Chapter 16

WATER MANAGEMENT TECHNIQUES ON SURFACE MINING SITES

Michael Gardner
Department of Environmental Protection, Greensburg, PA, 15601-0982

Introduction

Water plays a key role in the formation and transport of mine drainage. It is an essential part of the pyrite oxidation process and necessary for dissolution of neutralizing minerals such as calcite and dolomite (see Chapter 1). It is also the transport medium for pyrite oxidation and neutralizing products. Although water is an integral part of the mine drainage process and has been extensively studied in the context of mine drainage prediction and prevention, limited research has been done on the subject of water management techniques on surface mining sites. This chapter will examine the available literature and discuss water management case studies.

There are three primary means by which water enters surface mine spoil (Figure 16.1). These are surface infiltration (from precipitation and/or snowmelt), groundwater inflow from the highwall, and upward leakage from underlying aquifers (in groundwater discharge areas). All three can be important although the two primary players are surface infiltration and groundwater inflow from the highwall.

There are at least four means of managing water on surface coal mines. The first is to minimize infiltration into the spoil surface. A second is to minimize the contact time between groundwater and acid-producing mine spoil. A third is to promote the contact of infiltrating water with calcareous materials in the mine spoil. The fourth is to submerge acid-forming materials below the water table (flooding).

Examples of the first method include highwall diversion ditches and final surface grades which promote surface runoff. An example of the second method is spoil drains, which will be discussed in detail in this chapter. The third method usually employs trenches filled with alkaline materials strategically positioned to receive surface drainage from the mine before the drainage infiltrates into the backfill (Caruccio and Geidel, 1984). This method is designed to enhance the dissolution of calcareous minerals by promoting water contact with these minerals. Wirem and Naumann (1996) used a variation of this concept when they constructed alkaline material-filled trenches on top of highly permeable "chimney drains." In some ways this third method is a variation on alkaline addition, which

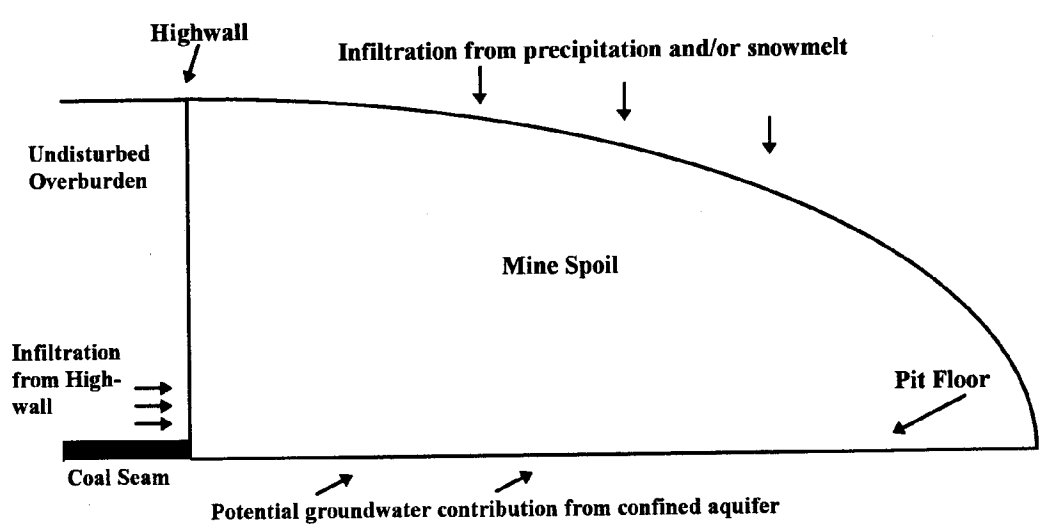

Figure 16.1 General schematic of mine site hydrology.

is discussed in Chapter 13. The fourth method, flooding, takes advantage of the limited amount of oxygen that can be dissolved in water. This topic is discussed in more detail in Chapter 14 which deals with special handling of acidic overburden.

Some of the earliest research pertains to the fourth method. Leitch et al. (1930) found that acidity concentrations from flooded deep mines were generally lower than in water from up-dip mines. Additional research in the mid-1930s revealed that flooded deep mines had 60 percent lower acid loads than non-flooded mines (Mihok and Moebs; 1972). Studies show that atmospheric oxygen, which is needed for pyrite oxidation, is greatly reduced under submerged conditions (Singer and Stumm, 1970; Watzlof and Erickson, 1986). Flooding, however, is generally impractical for surface coal mines. Most surface mines are located in groundwater recharge areas and spoil hydraulic conductivity is often too high to maintain a thick saturated zone. Additionally, the water table can experience short-term fluctuations due to precipitation events and can fluctuate seasonally. Thus portions of the spoil may be alternately saturated and unsaturated Perry et al. (1997) discuss two sites in the Appalachians where attempts at submergence failed because of an inadequately thick saturated zone and/or a fluctuating unsaturated zone.

The water management practices discussed below focus on the control of surface water runoff and infiltration, and groundwater management. Groundwater management is emphasized in this chapter and several case studies illustrate the use of highwall drains.

Management of Surface Water

Erosion and Sedimentation Controls

Although relatively simple, an adequate erosion and sedimentation plan is an essential component of water management on surface mines. Well designed and constructed erosion and sedimentation controls can prevent a significant amount of infiltration into a mine site. Poor controls may add to the problem. The use of erosion and sedimentation controls has been a recommended practice since the mid-1950s (Braley, 1954; Brant and Moulton, 1960).

An erosion and sedimentation control plan generally consists of sedimentation ponds and a network of associated collection and diversion ditches. Specific erosion and sedimentation features used to minimize surface water infiltration on a surface mining site include:

Diversion ditches: These features are positioned where they will divert surface water away from a surface mine site. They are usually located above the final highwall or in areas where it is necessary to divert surface flows away from spoil material. Diversion ditches may not be needed on all mine sites due to topography or the presence of highwall berms or topsoil piles. Nevertheless, their function to prevent excessive infiltration of surface water into backfilled spoils is often overlooked and should be considered in mine planning.

Collection ditches: The purpose of collection ditches is to collect runoff (mostly from precipitation) from active or recently backfilled areas and convey it to sedimentation ponds in a non-erosive manner. Collection ditches are normally located in undisturbed ground below the mining area; however, they may at times need to be constructed in relatively permeable spoil material. When constructed in spoil, collection ditches may direct large quantities of water into the backfill. To prevent this, ditches in spoil should be lined with impermeable material to prevent infiltration. Additional factors to consider are: (a) the elimination, where possible, of cross-site ditches; and (b) removal of ditches once vegetation is fully established. Promoting rapid reclamation and revegetation of the site will allow for rapid removal of these features.

Sedimentation and treatment ponds: As with collection ditches, ponds should be located with regard to possible infiltration of water. If constructed in spoil material and not lined properly, large amounts of infiltration are possible. Ponds should be located in original ground where practical or lined with impermeable material. Experience has shown that it is better to construct ponds in original ground rather than attempting to line them. Ponds to be left as permanent features or in acid mine drainage (AMD) prone areas should not be constructed in spoil.

Control of Surface Water Infiltration

Reclamation and revegetation can reduce the production of AMD by promoting surface runoff and evapotranspiration, thus minimizing infiltration into the backfilled spoil. The effect of reclamation and revegetation on mine drainage production is discussed in Chapter 12. Another method to reduce surface water infiltration is the construction of a low-permeability barrier immediately below the topsoil and subsoil. This barrier can be composed of clay or other suitable material such as a fly-ash cement (Sheetz et al., 1997). Barriers to infiltration can be constructed using con-

ventional mining equipment but can significantly increase the cost of reclamation. Also, other considerations such as slope stability and soil suitability for reclamation must be taken into consideration. Although a promising technique, this approach has been used sparingly and mostly as an abatement technique for sites that already have poor quality discharges. In one documented case (See Case Study 2), normal postmining flows were decreased by two-thirds after application of a three-foot compacted clay cap.

Speed of Reclamation

AMD problems may decrease significantly when sites are mined and reclaimed quickly (Perry et al., 1997). Rapid reclamation reduces the amount of available water as well as its contact time with acid-forming materials and limits the time available for pyrite oxidation, two important items in acid production (Chapter 1). One method to help insure rapid reclamation is to limit the total surface area disturbed and unrevegetated at any one time. Another is to minimize the temporary cessation of backfilling. Although Pennsylvania's mining regulations (25 PA Code, Section 87.157) do allow for suspension of mining, recent research has indicated that this can be the catalyst for AMD problems, especially on marginal sites (Perry et al., 1997).

Case Study 1 substantiates this point. The site was mined such that no vegetative cover was present over the winter season which resulted in combined flows of over 100 gpm (378 lpm) from the site. Once vegetation became established the following spring, the combined flow decreased by more than 80 percent.

Groundwater Management

Control of groundwater flow is not a new water-management technique. Several other disciplines use varying techniques such as grout curtains, interceptor trenches and rock drains to control surface and/or groundwater. For the most part, these have been fairly successful and have resulted in numerous articles including those by Atwood and Gorelick (1960), Gilbert and Gress (1987), Zheng, Bradbury and Anderson (1988), Das, Claridge and Garga (1990), and Duchene and McBean (1992). What is relatively new, however, is the application of these techniques to the surface mine backfill environment in order to prevent or minimize AMD formation.

Highwall Drains

Mining operators through the years have used various forms of drains in controlling water on surface mining sites. Some examples are rock drains under spoil piles and the establishment of first (or last) cut drains through the lowwall. Although very little literature is available on this subject, it is discussed in PA Department of Health (1958), Brant and Moulton (1960), and Perry et al. (1997).

In the last few years, however, the Pennsylvania DEP has conducted field studies on highwall drains on several mine sites. The idea behind highwall drains is quite simple; collect groundwater entering a mine site

Table 16.1 Highwall drain water quality from 5 Pennsylvania mining sites.

Site	Drain #	N	pH	Alkalinity mg/L	Acidity mg/L	Fe mg/L	Mn mg/L	Al mg/L	SO_4 mg/L	Location
1	1	26	6.49	228	0	5.26	8.55	0.42	122	Westmoreland County
1	3	16	6.63	273	0	18.4	6.92	0.47	160	
1	6	7	6.48	330	0	4.75	6.61	0.44	107	
1	7	9	6.34	226	0	14.5	7.85	0.77	72	
1	8	10	6.59	274	0	6.52	13.1	0.47	188	
2	1	82	6.9	280	0	5.85	19.5	0.79	945	Greene County (BOY)
3	1	12	6.48	200	0	1.54	5.49	0.89	571	Highwall Drain
3	2	10	7.36	151	0	1.07	1.02	1.07	369	Lowwall Drain
4	1	41	6.43	79	0	15.4	6.63	0.5	459	Raw Water
4	1	20	6.55	43	0	0.44	0.86	0.25	342	Bog Discharge
6	1	10	6.84	408	0	0.47	1.51	0.53	499	Greene County (BAL)

before it comes into contact with mine spoil and convey it rapidly through the site with minimal contact with spoil. In this manner, groundwater largely unaffected by mine drainage will "bypass" most potentially acid-forming material (i.e., pit cleanings and pyritic spoil) and exit the site with minimal chemical change.

The study sites fall into two categories: those that exhibited marginal overburden quality characteristics (i.e., near neutral or slightly acidic), or those where hydrologic conditions such as impounded groundwater in the spoil increased the potential for AMD. No sites with substantial negative net neutralization potentials were examined in these studies.

This study examined six surface mining sites with highwall-drain systems. Permits for these sites were issued over the past eight years. At the time of this report, five of the six sites have been completed. One site is still active. With the exception of one drain, water quality is within effluent standards when it leaves the permit boundary (Table 16.1). From this study, it appears that highwall drains can reduce the potential for AMD on sites with marginal overburden quality or can reduce the quantity of AMD which is generated.

Design and Installation of Highwall Drains

The design and installation of a highwall drain system must be tailored to each specific site. Some design parameters to consider include: (1) where to place the drains, (2) what materials to use, and (3) how to construct them. Although most designs are fairly simple and installation is inexpensive, one should expect minor revisions during construction due to subtle geologic changes discovered during mining.

The placement and number of drains are probably the most important items to resolve early in the design stage. To determine this, one must first review the mining plan and hydrologic data and predict the post-mining hydrologic regime. Items such as structural dip, amount of recharge, and configuration of mining will reveal, among other things, the amount of groundwater expected and where groundwater is likely to be impounded in spoil. It may not be unusual to have more than one drain on a site especially if the site is large or irregularly shaped.

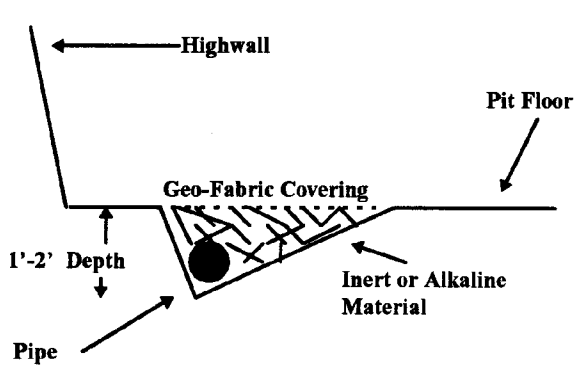

Figure 16.2 Example of drain in pit floor.

It is important to insure that drain systems are designed such that all groundwater is collected where it enters a mine site. This may be at the highwall, endwall or even the lowwall. Of equal importance is ensuring that drains are constructed such that positive drainage results. Surveying may be necessary in some instances.

The drain discharge location is also important as high sediment loads can be present during active mining. The most practical approach is to design the drains to discharge to a collection ditch, allowing any sediment-laden water to be transported to sedimentation ponds prior to final release. Discharging to a collection ditch may also be advantageous if treatment is needed. If circumstances prevent constructing the drain outlet into a collection ditch, thought must be given to providing sufficient sediment control at the drain outlet. Alternatives include the construction of sump areas and/or the use of filter fence or hay bales.

Drain installation must consider: (1) the construction method, (2) the transport medium (i.e., pipe or rock), and (3) protection of the drain, ensuring it is not crushed during backfilling. In this study, three different methods of pit floor drain construction were used. However, other techniques may also be appropriate.

The first drain construction technique starts with the excavation of a small channel in the pit floor with a backhoe or similar equipment to a depth just sufficient (about 1 ft (0.3 m)) to capture groundwater from the highwall. A pipe (4 or 6 in (10-15 cm)) is then placed in the bottom of the channel and covered with gravel or coarse-grained material. Finally, to prevent infiltration of sediment which could plug the pipe, filter fabric is installed over the ditch. (See Figure 16.2)

The second method is to install pipe at the low spot of each pit and allow water to naturally flow into it. This second method does not include any disturbance of the underclay. In the one instance where this method was used, an inert 2 ft (0.6 m) compacted clay

seal was placed on the pit floor under and on either side of the pipe. This permitted groundwater flow along the top of the inert clay rather than on the acidic underclays. Both Methods 1 and 2 involve the installation of a pipe to collect and transport groundwater.

The third procedure is generally the same as the first but does not use pipe. Using this approach, groundwater flows into a channel along the highwall (constructed similar to Method 1) and flows down-dip through a porous gravel (or on-site rock) medium. Whichever method is utilized, it is critical that positive drainage results. Surveying is usually necessary.

Although all three methods have resulted in satisfactory water quality, Method 1 is preferred. This allows for the capture of groundwater within a small area (ditch and pipe) and provides for rapid groundwater transport and little chance, barring plugging of the pipe, that groundwater will contact significant volumes of spoil.

To facilitate rapid transport of groundwater, operators have used flexible 4 in (10 cm) plastic pipe, Schedule 40 PVC pipe and, in one case, no pipe at all (i.e., ditch only). In the author's opinion, flexible pipe is a better choice as it is pliable and fits better in ditches which have undulations. Sturdy PVC pipe does not conform well to an uneven pit floor and can lead to groundwater flow under, rather than in, the pipe. It is important that the ditch be constructed such that it is has a gentle 1-2% slope and is free of rolls.

A potential problem is that the flexible pipe will be compressed by the weight of the backfill. Operators experienced with drain installation indicate that the potential for this is greatly reduced if the drain is covered properly. The best method appears to be to cover the pipe with 4 in (10 cm) diameter stone to a depth of approximately 2 ft (0.6 m) using a backhoe or small front end loader. If done properly, this will not compress or crush the pipe, especially if it is in a ditch similar to that shown in Figure 16.2. After that, normal backfilling can resume.

Normal mining operations must provide for the installation and covering of drains on a pit-by-pit basis, especially if the contour block mining method is used. Mine operators must also insure that the discharge end of each drain segment can be located. Methods of identification include the use of brightly colored 55 gal drums, spray painting of the spoil, or placement of easily identifiable material (such as limestone or red clays) over the end of each drain section.

Pit floor drain pipes have been perforated in two different styles to allow for groundwater infiltration: one is the construction of ½ in (1.27 cm) holes situated around the diameter of the pipe while the other uses much smaller perforations (Figure 16.3) (Duchene and McBean, 1992). Field experience has shown that the smaller perforations (Figure 16.3a) are preferable as they reduce the potential for plugging from sediment. The placement of filter fabric directly over the pipe can also help to reduce sediment inflow.

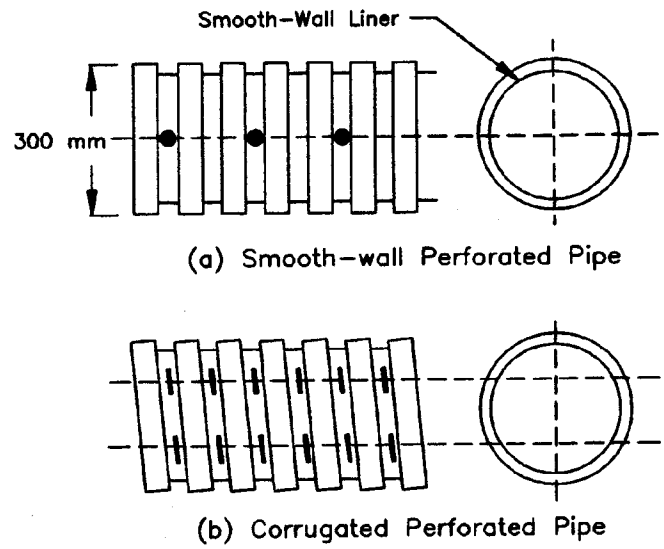

Figure 16.3 Pipe details used for pit floor drains.

Other factors which should be considered for sites where drains are proposed include the following:

1. All drain outlets should be designed with a "water trap" near the outlet to prohibit oxygen from entering the site via the drains. This can be done with a simple "U" joint or other type of apparatus. Although simple, the trap can be very effective. In Case Study 1, the installation of this feature decreased the dissolved oxygen in several drain discharges by approximately 50% and correlated to a major decrease in iron levels.
2. At a minimum, the discharge from drains should be monitored quarterly for quantity and quality. This will indicate how much groundwater is being intercepted and whether or not the intercepted water is being influenced by mine spoil.
3. Since sites with highwall drains often have marginal overburden quality (near neutral or slightly acidic), it is important that reclamation be conducted as rapidly as possible. Failure to accomplish this can lead to potential problems (See Case Study 1).

4. For large sites with significant infiltration from precipitation, it may be useful to construct dual highwall drains as shown in Figure 16.4. The primary drain along the highwall is slotted but connected to a solid pipe which allows for the rapid migration of unaffected groundwater through the site Additional groundwater resulting from infiltration is then captured by the slotted second pipe. Although infiltrating surface water does contact spoil as it migrates downward through the backfill, the overall contact time is reduced due to the presence of the second drain pipe.

The Pit Floor

The pit floor should also be considered in the management of groundwater to minimize AMD formation. This is the surface over which most groundwater eventually travels within the backfill and can be a likely source of contact with pyritic material. Pyritic material associated with the pit floor can come from coal cleanings, high-sulfur reject material, or the strata comprising the pit floor itself (i.e., the underclay).

Some coal remnants are found on the pit floor once the main coal seam is removed. Often this is just a result of normal mining operations but can also be associated with that portion of the bottom coal which does not meet market specifications. Barring the presence of substantial pit water accumulations, most operators will remove as much of this material as possible and "special handle" it prior to backfilling. This process can be time consuming and expensive to complete as it can easily take several hours to "clean' a 150 by 150 ft (30 by 30 m) pit. However, failure to remove this acidic material can lead to water quality problems later.

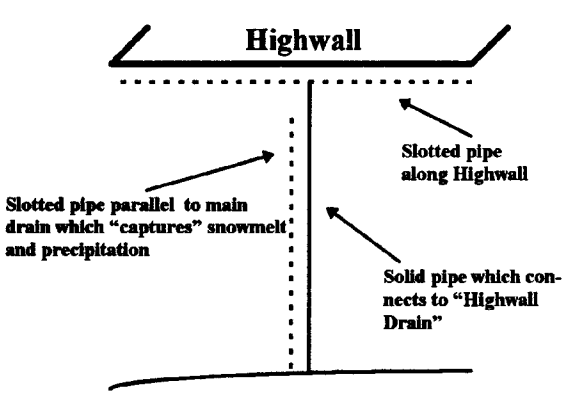

Figure 16.4 Schematic showing parallel drains.

Underclays can also be highly acid-forming, commonly having total sulfur contents in excess of 1.0%. If high-sulfur underclays are present, care should be taken to develop a mining plan which minimizes contact time with groundwater. This can be done by removing the high-sulfur material, by sealing off the high-sulfur zone (with clay), by liming the pit floor, or through the construction of drains to promote free flow conditions. Removal of high-sulfur underclays should be done with care so as not to cause additional AMD through the handling of the acidic material. It can also allow the downward migration of AMD or, if confined aquifers are present, the potential for increased groundwater into the backfill.

Water Management Case Studies

Case Study 1

Site 1 is a 170 ac (68 ha) site on a high quality stream in Westmoreland County, Pennsylvania. It is located in an upland area on the western flank of Chestnut Ridge. Over 100 ac (40 ha) of the upper Kittanning coal seam were mined and reclaimed over a 10-month period in 1995. The topography and general dip of the coal were both to the northwest at about 10% (Figure 16.5). The highwall height did not vary substantially during the life of the mine and was never over 50 ft (15 m).

Overburden data indicated near neutral conditions with little in the way of acidic or alkaline strata. Volumetrically, the site exhibited a NNP deficiency of approximately 0.9 ppt $CaCO_3$ due to sulfur in the coal and a 1 ft (.3 m) shale zone immediately above the coal. Pre-mining ground water levels and well yields were low, indicating that the pit would not encounter a large amount of water. The adjacent area had been previously mined on the same coal seam without creating any discharges. Mining was permitted following the submission of a detailed operations plan which included, among other things, a highwall drain system.

As can be seen in Figure 16.5, the configuration of the mining area was rectangular and required several drains. The drains were constructed per Method 2, above, and all outlets, except one, discharged into collection ditches. As expected, minimal flows occurred during active mining. Drain 1, structurally the lowest, was the only one which exhibited nearly constant flows and these were minor, ranging from 1 to 2 gpm (3.78-7.5 lpm). Flows from almost all drains, however, increased substantially beginning in December, 1995 due to a lack of vegetative cover and above average mid-

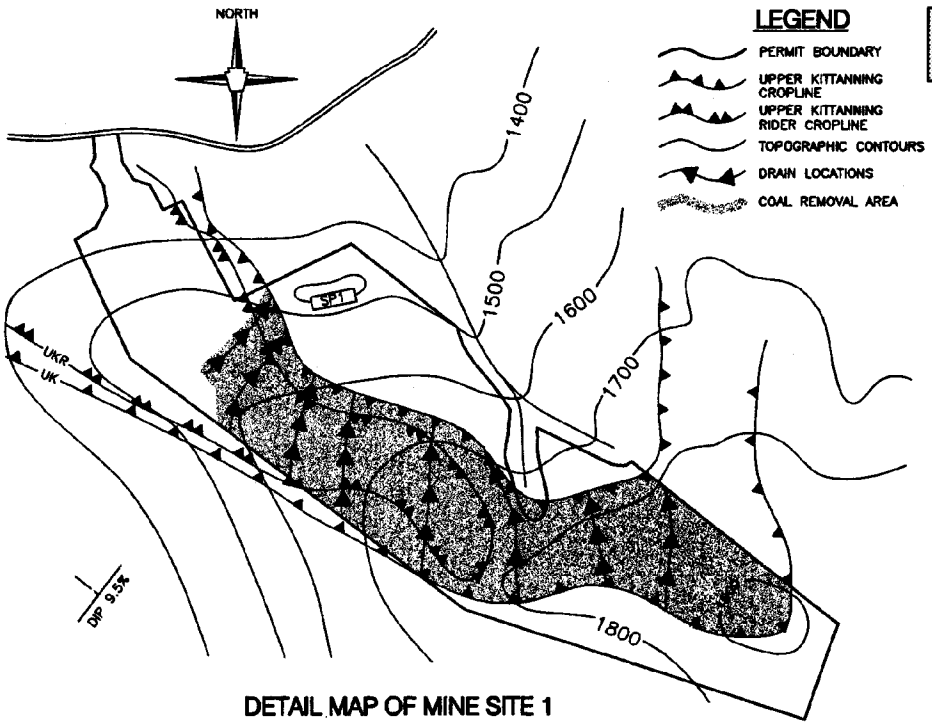

Figure 16.5 Drain locations on mine site in Case Study 1.

winter precipitation and snow melt. At its peak, the combined flow of the drains was over 100 gpm (378 lpm).

Table 16.3 shows that initial water quality results were very good and all parameters were well within permit effluent guidelines. The relatively low sulfate concentrations are especially significant, indicating minimal spoil/groundwater interaction and confirming rapid groundwater movement through the drainage system.

Subsequently, water quality deteriorated in late winter as concentrations of metals increased. Iron and manganese levels rose to 40 and 20 mg/L, respectively. This deterioration was probably due to two processes. First, a lack of vegetative cover coupled with the seasonal reduction in evapotranspiration allowed large amounts of precipitation and snow melt to infiltrate into the mine spoil. Second, the resulting groundwater interacted with pyritic pit cleanings and siderite ($FeCO_3$). The presence of siderite was confirmed by x-ray diffraction The result was high flow discharges with elevated metals. By June, 1996, however, early spring re-seeding succeeded in substantially increasing vegetative cover, reducing infiltration into the backfill and decreasing metal concentrations.

Another factor which appears to have helped to abate the elevated metals problem was the addition of air traps at the ends of the drain to prohibit the influx of oxygen into the site. The combined effect of surface vegetation and the addition of the traps resulted in nearly a 50% reduction in dissolved oxygen levels at the discharge outlets. Field results such as these show the advantage of "air traps" and demonstrate the need for concurrent reclamation and revegetation.

Case Study 2

Site 2 is a 48 ac (19 ha) surface mine located in Green County, Pennsylvania. Mining began in early 1985 but was not completed until September, 1991 due to the suspension of mining from mid 1985 to late 1988. During this period, an 850 ft (255 m) open pit remained. The Waynesburg coal seam was the only seam mined. Due to its upland location, minimal groundwater was present in the pit. Initially, no overburden analysis was performed.

Shortly after mining was suspended, a series of three discharges formed at the toe-of-spoil just above the sedimentation pond (Figure 16.9). Combined flows were approximately 5 gpm (19 lpm.). In addition, runoff from a spoil pile indicated severely degraded AMD as shown in Table 16.2.

Table 16.2 Water quality from mine site 2.

DATE	pH	Alkalinity mg/L	Acidity mg/L	Iron mg/L	Manganese mg/L	Aluminum mg/L	Sulfate mg/L
July-1987	2.5	0	7,400	>300	>300	>500	13,209

Table 16.3 Water quality from highwall drains on mine site 1.

DRAIN #	Date	Flow	pH	Alkalinity	Acidity	Fe	Mn	Al	SO_4	Comments
		gpm		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
Drain 1	5/16/96	1.0	8.0	117	0	0.28	0.8	0.4	28	First Sample
	3/26/96	13.5	6.1	168	36	23.4	15.2	0.5	181	Site Unvegetated
	9/11/96	3.0	6.7	266	0	0.69	9.2	0.5	331	Good Growth
Drain 3	5/16/95	0.4	7.7	188	0	0.3	0.99	0.5	36	First Sample
	3/26/96	3.0	6.2	280	0	33.9	13.5	0.5	169	Site Unvegetated
	9/11/96	1.0	6.8	312	0	34.5	10.9	0.5	218	Good Growth
Drain 6	9/26/96	1.0	7.2	173	0	0.05	2.2	0.1	53	First Sample
	3/26/96	18.0	6.3	270	0	5.7	9.3	0.5	113	Site Unvegetated
	9/11/96	1.25	6.6	480	0	0.36	9.04	0.5	156	Good Growth
Drain 7	12/6/95	3.0	6.5	190	0	49.3	16.7	0.5	98	First Sample
	3/26/96	19.5	6.1	242	0	8.59	8.21	0.5	84	Site Unvegetated
	9/11/96	1.25	5.9	226	0	3.5	4.96	0.5	80	Good Growth
Drain 8	10/19/95	1.0	6.9	452	0	1.63	2.99	0.29	123	First Sample
	3/26/96	13.5	6.2	182	146	7.28	18	0.5	205	Site Unvegetated
	9/11/96	0.12	7.7	366	0	0.3	12.6	0.5	170	Good Growth

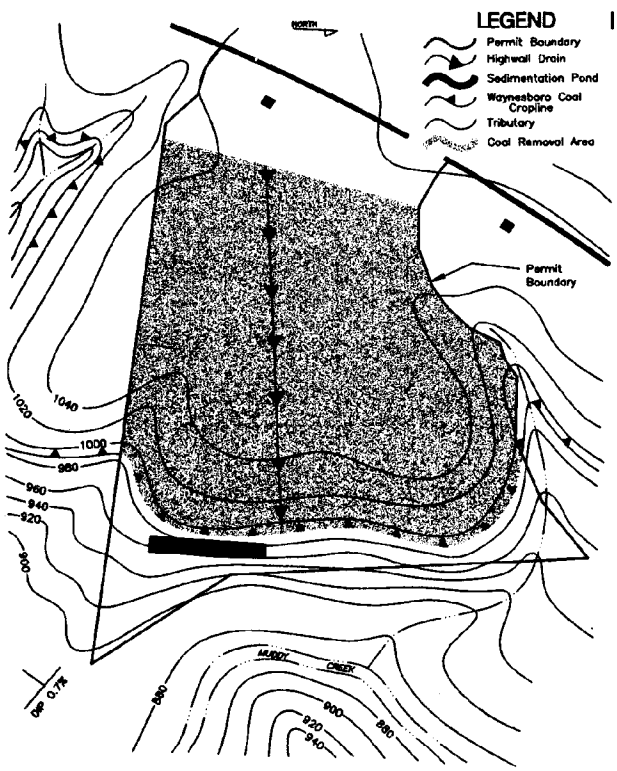

Figure 6.6 Drain installation schematic at mine site in Case Study 2.

A hydrologic evaluation was conducted which included acid-base accounting overburden analysis. Results indicated a lack of alkaline overburden and the presence of a high-sulfur shale interval immediately above the coal. This unit was variable in thickness and ranged from 5 to 8 ft (1.5 to 2.4 m). Volumetrically, the overburden results indicated a net neutralization potential deficiency of over 1,500 tons $CaCO_3$ per acre (551 t/ha).

A decision was made to allow continued mining with a revised mining plan. The revised plan included the establishment of a highwall drain, a 3 ft (1.0 m) compacted clay cap over the site, clay sealing of the first cut spoil, addition of alkaline material, and implementation of a revised special handling and blasting plan.

The highwall drain was installed using Method 1 as above and was installed at the lowest elevation of each cut. Due to structure, however, the pit floor at the highwall was about 8 to 10 ft (2.4 to 3.0 m) lower than at the outcrop. It was therefore necessary to breach the pit floor along the length of the drain in order to promote positive drainage. Due to the acid-forming nature of the underclay and the potential for the next lower aquifer to be contaminated, an inert clay seal was placed in the channel along the length of the drain. Slotted 4 in (10 cm) flexible pipe was then installed.

The operator chose not to extend the drain along the entire length of the final highwall in a "T" fashion (Figure 16.6). It was only extended 50 ft (15 m) to either side.

Once mining resumed and the initial section of the drain was installed (late 1988), water quality improved dramatically. Highly acidic water with elevated metals concentrations changed to alkaline water having low iron concentrations. Sulfate levels, although still elevated, decreased substantially after installation of the drain. Table 16.4 shows a compilation of water quality results from the drain.

In the author's opinion, the main factors in the substantial water quality improvement were the alkaline supplement and the establishment of the highwall drain and clay cap. This combination effectively supplied alkalinity to the ground water and provided for rapid flow of groundwater through the backfill while decreasing surface water infiltration by about two thirds. Gradual thinning of the highly acidic shale layer as mining progressed was also a significant factor.

It is interesting to note that many of the water quality problems on this site may have been avoided if the site would have been mined expeditiously and mining would have extended to the cropline on the southwest side of the permit 200 ft (60 m) away from final highwall. Mining to this cropline would have allowed for the free flow of groundwater off the site without creating a pooling effect. Unfortunately, this was not possible because of adjacent property interests which prevented mining.

The overburden on this site (high sulfur/low neutralization potential) represents conditions that today would be unlikely to meet the standards for permit issuance, even considering alkaline addition and the addition of a highwall drain/clay cap system. It was used here in an attempt to abate an existing acid mine drainage problem.

Case Study 3

Site 3 is a 60 ac (24 ha) site located in southern Armstrong County, PA (Figure 16.7). Approximately 20 ac (8 ha) of the upper Freeport coal were mined beginning in June, 1995 with final backfilling occurring in June, 1996. The site was seeded a month later and good growth is present.

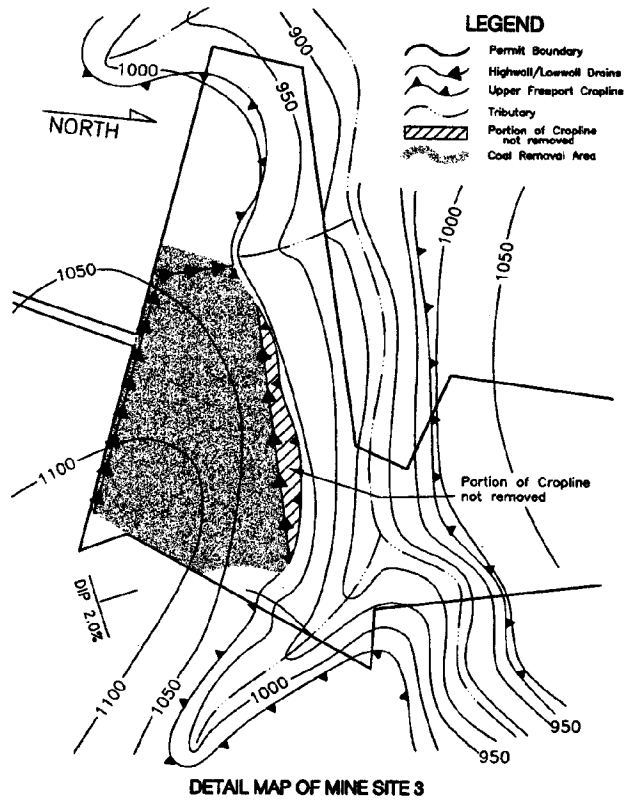

Figure 16.7 Drain installation schematic at mine site in Case Study 3.

An adjacent pre-act mine on the same seam had resulted in an alkaline discharge with high metals concentrations. Overburden analysis on Site 3, although indicating high sulfur coal (4 to 5%) and 2 to 4 ft (0.6 to 1.2 m) of moderately acidic overburden over the

Table 16.4 Water quality from mine site 2.

Sample point	Date	pH	Alkalinity mg/L	Acidity mg/L	Fe mg/L	Mn mg/L	Al mg/L	SO_4 mg/L	Comments
Discharge	6/88	3.7	0	386	123	48.3	20.6	1445	Last sample of discharge before drain installed
Highwall Drain	1/89	7.1	158	0	5	22.2	0.6	1218	First sample once drain installed
Highwall Drain	12/91	6.9	214	0	4.68	15.9	0.5	750	Highwall Drain completely installed
Highwall Drain	6/92	6.9	382	0	3.82	19.4	0.5	774	Site revegetated
Highwall Drain	9/96	6.6	296	0	5.7	25.3	0.5	1099	Latest sample

coal, also indicated a large net excess of alkaline material in the range of 3,000 tons $CaCO_3$ per acre (1102 t/ha). A moderate amount of groundwater was expected due to the number of springs in the area and the quantity of water encountered in exploratory drill holes.

Both the topography and the coal on the first phase of the operation dipped to the north, allowing unrestricted groundwater flow through the spoil along the base of the pit floor (Figure 16.7). However, a permit condition precluded coal removal in the area of the outcrop. Because of the adjacent mining problems, a highwall drain system was suggested as a means of minimizing the contact of groundwater with the backfill and of facilitating rapid groundwater flow through the outcrop coal barrier.

In this case, both a highwall and lowwall drain were constructed. The purpose of the highwall drain was to intercept the inflow of groundwater at the highwall and transport it down-dip. The intent of the lowwall drain was to prohibit any water from building up behind the portion of the coal cropline which would remain. Prior to constructing the lowwall drain, the exposed crop coal was sealed with clay to further minimize the chances of groundwater migration through this area.

Both drains were constructed without pipe per Method 3. A D9 dozer constructed a V-shaped channel along the highwall to a depth of 1 ft (0.3 m) and filled it with permeable low- sulfur sandstone from the mine site. Filter fabric was used to cover the drain prior to backfilling.

The drains have been in place since July and November, 1995 and both have discharged fairly continuously. Water quality parameters have been well within permit standards since installation as can be seen in Table 16.5. Interestingly, sulfate levels are elevated which may be linked to sandstone in the trench (instead of a pipe) resulting in slower groundwater flow and increased contact time or it may be due to the ability of groundwater recharge from surface water infiltration to enter the open trench system. No air traps were constructed for this site primarily due to the lack of any pipes in the drain. However, it would be fairly easy to include this feature as only a small area would need disturbed in order to install a 30 to 40 ft (10 to 12 m) solid section of pipe with a trap near the end.

Table 16.5 Water quality from drains at mine site 3.

Sample Location	N	pH	Alkalinity mg/L	Acidity mg/L	Fe mg/L	Mn mg/L	Al mg/L	SO_4 mg/L
Highwall Drain	12	6.48	200	0	1.54	5.49	0.89	571
Lowwall Drain	10	7.36	151	0	1.07	1.02	1.07	369

Summary

The use of water management techniques to prevent AMD on surface mining sites can be divided into three main practices: (1) erosion and sedimentation controls, (2) controls on surface water infiltration, and (3) groundwater controls. All three relate to the control of water on, around and within the mine. Key principles include the use of highwall drain systems to minimize contact between groundwater and acid-forming materials and rapid reclamation and revegetation to help prevent AMD formation.

Literature Cited

Atwood, D.F. and S.M. Gorelick, 1984. Hydraulic gradient control for groundwater contaminant removal. Journal of Hydrology, v. 72, pp. 85-106.

Braley, S.A., 1954. Chapter 9 - Mellon Institute Summary Report. Commonwealth of Pennsylvania Department of Health. February, 1954, pp 233-278.

Brant, R.A. and E.Q. Moulton, 1960. Acid Mine Drainage Manual #179. Columbus: Ohio State University, 40 p.

Caruccio, F.T., and G. Geidel, 1984. Induced alkaline recharge zones to mitigate acidic seeps. In: Proceedings of the 1984 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. December 2-7, Lexington, Kentucky, pp 43-48.

Caruccio, F.T., and G. Geidel, 1987. Leaky mines: maybe a benefit in disguise. In: Proceedings of the Eighth Annual West Virginia Surface Mine Drainage Task Force Symposium, April 7-8, Morgantown, W. VA, 4 p.

Caruccio, F.T., and G. Geidel, G., 1989. Water management strategies in abating acid mine drainage -- is water diversion really beneficial? In: Proceedings of the International Conference on Mine Planning and Design, May 23-26, Lexington, KY, pp 167-172.

Commonwealth of Pennsylvania Sanitary Water Board, 1958, Control of Acid Drainage from Coal Mines, Harrisburg, PA, 27 p.

Das, B.M., F. Claridge and V.K. Garga, 1990. The use of rock drains in surface mine waste dumps. CIM Bulletin, v. 83, no. 942, pp. 78-83.

Duchene, M., and E.A. McBean, 1992. Discharge characteristics of perforated pipe for use in infiltration trenches. Water Resources Bulletin, v. 28, no. 3, pp. 518-523.

Dyer, K.L., 1984. Water, friend or foe in the control of acid mine drainage. In: Proceedings of the Fifth Annual West Virginia Surface Mine Drainage Task Force Symposium, March 21-22, Morgantown, W VA, 14 p.

Geo-Con, Inc., 1989. Drilling and Grouting. Technical Brief T-DG-01-89, Pittsburg, PA., 2 p.

Geo-Con, Inc., 1990. Deep Drainage Trenches by the Bio-Polymer Slurry Trench Method. Technical Brief T-SW-02-87, Pittsburgh, PA., 2 p.

Geo-Con, Inc., 1990. Soil-Bentonite Slurry Walls. Technical Brief T-SW-01-85, Pittsburgh, PA., 2 p.

Gilbert, S.G., and J.J. Gress, 1987. Interceptor trenches for positive ground water control. Ground Water Monitoring Review, pp. 55-59.

Gorelick, S.M., and B.J. Wagner, 1986. Evaluating strategies for gound-water contaminant plume stabilization and removal. Selected Papers in the Hydrologic Sciences, pp. 81-89.

Guo, W., and C.A. Cravotta, 1996. Oxygen transport and pyrite oxidation in unsaturated coal-mine spoil. In: Proceedings of the 13th Annual Meeting of the American Society for Surface Mining and Reclamation, May 19-25, Knoxville, TN., pp. 3-14.

Hawkins, J.W., 1995. Impacts on ground-water hydrology from surface coal mining in Northern Appalachia. In: Water Resources at Risk Proceedings, May 14-18, Denver, CO., pp. 32-42.

Leach, E.G., and F.T. Caruccio, 1991. The effect of hydrologic zonation upon the acid production potential of pyritic rock. In: Proceedings of the Twelfth Annual West Virginia Surface Mine Drainage Task Force Symposium, April 3-4, Morgantown, W.VA.

Letich, R.D., W.P.Yant and R.R. Sayers, 1930. Effect of Sealing on Acidity of Mine Drainage. US Bureau of Mines Report of Investigation 2994, Washington, D.C.

Perry, E.F., M.D. Gardner and R.S. Evans, 1997. Effects of acid material handling and disposal on coal mine drainage quality. In: Proceedings of the Fourth International Conference on Acid Rock Drainage, May 31-June 6, Vancouver, B.C., Canada, pp. 1007-1025.

Scheetz, B.E., M.J. Menghini, R.J. Hornberger, T.D. Owen and J.H. Schueck, 1997. Beneficial use of coal ash in anthracite and bituminous mine reclamation and mine drainage pollution abatement in Pennsylvania. In: Proceedings, Air and Waste Management Association's 90th Annual Meeting and Exhibition, June 8-13, Toronto, Ontario, Canada.

Skousen, J.G., J.C. Sencindiver and R.M. Smith, 1987. A Review of Procedures for Surface Mining and Reclamation in Areas with Acid-Producing Materials. EWRC 871, West Virginia University, Morgantown, WV, 40 p.

West Virginia Surface Mine Drainage Task Force, 1979. Suggested Guidelines for Method of Operation in Surface Mining of Areas with Potentially Acid Producing Materials. Charleston, W VA, 27 p.

Wriam, V.P. and P.E. Naumann, 1996. Improving ground water in the backfill with alkaline addition. In: Proceedings of the American Society for Surface Mining and Reclamation, May 19-25, Knoxville, TN., pp. 336-354.

Zheng, C., K.R. Bradbury and M.P. Anderson, 1988. Role of interceptor ditches in limiting the spread of contaminants in ground water. Ground Water, v. 26, no. 6, pp. 734-742.