carbonates. This

background groundwater quality will not help significantly in identification of sulfur-bearing strata however, and it is possible to be misled by shallow flow springs, which typically do not reflect the chemistry of unweathered rock. The presence of alkaline water on a site can be helpful, even if the carbonates that generated it are located off site. Sites with natural groundwater quality low in buffering capacity due to an absence of carbonates can be prone to acid production.

11. Acid-base accounting has proven to be a valuable and reliable tool in predicting whether a mine site will generate acidic or alkaline water. The key to proper interpretation is to understand that a clear excess of carbonates is necessary to ensure alkaline drainage: predictions based on the assumption that NP need only equal or slightly exceed MPA will fail. Mine water chemistry is controlled by the typically small fraction of the overburden with significant carbonate and sulfide mineral content; as little as five percent of the rock on the site can control postmining water quality, while the remaining 95 percent of rock is essentially inert in terms of its effects on postmining drainage quality.

12. Proper reclamation and revegetation of a site can help reduce the potential for pollution by preventing excess infiltration. However, infiltration cannot be eliminated and even exceptional quality reclamation will not prevent acid mine drainage in an otherwise poor setting.

13. Alkaline addition can change the geochemical balance of a site and can produce alkaline drainage where acidic drainage would have otherwise occurred. However, on a typical site the amount of carbonate which must be imported to change the geochemistry, while small compared to the total overburden mass, is large when considered in terms of logistics and economics. The minimum amount needed is often cost prohibitive. Due largely to economic considerations, alkaline addition presently remains most viable on remining sites where lesser water quality standards, and therefore lesser amounts of carbonate addition may be acceptable. Alkaline addition may also be viable on sites with largely weathered overburden.

14. The effects of overburden special handling are not completely understood. On Pennsylvania surface mines, keeping the material well above the water table and limiting infiltration into it seems best. Continuous submergence has been shown to limit pyrite oxidation by limiting exposure to oxygen. However, hydrologic conditions are not conducive to continuous submergence on most Pennsylvania mine sites which are frequently located in upland recharge areas with highly fluctuating water tables.

15. The use of bactericides is a management technique presently best suited to limiting water quality problems, not preventing them. As with other management techniques, using bactericides may reduce the severity of a problem but is unlikely to prevent a problem in a setting with a high acid mine drainage potential. While bactericides can reduce bacteria catalysis, the presence or lack of carbonates controls whether a site produces alkaline or acidic drainage.

16. Water management is another technique that can be used to limit the potential for mine drainage problems, but which cannot completely prevent problems on a site otherwise likely to produce acid mine drainage. The emphasis should be on keeping the quality of water coming into the site good through the use of tools like surface water diversions and highwall drains. While capping of a site with ash or clay may be a helpful abatement technique once mine drainage pollution has developed, it is not generally possible, nor desirable, to completely eliminate infiltration into a site.

17. Remining can be an effective way to simultaneously develop energy resources and to reclaim previously abandoned mine lands. Reducing pollution loads by reducing flow can be an effective abatement technique on sites with pre-existing poor quality discharges. Implementing a combination of the management techniques described in this document can also provide positive results. Certain sites with particularly negative conditions may not be successfully rehabilitated by remining.

Data interpreters that approach the prediction of mine drainage quality and the prevention of mine drainage pollution with the preceding key principles in mind will make the right decisions most of the time.

Examples of Predictive Decisions

Examples of sites for which permits were requested from the PA DEP are presented in this section. The goal here is to illustrate the thought process that was

used to make a decision - sometimes in the face of somewhat conflicting evidence - not to establish whether the decision was right or wrong. The examples were chosen because of the points which they illustrate about the principles found in the other chapters in this document, and not because they necessarily are representative of permits that are either issued or denied. The reader is cautioned that these examples should not be applied directly to other sites, rather, all the information presented in all the other chapters of this document must be used to make predictive decisions about postmining water quality.

Site 1

Site 1 is located in Cambria County, PA. The operation proposed removing coal from 69.7 ac (28.2 ha), primarily on the lower Freeport coal (LF) with some upper Freeport coal (UF) to be encountered incidental to the LF mining. The operator also proposed mining 11.5 ac (4.6 ha) of upper Kittanning coal (UK).

The overburden includes the entire Freeport Formation of the Allegheny Group rocks and the lowermost part of the Glenshaw Formation of the Conemaugh Group, all of Pennsylvanian Age. At this locale these rocks are freshwater deposits with plant fossils common. The sediments typically include a significant amount of carbonate-bearing rock, suggesting that mine drainage associated with these strata should be alkaline. There are exceptions where the shales and fresh water limestones are replaced by channel sandstones and under low cover conditions where the carbonates have been removed by weathering. On Site 1, there were no significant channel sandstone formations present, so the overburden was comprised of the typically expected thin interbedded sandstones, shales and limestones.

Previous mining on these coal seams in Cambria County has generally led to alkaline water, typically with low metals concentrations. Some discharges from these seams may meet drinking water standards, with the possible exception of sulfate concentrations.

Drilling on the site confirmed the expectations about overburden quality formulated from a basic knowledge of the site geology. The data from the individual overburden holes will not be presented here in the interest of brevity. However, Table 18-2 displays a summary of the overburden geochemical data for the site. The data for each drill hole were weight averaged based on the acres and total mass of overburden represented by each drill hole. In Table 18-2 the overburden for both the UF seam and LF are combined into the "L. Freeport" category because the UF was to be mined only where encountered in the course of mining the LF. The UK seam was to be mined separately; consequently, it was considered separately in the overburden calculations.

Table 18.2 Overburden analysis data summary for Site 1. Calculated without thresholds from five drill holes on the LF seam and three drill holes on the UK seam.

COAL SEAM	MPA	NP	NET NP
L. FREEPORT (total tons)	68748	412772	344024
L. FREEPORT (ppt $CaCO_3$)	9.68	58.09	48.42
U. KITTANNING (total tons)	4118	45395	41277
U. KITTANNING (ppt $CaCO_3$)	2.61	28.8	26.19

The data show a compelling excess of carbonates in the LF overburden. The net NP of 48.42 ppt $CaCO_3$ is well above the 12 ppt $CaCO_3$ identified by Brady et al. (1994) as necessary to ensure alkaline drainage. A similar case can be made for the UK mining where the net NP is 26.19 ppt $CaCO_3$. The net NP for the UK overburden takes into account a plan presented by the mine operator to scour the proposed pit floor, which was composed of approximately 0.7 ft (0.2 m) of low-sulfur clay to expose the top of the Johnstown limestone to any water on the pit floor. When analyzed using threshold values of 30 NP, 0.5% S, and a 1 fizz rating, the LF overburden showed a calcium carbonate equivalent of 6724 t/ac excess while the UK overburden showed a 3289 t/ac excess.

Row 1 of Table 18.3 represents premining quality of a spring/headwater tributary whose entire potential recharge area lies within the mining area. The premining spring quality is typical for shallow groundwater flow springs in the Appalachian Plateau except that the pH is higher than expected, probably due to the carbonates in the overburden. Note that the alkalinity is low, demonstrating a point made in Chapter 10 that, as expected, shallow groundwater springs often do not reflect groundwater and overburden quality under higher cover. The site geology, acid-base accounting overburden analysis data, and mining plan seems to indicate that this site could be mined with little threat of a problem.

There was one other significant factor to consider. The site is located on a relatively undeveloped watershed which is classified as High Quality and which supports a wild brook trout population. The receiving

stream has very little buffering capacity and is only marginally supporting the trout population because of elevated acidity and aluminum concentrations. The acidity and aluminum come from natural weathering of Pottsville Group rocks in the headwater areas of the stream and from acid precipitation. Given the stream conditions, even a relatively minor acid mine drainage discharge could eliminate the aquatic life in downstream areas. These facts raised significant public opposition to the proposed mining. This was a very high-risk site where even a partially wrong predictive decision could have caused significant downstream impacts.

Site 1 is typical of those where all, or nearly all, of the predictive factors need to point strongly toward alkaline drainage, because of the unusually high degree of risk. In this case, because the major predictive tools did point strongly toward alkaline low-metals drainage, the mining was approved. It was also thought that in-stream alkalinities could even be raised by accelerated weathering of the carbonate-rich overburden. Mining of this site is nearing completion as of the date of this writing. Row 2 of Table 18.3 shows the postmining quality of the headwater stream which originates within the mining area. Both alkalinity and sulfate have increased substantially. The sulfate levels should have no negative impacts on aquatic life, while the alkalinity increases in this small tributary should help buffer the natural acidity in the main stream to which it discharges. (Note that had a public water supply intake been located in close proximity downstream of the site, the potential sulfate increase was another risk factor which would have to be considered.)

Table 18.3 Median water quality at the mouth of the headwater stream emerging within Site 1, based on the first five premining samples and the last five postmining samples collected.

Date	Flow (gpm)	pH (su)	Alkalin. (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)	Sulfate (mg/L)
Premining	41.0	6.88	9	0.05	0.02	<.10	10
Postmining	15.0	7.92	159	0.06	0.03	0.11	327

Site 1 illustrates several of the key principles from the previous chapters. The key to interpreting acid-base accounting data, and the geologic setting, is to evaluate the amount of carbonates on the site (Chapter 11). Background groundwater information can be useful, but shallow groundwater springs may not fully represent site geology (Chapter 10). Not all surface coal mining sites make acid mine drainage, and high levels of alkalinity can be produced (Chapter 1). Special care must be taken in high-risk areas, but when the scientific data clearly shows that the risk of a problem is remote, the decision making should follow the lead of the data.

Site 2

Site 2 is also located in Cambria County, PA. Mining was proposed on 25.5 ac (10.3 ha) of lower Kittanning coal (LK), 28.8 ac (11.6 ha) of middle Kittanning coal (MK) and 8.6 ac (3.6 ha) of upper Kittanning (UK) coal.

The overburden on Site 2 includes all the Allegheny Formation and the lowermost section of the Freeport Formation in the Allegheny Group. In the area of this site, the LK and MK overburden rocks are generally brackish water deposits. Channel sandstone deposits frequently exist within a framework of finer-grained sediments such as shales and mudstones. Within the Allegheny Formation in this area, the only significant zone rich in carbonates is the Johnstown limestone horizon (freshwater) which is typically located at or a few feet below the bottom of the UK coal. The shale units, especially those which directly overly the LK and MK coals frequently include significant amounts of sulfide minerals. With the lack of carbonates in the overburden and the high sulfur shales located around the coals, one would expect LK and MK mining to produce poor quality water, although the role of the Johnstown Limestone has to be considered in that conclusion.

Surface and deep mining on the LK and MK seams in the area of Site 2 generally has resulted in acid mine drainage. Because of its persistence, thickness and quality, the LK seam has been extensively deep mined, so is generally available for surface mining only under lower cover. The MK seam, while usually of good quality, is usually not thick enough for deep mining and often occurs in multiple benches. Surface mining on these seams, therefore, often cannot take place to a high enough cover to encounter much, if any, of the Johnstown limestone. This is a case where the mining plan must be accounted for in interpreting the overburden analysis data. Holes drilled at high cover through the Johnstown limestone may indicate an ample excess of carbonates, but mining may be limited to low cover. While the overburden for these seams can be problematic, the previous mining that has occurred and the resultant unreclaimed spoil, deep mines and discharges

present remining opportunities at locations where appropriate mining plans can be developed.

The exploratory data on Site 2 confirms what is known about the regional geology. Over most of the site, the LK coal is directly overlain by a shale of 0 to 12 ft (0 to 4 m) in thickness. Above that is a thick channel sandstone, which cuts down to the top of the coal in places. There is a thin clay layer beneath the MK coal. The MK overburden over most of the site is shale, with minor sandstone units in places. The Johnstown limestone is not present on the site, but at the horizon where it would be expected, there is a shale unit which contains significant amounts of carbonate, as high as 27 % (NP = 270 ppt $CaCO_3$). Unfortunately, the high-carbonate shale exists only at the highest cover in an unweathered state and only a limited amount of it will end up in the backfill. The UK coal would be mined incidental to the MK on this site, and due to its thinness and weathering, it is doubtful that much of it is actually recoverable.

Table 18.4 displays a summary of the overburden data for the site. These data show a probability for the site to produce acid mine drainage. The LK overburden has a net NP of -5.80 ppt $CaCO_3$ and the MK has a net NP of -0.66 ppt $CaCO_3$. The positive NP for the MK overburden is from the carbonate in the Johnstown Limestone horizon. In terms of calcium carbonate equivalence, the LK overburden showed a deficiency of 653 t/ac and the MK overburden showed a deficiency of 65 t/ac.

Table 18.4 Overburden analysis data summary table for Site 2. Calculated without thresholds. Represents six drill holes on each coal seam.

COAL SEAM	MPA	NP	NET NP
L. KITTANNING (total tons)	14514	0	-14514
L. KITTANNING (ppt $CaCO_3$)	5.8	0	-5.80
M. KITTANNING (total tons)	15310	13433	-1876
M. KITTANNING (ppt $CaCO_3$)	5.4	4.74	-0.66

Table 18.5 shows the water quality associated with Site 2. MW-2 is a monitoring well drilled into the Kittanning sandstone of the Clarion Formation, but the recharge area for the well includes the area being mined. MD-1 is an abandoned LK deep mine discharge which is of acid mine drainage quality. The premining data from MW-2 represents natural background quality in an area of the site not substantially affected by previous mining. Note the low pH and natural acidity of the water reflecting the lack of carbonates in the overburden.

Table 18.5 Median water quality data from Site 2. MD-1 data represents the median values from 21 samples. MW-2 data represents the first 4 and last 4 samples collected

Sample Point	Date	pH (su)	Acid. (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)	Sulfate mg/L)
MW-2	Premining	5.3	8.5	2.06	0.26	0.30	48
MW-2	Postmining	3.5	150	16.80	14.40	6.92	427
MD-1	Premining	2.6	570	66.86	5.47	34.14	790

Mining on Site 2 included a proposal to daylight some of the abandoned deep mines, and to reclaim old spoil and an abandoned highwall on the site. The mining plan also proposed alkaline addition in the form of ash from a circulating fluidized-bed combustion boiler power plant, which burns coal refuse to generate electricity. The proposed ash had a NP of about 240 ppt $CaCO_3$ and the proposed ash addition rate was 2160 t/ac (4850 t/ha) averaged over the site, which equates to approximately 500 tons of calcium carbonate addition per acre (1,123 t/ha). The ash was to be added to the pit floor, mixed with the spoil, and added to special-handled material at different rates for each coal seam being mined. Effluent limits for two preexisting discharges on the site, including MD-1, would be determined by the baseline pollution load for the discharges under the Department's Subchapter F program.

The receiving stream at this site was already degraded by the past mining. However, approximately 4 to 5 miles (6.4 to 8 km) downstream, it does improve enough to allow for stocking of brook trout.

In this case a decision was made to permit the site. While many of the predictive factors indicated that there was a risk of mine drainage production, the benefits of the reclamation which would be gained were also weighed. Other mitigating factors were the alkaline addition proposal and the effluent limits equal to baseline conditions for the existing discharges.

Shortly after the permit was activated problems developed. Mining began in an area upgradient of MW-2. The postmining data for MW-2 in Table 18.5 showed that the character of the groundwater in the area began to change to one representative of acid mine drainage. A spring downgradient from the site showed similar changes. Factors considered as possible causes for the changes were an alkaline addition rate which may not have been high enough and rerouting of water from the existing deep mines along flow paths which could not be anticipated. Because the problems were identified early in the operation, changes were made to

the mining plan in an attempt to salvage the situation. At the time of this writing, these changes are being implemented. A series of anoxic limestone pit floor drains are being installed as mining progresses to route the deep mine water through the site without contacting additional acid-forming material. The operator is trying to obtain additional amounts of ash so the alkaline addition rate can be increased. Passive treatment systems may eventually be added to the end of the pit floor drains, depending on final postmining water quality. Mining at the site is on-going so the final outcome is unknown at this point.

Site 2, although its final results are unknown, illustrates several key points. The site geology (Chapter 8), premining groundwater quality (Chapter 10) and the acid-base account overburden analysis data (Chapter 11) were all in agreement as to the lack of carbonates on the site. That, along with the previous history of mine drainage (Chapter 9), indicated the potential for problems. Because the risk factors were relatively low in terms of direct in-stream environmental impacts and because of mitigating factors like reclamation work (Chapter 17) and a substantial alkaline addition proposal (Chapter 13), a decision was made to approve mining on the site. The problems that did develop illustrate the need to ensure a clear excess of carbonate on a site when alkaline addition is proposed (Chapters 1, 8, and 11); it also illustrates the need to understand and consider to the extent possible groundwater flow systems (Chapter 2) in and around the site, especially when there is pre-existing pollution present. The fact that adjustments could be made to the mining plan relatively early in the operation, with some hope of salvaging the situation, illustrates one of the benefits of a good groundwater monitoring plan and demonstrates the applicability of mitigation tools such as pit floor drains (Chapter 16).

Site 3

Site 3 is located in Somerset County, PA. The mining plan proposed the removal of 65.2 ac (26.4 ha) of upper Freeport coal, so the overburden to be disturbed was the lowermost portion of the Glenshaw Formation of the Conemaugh Group. As noted in the discussion of Site 1, in Cambria County, these sediments are typically freshwater shales and limestones, and significant amounts of carbonate can be present. However, as one approaches the Maryland border in southwestern Somerset County, conditions change.

Drilling data from Site 3 revealed that much of the overburden was a thick sequence of massive sandstone, although a shale unit did directly overlie the coal in some holes. On a mass-weighted basis across the site, sandstone represented 64% of the overburden, but in some locations comprised up to 90% of the overburden.

A monitoring well was installed on the site to determine background groundwater quality. However, the well was constructed with portland cement grout. When sampled during pump tests, the well would initially produce highly alkaline water, but the alkalinities would decline with time. It was apparent that the grout was affecting the well quality to an extent that the data from the well could not be reliably used, so background groundwater quality was an unknown for the site. The hydrologic setting for the site was such that there were no springs or discharges which could be reliably used to determine background quality. The UF seam had been mined on areas adjacent and near to the proposed mine site, resulting in acid mine drainage discharges.

Table 18.6 summarizes ABA overburden analysis data for Site 3. When analyzed without using thresholds the site has a positive net NP of 3.80 ppt $CaCO_3$. When examined using thresholds, there are no individual sampling units with a significant NP (>30 ppt $CaCO_3$), and very few units with >0.5% sulfur; the average calcium carbonate equivalence of the entire overburden column is -36.0 t/ac (-80.8 t/ha). This is a classic example of the low NP/low sulfur site that falls into the difficult gray area of interpretation for ABA data.

Table 18.6 Overburden analysis data summary table for Site 3. Calculated from six drill holes without using thresholds.

COAL SEAM	MPA	NP	NET NP
U. FREEPORT (total tons)	24912	57401	32489
U. FREEPORT (ppt $CaCO_3$)	2.91	6.71	3.80

The permittee drilled an overburden hole on one of the adjacent sites which had produced poor water quality to determine if there were geochemical differences between the proposed site and the adjacent site. That hole revealed an overburden column, when examined without thresholds, with a negative net NP of -3.45 ppt $CaCO_3$. With thresholds the calcium carbonate equivalence of the adjacent site was -1695 t/ac (-3084 t/ha). The adjacent site overburden had several

zones high in total sulfur. There were also lithologic differences between the sites in that there was a higher percentage of shale in the overburden of the adjacent site. It appeared that there was some validity to the argument that the results of the adjacent mining may not fully represent what could be expected to occur on the new site.

This proposed mine site was located on a high quality stream that supported a trout fishery. The stream had suffered some degradation from the nearby mine sites, some of which had mined the UF seam, but the fishery was still viable. In addition to the risk of degradation to a valuable stream, the risk of cumulative impacts was especially important here, because the stream had already suffered some degradation from the previous mining.

In the end, Site 3 was not permitted for mining. While there was some ambiguity in the ABA data, none of the predictive tools indicated that alkaline drainage was likely, and there were indications that acid mine drainage would result. The prevalence of sandstone in the overburden was a concern (Chapter 8). There was not a clear abundance of carbonates on the site (Chapters 1, 8 and 11); in fact, there was very little carbonate present. While the comparability of the historical water quality data from previous mining (Chapter 9) was questionable, there was no evidence that previous mining had produced good quality water in the vicinity. While the UF overburden is part of a geologic section that frequently does produce good quality water, the site-specific lithologies showed that the conditions which normally generate the alkaline drainage were not present on this site (Chapter 8). Background groundwater quality was essentially a piece of missing information here (Chapter 10.) This was a high-risk site in terms of its location on a high quality stream and the potential for cumulative impacts on a fishery. There was little positive data which supported mining.

Site 4

Site 4 is located in Redbank Township, Armstrong County. Approximately 30 ac (12.1 ha) of lower Kittanning (LK) coal were proposed to be mined on this site. The overburden comprises the lowermost section of the Kittanning Formation of the Allegheny Group. On-site drilling showed that shale made up most of the strata. The two overburden analysis holes on the site contained three percent sandstone, with the remainder of the strata being fine- grained sediments, primarily shale. The rocks to be disturbed were deposited in a shallow marine environment, based on the fossils found in them. Many of the fossils appeared to be comprised of secondary calcite (Richard Beam, PA DEP, personal communication, 1997).

The site had previously been surface mined to a relatively low cover height, so that most of the background groundwater quality was at least slightly affected by previous mining. In general, that water quality was alkaline with slightly to moderately elevated sulfate concentrations and low metals concentrations. The site setting is such that, beyond the mine site, the LK coal was overlain entirely by the Allegheny Group. Groundwater coming onto the site may have been deriving some alkalinity from the limestones higher up in that group (Richard Beam, PA DEP, personal communication, 1997).

Site 4 is located on the Mudlick Creek watershed. Mudlick Creek is classified as a cold water fishery, and supported aquatic life, including fish. However, previous mining had resulted in increased sulfates in the stream. The risk factors associated with this site could best be described as moderate: the stream was not of pristine quality and did not serve as a public water supply, but was nonetheless of decent quality.

Table 18.7 summarizes the ABA overburden analysis data for Site 4. The overburden included several feet of relatively high sulfur (%S >0.5) strata and several feet of strata with significant neutralization potential (NP > 30 ppt $CaCO_3$). However, the NP values were only marginally significant and the highest in either hole was 42 ppt $CaCO_3$. The NNP for the site was 1.00 ppt $CaCO_3$, calculated without using thresholds. The overburden analysis data considered alone indicate that Site 4 has a high probability of producing acidic drainage.

Table 18.7 Overburden analysis data summary table for Site 4. Calculated without thresholds. Represents weighted average of two drill holes.

COAL SEAM	MPA	NP	NET NP
L. KITTANNING (total tons)	70284	73336	3052
L. KITTANNING (ppt $CaCO_3$)	23.02	24.02	1.00

The lower Kittanning coal has been mined throughout northeastern Armstrong County and southwestern Jefferson County. The site conditions and overburden analysis results for Site 4 are typical of the LK coal in this area. The LK mines in the area have consistently

produced alkaline drainage with low metals concentrations, despite the overburden analysis data which indicate that acid drainage will occur. Adjacent mining is frequently given precedence when prediction tools conflict and where there are not hydrogeologic or other differences between sites which may lessen the validity of comparisons made between sites. Based largely on the results of previous mining done in the area under very similar conditions, Site 4 was permitted and mined.

Table 18.8 displays water quality data from a postmining discharge that emerged when Site 4 was completed. The data in Table 18.8 are average values of 10 samples collected from the discharge. The discharge is alkaline with low metals concentrations and moderately elevated sulfate concentrations.

Table 18.8 Median postmining water quality data from Site 4. Average values based on ten samples.

Sample Point	Date	pH (su)	Alk. (mg/L)	Acid. (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)	Sulfate (mg/L)
Discharge	Postmining	6.7	68	0	0.23	0.25	<.50	267

Site 4 illustrates a problem with interpreting neutralization potential values in the range of a few tens of ppt. It is typically unknown what carbonate minerals are present. The common iron-carbonate mineral siderite frequently produces NP values in this range. Siderite, as discussed in other chapters of this document, does not generate alkalinity. X-ray diffraction analyses were performed on the overburden for Site 4. The X-ray diffraction showed that the NP present on Site 4 was from calcite rather than siderite (Richard Smith, PA Geological Survey, personal communication, 1996). It is possible that the intimate association of the calcite with the pyrite inhibits pyrite oxidation. (The overburden samples containing significant percent sulfur were typically the samples which included the highest NP values.)

Site 4 illustrates the need to understand the geologic setting of the site being evaluated (Chapter 8). On Site 4 the LK overburden is of marine origin, while on Site 3 it is of brackish origin, which is a significant factor in the geochemical differences between the sites. The results from previous mining results was the key predictive tool used here (Chapter 9). The role of siderite, as discussed in several previous chapters also is a significant consideration here. As emphasized elsewhere in this chapter, predictive decisions need to be made in the context of all the available data; it would have been easy to mistakenly assume that Site 4 could not be successfully mined, if a decision was made based solely on the overburden analysis data.

Conclusions

Much progress has been made over the past twenty to twenty-five years toward better predictions of postmining water quality. One area where some of the greatest increases in understanding have come is in the use of ABA data and the corollary understanding of the important role that carbonates play in defining mine drainage quality.

There are four areas that stand out as needing further work to continue the progress so far made, and those engaged in research concerning mine drainage prediction are urged to pursue work in these directions to further advance the science:

1. Industry, consultants, academic researchers and regulators need to take a closer look at the vast amount of data currently available, and which continues to become available, to better record and refine predictive techniques. The best way to improve predictive tools is to study completed sites to determine which factors had the most significant role in influencing water quality. To this end a sound representative monitoring program for each site should be seen as providing a future benefit to all who have an interest in understanding postmining water quality
2. Kinetic tests need to be standardized if they are to fulfill their potential role as an important tool in predicting postmining water quality. The fragmented and repetitive nature of much of the work which has been done with these tests has made the interpretation of the results quite challenging.
3. The potential value of mitigating tools such as alkaline addition, special handling, bactericides, and hydrologic controls needs to be documented and understood. It is especially important to thoroughly monitor and study sites that employ one or more of these techniques.
4. There is a need to move into the realm of quantifying postmining predictions. Today, the best that can be obtained is a determination of whether drainage will be net alkaline or net acidic. In many sensitive areas it is necessary to go a step beyond to determine what concentrations of various parameters may occur.

While much improvement has been made over the past twenty years in predicting postmining water quality, there are significant advances yet to achieve. Those engaged in making predictions must always keep in mind that the best predictions will be those using as many of the predictive tools as are available.

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