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Chapter 17

REMINING

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Introduction

In general, remining is defined as any operation where additional mining occurs subsequent to the original mining or site abandonment regardless of the existence or quality of mine discharges. However, the term remining as it is used in this chapter, primarily refers to surface mining of abandoned surface or underground mines or reprocessing of coal refuse piles where pre-existing pollutional discharges will be affected by remining under Pennsylvania's Subchapter F and Subchapter G (anthracite) program. Site-specific effluent standards are established based on loading rates rather than conventional concentration-based BAT effluent standards. Mine drainage prediction of remining sites where the discharges are required to meet conventional effluent standards is covered by standard prediction techniques discussed in the preceding chapters of this manual.

Prediction of additional mine drainage from remining sites is distinctly different compared to normal mine drainage prediction at previously unmined sites. Instead of contaminant concentration (e.g., mg/L) levels and pH of the effluent, prediction of contaminant load (e.g., lbs/day or kg/day) levels become the primary objective for remining mine drainage prediction. Discharge flow rate is used to determine contaminant load and becomes a primary determinant of the reviewed effluent standard. There is a direct positive correlation between discharge rate and pollution load. Smith (1988) and Hawkins (1994a; 1994b) have observed that discharge flow rate is a major element of contaminant load. Therefore, the physical hydrology of the mine becomes a larger component of mine drainage prediction than overburden geochemistry in remining situations compared to mining virgin sites.

Historical Impacts of Remining

Remining in the bituminous coalfields of Pennsylvania has, at the majority of sites, resulted in no change or an improvement in the water quality in terms of contaminant (acidity, iron, and sulfate) loads (Hawkins, 1994b). Analysis of 24 reclaimed western Pennsylvania remining sites illustrated that a large majority of the sites either did not change or significantly reduced post-remining acidity, iron, and sulfate loads. For that study, data were analyzed from remining sites in the bituminous coal fields of Pennsylvania that had been reclaimed (backfilled to rough grade) for one year or longer.

The study determined changes in the post-remining contaminant load data using the methodology employed by the Pennsylvania Department of Environmental Protection and two other applicable analytical methods (Mann-Whitney U test and nonparametric upper prediction limits). All three of the methods indicate that remining either successfully reduced or did not significantly change the contaminant loads for at least 20 of the 24 sites. More sites (8) exhibited a significant reduction in acidity, iron, or sulfate load than the number of sites that exhibited a significant load increase (3 or 4) (Hawkins, 1994b).

There were a few cases where the post-remining water quality was significantly improved in terms of contaminant load and began to meet the concentration-based statutory effluent standards (25 PA. Code 87.102). This situation usually occurred on sites where surface mining daylighted (i.e., remined abandoned underground mines by surface mining methods) a substantial area of abandoned underground mines. Figure 17.1 illustrates an example of acidity concentration meeting 25 PA. Code 87.102 standards approximately 900 days after backfilling. The water quality improvement appears related to the presence of significant amounts of alkaline material (e.g., limestone or calcareous shales) in the overburden. Removal of the coal itself and redistribution of roof material that collapsed in the open voids may have contributed to the water quality changes. Before the underground mine was daylighted, the groundwater had limited and transient contact with this alkaline material. Groundwater passing through the underground mine had prolonged exposure to the floor rock, coal and roof rock, all of which are commonly acid-forming materials. Additionally, roof falls and pillar weathering continue to add new

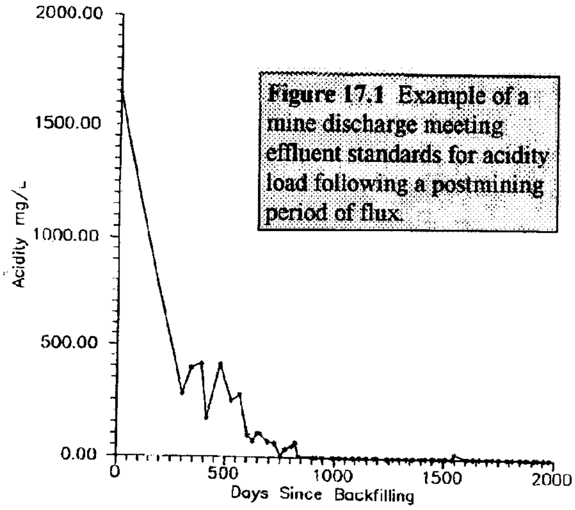

Figure 17.1 Example of a mine discharge meeting effluent standards for acidity load following a postmining period of flux.

sources of acidity from the freshly exposed rock material. Daylighting radically alters the groundwater flow regime, the rock material contacted, and greatly increases the rock surface area and groundwater contact time. Therefore, when limestone in the overlying strata is removed and backfilled, it has the potential to yield substantially more alkalinity to the groundwater, which can significantly improve the groundwater quality.

In the cases where the remining increased pollution loads there are several possible causes. The first reason may be that remining has created additional pollution. However, short-term changes in flow and/or contaminant concentration that commonly occur during the initial 1-3 years after backfilling is another possible cause. The first 1-3 years after backfilling is a period of substantial physical and chemical fluctuation within the spoil aquifer. During this period, the water table is reestablishing and the spoil is undergoing considerable subsidence, piping, and shifting. The sulfate salts, created by oxidation when the cast overburden was exposed to the atmosphere during mining, are flushed through the system (Hawkins, 1995). Figure 17.2 is an example of a discharge acidity load during this transient period. If the data for that discharge were analyzed after only 1000 days, the remining would appear to have failed because the acidity load frequently exceeds the upper bound of the 95% confidence limits. However, when the post-remining sampling period is extended to over 1800 days, that conclusion is no longer valid. Therefore, the true impact of remining on pollution loads may require monitoring beyond 3 years after backfilling and short-term degradation may not be unexpected. Figure 17.2 is an extreme example of water quality changes that can occur during this transient period. The majority of discharges exhibiting water quality changes during this period are usually less extreme.

Daylighting of underground mines does not necessarily improve the discharge water quality. Reed (1980) analyzed the impact of daylighting an abandoned 850 ac (344 ha) underground mine in Tioga County, Pennsylvania. He observed that the daylighting, still active during his study, was increasing the acidity concentration of the discharges. A direct relationship between the amount of daylighting and the acidity concentration increase was noted. Concentration is frequently a function of discharge rate (an inverse relationship), therefore load is a better assessment of water quality improvement. However, the impact of the mining on the acid load was not determined. The cause of the apparent acidity increases is not known. However, it is possible the overburden may have had significant amounts of acid-producing strata, or it may have been a case of temporary degradation, as previously discussed. Subsequent analysis of the acid loading data from the three main discharges, after reclamation of the corresponding recharge area, showed no statistically significant changes from preremining levels. Although, the acid loads may have lowered from the levels recorded during the active daylighting phase (Meiser, 1982). Daylighting on the same coal seam at a near-by site also resulted in degraded water quality, due to the substantial high-sulfur strata and the lack of significant alkaline strata overlying the coal (Naylor, 1989).

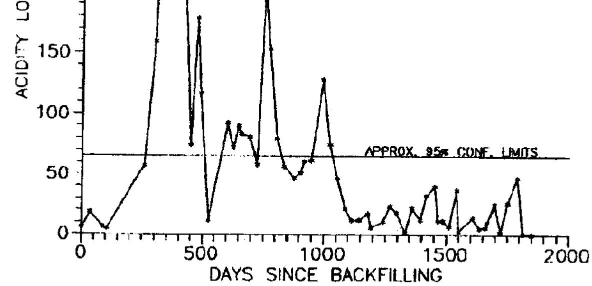

Figure 17.2 Example of a mine discharge meeting acidity concentration statutory effluent standards after remining

Similarly, Ackerman and others (undated) evaluated the impact of daylighting an abandoned underground mine in Garrett County, Maryland. They observed that the post-remining pollution loads did not significantly change from pre-remining levels. However, a slight improvement in pollution load may have occurred shortly after reclamation. They also observed that the pollution load seasonal fluctuations were greater than pre-remining levels.

Remining Techniques

An important aspect of remining is determining what elements of the original mining caused the degradation. This "post mortem" analysis performed on the abandoned mines will indicate what, in terms of past mining practices, geology, hydrology, or other factors caused or contributed to the production of acid mine drainage (AMD). This analysis will identify what abatement procedures, implemented during the remining operation, will preclude further degradation and possibly ameliorate the existing pollution problem. The causes of AMD formation at abandoned surface mines generally differ from that of abandoned underground mines, because their groundwater flow systems are substantially different (open conduit vs. a double porosity system).

In conducting this post mortem evaluation, several possible reasons why abandoned surface mines will produce AMD can be considered. In some cases, overburden quality is such that AMD formation is inevitable, even if the operation was conducted entirely within the existing regulations and prevailing best mining practices. In those cases, the original permit probably should not have been issued, and, with the advances in mine drainage prediction in Pennsylvania in the last 15 years, it probably would not now be issued. In other cases, older mining methods and practices (or lack thereof) may have caused or accentuated AMD production. For example, the mine may not have been backfilled in a timely manner or never completely reclaimed. Improper disposal of acid-forming materials (pit or tipple cleanings) with respect to the postmining water table may have caused or increased AMD formation. At a few sites, additional acidic materials may have been brought to the site and disposed in the backfill. It is possible the overburden was slightly alkaline or neutral, but the addition of the acid-forming materials overwhelmed the modest amount of natural alkalinity available. Certain hydrologic conditions within the mine, such as pit water accumulations unchecked during the original mining, can also contribute to AMD formation. The abatement plan will outline how the remining operation will be conducted differently from the original mining as well as what additional measures will be taken in an attempt to improve the water quality.

Abandoned underground mines are commonly ideal environments for the formation of AMD. Therefore, a post mortem of these environments is generally simpler than that for abandoned surface mines. AMD formation is facilitated by the normal configuration of the mine which permits groundwater to preferentially encounter acid forming materials. Subsidence can route surface water that normally runs off the surface directly into the mine workings. Even properly sealed mines commonly continue to have significant oxygen content, often approaching atmospheric levels in the unflooded sections and the open entries permit periodic unrestricted flushing of the substantial amounts of sulfate salts during flooding episodes. Roof falls and pillar deterioration continue to introduce additional acid-forming materials into the system. AMD abatement procedures conducted during remining of underground mines is primarily just the process of daylighting. The act of daylighting is radically different than the mining processes that caused the underground mine to create AMD, because the coal, mine entries, and gob are eliminated. The post-remining configuration of the daylighted sections is similar to a reclaimed surface mine. Although, because of roof falls and pillar deterioration, there may be a higher amount of unrecoverable coal mixed in with the spoil associated with daylighting than with remining surface mines. After daylighting and in the absence of selective spoil handling, groundwater flowing through the reclaimed portions should encounter acidic, alkaline, or relatively inert spoil materials at a frequency based on the volumetric content of the spoil and the groundwater flow regime.

Impact of Discharge Flow on Contaminant Loading

Previous studies (Smith, 1988; Hawkins 1994a; Hawkins, 1994b) have illustrated that the discharge flow rate is a strong determinant of contaminant load. The strong influence of flow on load is illustrated by figure 17.3, which compares acid load, acid concentration, and flow data from a remining discharge in western Pennsylvania. Not all discharges show this strong of a relationship between flow and load, but significant positive correlations are extremely common (Hawkins, 1994a). Smith (1988) stated that "Proper flow measurement is of overriding importance in monitoring pollution load." He also observed that flow changes dominate baseline acidity load variations.

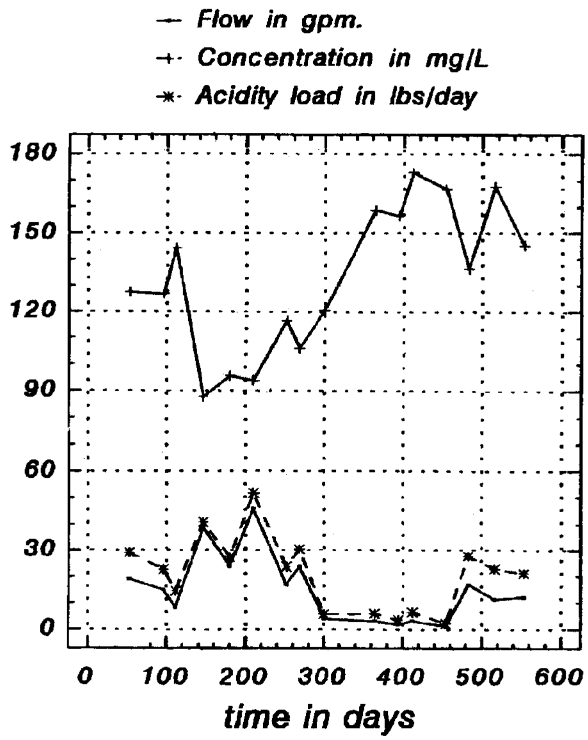

Figure 17.3 Example of the strong influence of flow on contaminant load.

Hawkins (1994a) analyzed pre- and post-remining hydrologic data from 24 remining sites in Pennsylvania using normality testing (skewness and chi-square), exploratory data analysis techniques (notched box-and-whisker plots), and correlation analysis (Spearman's rank correlation). All three types of analyses illustrated that flow dominates acidity, iron, and sulfate loads before and after remining. Hawkins (1994b) observed that when a significant load change (increase or decrease) occurred after remining, a flow rate change was the most common cause.

Concentration was found to be subordinate factor in some instances; therefore, the role of contaminant concentration in load determination cannot be completely discounted. Hawkins (1994b) noted that 71% of the excursions above the 5% significance level were accompanied by "substantial concentration level changes." With this in mind, overburden analysis is still necessary to determine the potential impact of remining on the contaminant concentration levels.

Discharge Flow Rate Reduction

The aforementioned studies have shown that if the discharge flow rate can be controlled (decreased), a reduction in the load is highly likely regardless of fluctuations in contaminant concentration. Reductions in the flow from the mine site can be achieved by controlling recharge to the spoil through the implementation of the pollution abatement plan. Decreasing surface water infiltration as well as lateral recharge from adjacent mined and unmined areas is required to diminish the discharge rate from remining sites. The control of groundwater and groundwater recharge is discussed in detail in Chapter 16. However, there are several reclamation techniques that can be applied to remining sites to reduce the discharge rate. Flow reduction is achieved by diverting or excluding ground and surface water from the backfill.

The exclusion of surface water from the backfill includes installation of diversion ditches, capping the site with a low-permeability material, spoil regrading, and revegetation. Diversion ditches prevent surface water from entering backfilled areas or facilitate rapid drainage away from the surface of the backfill. A seal covering the backfill reduces or prevents surface infiltration. This cap can be comprised of a variety of materials such as on-site clays, self-cementing coal ashes, or a geotextile. Abandoned surface mines, prior to remining, commonly have unreclaimed pits and other closed contour depressions in poorly sorted spoil that act as recharge areas. Regrading these areas significantly increases runoff and reduces surface water infiltration by eliminating surface impoundments and rapid infiltration zones. Revegetation with certain plant types further reduce infiltration by facilitating runoff or retaining and using infiltrated water at the soil horizon. The water held in the soil is subsequently transpired or evaporated.

There are several methods for decreasing lateral recharge to the backfill from adjacent or underlying sources including the installation of highwall and lowwall drains, floor drains, grout curtains at the highwall and lowwall, sealing the pit floor, horizontal free-draining or vertical dewatering wells in adjacent strata, and sealing of exposed underground mine entries with low-permeability materials. Groundwater drains intercept groundwater prior to entering the backfill or rapidly remove existing groundwater from the spoil and then divert it off site. Optimally, highwall, lowwall, and floor drains should be installed while the operation is active, prior to reclamation. Drains that collect and route water from underground mines through (bypassing) the backfill are becoming increasingly common. Grout curtains and sealing the pit floor precludes lateral and vertical groundwater flow into the backfill from adjacent and underlying strata. Grout curtains can be installed after reclamation, whereas the pit floor is must be sealed as mining progresses. The dewatering wells prevent a positive hydraulic gradient in adjacent areas toward the backfill by suppressing the water levels in the adjacent or underlying strata. These wells can be installed at anytime during the operation. Sealing of exposed mine entries with a low-permeability material is very important in preventing lateral movement of groundwater from flooded mine workings into the backfill. They should be sealed while the site is open at the final cut, although they can be sealed later by backstowing and grouting via large drill holes.

Proven Track Records and Experience-Based Rules-of-Thumb

Within Pennsylvania there are certain areas, coal seams, and mining situations (e.g., abandoned underground mines, surface mines, or coal refuse piles) that are known to mining professionals to have either a good or bad track record when disturbed by remining. Some regions and coal seams are known to yield greatly improved water quality after remining virtually regardless of how the operation is conducted. Other areas and coals seams are notorious for producing worse quality discharges, regardless of how well the operation was conducted.

Experience has shown that daylighting of Pittsburgh coal underground mine workings in Washington, Beaver, and Allegheny Counties, Pennsylvania substantially yields improved water quality over pre-remining conditions. When the daylighting is substantial, the discharges change from being strongly acid to being significantly alkaline. This change in water quality is illustrated by figure 17.1. Some acidic mine discharges improve somewhat after remining, but do not become alkaline. An example of this situation was an operation in Washington County, where there were 5 pre-existing acidic mine discharges. Some of the discharges went from being acid to alkaline (acid loads went from 75.6 lb/day (34.3 kg/day) to no acid load), while others exhibited reduced acid loads, but remained acidic. The degree of change of the discharges appeared to be related to amount of the recharge area that was daylighted. The water quality changes appear to be directly related to both the removal of the coal, which has sufficient sulfur content to be acid producing, and breakup of the overburden, which possesses a significant amount alkaline material. Entire streams, such as Potato Garden Run in Beaver County, have recovered because of nearly complete daylighting of abandoned underground mine working in that area.

Examples exist where complete daylighting of an underground mine will eliminate or nearly eliminate the discharges through substantial changes to the groundwater flow system. At a 43 ac (17 ha) mine in Clinton County, the underground mine workings were completely daylighted. Subsidence and collapse features that facilitated recharge to the mine were removed. The postmining recharge rates through the spoil were significantly below pre-remining levels (See Chapter 3 for a discussion on recharge to mine spoil). Three years of postmining data seldom showed any measurable flow at the one discharge point. It is unlikely that the discharge was completely eliminated, because some of this monitoring was conducted while the water table was reestablishing. However, the data indicate that the flow was and will continue to be substantially lower than pre-remining levels.

There are coal seams in parts of the coalfields where remining is known to leave discharges unchanged from pre-existing levels. Examples of this are the Freeport coal seams in northern Armstrong County, which are known to have marginal overburden quality, yet remining seldom increases the pollution loads. The pre-remining acidity loads (the discharges are slightly acidic) are generally low and the metals (iron, manganese, and aluminum) commonly at times meet Best Available Technology (BAT) (87.102) effluent standards. The overburden is characterized by low amounts of alkaline material coupled with low sulfur values. Both of these constituents appear to have been leached from the strata by weathering, leaving little to react (Michael W. Gardner, personal communication).

There also are certain seams and areas within Pennsylvania where remining without additional abatement measures such as alkaline addition, typically increases the pollution load for acidity and/or metals. For example, commonly remining on the Waynesburg coal seam in Greene County increases the pollution load. Manganese and iron loads are frequently observed problems associated with the Waynesburg coal (Michael W. Gardner, personal communication). The Waynesburg sandstone is thought to be the main AMD producing unit. Remining on the Lower Kittanning or Clarion coal in northcentral Pennsylvania generally increases acid loads unless flow reduction measures are taken and alkaline materials are brought to the site (Michael W. Smith, personal communication).

Recommendations

Mine drainage prediction for remining sites must be viewed differently than for virgin sites. Discharge contaminant loads instead of concentrations are regulated and forecasted. Because of the dominance of flow in contaminant load determinations, abatement and reclamation plans should stress the implementation of flow reduction techniques. Abatement practices to reduce recharge to the spoil aquifer should yield a predictable (within a range of projected values) decrease in flow using known site conditions along with standard geologic and hydrologic techniques. The flow reduction will subsequently yield a predictable contaminant load reduction.

Given the track record in Pennsylvania and the observed benefits that reducing flow has on contaminant load, remining can be a viable means of abating or diminishing AMD discharges in many areas. This may be the only economically viable solution for reducing some of the highly-degraded/high-volume underground mine discharges. Long-term discharge treatment is typically not viable and in many instances cost prohibitive.

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