# Section 3.0: Operational Best Management Practices

## Introduction

Some remining Best Management Practices (BMP) are operational procedures that specifically should or should not be implemented during mining. Other operational BMPs pertain to how, where, and under what circumstances a certain procedure should be employed or to what areal extent it should be implemented. The BMPs discussed in this chapter deal with a broad range of mining practices such as: the rate of mining, the speed of reclamation, handling and disposal of pit and tipple cleanings, auger mining, on-site coal stockpiling, issuance of permits with acid-forming overburden, coal refuse reprocessing, and the scope of underground mine daylighting.

In certain mine sites, the proposed remining operation is within a “gray area” with regard to whether the pollution load will be reduced or increased. In these marginal situations, there are operational procedures that, if implemented, can improve the likelihood of pollution load reduction. These operational BMP procedures are generally sound environmental practices even when the site is not considered marginal.

## Theory

The production of acid mine drainage (AMD) requires three basic components: a sulfide mineral (i.e., pyrite), oxygen, and water. If any one of these components is missing or controlled, AMD production will not occur. In the production of AMD, pyrite is oxidized to form hydrous iron sulfates (salts). Pyrite oxidation is catalyzed to a high degree by the iron-oxidizing bacteria *Thiobacillus ferrooxidans* (Erickson and others, 1985). These salts are subsequently dissolved in water and a hydrolysis reaction occurs yielding acidity ($H^+$), iron ($Fe^{2+}$), and sulfate ($SO_4^{2-}$). AMD production can be attenuated or prevented if:

- Pyrite is not present in significant quantities.
- The contact of oxygen with pyrite is limited or prevented.
- The proliferation of iron-oxidizing bacteria is prevented.
- The contact of ground water with pyritic materials is prevented.

The BMPs discussed in this chapter are based on limiting one or more of the basic components that cause the formation of AMD.

## Site Assessment

The mining operation should be reviewed in terms of whether or not the concurrent reclamation is an viable option. Will the topography, type of surface mining, number of coal seams, mining equipment allow for concurrent reclamation? Are there other factors that may impact the speed of reclamation? If so, the question of how these factors be mitigated to ensure concurrent reclamation should be addressed.

As part of site assessment, the amount of tipple refuse material that the remining will produce should be determined. This determination will require lithologic logs and chemical analyses of the coal, partings, and enclosing strata. Information should be provided on how this material will be segregated and temporarily stored on-site. The type and location of an off-site disposal facility also should be given.

Information on the hydrogeologic properties of the site should be obtained. The location, direction, and depth of auger mining needs to be delineated on mine maps. Depth of the overlying cover also needs to be determined from drill holes. Using monitoring wells and boreholes, the stratigraphic location of aquifers can be determined. Aquifer tests (e.g., slug or constant-discharge tests) will yield information on the hydraulic properties (transmissivity and hydraulic conductivity) of the aquifers. Water levels in the monitoring wells should be measured at least monthly to determine seasonal variations and response to precipitation. A literature review of spoil testing and/or on-site testing of existing spoils, where present, will provide data on the projected hydrologic properties of the post-mining backfill. Analysis of the hydrogeologic data will yield insight into the potential post-mining water levels with respect to the auger holes.

Assessment of on-site coal stockpiling will require information on coal sulfur values, location and construction details of the stockpile pad, and determination of pad construction material (e.g., clay or other low-permeability substance). Engineering specifications on the pad material compactibility, permeability, and stability should be available. Available space to construct a treatment facility down gradient for any stockpile leachate should be demonstrated. If on-site stockpiling is deemed undesirable, an operational plan to haul off-site the coal as soon as it is excavated should be required.

Assessment of the additional overburden to be disturbed by remining requires that the overlying rocks be analyzed using standard overburden analysis techniques as described in Section 2.0, Geochemical BMPs. The drill holes need to be distributed in a manner to ensure that the entire site is characterized. The overburden analysis can be used to calculate alkaline addition rates, if needed.

Refuse piles commonly contain areas where burning has occurred in the past from spontaneous combustion or ignition by trash fires. If these areas are extensive, they can dramatically impact the economics of the operation. The refuse pile needs to be drilled to the extent that an accurate assessment of the amount of recoverable coal can be made. Once reprocessed, some type of cover material that will support vegetative growth is required. Availability of enough topsoil or a soil substitute to reclaim the site also needs to be determined. A survey of support areas surrounding the pile will yield information regarding the on-site availability of topsoil materials.

A pre-remining assessment of the amount of daylighting that will occur should be performed. This assessment is based on the amount of cover to be disturbed and, perhaps more importantly, on the amount of recoverable coal. Determination of the recoverable coal reserves needs to be accurate. This level of accuracy is achieved by an extensive drilling program. It is not uncommon for different sections of an underground mine to contain significantly different recoverable percentages. If these differences exist they need to be delineated. If the entries are relatively open, a borehole camera can also be used to visually inspect the remaining pillars. The amount of cover can likewise be determined by drilling.

## 3.1 Implementation Guidelines

***Rapid Mining and Concurrent Reclamation***

In recent years, many mine operators have come to the realization that expedient reclamation reduces the potential for AMD production. Concurrent reclamation thus, has become an integral part of mining operations. The speed at which mining and subsequent reclamation are conducted can have a substantial impact on the resulting post-mining water quality. Accelerated pyrite oxidation occurs when the overburden is broken up and exposed to atmospheric oxygen. The process of overburden removal during mining breaks the rocks into clay- to large boulder-sized particles, which increases the exposed surface area by several orders of magnitude. This greater exposed surface area in turn greatly increases the potential amount of pyrite that is freshly exposed to the atmosphere and is susceptible to oxidation. A certain amount of pyrite oxidation is expected and inevitable in the course of surface mining. However, when a mine spoil is permitted to remain exposed to the atmosphere for a protracted period of time prior to reclamation, accelerated and extraordinary oxidation of the pyrite-rich rocks (>0.5 percent total sulfur) in the overburden can occur.

The scale and scope of acid mine drainage formation from mining cessations depends on several factors, including but not limited to:

- Length of the cessation period;
- Amount and sizes of pyrite-rich rocks that are exposed;
- Concentration of the pyrite in the exposed rocks; and
- The form of the pyrite (e.g., massive versus widely disseminated).

Other geochemical factors also come into play in the protracted cessation scenario. The chemical reactions that create acid mine drainage are accelerated by protracted subaerial exposure. The chemical reactions that can prevent or ameliorate AMD are attenuated by this exposure. If present, alkaline materials (e.g., calcium carbonate-rich rocks) will yield alkalinity to water when exposed. At atmospheric carbon dioxide ($CO_2$) concentrations (mean 0.03 percent by volume or 0.0003 atmosphere), an approximate maximum of 61 mg/L as bicarbonate ($HCO_3^-$) alkalinity or 20 mg/L calcium can be released into water (Hem, 1989; Smith and Brady, 1998). When alkaline rocks are buried, they can yield substantially more alkalinity through calcium carbonate dissolution. The release of alkalinity is governed by several factors, including to a large extent the $CO_2$ concentration of the surrounding atmosphere. Figure 3.1a illustrates the relationship between the solubility of calcium carbonate in water at 25°C and the partial pressure of $CO_2$ ($Pco_2$) in the atmosphere. Lusardi and Erickson (1985) and Cravotta and others (1994) recorded $CO_2$ concentrations in mine backfills exceeding 20 percent by volume. A $Pco_2$ of 0.2 (20 percent) is capable of yielding calcium concentrations up to and exceeding 200 mg/L, which yield substantially higher bicarbonate alkalinities (610 mg/L) than produced at atmospheric $CO_2$ concentrations.

Unreclaimed spoil will likely produce much less alkalinity than the same spoil after reclamation has occurred and once the natural background levels of gases in the vadose zone are re-established. Carbon dioxide is produced in soils from plant root respiration and bacterial decay of organic matter. Concentrations of 1 to 2 percent in soil are common. However, higher concentrations can occur (Jennings, 1971). When spoil is unreclaimed there is no soil cover to aid $CO_2$ production and retard its escape. Exposed spoil is highly subject to advective forces driven by winds, temperature gradients, and other factors, which permit the flow of the surrounding atmosphere through the piles. With continual advection, near atmospheric levels of $CO_2$ are maintained within the spoil. Figure 3.1b illustrates advective impacts on unreclaimed mine spoil. The relatively low permeability of a soil cover slows the rate of gases released from the backfill, thus preventing the escape of $CO_2$ once it is introduced into the subsurface. Infiltration of atmospheric gases into the spoil is likewise impeded by the soil cover.

**Figure 3.1a: Relationship Between the Solubility of Calcium Carbonate and the Partial Pressure of Carbon Dioxide at 25°C (modified after Hem (1989))**

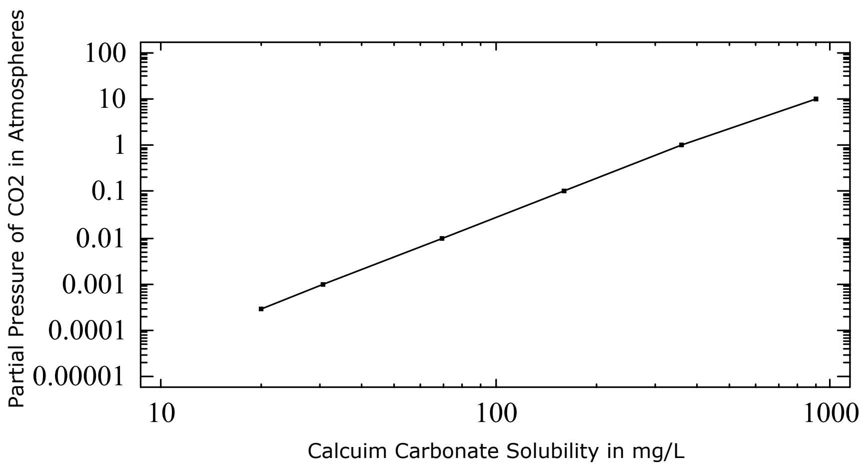
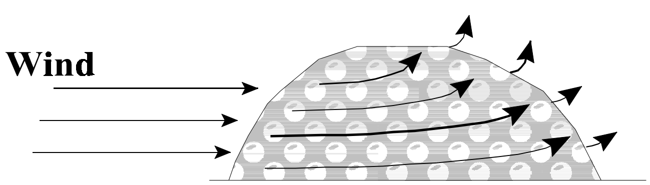



**Figure 3.1b: Advective Impacts on Unreclaimed Mine Spoil**



The reaction rate of sulfide (pyrite) oxidation and subsequent hydrolysis to form AMD is generally much faster than the dissolution of calcium carbonate to yield alkalinity under normal backfill conditions. With prolonged atmospheric exposure of spoil, this inequity of reaction rates is accentuated even more. The rate-determining step for AMD production at low pH is the oxidation of ferrous iron ($Fe^{2+}$) to ferric iron ($Fe^{3+}$) which is facilitated (catalyzed) by certain iron oxidizing bacteria (Stumm and Morgan, 1996) that thrive under acidic conditions. Then, because the $Fe^{3+}$ will oxidize pyrite much faster than $O_2$ (atmospheric oxygen) in a low pH environment (Rose and Cravotta, 1998), AMD production greatly increases once a low pH is established. Substantial pyrite oxidation from protracted mining cessation and associated spoil exposure can accelerate the progression to this higher phase of AMD production. With accelerated AMD production, any alkalinity that is released may be overwhelmed, resulting in a net acidic discharge. If the backfill is prevented from reaching this high rate of AMD production, alkalinity released from the spoil may be able to prevent or neutralize AMD.

Some possible exceptions to the necessity of this operational BMP include but may not be limited to those listed below.

- Situations where the pyritic content of the overburden material is extremely low, there are no disturbed rock units with any significant pyrite concentrations or most overburden samples are well below the threshold of concern (0.5 percent total sulfur). For example, overburden associated with many of the coals in the southern West Virginia coalfields fall into this category. Table 3.1a summarizes overburden analysis data from a surface mine located in Logan County, West Virginia. These data are indicative of the low-sulfur values common to these coalfields, but they are not necessarily representative of the quality of the entire coalfields.
- It is possible that the application of massive amounts of bactericides on the unreclaimed spoil may temporarily prevent the deleterious effects of a protracted cessation. Bactericides can, for a time, dramatically slow the rate of pyrite oxidation. However, the use of bactericides on surface mines in the past has been less than successful. Some success has been observed for the temporary stockpiling of coal refuse subsequent to

burial (Sobek and others, 1990). Additionally, because the use of bactericides is expensive, it may not be economically feasible for many remining operations.

**Table 3.1a: Summary of Overburden Analysis Data from a Surface Mine Located in Logan County, West Virginia**

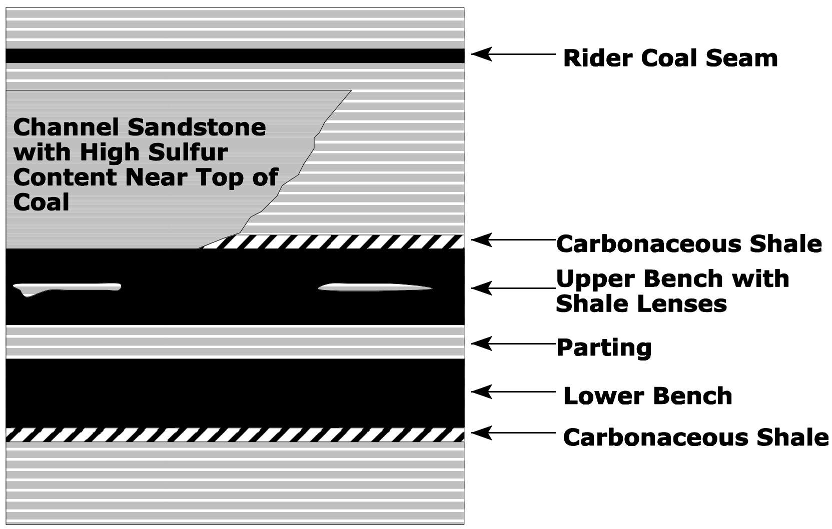
| Coal Seam | Total Overburden Thickness ( feet) | Sample Thickness Range ( feet) | Highest Sulfur Value (percent) | Lowest Sulfur Value ( percent) | Median Sulfur Value ( percent) |
|---|---|---|---|---|---|
| Lower Stockton | 44.70 | 1.30-15.00* | 0.10 | <0.01 | <0.01 |
| Lower Stockton Leader | 14.95 | 0.95-3.65 | 0.09 | 0.02 | 0.04 |
| Upper Stockton "A" | 16.40 | 1.60-3.40 | 0.06 | <0.01 | 0.03 |
| Lower Stockton "B" | 95.10 | 0.30-5.00 | 0.10 | <0.01 | <0.01 |
| Coalburg | 91.05 | 0.30-5.00 | 2.21** | <0.01 | 0.01 |

* The first 15 feet of soil and subsoil was grouped.
** This was a 1.45 foot thick unit and the only one to exceed 0.50 percent total sulfur.

### *Off-Site Disposal of Acid-Forming Materials*

In the course of a remining operation, quantities of acid-forming rocks associated with the coal (e.g., pit and tipple cleanings) are removed and frequently stockpiled for later disposal within the spoil. These rocks include rocks immediately overlying the coal (commonly a black shale or pyritic sandstone), parting or binder (usually a carbonaceous black shale or bone coal), immediate seat rock (carbonaceous and/or pyritic shales or claystones) removed along with the coal, unsaleable rider or split seams, and other acid-forming materials separated from the coal during loading out of the pit or during the initial coal cleaning at the tipple/breaker. See Figure 3.1b for examples of sources for pit and tipple cleanings. Total sulfur concentrations of several percent are common in these rocks. Table 3.1c contains total sulfur values for stratigraphic sections surrounding the coal in an overburden analysis hole drilled on a remining site is located in Westmoreland County, Pennsylvania (Appendix A, EPA Remining Database, 1999, PA(3)).

**Figure 3.1c: Potential Sources of Pit and Tipple Cleanings**




Remining operations typically occur on abandoned mine sites that are already producing AMD from prior coal mining activities. Therefore, it is generally a sound practice to remove acid-forming materials from the remining site and dispose of them elsewhere. Disposal of materials that have been identified as acid-producers within backfill that is already producing AMD has the potential to accentuate or aggravate the existing problem.

**Table 3.1b: Total Sulfur in Stratigraphic Sections Enclosing the Coal at a Remining Site in Westmoreland County, Pennsylvania (Appendix A, EPA Remining Database, PA(3))**

| Lithology | Interval Thickness (feet) | Total Sulfur (Percent) |
|---|---|---|
| medium gray claystone | 1 | 0.80 |
| black shale | 1 | 1.86 |
| coal | 1 | 2.31 |
| grayish black shale with coal layers | 3 | 1.16 |
| coal | 6 | 1.01 |
| medium dark gray calcareous fireclay | 1 | 1.48 |

There are a few circumstances that would allow on-site disposal of acidic pit and tipple cleanings while limiting the potential to produce more acid. These conditions include, but may not be limited to:

- Sites where the overburden is composed to a great extent of calcareous (alkaline) material. Any potentially acidic material can be entirely encapsulated within this material. In these situations, the production of alkalinity will most likely either preclude acid production (iron oxidizing bacteria do not thrive in an alkaline **environment**) or overwhelm any acidity that is produced.
- Sites where the amount of pit and tipple cleanings are relatively small in volume and insignificant compared to the entire volume of the spoil. In these cases, the acidic material can be specially handled (e.g., strategically placed, capped, encapsulated, etc.) to prevent additional acid production. Care should be taken in these situations to ensure that the special handling technique is physically viable (See Section 2.4, Special Handling of Acid-Forming Materials). For example, if the special handling plan is to place the acid-forming materials above the water table, the backfill should be thick enough allow material placement well above the anticipated highest level of the post-mining water table.

### *Auger Mining*

Similar to on-site disposal of pit and tipple cleanings, auger mining during a remining operation is generally not recommended. Auger holes, depending on the hydrologic system of the site and the sulfur content of the coal, have a high potential to create additional AMD. Because remining sites are usually already yielding AMD, it is generally not a good practice to permit auger mining.

Auger holes can create similar environmental conditions to those previously described for underground mine workings, substantially increasing exposed surface areas in potentially acidic strata. Ground water entering the auger holes contacts primarily coal and perhaps a minor amount of roof and seat rock. All three of these rock units are composed of potentially acid-forming materials as illustrated in Table 3.1c. At the final highwall, auger holes typically are sealed with a low-permeability material to a depth up to three times the diameter of the hole. The sealed holes are then covered with spoil. A large portion of the holes remains empty, allowing the exposure and possible oxidation of pyrite. Ground water entering auger holes will dissolve the salts created by the pyrite oxidation and subsequently hydrolyze, creating acid mine drainage.

The amount of increased surface area caused by auger holes can be considerable compared to exposure of the remaining coal at a final highwall. For example, a mine with a 1000-foot final highwall, no augering, and a four-foot coal seam would have 4000 $ft^2$ of coal exposed prior to reclamation. If the same site incurred augering, the exposed surface area would include the area defined by the auger holes plus the remaining coal exposed at the highwall. If the auger holes were 3.5 feet in diameter, spaced on eight-foot centers (leaving one foot between holes) and augered to a depth of 400 feet, the additional area is equal to 549,750 $ft^2$ or an increase in exposed surface area of over two orders of magnitude (137-fold).

In addition to the increased exposure of acid-forming materials, the hydrologic system of the auger holes is drastically different from spoil that is simply backfilled against a highwall. These differences in the hydrology can result in differences in the types of drainage produced. The nature of many surface mines may permit the auger holes to experience alternate dewatering and flooding, which allows oxidation of pyrite followed by flushing from the influx of ground water. Depending on the dip of the strata, overlying topography, aquifer characteristics, and other hydrogeologic factors, it is possible that the coal will be below the water table. If the water table levels are somewhat stable and the coal lies below water level, the coal seam will be essentially inert in terms of AMD production, because of the exclusion of atmospheric oxygen. Thus, depending on the hydrologic system, auger holes can become AMD generating systems.

There are circumstances where auger mining may be permissible at remining operations with little chance of increasing the pollution load. These include, but are not limited to:

- If the hydrologic system is such that the auger holes are likely to be flooded and remain so permanently, auger mining may be acceptable. Permanent flooding will preclude the introduction of atmospheric oxygen, thus the acid mine drainage production should cease. Watzlaf (1992) and Watzlaf and Hammack (1989) observed that subaqueous positioning of pyrite virtually stops the oxidation. Even if the ground water is saturated with dissolved oxygen (12.75 mg/L at 5°C (Hem, 1989)), pyrite oxidation is halted by submersion. Augering below the regional drainage system will likely allow for complete and permanent inundation the auger holes.
- Augering above regional drainage may be permissible if auger hole sealing can be achieved to a degree that precludes the infiltration of atmospheric oxygen and/or inhibits ground-water drainage from the holes. If the auger holes, once sealed, flood and the flooded conditions are maintained, AMD production should be prevented.

***Stockpiling of Coal***

Stockpiling of coal on-site for extended periods is not recommended. Coal is often the most acidic material encountered during mining and therefore can produce the worst water quality. Leaving a large stockpile of acidic material exposed to the atmosphere and precipitation will create extremely acidic, metal-laden water that can infiltrate into the backfill and foster additional AMD production.

Often the least saleable coal is the coal with the highest sulfur concentration. This lower quality coal is commonly held until it can be blended with a higher quality (lower sulfur) coal to promote sales. This coal is the most frequently stockpiled and held for extended periods of time, prior to sale. This coal also creates some of the worst water quality associated with coal mining.

Acidity concentrations in the thousands of milligrams per liter are not uncommon for water draining from these stockpiles. Concentrations exceeding even 10,000 mg/L have been recorded. Total iron concentrations frequently exceed 300 mg/L. If drainage of this quality enters the ground-water system, AMD production within the backfill can greatly accelerate. Thus, it is probable that more AMD will be produced under this scenario than would be produced if the two sources (stockpile and backfill areas) remained hydrologically separate. Additionally, if stockpile runoff infiltrates into the spoil, it may overwhelm any natural alkalinity in the backfill. The alkalinity in the backfill may be able to ameliorate acid production from the spoil, but not from the additional high-acid source. Exceptions to this BMP include, but are not limited to, sites where:

- The coal has an extremely low reactive sulfur (pyritic and sulfate) concentration (<0.5 percent).
- The stockpile and associated treatment facilities are underlain by a liner material to prevent infiltration and the runoff is treated to effluent standards prior to discharging. The liner material, commonly an on-site clay, should be nonacidic and have a sufficiently low permeability (e.g., less than $10^{-8}$ m/s).
- A bactericide is used to prevent or delay the oxidation of the pyrite. This is only a short-term solution, and the bactericide may have to be reapplied periodically.
- The stockpile is covered or otherwise sheltered to prevent the infiltration of precipitation.
- The amount of time the coal is permitted to stay on-site (e.g., one or two weeks) and perhaps the size of the stockpile are greatly limited.

### *Consideration of Overburden Quality*

There are cases where hydrogeologic conditions inherent to specific sites will (with remining) cause the pollution load to be increased. Permits for these sites are not issuable. The potential for reclaiming abandoned mine lands should not override the potential to increase the pollution load. The decision of whether or not to issue a remining permit to some extent hinges on the quality of the overburden material. The associated strata for some coal seams in certain areas of the coalfields are going to produce AMD if disturbed by surface mining. When mining occurs on these sites, there is little that can be done to prevent AMD.

AMD emanating from abandoned and unreclaimed surface mines does not necessarily have to be caused by poor mining and reclamation practices in the past, such as improper handling of acid-forming materials, poor ground- and surface-water handling practices, open pits, exposed highwalls, unclaimed and unvegetated spoil piles, and protracted on-site coal stockpiling. The cause of the AMD can be due, in some cases, to the fact that the overburden quality is such that AMD production was almost inevitable. The overburden is simply net acidic.

A particular rock unit in a coal overburden is considered acidic if the net potential acidity, based on the total sulfur content, exceeds the net potential alkalinity, based on the neutralization potential. Both these values are given in terms of calcium carbonate equivalency. The threshold for significant acid-producing potential of a particular rock unit has been empirically derived as 0.5 percent total sulfur by weight (Brady and Hornberger, 1990). At or above this value, the rock unit has a good potential to produce acid mine drainage. The threshold for significant alkalinity generation has been empirically defined as a neutralization potential of 20 to 30 (tons per thousand tons calcium carbonate equivalent) with a noticeable “fizz” (Brady and Hornberger, 1990; Perry, 1998). A fizz is the effervescence that is released when a few drops of a 25 percent solution of hydrochloric acid is applied on sufficiently alkaline material (Kania, 1998). For a comprehensive and detailed discussion on overburden analysis and mine drainage prediction the reader is directed to “Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania” (1998), published by the Pennsylvania Department of Environmental Protection.

In situations where the overburden quality is such that additional AMD production is predicted, and BMPs will not effectively offset additional AMD production, remining should not take place. In some cases, where it is economically feasible, other BMPs can be increased to compensate for and prevent the increased acid-production. BMPs that can be used to offset the effects of acidic overburden include, but are not limited to:

- Alkaline addition based on the net acidity of the material. Alkaline addition rates above the net acidity for the spoil are recommended to provide a margin of safety and offset the inequity of the reaction rates (See Section 2.2, Alkaline Addition).
- Removal and off-site disposal of delineated acidic material (See Section 2.4, Special Handling of Acid-Forming Materials).
- Encapsulation of the acidic material within an alkaline or a low-permeability material (See Section 2.4, Special Handling of Acid-Forming Materials).
- Physical ground-water controls such that either the water will not contact the acidic spoil or the forecasted decrease in post-mining flow rates are more than sufficient to offset the projected increase in concentration (See Section 1.2, Exclusion of Infiltrating Ground Water).

If the proposed BMPs are sufficient to overcome the acid potential expressed by the overburden, remining without contributing to AMD production may be possible. This evaluation will have to be made on a case-by-case basis. A significant decrease in the flow rate may be able to more than compensate for a predicted increase in concentration. For example:

> An extensive daylighting operation is forecasted to decrease the discharge rate from a median of 300 gpm to a median of 80 gpm. The pre-mining median acidity concentration is 120 mg/L, which yields a median pollution load of 433 lbs/day of acidity. The overburden, which has been identified as potentially acidic, will be disturbed by the daylighting. This scenario could accommodate an increase in the median acidity concentration to 450 mg/L without a concomitant acidity load increase.

It is recommended that remining permits, where the contaminant concentrations are predicted to be increased, either be amended to include BMPs to prevent additional pollution or be reconsidered for issuance. However, the opportunity to gain significant reclamation without truly increasing the pollution load may bear heavily on the final permitting decision.

***Coal Refuse Reprocessing or Cogeneration Usage***

Remining operations where abandoned coal refuse piles are reprocessed to glean out the remaining coal or the entire pile is excavated and hauled to a electricity-producing cogeneration plant are almost without exception highly beneficial. These operations remove a significant portion of the acid-forming materials in addition to regrading and vegetating the remaining material to inhibit water infiltration. All reprocessing activities work to greatly reduce, if not eliminate, the pollution load.

Abandoned coal refuse piles are common in areas with historic mining. In the past, the coal cleaning process was not nearly as rigorous or technologically advanced as it is today and large piles of waste material were dumped at the surface. Older coal refuse piles tend to have commercially recoverable quantities of coal or enough burning ability for use in newer technology, such as electrical cogeneration.

These piles, even though some may be approaching 100 years old, are still producing AMD. The coal and true refuse material (e.g., carbonaceous black shales, some roof and seat rock) that comprise refuse piles usually have a significant sulfur content (>0.50 percent total sulfur) making acid generation almost inevitable. Acid production is additionally facilitated by the fact that coal refuse does not readily support vegetation. The acidic nature of the refuse inhibits plant growth, and the commonly dark color generates considerable heat in the summer causing heat toxicity. Without vegetation, the infiltration of atmospheric oxygen and surface water into the pile is virtually unimpeded, promoting continual acid generation within the pile. If the size of the piles and the amount of acid-forming material they contain can be reduced, and if the piles can be regraded, topsoiled, and vegetated, the volume of acid generation will be reduced. In the case of refuse used in cogeneration, the entire pile is commonly removed for burning, and ash from the cogeneration plant is frequently returned to the site. This ash, depending on the type of cogeneration plant and original sulfur content of the refuse, may be highly alkaline.

It is not uncommon for refuse piles located in the bituminous regions of western Pennsylvania, eastern Ohio, and northern West Virginia to have rates for recovery of coal from coal refuse piles exceeding 20 percent. Similar values are found elsewhere in the coalfields. Some positions within individual piles have reportedly had recoveries exceeding 50 percent. Much of this coal is economically recoverable using modern coal processing techniques, and many of these piles (anthracite and bituminous) have overall burning abilities of several thousand BTUs. This refuse is commonly burned in conjunction with oil, natural gas and other materials to produce heat or electricity. Because of the relatively high sulfur content, limestone is frequently burned with the refuse to aid in desulfurization of the smoke stack emissions. The ash created is commonly alkaline and can be returned to the site or used at other sites to add alkalinity.

The operation of reprocessing performs several functions that work toward reducing the pollution load. First, a significant portion of the pile, containing acid-forming materials, is removed. Second, the refuse material is crushed to a much finer particle size and, when replaced, the pore space percentage is dramatically reduced. Thus, water will move through the piles more slowly, and much less water will be stored. It will also be more difficult for water to infiltrate initially. These piles are regraded to promote surface water runoff and reduce infiltration. The piles are topsoiled and vegetated, which also reduces surface-water infiltration and inhibits the infiltration of oxygen into the pile. In other words, reprocessing has the ability to reduce the rate of acid generation, reduce the amount total amount of acidity generated, and reduce the discharge rate from the pile.

The use of refuse piles for cogeneration has the potential to completely eliminate acid generation from these piles. Complete removal removes the acid-generating source. Additionally, if alkaline coal combustion waste (CCW) is returned, the site may begin yielding alkaline waters, offsetting acid generation elsewhere in the basin from other piles where remining is not economical.

Very few limitations exist for coal refuse reprocessing or cogeneration use. However, the potential exists that if a relatively stable (physically and geochemically) pile is excavated, acid generation may be reactivated or accelerated. The sediment load could also be increased, albeit temporarily. In the case where CCW is returned to the site, care should be taken to ensure that higher amounts of trace metals will not be liberated from the ash. Testing of the CCW, for example by using the Toxicity Characteristic Leaching Procedure (TCLP), should performed to establish the potential for trace metals leaching.

***Maximizing Daylighting***

In general, daylighting as much area of an abandoned underground mine as possible yields positive results in terms of reducing pollution loads. Daylighting can work both physically and geochemically to effect a pollution load reduction.

First, and perhaps the most salient mechanism that works toward reducing pollutant loads, is the reduction of potential surface water infiltration zones. As previously discussed in Section 1.2, daylighting tends to eliminate large portions of subsided mine sections where considerable vertical ground-water infiltration into the mines occurs. The reduced infiltration rates in turn facilitate reduced loads. Surface-expressed subsidence features, such as exposed fractures and sinkholes, tend to collect surface and ground water and divert it directly into the mine. When surface mining eliminates these subsidence features, water infiltration into the mine is significantly reduced. Daylighting also eliminates substantial void spaces that serve as mine water storage areas, which tend to facilitate a more continuous source of lateral recharge to the adjacent reclaimed remining operation.

Daylighting dramatically changes the ground-water flow system from open conduit-type of underground mines to the double-porosity system exhibited by mine spoils (Hawkins, 1998). In underground mines, once ground water has entered the workings, it tends to contact only seat rock, roof rock, and coal. All of these units are commonly sulfur-rich, hence, potentially acid-producing (Table 3.1c). The data in Table 3.1c is from a mine in Donegal Township, Westmoreland County (Appendix A, EPA Remining Database, 1999 (PA(5)). The strata that the ground water will contact in this mine, based on this drillhole, have a total sulfur range of 0.574 to 1.637 percent. In short, everything the water contacts is potentially acidic (i.e. <0.50 percent). Once in the underground mine, ground water tends to follow the path of least resistance, which is through the open void areas. Therefore, the ground water continues to contact acidic rock units until it exits the mine via a discharge point or infiltrates into other ground-water systems (e.g., adjacent surface mine spoil or undisturbed strata).

Once surface mining and reclamation have occurred, the ground-water flow system changes dramatically, and the strata encountered are reflective of the entire overburden quality. Rather than only encountering acidic strata exposed in the underground mine, ground water will contact strata in the spoil that can be potentially alkaline or acidic or relatively inert. The amount of each type of rock intersected by the ground water is directly related to the volume of the material in the spoil, and to some degree, the mining and reclamation methods. Daylighting operations may need to have special conditions to require mining to a predetermined overburden thickness to ensure that a sufficient amount of alkaline strata are encountered and spoiled.

**Table 3.1c: Coal and Enclosing Strata Sulfur Values (Appendix A, EPA Remining Database, 1999, PA(5) hole OB-5)**

| Interval | Lithology | Total Sulfur (percent) |
|---|---|---|
| 95-97 | light gray shale and interbedded sandstone | 0.344 |
| 97-98 | medium dark gray clay shale | 0.574 |
| 98-101 | coal -Lower Kittanning | 1.637 |
| 101-104 | light gray fireclay | 1.201 |

Table 3.1d summarizes overburden analysis data from an acid-producing underground mine in Armstrong County, Pennsylvania, on the Upper Freeport Coal. The data illustrate that the coal itself is the acid-producing rock unit, with total sulfur ranging from 1.60 to 2.78 percent. Remining will remove most of the coal. As is common with most daylighting, some of the coal will be unrecoverable. On the other hand, the overburden itself exhibits relatively low total sulfur values (i.e., <0.50 percent). Total sulfur in the overburden ranges from 0 to 0.32 percent with the bulk of the strata being less than 0.10 percent. However, the overburden does exhibit several zones of significant alkaline material with neutralization potential (NP) of up to 209.7 tons of calcium carbonate equivalent per thousand tons. About 22 feet or 26 percent of the overburden exhibited NPs exceeding 30.

When the overburden is removed and then replaced, this material is highly broken up, increasing the exposed surface area, and it is mixed to some degree in the backfill. Ground water should contact each stratum to a degree similar to the volumetric content of that rock unit. Therefore, in the aforementioned site, roughly one fourth (26 percent) of the time during transit through the spoil the ground water should be contacting alkaline strata. Most of the remaining time, the material encountered by the ground water will be relatively inert in terms of acidity and/or alkalinity production. Thus, once mining has occurred at this site, the ground water will contact very little acid-producing materials. This illustrates how daylighting has the potential to greatly improve the quality of the material that the ground water will potentially contact.

**Table 3.1d: Overburden Analysis from an Acid-producing Underground Mine in Armstrong County, PA (Appendix A, EPA Remining Database, 1999, PA(6) hole OB-4).**

| Interval | Lithology | Total Sulfur (percent) | Neutralization Potential (tons per 1000 tons of $CaCO_3$ equivalent) |
|---|---|---|---|
| 0-1 | soft light brown sandstone | 0.02 | 0.47 |
| 1-5 | medium light gray clay | 0.02 | 3.15 |
| 5-10 | dark yellowish brown sandstone | 0.01 | 5.29 |
| 10-17 | pale yellowish brown sandstone | 0.04 | 9.63 |
| 17-20 | dark to medium brown sandy shale | 0.16 | 6.41 |
| 20-25 | moderate brown shale | 0.04 | 8.77 |
| 25-28 | medium gray shale | 0.14 | 3.73 |
| 28-31 | pale red to grayish red shale | 0.02 | 3.50 |
| 31-33 | moderate yellowish brown shale | 0.02 | 40.1 |
| 33-35 | moderate yellowish brown shale | 0.03 | 44.07 |
| 35-38 | pale brown sandstone | 0.00 | 29.85 |
| 38-40 | pale brown sandstone | 0.02 | 29.85 |
| 40-42 | pale brown sandstone | 0.02 | 209.70 |
| 42-45 | dark yellowish brown shale | 0.04 | 4.66 |
| 45-48 | dark yellowish brown shale | 0.00 | 7.00 |
| 48-51 | dark yellowish brown shale | 0.04 | 82.05 |
| 51-54 | dark yellowish brown shale | 0.00 | 125.82 |
| 54-56 | dark yellowish brown shale | 0.02 | 7.46 |
| 56-58 | dark yellowish brown shale | 0.02 | 5.60 |
| 58-61 | medium light gray shale | 0.18 | 3.96 |
| 61-64 | medium light gray shale | 0.14 | 16.90 |
| 64-67 | medium light gray sandstone | 0.10 | 16.21 |
| 67-69 | medium light gray sandstone | 0.06 | 8.74 |
| 69-71 | medium light gray sandstone | 0.06 | 11.31 |
| 71-74 | brownish gray sandstone | 0.04 | 77.19 |
| 74-77 | medium light gray sandstone | 0.06 | 31.61 |
| 77-80 | medium light gray sandstone | 0.02 | 44.37 |
| 80-82 | medium gray sandy shale | 0.14 | 12.82 |
| 82-84 | medium gray sandy shale | 0.11 | 3.38 |
| 84-85 | medium gray sandy shale | 0.32 | 9.09 |
| 85-88 | coal | 1.60 | 0.82 |
| 88-90 | coal | 2.78 | 0.12 |
| 90-91 | medium gray clay | 0.11 | 4.20 |
| 91-93 | medium gray clay | 0.10 | 10.73 |

If the entire mine is not daylighted, the remaining underground mine entries need to be adequately sealed to restrict or prevent ground-water movement between the underground mine and the backfill, and to preclude oxygen infiltration into the mine entries.

Daylighting underground mines does not always yield a decrease in the pollution load. The predicted decrease in flow rates and the change in the ground-water flow system, as described in Section 1.2, can be offset by the increased exposure of highly acidic overburden material to atmospheric oxidation and subsequent contact of ground water. This situation could in turn produce a higher pollution load (acidity and/or metals) than previously existed. Reed (1980) observed that daylighting of a underground mine in Tioga County, Pennsylvania, on the Bloss Coal seam, increased the acidity concentrations. In fact, he observed a direct relationship between the amount of daylighting and the acidity concentration. The overburden of the Bloss Coal was "mostly shale containing pyrite," indicating the potential for acid production. However, this site is an exception, rather than the rule. In most cases, daylighting successfully decreases the pollution loads.

***Implementation Checklist***

The efficiency of these operational BMPs is related to a large degree to the restraint of certain activities, the promotion of others, and effective management operation activities. All have the specific goal of reducing the pollution load; however, these BMPs are somewhat diverse in regards to how this goal is achieved. The following list includes some recommended implementation guidelines for these BMPs.

Rapid Mining and Concurrent Reclamation

- The amount of time the spoil is sub-aerially exposed should be minimized.
- Regrading and revegetation should be performed as soon as possible after coal removal.

Off-Site Disposal of Acid-Forming Materials

- High-sulfur strata should be noted and segregated.

- Acid-forming materials should be stockpiled and hauled off-site.

Auger Mining

- Auger mining above the water table should be avoided.
- If augering is necessary for economic reasons, all holes should be properly sealed to preclude ground-water movement and oxygen infiltration.

Stockpiling of Coal

- Uncontrolled drainage should not be permitted.
- The stockpile should be covered or lined to prevent drainage.
- The maximum time allowed prior to removal should be set or stockpiling should be completely precluded.

Consideration of Overburden Quality

- The net acidity/alkalinity for the entire volume of overburden to be affected should be determined.
- If the overburden is acidic, other BMPs should be employed to compensate for the negative impacts of disturbance.

Coal Refuse Reprocessing or Cogeneration Use

- Regrading and vegetation should be performed to promote runoff and inhibit infiltration.
- Where possible alkaline coal combustion waste (CCW) should be returned to the site.

Maximizing Daylighting

- As many of the existing water-infiltration areas as possible should be eliminated.
- Contact between acid-forming materials and ground water should be removed or decreased.
- Mining should disturb as much alkaline overburden as possible.
- Unmined entries should be properly sealed.

## 3.2 Verification of Success or Failure

As with all BMPs, verification of proper implementation during remining operations is crucial to effective control or remediation of the discharge pollution loadings. The importance of field verification of all aspects of a BMP cannot be overstated. It is the role of the inspection staff to enforce the provisions outlined in the permit. The inspector generally does not need to be present at all times to assess the implementation of the BMPs in this chapter. However, some BMPs will require closer and more frequent field reviews than others. Monitoring of water quality and quantity will be the truest measure of BMP effectiveness.

During rapid mining and concurrent reclamation, the inspection staff needs to verify that the site is reclaimed shortly after the coal is removed. It is possible for permits to require notification by the operator of certain reclamation phases and/or require certification by an engineer or registered surveyor that the reclamation occurred within the predefined guidelines. An inspector should be able to visually assess that reclamation is occurring concurrently during each site visit.

The removal of pit and tipple cleanings can be verified using a lined stockpile area and review of weigh slips from the waste disposal facility. The refuse material may be stockpiled for short time periods, until it is hauled to the waste disposal site. Copies of the weigh slips from the waste disposal site and an estimate of the amount of material stockpiled should be submitted to the inspector, for comparison of the amount of material sent to the waste site to the amount previously stockpiled. The amount of material stockpiled can be estimated from the dimensions of the pile or from company-supplied records. The total amount of refuse to be removed from the site can be estimated from the overburden analysis and volumetric calculations, based on the strata thickness and the area mined. This estimated amount then can be compared to the total amount that was actually shipped off-site. The inspection staff should also observe the segregation of the acidic material during overburden removal.

Verification that no auger mining has taken place is relatively straight forward. If augering is permitted, affirmative proof should be submitted that all of the augering occurred below drainage and/or the holes were sealed as approved. The determination that augering is below drainage is initiated during the permitting stage. The operator should submit hydrologic data showing that the coal where the augering is proposed is below the regional drainage. Data needed for this determination include, but are not limited to:

- Pre-mining water levels
- Stratigraphic location of aquifers
- Transmissive properties of the aquifers
- Dip of the strata
- Projected post-mining water table
- Anticipated post-mining recharge rates
- The location of potential nearby dewatering sources
- The location and relative elevation of adjacent streams
- Specifics of the auger mining plan (e.g., location, direction, depth, etc.)

Once mining operations have begun, an inspector should make certain that the augering is conducted in the locations and in the manner indicated in the approved permit. Verification that the auger holes have been properly sealed is a difficult procedure and is discussed in detail in Section 1.2, Control of Infiltrating Ground Water. If it is deemed important to verify that the auger holes are below the water table and flooded after reclamation, monitoring wells can be installed in and adjacent to the holes to monitor the ground-water conditions.

Verification that coal is not being stockpiled is accomplished by a simple visual inspection. However, where stockpiles are allowed under limited circumstances, slightly more effort is required. Verification will be needed to ensure that a liner was installed, that the pile is usually covered, or that there is a limited on-site holding time.

The sulfur concentration (acid-producing potential) of coal can be determined from the analysis of the coal quality or the overburden analysis. An inspector will need to verify that a liner was constructed for the stockpile area, and stockpiling of the liner material will be required prior to placement. This determination can be performed on-site during construction or after installation, but before use. An inspector can also verify that the runoff is collected and routed to a treatment facility. If there is a discharge visible at the base of the pile, but it is not reaching the treatment facility, it is an indication that the leachate may be infiltrating into the ground and will eventually reach the water table. If no drainage is observed from the stockpile during or immediately following a wet period, it is also an indication that the liner is leaking, and steps will need to be taken to remedy the situation. Elimination of coal storage or reconstruction of the liner may be required.

Verification of the application of a bactericide can be performed by reviewing sales receipts or being present when the material is applied and reapplied. Stockpile covering is accomplished by visual inspection. The lack of any runoff from the pile is an indication that the cover is being used consistently and effectively. Verification of short-term stockpiling can be performed by comparing the amount of coal removed from the pit to the amount shipped to the buyer. The amount taken from the pit is a simple calculation:

Coal Thickness x Acreage x 1750 tons per acre/foot of Thickness = Coal Tonnage

Verification of the amount trucked off-site is available from dated weigh slips or sales receipts. The inspector can also observe the removal of coal from the stockpile while no coal is being actively excavated from the pit.

The delineation of acid-forming materials is verified by review of the overburden analysis submitted with the permit application and discussed in Section 2.0. However, it is recommended that the inspector periodically examine the exposed highwall, to ensure the lithology expressed by the overburden drill hole logs does not appreciably change across the site. Channel samples (a vertical series of overburden samples collected by hand, comprising the entire exposed strata) may need to be collected at the highwall and analyzed to verify that the overburden quality has not changed laterally from the nearest overburden hole.

Visual inspection will determine whether the amount of reprocessing, or refuse removal, taking place matches the original plan. The amount of CCW returned to the site can be determined from weigh slips and volumetric calculations. The quality of the CCW and potential to leach toxic trace metals can be determined from laboratory analysis. Adequate post-mining slopes and vegetation can be measured in the field and compared to those proposed in the permit.

To ensure that the maximum amount of daylighting is completed, certification from an engineer or registered surveyor may be needed. The inspector can visually estimate the daylighted acreage to a reasonable degree of accuracy. The operator may need to flag the site to define the limits of the daylighting on the surface.

### *Implementation Checklist*

Monitoring and inspection of BMPs in order to verify appropriate conditions and implementation should be a requirement of any remining operation. Though BMP effectiveness is highly site-specific, it is recommended that implementation inspections of Operational BMPs include the following practices:

- Flow should be measured and sampling for contaminant concentrations should be performed before, during, and after mining .
- Monitoring should continue well beyond initial water table re-establishment period (e.g., about 2 years after backfilling).
- Hydrologically connected units and/or individual discharges should be assessed.
- Liner material weigh slips or receipts and/or marked stockpiles should be inspected.
- Any deviation from the approved implementation plan should be assessed.
- Salient phases of the BMP implementation should be inspected.
- Frequent inspection to determine reclamation concurrency should take place.

- Frequent observation of the handling of pit and tipple cleanings and stockpiled coal.
- Augering operations, if present, should be inspected.
- Coal recovery or refuse shipping records should be reviewed.
- The scope of daylighting should be monitored.

## 3.3 Literature Review / Case Studies

Perry and others (1997) discussed the impacts of operational cessations on post-mining discharge water quality for several surface mines in Pennsylvania and West Virginia. Their conclusions were that rapid mining without delays generally yielded improved post-mining water quality, compared to similar mines that experienced delays or cessations during mining. One site in particular (the Greene Mine) had two discrete mining phases. Mining and reclamation on Phase 1 proceeded without delays, while the mining on Phase 2 was interrupted by a two and a half year cessation of operations. The two phases were also hydrologically separate. Phase 1 was mined without any work stoppage. While Phase 2 was idle reclamation was incomplete and the acid-forming overburden material was exposed to atmospheric oxidation. The post-mining water quality of the two phases was distinctly different. The net alkalinity for Phase 1 was 151 mg/L, while that of Phase 2 was -128 mg/L (net acidic). Iron concentration for Phase 1 was 1.88 mg/L, while Phase 2 yielded 18.7 mg/L. Manganese concentration for Phase 1 was 16.4 mg/L, while the concentration for Phase 2 was 62.7 mg/L (Perry and others, 1997). Sulfate concentration, while not a regulated effluent parameter, is a viable and direct indicator of acid mine drainage production. The sulfate ion is released as part of the mine drainage reactions and, except under extreme conditions, sulfate remains in solution. The sulfate values for the two phases of the Greene Mine also differed significantly, indicating a difference in the volume and rate of mine drainage production. Phase 1 had a sulfate concentration of 1197 mg/L, while that of Phase 2 was 1770 mg/L or an increase of 48 percent. The lack of acid production at several other sites included in the study was attributed to the rapid mining followed by concurrent reclamation of the sites (Perry and others, 1997).

## 3.4 Discussion

The operational BMPs discussed in this section are recommended during remining for controlling the effects of the mining activities. Rapid and concurrent reclamation, appropriate location of auger mining (if allowed at all), off-site disposal of acid-forming materials, control of coal stockpiling, and thorough daylighting are operational procedures that should be implemented as part of the mining plan. Coal refuse reprocessing is a type of remining that should be encouraged. These BMPs do not preclude application of other BMPs discussed in this guidance document or required for environmental maintenance or improvement.

**Benefits**

- Rapid/concurrent reclamation reduces the risk of the operator falling behind which often results in incomplete reclamation and promotes AMD formation.
- Off-site disposal of pit and tipple cleanings may transform a remining site from producing additional acidity to producing less acidity.
- Appropriate implementation of auger mining can maximize the amount of coal recovered while reducing the risk of increased AMD production.
- Short-term or no coal stockpiling reduces the risk of accentuating AMD production.
- Reviewing the overburden quality and making a decision on permit issuance or denial based on this review will lessen the likelihood of making the pollution loads worse and the operator assuming treatment liability.
- Removal of significant amounts of acid-forming materials from refuse piles and introduction of alkaline material decreases acid and metal loads.
- Daylighting radically changes the geochemistry and hydrology of the site, reducing the amount of acidic material, increasing the potential for ground water to encounter alkaline material, and reducing the water infiltration volume.

**Limitations**

- Unscheduled or unforeseen circumstances may prevent maintenance of concurrent reclamation.
- Off-site disposal of pit and tipple cleanings may not be economically feasible.
- Without the approval to auger mine, some abandoned mines may not be economically viable to remine, because of the limited coal recovery.
- Auger mining above drainage areas may not be permissible.
- The coal market may dictate whether or not the coal may need to be stockpiled. Avoidance of stockpiling may induce coal sales at below anticipated prices, possibly compromising the economics of the operation.
- Redisturbance of a refuse pile may reactivate or accelerate acid production.
- In many cases, it may not be economically feasible to daylight large amounts of an underground mine. The low coal recovery rates and higher cover may make additional daylighting unprofitable.

**Efficiency**

Analysis of sites with Coal Refuse Removal or off-site disposal of pit and tipple cleanings showed that two thirds of the discharges were eliminated or significantly improved in terms of acidity loading (Appendix B, PA Remining Site Study). The remaining one third were unchanged. Almost 86 percent of the discharges exhibited either no change or a significant improvement in the iron loading with about 14 percent exhibiting some degradation. Most (83 percent) of the discharges were unchanged for manganese load with the remainder being significantly worse. No discharge was degraded in terms of aluminum load. All were unchanged or significantly better.

The success of Mining of Highly Alkaline Strata is directly related to the overburden quality. At sites where alkaline overburden existed, no discharges were made worse by remining, while over 67 percent were significantly improved or completely eliminated in regard to acidity load.

Twenty-three percent of the discharges exhibited significantly higher iron loads. Another 39 percent were unchanged and the remaining 38 percent were significantly better or eliminated. None of the discharges exhibited degradation in terms of manganese or aluminum loads.

Less than one percent of the 170 discharges analyzed for daylighting showed degradation due to acidity loading. Over 58 percent were unchanged, with the rest being eliminated or significantly better. Iron, manganese, and aluminum loads exhibited similar results with a slightly higher degradation rate (about 4 to 6.5 percent).

## 3.5 Summary

In general, operational BMPs are “rules-of-thumb” for good mining procedures. Research and experience has demonstrated that these BMPs will minimize the potential for additional AMD production and thus increase the likelihood of reduced pollution loads.

These recommendations are intended to prevent unchecked, large-scale pyrite oxidation within the spoil and adjacent areas. Once accelerated oxidation has occurred, abatement or treatment of the acidic drainage becomes increasingly difficult, if not impossible. I n general:

- Rapid, concurrent reclamation is a good practice regardless of the overburden quality.
- Off-site disposal of pit and tipple cleanings reduces the probability of additional AMD production.
- Auger mining should only be permitted below drainage or where effective auger hole sealing will preclude AMD production.
- Unless the drainage is controlled, extended on-site coal stockpiling is discouraged.
- Overburden quality should be a consideration during permitting remining operations.
- There are very few, if any, problems associated with coal refuse pile utilization.
- The greater amount of daylighting during remining will produce the most positive reduction in pollution loads.

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