ACCIDENTAL RELEASES OF SLURRY AND WATER FROM COAL IMPOUNDMENTS THROUGH ABANDONED UNDERGROUND COAL MINES

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Coal refuse is a waste byproduct of coal mining. It consists primarily of fragmented rock that is unavoidably removed with coal during the mining operation. It also contains coal that was not separated during processing. Prior to the early 1920's, before mechanization of underground coal mines, mining was performed primarily in the thicker seams. At that time, coal was removed by hand picking and loading. Since miners were only paid for the coal they produced, and cars containing too much waste could be altogether rejected, they would be very careful not to include waste rock in their coal car. Hand breaking and loading made this possible. Since coal seams were thick and apparently endless, roof and floor coal could be left to ensure that a minimal amount of waste rock was mined with the coal. Much of the waste that was taken could be sorted out underground during the hand-loading phase of the job. The waste would simply be left underground. Due to the small volume of waste generated, waste dumps remained relatively small and waste management was not a significant problem.

After the early 1920's, mechanization replaced hand breaking and loading in the larger mines. Machines could remove large amounts of coal in the same time a person could load a single car by hand. This made it possible to profitably mine thinner coal seams. Coal production rates increased dramatically. However, the large machines used in the mining process could not distinguish between the coal and waste material. Nearly all of the material mined by the machine would be transported to the surface. Today, very few mining operations exist which use hand mining methods.

Prior to mechanization, coal brought to the surface would be hand sorted for size. The small amount of waste transported with the coal would also be sorted out. The waste would then be transported to a dump site. Following widespread mechanization and the subsequent increases in production, mechanical methods of sorting the coal had to be developed to keep pace with production. Efficient and productive preparation facilities were designed to size the coal mechanically and remove the waste. As coal production rates increased, so did the volume of waste produced. Waste rock, typically referred to as coarse coal refuse, was still placed in dumps, often in a haphazard manner, without thorough engineering design.

With time, market conditions created a demand for cleaner coal. This meant that methods more sophisticated than mechanical separation were needed to clean the coal. Cleaning methods such as dense medium and hydraulic separation were developed and became widely used. The raw coal would be crushed to a size sufficiently small to allow for removal of the desired amount of waste. This resulted in production of a waste product comprising a fluid mixture of water and finely crushed coal and rock. This material was referred to as fine coal refuse or slurry. The slurry would typically be discharged into the nearest stream or river. However, heightened environmental awareness and public pressure for clean waters eventually forced coal operators to construct storage ponds to contain the slurry. Since the coarse coal refuse was still being produced in abundant volumes, it became the construction material of choice for structures to impound the slurry.

Although their primary function was for waste disposal, these impounding structures were similar to conventional dams in many ways. They were often constructed across a drainage course and would subsequently alter the site's drainage conditions. Under normal operating conditions, the slurry produced by the coal cleaning plant would be pumped behind the structure for storage. Figure 1 shows a typical cross-valley configuration. Although these structures were functioning as dams, they were not always designed and operated as such. While some of these dams were well engineered and constructed, others were built with very little engineering. The specific techniques used to construct the refuse dams varied with the materials and equipment available at each mine site. There were no design standards or regulations to govern this activity. As a result, impoundment sites were often selected solely on the basis of convenience and cost. In some cases, few, if any, site preparations were made. Construction usually proceeded by dumping the coarse refuse either from an aerial tram or from a truck. Often, no compaction was used other than that incidental to the trucks traveling over the material. Seepage of water through the embankment may not have been considered. Spillways, when provided, were sometimes inadequate or improperly constructed, and adequate storage capacity for runoff from extreme storm events was seldom provided.

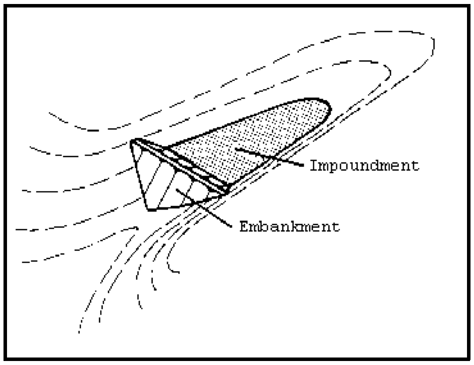

Figure 1
Cross-valley configuration

The slurry was piped from the preparation plant to the impoundment. The solids settled out of the slurry and formed a deposit overlain by water. This pumping and deposition would continue as the impounding embankment was raised concurrently using coarse refuse, creating additional storage capacity. This practice generally resulted in the embankment crest moving in a downstream direction. This type of construction is referred to as the downstream method. When sufficient quantities of coarse refuse were not available, or other site conditions dictated, alternative construction methods were employed to raise the embankment crest. One method, which required significantly less coarse refuse, was the upstream construction method. In this method, coarse refuse is placed over the existing settled fine refuse, resulting in the embankment crest moving in an upstream direction. A third method of construction is the centerline method, which is essentially a combination of the previous two methods. Figure 2 illustrates these various construction methods.

Due to the increase in the amount of coal refuse produced and the sometimes casual methods used to dispose of the material, many unsafe and environmentally undesirable refuse structures were constructed. Sporadic failures occurred, primarily in rural areas, yet these failures gave no indication of the magnitude or seriousness of the coal refuse problem being created.

On February 26, 1972, a coal refuse dam near Saunders, West Virginia, which was owned and operated by the Buffalo Mining Company, failed. The flooding downstream resulted in 125 deaths, the loss of more than 500 homes, and extensive flood damage to other property. The task force assembled to investigate the failure concluded, among other things, that the facility was constructed with little or no engineering design.

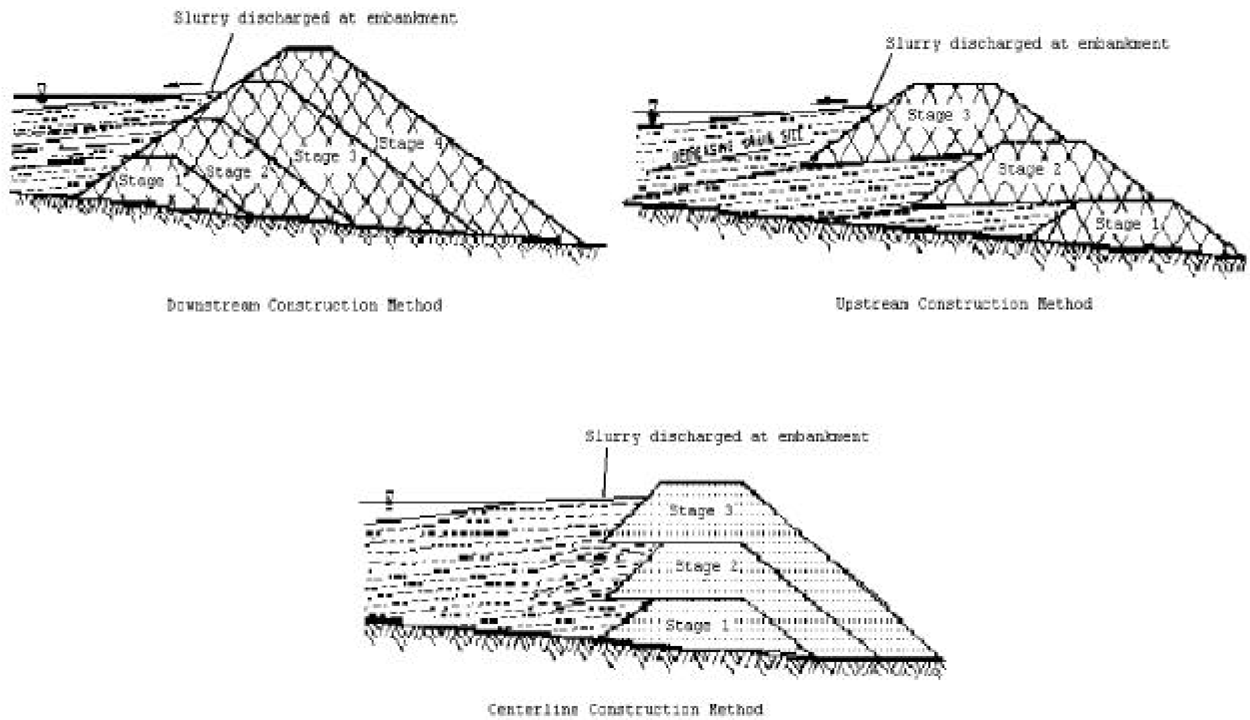

Figure 2
Typical refuse facility construction methods.

Following the Buffalo Creek disaster, the predecessor to the Mine Safety and Health Administration (MSHA), the Mining Enforcement and Safety Administration (MESA), took steps to prevent future failures. Existing regulations were reviewed and major revisions were made in 1975. The revised regulations required that detailed engineering plans for impounding structures be submitted to the agency for review and approval. The agency initiated programs to determine the current level of knowledge in the area of coal refuse disposal, to determine acceptable engineering and design practices, and to identify areas requiring additional research. Another step taken to help reduce the possibility of future failures was the creation of specialized engineering divisions within MESA's Technical Support office whose primary mission was to review impoundment design plans. Also, impoundment specialists were stationed in each district enforcement office. These inspectors are responsible for inspecting impoundment sites during construction and operation.

Presently, MSHA has regulatory authority for nearly 600 coal refuse impoundments and over 350 non-coal tailings disposal sites. It is becoming increasingly difficult to locate new construction sites that have not been undermined. Additional precautions must be provided in the design plan to ensure public and miner safety as well as to protect the environment. Many sites have been constructed over active and abandoned underground mines with no apparent problems. This paper will describe three incidents where water/slurry broke from an impoundment into abandoned mines, the steps taken to prevent a recurrence, and will discuss efforts to prevent this type of incident at other sites.

Miller Cove Slurry Impoundment

In August and October of 1996, releases of coal slurry occurred through an abandoned underground coal mine. This incident occurred at the Miller Cove Slurry Impoundment near St. Charles, Lee County, Virginia.

Background

In early 1995, the mining company obtained a permit from MSHA to begin construction of the Miller Cove Slurry Impoundment, a refuse disposal facility to serve its coal preparation plant. Prior to construction of the facility, the company disposed of its coarse refuse in a refuse pile and its fine refuse in abandoned underground mines. Growing concerns about available disposal capacity resulted in the need to design a surface storage facility.

Design plans for construction of the site were first submitted to MSHA in 1993. After several revisions, approval to construct the site was granted in early 1995. The cross-valley impoundment was to be placed in the hollow known locally as Miller Cove of Straight Creek of North Fork of the Powell River. It is to be constructed in 7 stages over a period of approximately 13 years using a combination of centerline, downstream, and upstream construction methods. The final height of the embankment is to be approximately 335 feet. Construction of Stage 3 is currently in progress. Coarse coal refuse is being used to construct the embankment, and slurry is being pumped into the impoundment upstream of the structure.

Abandoned room and pillar mine workings are present in the Darby No. 5 coal seam beneath the embankment and the impoundment. The seam has a height of approximately 48 inches. The coal seam outcrops in the Miller Cove hollow and several openings into the mine had been identified prior to the beginning of construction. The approximate elevation of the mine openings in the hollow is 1925 feet mean sea level (MSL). The designer determined that future subsidence would not occur or would be minimal.

Seals for mine openings located within the dam's footprint were designed to control the flow of water and strengthen the surrounding rock. Seals for openings within the impoundment area were designed to prevent the loss of fine refuse while allowing water to flow under controlled conditions. Seal construction typically began by clearing loose rock and soil from around the opening, pushing shot rock into the opening and packing it tightly. A graded filter or geotextile was placed over the rock fill. Finally, a protective layer of coarse refuse or spoil material was placed over the entire area.

August 1996 Release of Slurry/Water

On August 9, 1996, construction of Stage 2 was in progress. This stage was to have a final crest elevation of 1998 feet MSL. The pool elevation was approximately 1927 feet MSL when approximately 3 inches of rain fell in a period of less than two hours. The runoff caused the pool to rise 3 feet to elevation 1930 feet MSL. Within a short time, slurry was observed in the adjacent Gin Creek hollow. Company personnel observed that the pool elevation had dropped and could see a possible exit location on the western side of the pool area. The area coincided with the location of mine openings sealed during earlier stages of construction.

Pumping of slurry into the impoundment was immediately stopped. Since the area was not accessible due to the level of the pool, a road was constructed of earthfill out to the suspected leak area. The road was also to serve as a dike to hold back slurry while excavations were made in the vicinity of the suspected leak. After completing the excavation down to the elevation of the coal seam, it was found that the seals constructed in known mine openings were intact. Further exploration revealed that the leak had occurred in an area that was originally thought to have a thick, solid barrier of coal. Available mine maps indicated that at least 25 feet of solid coal were present between the outcrop and underground mine workings in this area. The barrier was found to be less than two feet thick. It is believed hydrostatic pressure from the slurry had opened cracks in the coal seam and a piping type failure had begun. The thin coal barrier was progressively eroded, allowing water/slurry to flow uncontrolled into the mine. Figure 3 shows a portion of the mine map and the locations of mine openings.

To repair the situation, several hundred feet of the outcrop along the west abutment were cleared and thoroughly inspected. Weak areas and newly discovered openings were excavated and closed with designed seals. Then, a 20-foot-wide layer of low permeability earthfill was placed against the original hillside to impede the flow of water to the seals and to separate the fine refuse from the hillside. This liner was to be placed in compacted lifts and carried up the hillside until a vertical thickness of 100 feet was reached between the top of the liner and the coal seam. Figure 4 shows a cross-section view of the liner details.

October 1996 Release of Slurry/Water

The repairs made following the August incident appeared to be working well. No additional releases were observed and the impoundment was holding water as expected. On October 24, 1996, a second release occurred. At this time the pool elevation was at approximately 1952 feet MSL. This release was more serious than the August event because the water contained more solids. The slurry exited the mine in the adjacent Gin Creek hollow. The black, refuse-laden water flowed approximately 11 miles before entering the Powell River's North Fork. It was reported that the river was discolored for more than 40 miles. The Virginia Department of Environmental Quality estimated that 11,500 fish died as a direct result of the spill.

The steps taken to locate this leak were identical to those taken following the August incident. A road was constructed to the suspected leak point and the area was excavated to expose any openings or cracks. Again, it was found that the leak area coincided with the location of known mine openings and was upstream of the earthen liner constructed following the August incident. The excavations revealed that the seals were intact and were not the cause of the release. A subsidence crack was located about 25 to 30 feet above the mine seals. This area coincided with a small topographic "point" on the hillside. It appeared the tip of the point behaved as a cantilever beam that broke when loaded. The resulting crack intercepted the mine and allowed slurry and water to flow uncontrolled.

The repair work for this incident was also similar to that for the August incident. Excavations were made to locate additional cracks or openings. All openings were cleaned out and backfilled. A low permeability earthen liner was then placed over the entire area. Following this incident, the company decided to extend the liner completely around the impoundment area. The liner will be continued up the entire hillside as shown in figure 4. As an additional precaution, extensometers were installed to monitor ground movements in the impoundment area. A sediment pond was constructed outside the mine opening in Gin Creek to allow any solids to settle from water exiting the mine. Neither release had any impact on the main embankment, and no injuries resulted from these incidents.

On November 30, 1996, a four-inch rainfall caused the pool level to rise significantly above the earthen liner. No slurry discharge was observed at the mine exit. As of July 1997, the pool elevation was at approximately 1985 feet MSL. Several slurry discharges have occurred from the abandoned mine since the October incident. However, it is believed slurry deposited in the mine from the August and October incidents is being flushed out. Several additional subsidence cracks were observed in the abutment and reservoir areas during routine ground clearing. These cracks have been cleaned and grouted. MSHA, the Department of Interior's Office of Surface Mining, and the Virginia Department of Mines, Minerals & Energy, Division of Mined Land Reclamation, have worked closely together to evaluate these incidents and minimize the possibility for future releases.

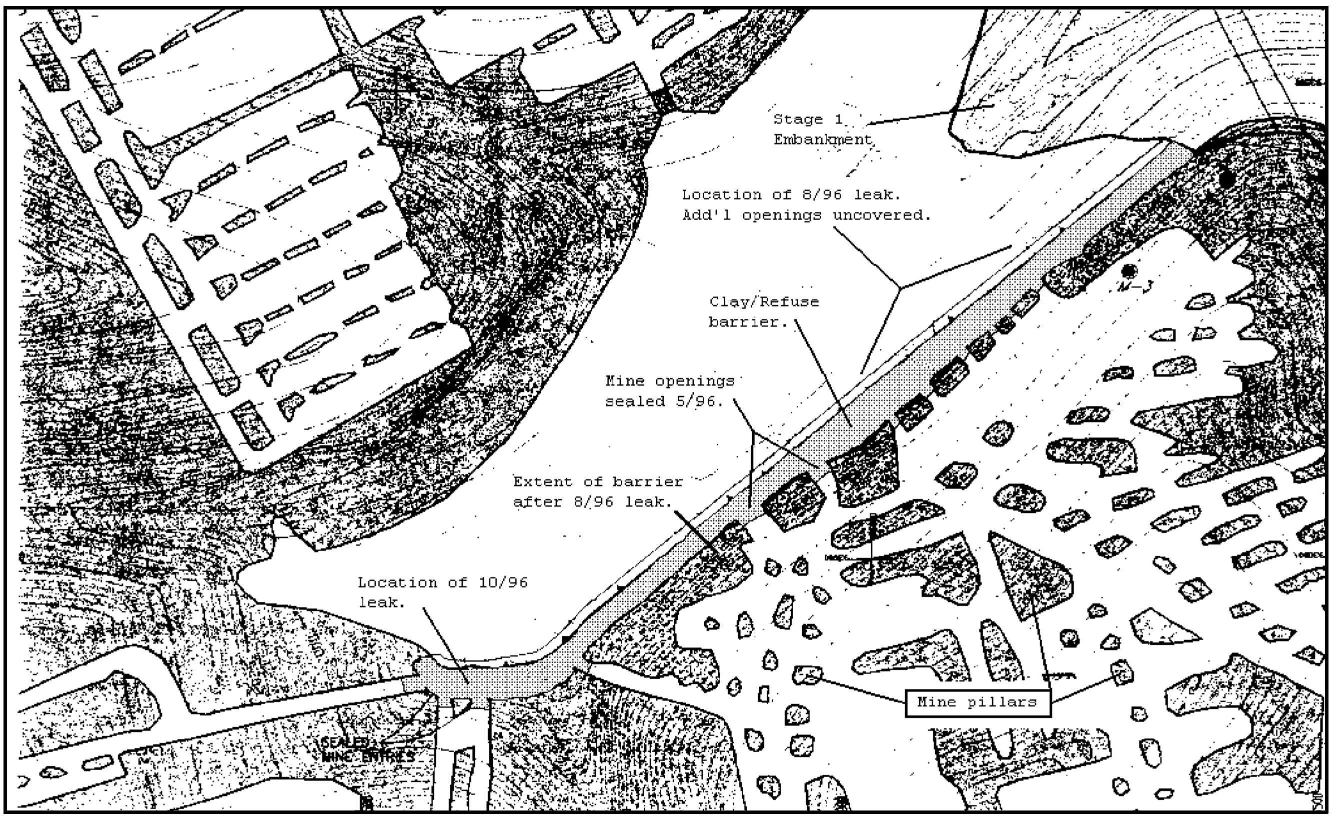

Figure 3
Plan view of Miller Cove Impoundment showing extent of mining in upstream abutments and locations of mine openings.

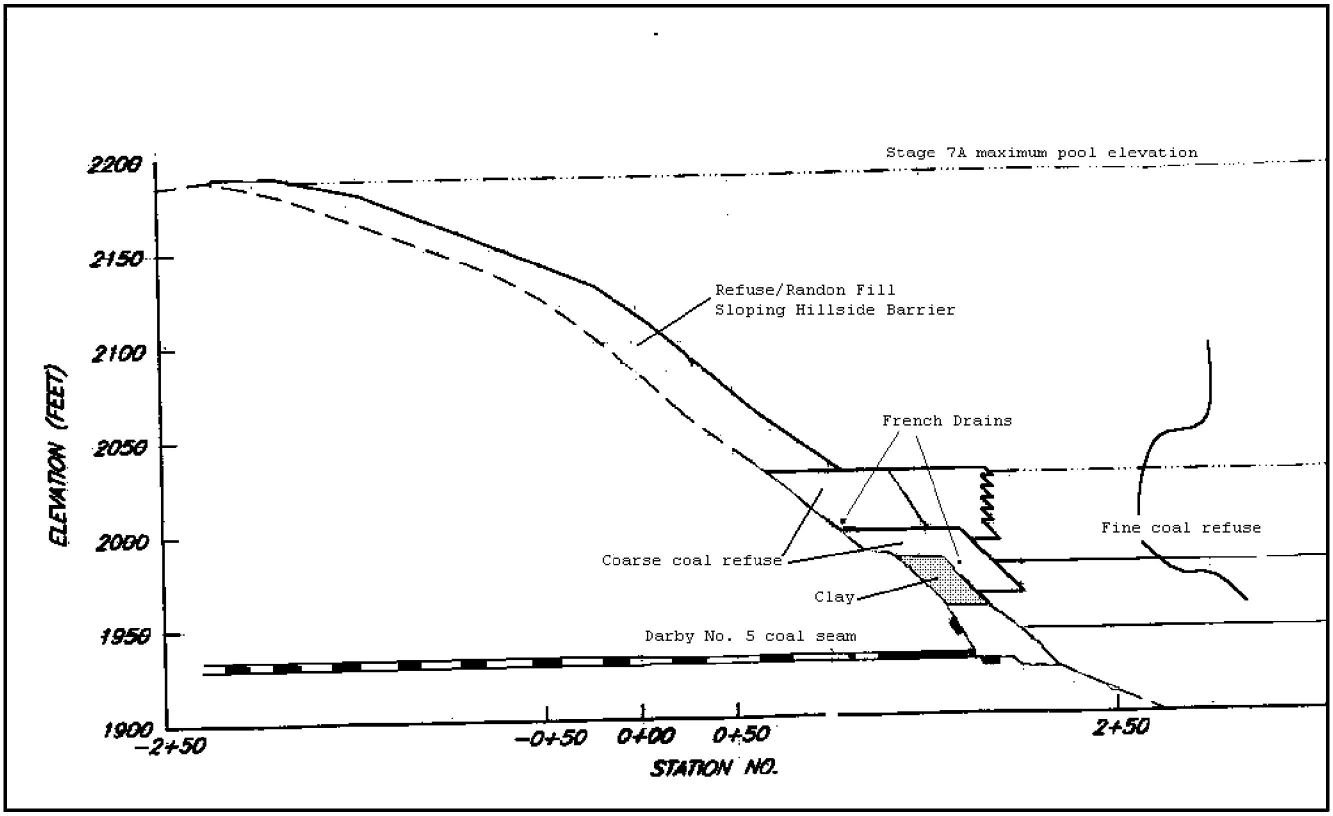

Figure 4
Cross-section showing earthen liner to be constructed around impoundment.

Buchanan #1 Slurry Impoundment

On November 26, 1996, another release of coal slurry occurred through an abandoned underground coal mine. This incident occurred at the Buchanan #1 Mine, Big Branch Coal Refuse Disposal Facility, located near Oakwood in Buchanan County, Virginia.

Background

An engineering plan was submitted to MSHA in 1981 proposing construction of a coal refuse disposal facility. This facility was to provide refuse disposal for the life of the Buchanan #1 Mine, which was estimated to be approximately 35 years. Disposal capacity was provided for 4.1 million tons of fine refuse and 13.2 million tons of coarse refuse. Due to significant increases in refuse production, various design modifications have been made over the years. The current plan involves the staged construction of a dam of coarse coal refuse using the downstream method to impound slurried fine coal refuse and water. The maximum proposed height is approximately 300 feet. Hydrologically, the dam has been designed to store the runoff attributable to the 72-hour Probable Maximum Flood and to decant it through a principal spillway pipe. In the final stages, an open-channel spillway is to be constructed to route the design storm flows.

The engineering reports indicated that both strip mining and deep mining of the Kennedy coal seam had been performed in the site area. The Kennedy seam outcrops in the embankment and reservoir areas, dipping in the northwest direction. The strip mining preceded the deep mining, and had been completed prior to the initial proposal for the disposal facility. By 1981, the strip mine bench had already been reclaimed and the highwall had been buried with soil. The deep mining of this seam was later performed using room and pillar mining methods. The mine is currently inactive, and was reportedly sealed on January 7, 1987. The effect of mining on the coarse refuse embankment was considered in the company's engineering evaluation, however, no mention was made of any auger mining or of the possibility of a direct connection between the reservoir and the underground mine. No engineered seals were proposed, and construction of the refuse facility did not involve removing the soil material which was covering the highwall.

Release of Slurry/Water

On November 11, 1996, slurry and water flowed into the deep mine from the northwest corner of the reservoir, passed approximately 1000 feet through the abandoned mine (in the Kennedy Coal Seam) and emerged on the other side of the mountain. The slurry discharged through two mine portals into the adjacent North Branch Hollow of the Levisa Fork of the Big Sandy River. At the time of the release, it was not known whether the flow had occurred through an existing auger hole, mine entry, thin coal barrier, or subsidence feature. In any event, the inflow occurred in a location where underground mines existed in very close proximity to a previously-mined strip bench and at an elevation near the lowest point of that strip mine bench in the reservoir area (at approximate elevation 1975 feet MSL). In fact, the strip bench was submerged only in the northwest corner, but remained above the slurry/water level around much of the reservoir. The slurry elevation prior to the breakthrough was reported to be approximately 1988 feet MSL. The embankment crest was at approximate elevation 2060 feet MSL. There was reportedly very little standing water in the impoundment at the time of the release. The outflow created an erosion channel resulting in a low area near the inflow point.

Water and slurry emerged from the sealed entries in the North Branch hollow at approximate elevation 1938± feet MSL. Evidence of the discharge was found in North Branch, Garden Creek, the Levisa River, and Fishtrap Lake extending 30 to 35 miles downstream. It was estimated that 21,045 fish were killed over 18.3 miles of this waterway. The discharge was estimated to be about 1,000 gallons-per-minute (gpm) at its peak. There were 3 shafts leading to an active underground mine approximately 1.5 miles downstream of the discharge point. No water entered the mine shafts. The release did not have any detrimental impact on the main dam, and there were no injuries or fatalities.

The company took measures to stop the flow and minimize the potential for any subsequent slurry discharges. Measures were taken in both the reservoir area of the Big Branch Impoundment and in the North Branch hollow where the discharges emerged. In the reservoir area, a dike was constructed along the existing strip bench using coal refuse borrowed from the crest of the existing embankment dam. This dike effectively isolated that area where slurry and water entered the mine from the rest of the reservoir. In the area where the strip bench had been submerged, this dike was constructed directly on the settled fines. The dike was reportedly completed to an elevation of 1995 feet MSL by November 29, 1996. This elevation provided sufficient capacity to contain a 100-year storm. In addition, a sediment control dam was constructed on the North Branch side to intercept the discharge which continued to exit at a rate of approximately 100 gpm. The discharge by that time reportedly contained very little sediment. These measures effectively eliminated the immediate concern that precipitation would result in additional slurry being washed into the mine.

A preliminary plan for the long-term correction of the conditions which led to this release was provided to MSHA, the Office of Surface Mining, and the Virginia Department of Mines, Minerals & Energy, Division of Mined Land Reclamation. Following an agreement made with these agencies, the company resumed pumping slurry in order to create a fine refuse delta on the impoundment side of the coarse refuse berm. This fines deposit created a relatively impermeable barrier and forced the standing water away from the dike, thereby improving its stability.

Exploratory drilling was then performed in order to determine the extent of slurry displaced during construction of the dike. It was determined that the slurry had been entirely displaced and that the barrier was essentially founded upon the strip bench. The crest of the dike was maintained at least 6 feet above the normal pool elevation as the fines level rose, so that the crest would not be overtopped during a storm event with a 100-year recurrence interval. Pumps were maintained to remove clarified water from the impoundment and to pump water which accumulated immediately upstream of the coarse refuse dike to the rear of the impoundment. The company maintained construction equipment on-site for use if needed during emergency activities. The impoundment was monitored continuously, the discharge point was monitored at least once each work shift, and a daily log of the conditions was maintained and reviewed by the company's engineers and consultants.

Once the coarse refuse dike was completed, an excavator was used to remove fine refuse from between the dike and the highwall. The removal of fine refuse and the existing soil cover permitted the company to locate and examine the existing auger holes and mine openings. At least 50 auger holes and three drift openings were uncovered. An excavator with a piston/ram assembly was used to push gravel and rockfill into the mine openings to a depth of 20 feet. The material used to fill the voids consisted of AASHTO #57 stone for the auger holes and cobbles for larger mine openings. Geotextile fabric was then placed against the filled holes and against the coal outcrop exposed in the excavation, and available soil or decomposed shale was placed against this fabric to create a relatively low permeability zone. Coarse coal refuse was also placed between this low permeability zone and the dike to create the designed mine seal. Figure 5 illustrates the backfilling of the mine void and initial construction of the mine seal.

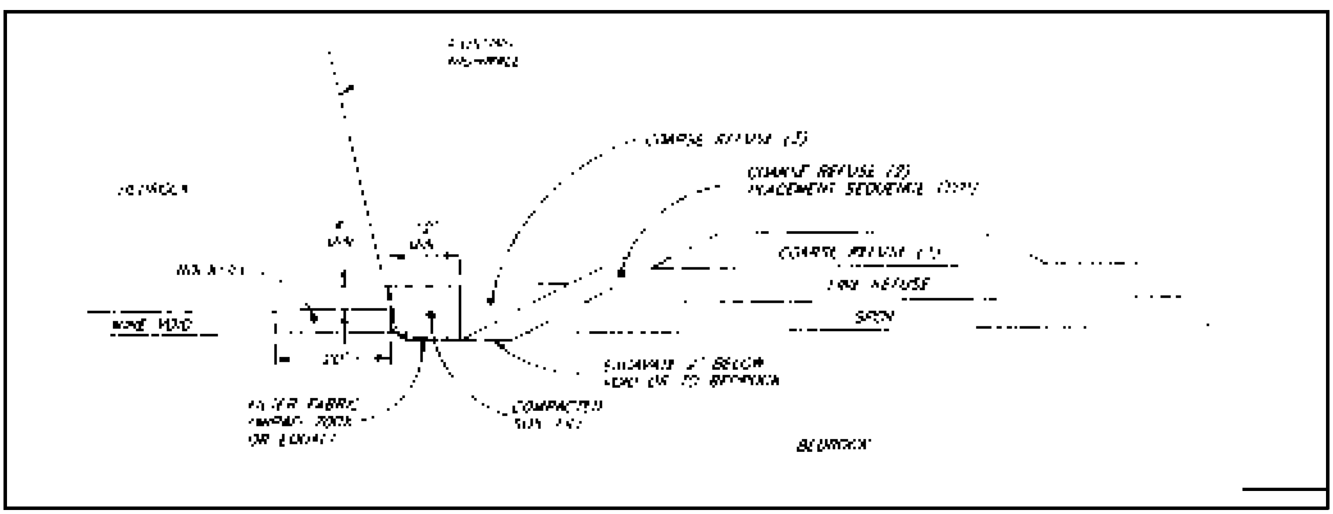

Figure 5
Initial construction of the mine seal.

The long-term remediation plan requires the mine seal barrier to eventually be constructed entirely around the reservoir. It is to be constructed such that free water is maintained as far as practicable from the mine openings. An extensive network of French drains will be installed to minimize the head and subsequently the flow into the mine openings. These drains have been designed to handle the anticipated seepage determined using finite-element methods. Piezometers were also installed at various locations around the barrier to confirm that excess hydrostatic pressures do not develop. Further, provisions were included in the specifications to inspect the hillsides for any evidence of subsidence.   Figure 6 shows a cross-section of the proposed mine seal.

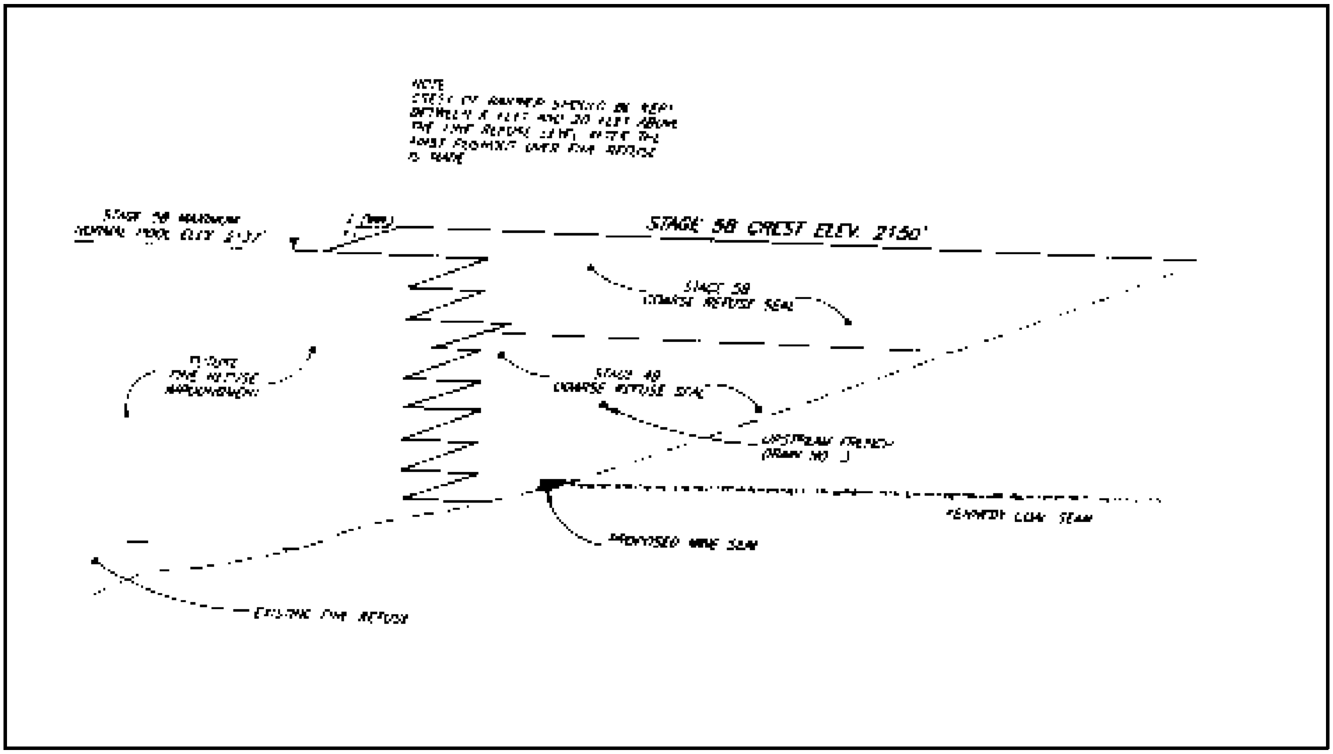

Figure 6
Proposed long-term mine seal.

Revised hydrologic and hydraulic calculations have been performed to account for the large volume of coarse refuse being deposited in the reservoir area. The decant inlet, emergency spillway invert, and crest elevations have been adjusted accordingly. In addition, seals will be installed at the mine entries in the North Branch hollow, where the slurry and water discharged. These seals will contain pipes to prevent significant accumulation of head in the mine.

The modifications proposed by the coal company were considered to be a practical and effective means of preventing future releases of slurry from the reservoir and have been accepted by the Mine Safety and Health Administration. Implementation of the plan is currently underway.

Discussion

In the Eastern United States, ideal sites for the construction of coal refuse disposal facilities are often unavailable. One reason for this is the fact that many areas have been undermined. The engineering community involved in the design, operation, and permitting of these facilities should be aware of the hazards created by these conditions.

The stability of refuse disposal facilities, the safety of the public, and that of the miners working underground are paramount concerns. These are followed by environmental and property damage concerns. It is not within the scope of this paper to address all the issues involved in safeguarding an embankment from mining-related damage. The potential for ground movements should be evaluated and appropriate defensive measures should be incorporated into the design. When considering the potential for release into an underground mine, each site should be evaluated based on the conditions present. The following conditions may be present at any site:

1) Deep mining where the coal seam does not intersect the surface at the impoundment.
2) Deep mining where the coal seam intersects the surface at the impoundment.
3) Auger mining where the coal seam intersects the surface at the impoundment.

Once the mining condition has been identified, the potential mode(s) of failure can be considered. The following possible failure modes should be considered:

1) Failure through an opening with a designed seal. Water or slurry flows in an uncontrolled manner through an inadequate seal.
2) Failure through an opening without a designed seal. Water or slurry flows in an uncontrolled manner through an opening that has not been closed with the intent of preventing or controlling such flows.
3) Failure through a coal barrier. Pressures resulting from deposition of water and slurry cause failure of a coal barrier and allow water or slurry to enter the mine in an uncontrolled manner. Examples include thin outcrop barriers or thin barriers between the end of auger holes and underground mines.
4) Failure through strata overlying a mine opening. Natural or mining-induced fractures within the overlying strata allow water or slurry to enter the mine in an uncontrolled manner. Examples include subsidence cracks, subsidence sinkholes, and rock joints.

The appropriate engineering response for each condition will depend on site specific conditions. Factors that should be considered when evaluating the unintentional release potential include depth and areal extent of mining; mining method; seam height; pillar and barrier dimensions; overburden, floor, and roof stratigraphy; and depth of auger holes.

Maps will play an important role when evaluating any condition. Maps of old mine workings, when available, are often unreliable. In general, maps produced after the Federal Mine Safety and Health Act of 1969 may be more reliable than those produced prior to that time due to requirements for more accurate mapping specified in the Act. However, all mine maps should be closely scrutinized prior to their use. Surface topographic maps sometimes lack necessary precision and may not be updated frequently enough to reflect surface modifications due to mining. Finally, underground and surface surveys should be tied to a common coordinate system. This practice would allow more reliable coordination between mine and impoundment planners.

Conclusion

As noted earlier, many currently operating disposal facilities have been constructed over active or abandoned underground mines with no apparent problems. However, the recent incidents discussed in this paper have heightened the awareness within MSHA and the mining industry of the potential for significant discharges of slurry and water through active or abandoned coal mines. A program is currently being developed to systematically address existing sites which may be adversely affected by mining.   MSHA has been re-examining existing plans in an effort to categorize sites according to their potential to release slurry through mines. This assessment is based on physical conditions at each particular site and consideration of the pertinent engineering parameters. In addition to determining the likelihood of a release, these sites are being further categorized with respect to the likely consequences of a release. Following these categorizations, sites will be prioritized and efforts will be turned toward correcting any deficiencies which may exist. In such cases, the conditions at the particular refuse sites will be evaluated to determine what corrective actions may be necessary. We anticipate that through the concerted efforts of the coal companies, consulting engineering firms, and federal and state regulatory authorities, the potential for future releases of slurry and water through active or abandoned underground mines can be effectively minimized.