

PREVENTING BREAKTHROUGHS OF IMPOUNDED-COAL-WASTE-SLURRY INTO UNDERGROUND MINES

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Abstract

The Surface Mining Control and Reclamation Act authorizes the disposal of coal processing waste in steep-sloped central Appalachia by constructing a coarse coal waste (also known as “refuse”) embankment across a valley and then pumping fine coal waste (slurry) into the basin. A concern shared by many engineers, geologists, and mine inspectors familiar with coal waste slurry impoundments in steep-sloped terrain is related to the common occurrence of underground coal mine workings adjacent to or beneath the impoundments and the potential for slurry to “breakthrough” into the mine works and subsequently emerge from mine openings into streams. This concern was dramatized on October 11, 2000, when an estimated 306 million gallons of water and slurry drained from an impoundment in Martin County, eastern Kentucky into an adjacent underground mine. Approximately 230 million gallons of the water and slurry discharged from two underground mine portals and affected over 75 miles of streams in Kentucky and West Virginia. In response to this and several other similar events, the U.S. Office of Surface Mining Reclamation and Enforcement (OSM) established a technical team to identify geotechnical issues that should be addressed to ensure that slurry impoundment designers and inspectors adequately evaluate breakthrough potential. Seven questions were identified. The central issues involve: (1) appropriate measures and available methods to identify and accurately locate underground

mines proximate to the impoundments; and (2) the flowability of slurry—not only in active impoundments still receiving pumped slurry but also in “idle” and reclaimed facilities.

Keywords: impoundment; slurry; waste; refuse; mining; coal; breakthrough

Introduction

The Surface Mining Control and Reclamation Act (SMCRA) authorizes the disposal of coal mine waste in steep-slope central Appalachia by constructing a coarse coal mine waste embankment across a valley and then pumping the fine coal mine waste (slurry) into the basin (Figure 1). A concern shared by many engineers, geologists, and mine inspectors familiar with coal mine waste slurry impoundments is related to the common occurrence of underground mine workings adjacent to or beneath the impoundment and the potential for slurry “breakthroughs” into mine works and subsequent breakouts into the surface waterways.

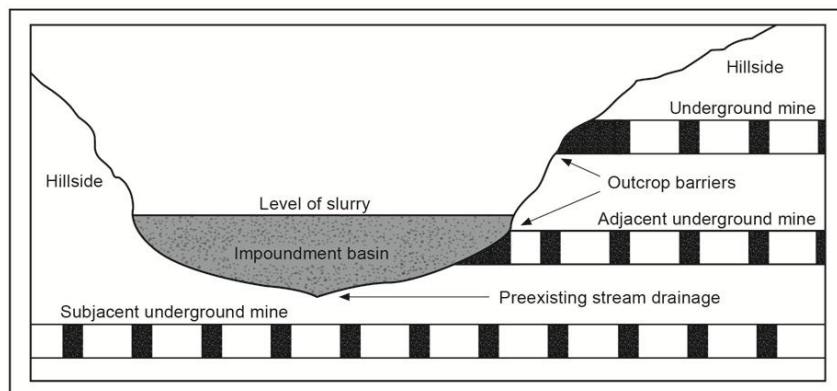


Figure 1: Schematic cross section of impoundment basin and proximate underground mines (diagram modified from NRC, 2002).

Sudden events of this nature can endanger underground mine workers and the downstream inhabitants; and negatively impacts local ground-water resources and stream and river ecosystems. This concern is particularly applicable to impoundments within the steep-slope topography of Central Appalachia, where the structures are within narrow hollows and in contact with numerous coalbeds.

This paper presents a brief overview of the construction and reclamation of coal-waste-slurry impoundments and the breakthrough events that lead to several OSM investigative initiatives. It identifies the issues the OSM identified regarding impoundment breakthrough potential and summarizes the agency’s approach to deal with each issue. The reader is directed to the Technical Position Paper entitled, “Potential of Impounded-Coal-Waste-Slurry Breakthroughs into Underground Mines,” for a more thorough discussion of the topics (USOSM, 2011). The paper is available at:
<http://www.techtransfer.osmre.gov/ARsite/arpublications.shtm>.

Background

On October 11, 2000 a combination of coal waste slurry and water from the Big Branch impoundment in Martin County, Kentucky broke through into an underground mine and subsequently discharged into the receiving streams. An estimated 306 million gallons of water and slurry drained from the impoundment into the adjacent underground mine. Approximately 230 million gallons subsequently discharged from the underground mine at two portals, polluting 75 miles of streams until reaching the Ohio River. At some locations, the water-slurry mixture spilled over the stream banks and deep deposits of slurry covered adjacent property and surrounded buildings. Six public-water intakes were adversely affected and alternative water supplies were arranged. It was reported that the cost to clean up the waterways and affected lands exceeded 56 million dollars.

This was the second breakthrough event at this impoundment, the first having occurred in May 1994. The breakthrough in 2000 differed from the 1994 breakthrough, in that it resulted in severe stream degradation and property damage. Fortunately, no personal injuries were reported as a result of the either breakthrough.

The 2000 event is the latest breakthrough of several past occurrences and, hopefully, the last such event, due to increased vigilance through routine and thorough evaluation of breakthrough potential in the regulatory permitting process for slurry impoundments. Other documented breakthroughs, in addition to the Big Branch events, include three breakthroughs in Virginia in 1996. Owing to the short time period over which these events took place and the severity of effects from the one in 2000, several investigations were undertaken with the ultimate goal of preventing future impoundment breakthroughs. Prominent among those include "Coal Waste Impoundments" by the National Research Council (NRC, 2002) which examined current engineering practices and standards applied to the impoundments; explored ways to ensure underground mine location relative to the impoundments; and evaluated alternative technologies that could reduce the amount of coal waste generated and allow productive use of the material.

Studies that specifically focused on the Big Branch impoundment were conducted by the U.S. Department of Labor, Mine Safety and Health Administration (MSHA) in 2001 and the OSM in 2002. Both evaluated on-site conditions, and construction, regulatory, and enforcement practices that contributed to the failure. MSHA administers the provisions of the Federal Mine Safety and Health Act of 1977 (FMSH) to enforce compliance with mandatory miner safety and health standards. OSM was established by SMCRA to oversee the enforcement of surface coal mining and reclamation regulations from the stand point of public safety and environmental protection.

OSM announced a regulatory-program oversight initiative in February 2001 to address potential future slurry impoundment breakthroughs. Oversight studies of the Appalachian state and federal SMCRA regulatory programs were co-performed by the state or federal regulatory authorities and the pertinent OSM field offices. In West Virginia, the OSM Charleston, West Virginia Field Office and the West Virginia Department of Environmental Protection (WVDEP) began an evaluation of the State's review of permit applications with regard to breakthrough potential. Initially, seven impoundments identified by the WVDEP as

those having the greatest breakthrough potential were investigated (Phase 1). Since this was a small sample of older permits, OSM, with WVDEP concurrence, decided to evaluate three recently permitted impoundments at which construction was not complete (Phase II). Review of new (under construction) impoundments was expected to permit visual inspection of design features aimed at breakthrough prevention, which was not possible at the previously evaluated, older impoundments.

During the first two phases, several instances were noted in which the permit review failed to adequately identify or address breakthrough potential. OSM worked with state officials and resolved the problems on a case-by-case basis. OSM then decided to conduct a third investigation of more permits, employing experts from different offices in its agency to determine if these cases were permit-specific or if they pointed to programmatic flaws in the regulatory authority review process. OSM assigned teams of engineers and geologists from five different office locations to review 15 permits in West Virginia.

During the review, these teams began asking questions that were not been emphasized in previous oversight activity. Therefore, OSM management diverted the team members from the oversight permit reviews and asked that they develop a peer-reviewed Technical Position Paper (or “white paper”) on technical issues that were not only noted in West Virginia but also known to the reviewers from their multi-state general experience. The purpose of the paper was to address the following concerns relating to current permit-review procedures:

- (a) Is there a sufficient accounting for all minable coal seams cropping out within and underlying slurry impoundments?
- (b) Is there an over reliance on the existence and accuracy of mine maps when determining whether minable coal seams have been mined and the thickness of barriers between underground mines and the impoundment footprint ?
- (c) Is sufficient information being obtained to determine fine-refuse flowability when impoundments are either expanded in size or “eliminated,” i.e. capped, and no longer considered to be impoundments?

As a result of the discussions, the authors of the white paper identified seven technical issues regarding risk and prevention of breakthrough. The issues and a synopsis of the authors’ opinions pertaining to them are presented below. They served as justifications for the findings and recommendations in the final West Virginia oversight report (see USOSM, 2013). They now serve as a technical reference for additional oversight evaluations in the other states of the Appalachian Region.

There were other documented topical studies, in addition to the white paper, that supported the OSM oversight initiative. Michael, et al. (2005) conducted a survey of current knowledge pertaining to the flow properties of impounded fine waste (henceforth referred to as the “2005 study”). Under the assumption that impounded slurry may be in a flowable state, Michael and Chavel (2008) evaluated the potential for breakthroughs resulting from additional surcharges imposed on mine outcrop barriers during part of the impoundment-reclamation process, i.e., the placement of cap material over the slurry basin. Finally, Michael et al. (2010) provided a summary of OSM’s breakthrough-potential concerns and a

review of pertinent literature on slurry-impoundment stability that was published subsequent to 2005.

OSM's most recent action in its involvement with the breakthrough issue has been to fund a project under the agency's Applied Science Program that is testing the geotechnical and rheological properties of sampled coal waste slurry (Zeng, 2011). In addition to standard engineering lab tests, such as for consolidation rates, permeability and viscosity, the study will employ small-scale flow models and centrifuge modeling to assess flow behavior under both static and dynamic loading. The project is scheduled to be completed in 2015.

Coal Waste Impoundments

“Coal waste” is material that results from the preparation of mined coal for energy production. Some of the material is placed in dry landfills, but most is disposed in slurry impoundments. In the latter case, waste is first separated into relatively coarse and fine fractions, known as coarse and fine waste. The coarse waste (grain sizes ranging from 0.1 to 70 mm) is relatively dry and free-draining and is used to construct compacted embankments across headwater stream valleys adjacent to the coal cleaning/preparation plant. The fine waste (from 0.001 or less to 20 mm) is mixed with water and transported in pipes as slurry to the impoundment basin.

The proportion between the dry coarse waste and fine waste slurry constituting an impoundment depends on the relative amounts of the materials produced at the preparation plant(s) and commonly governs how the impoundment is constructed. Figure 2 is a schematic diagram of the “downstream,” “upstream,” and “centerline” construction methods. Many impoundments amount to a hybrid among these three construction methods. It is important to note that there generally is no preconceived final design for these structures. More often than not, coal-waste slurry impoundments are periodically re-designed for expansion to accommodate additional waste as the existing stage reaches capacity. In the narrow hollows of steep-slope Appalachia the embankment structures increase in height and the impounded slurry deepens, thus incrementally adding overlying bearing pressure on mine outcrop barriers.

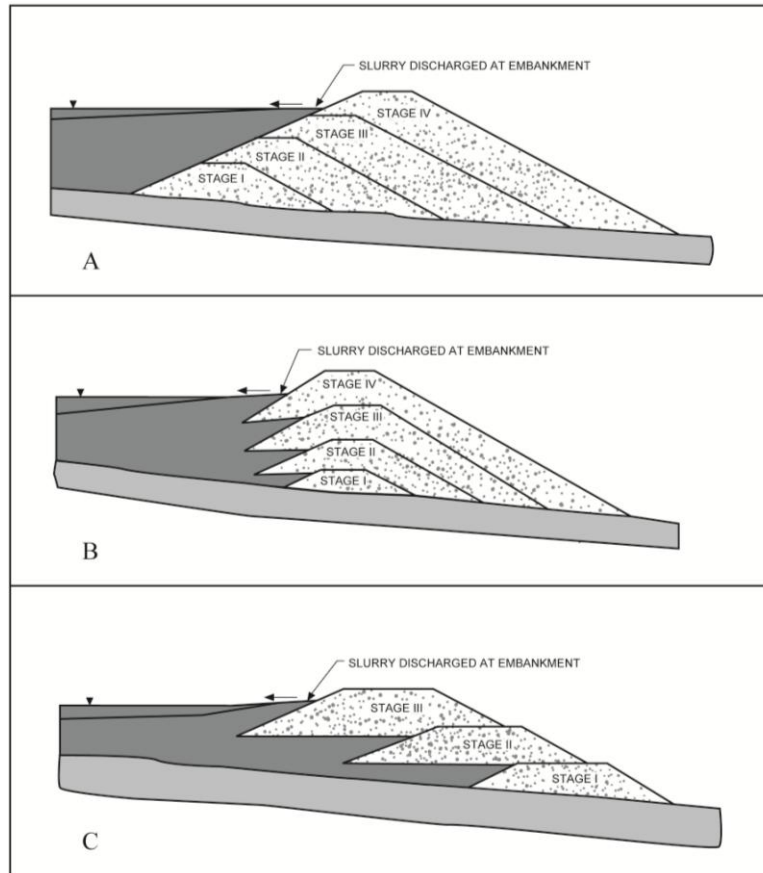


Figure 2: Schematic cross sections of downstream (top), centerline (middle), and upstream (bottom) slurry-impoundment-construction methods (diagrams from D’Appolonia Engineering, 2009).

MSHA and OSM regulatory requirements for the engineering design, construction, maintenance, inspection, and elimination of slurry impoundments are provided in 30 CFR § 77.216 and § 780.25 respectively. Detailed guidance is available in MSHA’s Engineering and Design Manual – Coal Refuse Facilities (D’Appolonia Engineering, 2009). The MSHA guideline document is pertinent to on-site reconnaissance of foundation conditions—including the identification of underground mines—and evaluation of and prevention against mine-subsidence and breakthrough potential (see Chapter 8). Breakthrough prevention techniques are designed to ensure that adequate horizontal barriers (i.e. outcrop barriers) and vertical barriers (barriers above mines that lie below the bottom of the impoundment) exist; or improve barriers when necessary (by backstowing underground mines or covering the outcrops of mined coalbeds with a seepage barrier).

Coal waste slurry impoundments may be active (i.e., still receiving coarse coal waste or slurry from an active coal-cleaning operation), inactive (reactivation planned), or reclaimed (Figure 3). Those structures that are inactive may be under a current permit, or “orphaned”. Orphan impoundments are those for which there is no mine operator with continuing reclamation liability accountable for the structure under MSHA or SMCRA programs. Such impoundments are not properly reclaimed to MSHA and SMCRA standards. Generally, inactive impoundments constructed prior to the passage of the SMCRA are not reclaimed

unless re-permitted or they present an imminent safety hazard to the public or harm to the environment. Impoundments on bond-forfeiture sites may not be reclaimed if there is insufficient bond or insurance money to cover the cost of the work.

Impoundments which become inactive following SMCRA are required to ensure public and environmental safety while not in operation and ultimately must be reclaimed to MSHA and SMCRA standards when their use is no longer planned or viable. Most impoundments that are reclaimed are capped with coarse waste or surface mine spoil to eliminate impounding potential and revegetated. Surface drainage around the sites must preclude erosion of the structure and are engineered for the long-term to safely convey 100-year storm events around the site. A few slurry impoundments have been converted into ponds or lakes for recreational use under the SMCRA experimental practice program, but the regulations require that impounding potential be eliminated upon completion of mining activities. Other impoundments are re-mined. Still others are capped when there are concerns that a breakthrough may occur, but also converted to accommodate slurry-cell structures on top of the capped basin to allow for additional waste disposal.

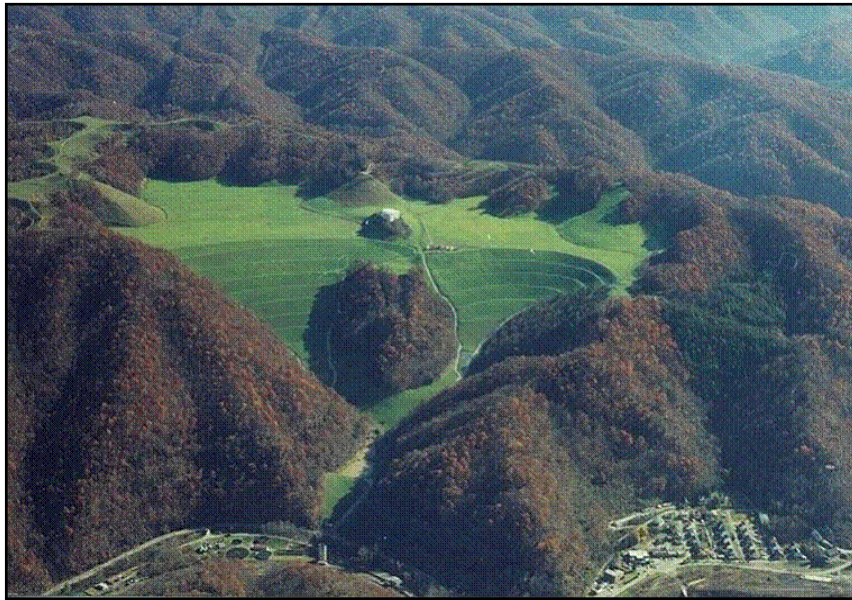


Figure 3: Reclaimed impoundment.

The Issues

- (1) **What is a minable seam?** All coal seams in the vicinity of major impoundments with a reported or known thickness equal or greater than 24 inches should be investigated. This opinion is based on current mining technology. The SME Mining Engineering Handbook 2nd Edition, page 1557, states that seam heights as thin as 26 to 30 inches can be mined (Hartman, 1992). When the demand is high, top quality coal, including metallurgical coal, in seams as thin as 24 inches, is mined by extracting additional rock above the coal.
- (2) **Can we trust mine maps to give us all the mining-related information we need?** No. Mining extents should be independently verified for each coal seam. Mine maps can be useful to estimate distances between the impoundment and the boundaries of adjacent

mine workings or elevations of subjacent workings. However, there are numerous undocumented mines (i.e. without mine maps) or with inaccurate or out-of-date maps. Many factors affect the reliability of maps. The surveying profession has developed over centuries, with methods being devised to discover errors through checks and balances, maximizing map reliability. However, underground conditions place additional hardships on surveyors, and eliminate or reduce the effectiveness of some of the checks and balances.

In addition to these factors, some locations in mines cannot be safely surveyed. These include terminated entries near seam outcrops or beneath valley bottoms. Terminated entries are typically not roof bolted, and therefore are not entered for precise survey. Consequently, the horizontal distance from the terminal face to the ground surface is not precisely known. If an impoundment is proposed at the site, the actual coal barrier thickness is unknown. Those factors, and the past occurrence of catastrophic breakthrough events, warrant conservative decision making when based on underground mine mapping. Many mine maps are accurate; however, there is no way to know whether a particular map is accurate without independent confirmation. A mine map should not be accepted as reliable prior to its verification. Figure 4 is an example of a map of a room-and-pillar underground mine adjacent to an impoundment. Figure 5 identifies a mine-map inaccuracy.

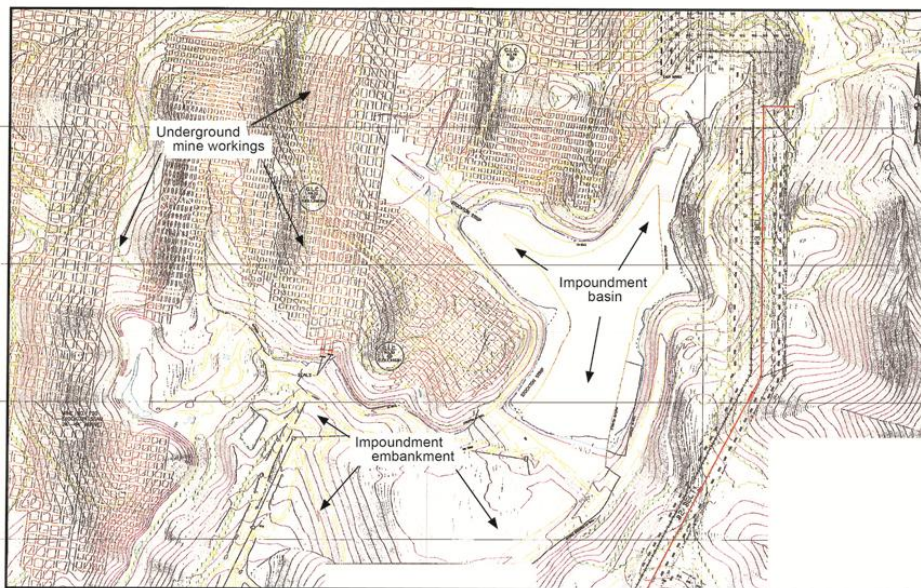


Figure 4: Example permit mine map of room-and-pillar underground mine workings adjacent to a coal waste slurry impoundment.

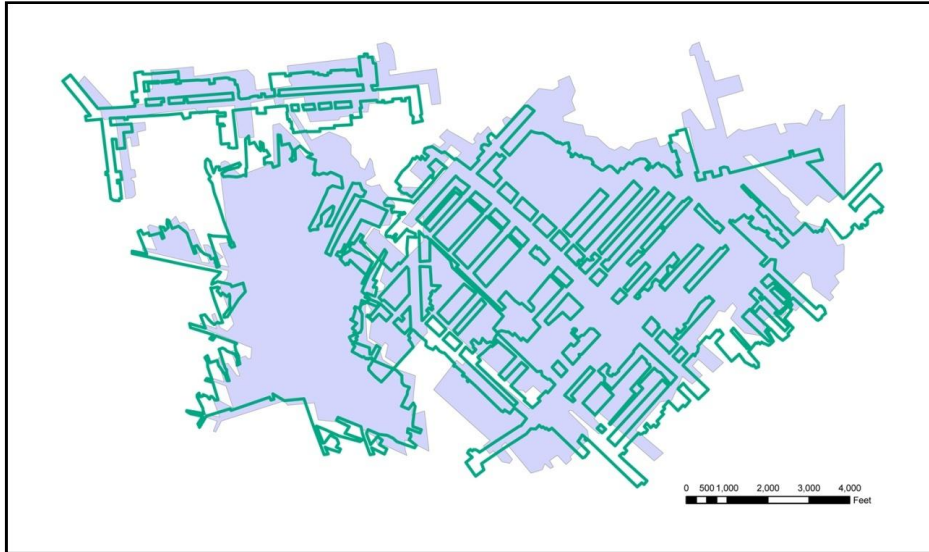


Figure 5: Contrast in the documented location of mine workings. The solid pattern was presented in a permit application for additional mining in the coal seam. The map shown in outline was provided by an earlier mining operation. The latter map was obtained from the OSM Mine Map Repository in Pittsburgh, Pennsylvania, and geo-referenced to compare with the geo-referenced permit map.

- (3) **How can we determine whether minable seams have been mined?** Each coal seam identified as “minable” needs to be thoroughly investigated to determine if it has or has not been mined. The investigation needs to document areas adjacent to and below the impounded slurry area and the embankment. Existing documentation of mining should be researched and evaluated. Site specific information should be collected to verify the existing documentation. For mineable coal seams where no documentation is available, additional investigations will have to be done to identify the presence or absence of mining.

Interviews with experienced miners and local residents; surface reconnaissance of outcropping coal seams and rock cover for mine adits and evidence of mine subsidence; drilling; and (possibly) geophysical surveying are methods which should be employed. However, if used under practical economic constraints, even the sum of these methods may not guarantee that all mining surrounding the entire perimeter of an impoundment is identified. Without a high degree of confidence that mining extents adjacent to proposed or existing impoundments are established, preventative designs to minimize breakthrough potential are advisable.

- (4) **What do we know about the flowability of slurry in active, inactive, capped impoundments; and capped impoundments with subsequent coal waste or excess spoil disposal loading (on top of) the cap?** The 2005 study found that, in the absence of appropriate engineering test data, there are no assurances that impounded slurry would not flow if there were an opening into an underground mine. Supporting this conclusion is the slurry material’s high void ratio and low permeability, and consequent high water

retention and the slow rate of consolidated strength development. These conditions are potentially conducive to flow in a breakthrough scenario.

Some impoundments are capped specifically because of breakthrough concerns, but are then converted to a foundation site for slurry cell structures to accommodate continued waste disposal (Figures 6 and 7). Slurry cells are small impounding structures holding fine waste separated by dikes of compacted coarse waste. They are constructed in layers, the total depth of which can equal or exceed that of the original impoundment. One purpose of the cells is to ensure a low hazard classification of the structure, which imposes less-stringent design criteria. Cell construction also limits the volume and flowability of slurry that would be released (relative to an active impoundment of equal size), should a breakthrough into an underground mine occur. Slurry cells are also employed to allow alternating cell use to attempt to dry out and consolidate cell contents before adding additional cells/dikes on top. However, capping the original impoundment and placing slurry cells on top of the capped area does not necessarily diminish breakthrough potential from the original impoundment. Surcharge from the stacked slurry cells can still increase hydrostatic pressure in the fine waste slurry below the impoundment cap. Water from the overlying slurry cells can also migrate into the abandoned slurry pool below.

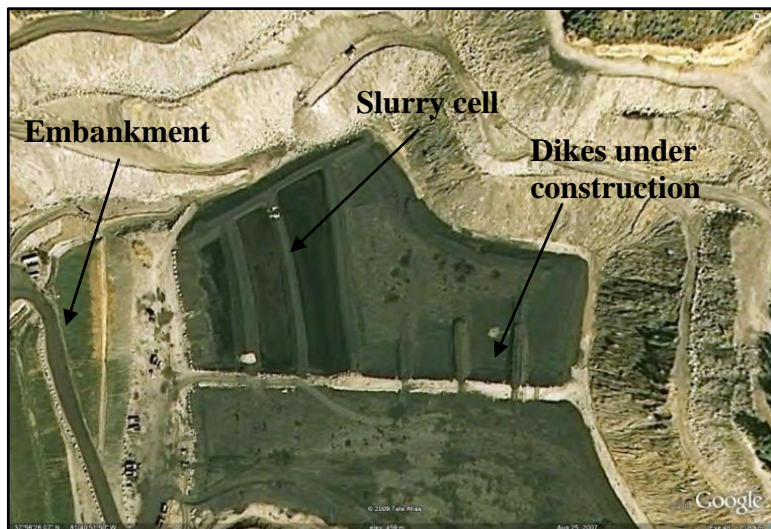


Figure 6: Aerial photograph of slurry cells.

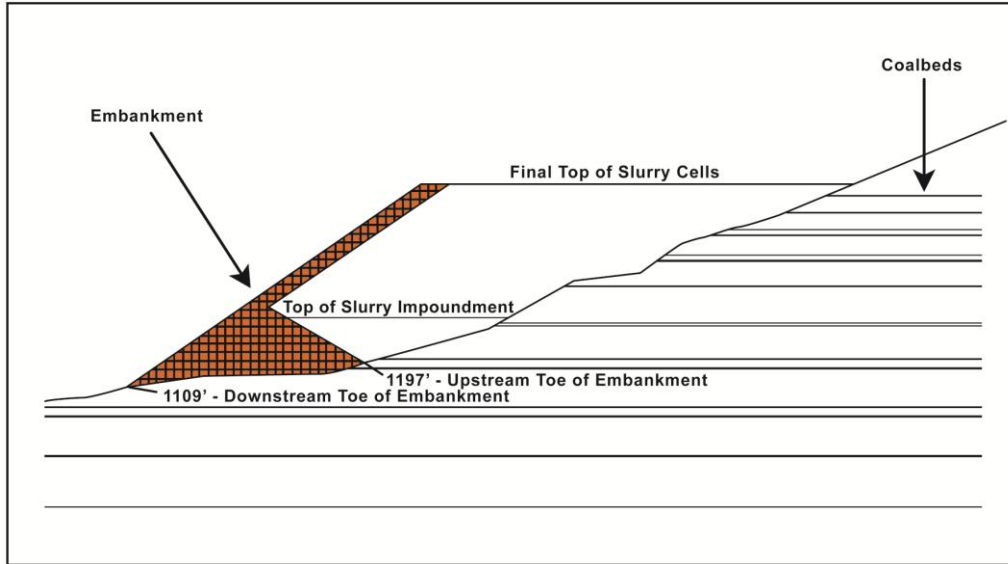


Figure 7: Schematic of slurry cell construction above a capped impoundment.

- (5) **How can we test the impounded slurry for its flow characteristics?** Capping of an impoundment does not necessarily eliminate the potential for breakthrough into underground mine works. This is especially true in cases where (a) underground mines exist in the impoundment's safety zone and additional loading (slurry cells, excess spoil fills etc.) is considered or (b) future underground mining within the structure's safety zone is proposed. Under these circumstances, the impounded slurry should be tested to ensure its properties preclude potential for flowing into the underground works. One method to determine flowability is to compare the moisture content of sampled slurry with its liquid limit. The test for liquid limit is routinely and successfully used by engineers to determine the moisture content above which soils can behave as liquids, and below which they behave as plastic solids. The liquid limit and several methods for determining moisture content are simple and economical. The number of liquid limit tests required would depend on the uniformity of the slurry materials. Tests at several locations and at multiple depths (e.g. near the bottom, mid-depth, and near the surface) should be performed. If test results vary significantly, more tests may be prudent. Once the liquid limit is established (lowest test result), moisture content can be used as a dividing line between flowable and non-flowable for any samples obtained from the impoundment.
- (6) **What precautions and restrictions should we recommend to prevent breakthroughs?** Recommendations for further assessment of slurry flowability and control of flowability were made in the peer reviews of the 2005 study report and the OSM Technical Position Paper. They include: an in-depth review of the rheology of other materials (e.g. mud, ceramics, refractory clays, and pharmaceuticals); lab and in situ testing of slurry consolidation, shear strength, liquefaction potential and rheology; modeling of slurry response to breakthroughs; and experimentally combining admixtures with the slurry or mixing slurry with coarse mine waste or mine spoil to increase strength.

Special studies would provide a better understanding of the magnitude of the breakthrough-potential problem and of factors affecting slurry flowability. However, there are also readily available preventative site-specific construction practices to consider. Where there is uncertainty as to whether coal seams in the impoundment footprint were mined, the operator should consider surface mining the coal seams and placing designed, artificial barriers on the benches and against the highwalls. That way, a natural barrier with unknown properties is replaced with a constructed barrier with known properties that does not rely on any remaining coal barrier for support. Also, where there are plans to: (a) increase the size of active impoundments (beyond original designs), (b) construct slurry cells or excess spoil fills on top of capped impoundments, or (c) undermine the impoundments, the impounded slurry can be sampled and tested to ensure the material's water content is not above its liquid limit.

(7) If an underground mine that intersects or lies below an impoundment is below drainage, should we still be concerned about breakthrough potential? Yes. The mine workings may be interconnected with other works. Consequently, the possibility of artesian breakouts at locations some distance from the impoundment should be considered (Figure 8). Even if a discharge does not occur, the breakthrough of the slurry may contaminate local aquifers hydraulically connected with the coal seam.

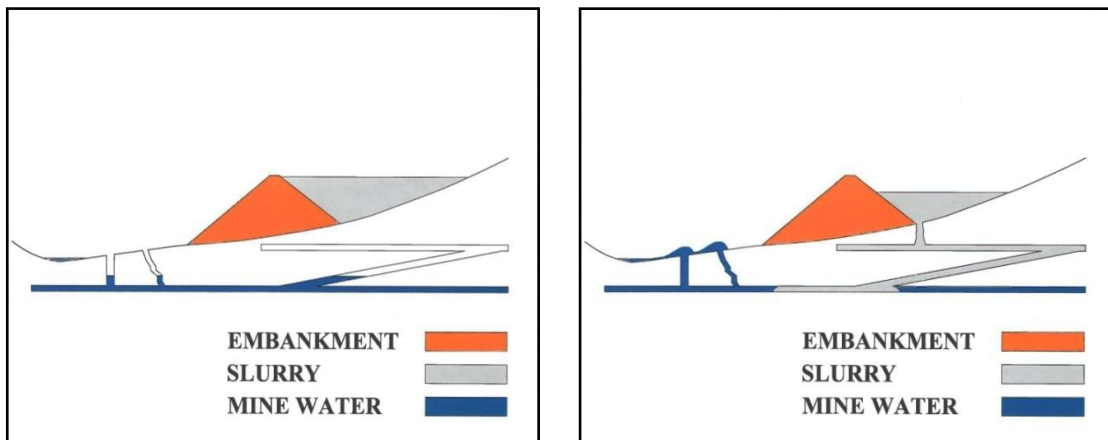


Figure 8: Schematic longitudinal sections of flooded below-drainage mine (left) and artesian mine-water breakouts in response to slurry breakthrough into the mine (right).

Conclusion

The design and operation of coal-waste slurry impoundments should include thorough preconstruction investigations and careful monitoring during construction to minimize potential slurry breakthroughs into underground mines. Towards this end, the impoundment designer and operator should identify: all minable coal seams intersecting and underlying an impoundment footprint; all adjacent and underlying underground mines and the competence of horizontal and vertical barriers between them and the impoundment; and the flowability of the impounded fine waste.

References

D'Appolonia Engineering, Inc., 2009, *Engineering and Design Manual: Coal Refuse Disposal Facilities*: prepared for the U.S. Mine Safety and Health Administration, Pittsburgh, PA, 826 p., plus appendices.

Hartman, H. (ed.), 1992, *SME Mining Engineering Handbook*: Society of Mining, Metallurgy, and Exploration, Inc., Littleton, CO, 2nd Ed., vol. 1, 1,294 pp.

Michael, P. and L. Chavel, 2008, *Environmental Risks Associated with Coal Refuse Impoundment Reclamation: An Assessment of the Possibility of an Underground Mine Breakthrough Occurring as a Result of the Impoundment Reclamation Process*: open file report to the U.S. Office of Surface Mining Appalachian Region Management Council, Pittsburgh, PA, 14 p.p., Available at: <http://www.techtransfer.osmre.gov/ARsite/Publications/RIR%20final%20report%209-25-08.pdf>.

Michael, P.; R. Murguia; and L. Kosareo, 2005, *The Flowability of Impounded Coal Refuse: a Review of Recent work and Current Ideas in the Engineering Profession*: open file report to the U.S. Office of Surface Mining Appalachian Region Management Council, Pittsburgh, PA, 25 pp. plus appendix. Available at: <http://www.techtransfer.osmre.gov/ARsite/Publications/ViscosityReport Aug05.pdf>.

Michael, P., M. Richmond, M. Superfesky, D. Stump, and L. Chavel, 2010, Potential of Breakthroughs of Impounded Coal Refuse Slurry into Underground Mines: *Environmental and Engineering Geoscience*, Vol. XVI, No. 3, pp. 299-314. Available at: <http://www.techtransfer.osmre.gov/ARsite/Publications/Potential breakthroughs.pdf>.

National Research Council (NRC), 2002, *Coal Waste Impoundments: Risks, Responses, and Alternatives*: National Academy Press, Washington, D.C., 185 p., plus appendices.

U.S. Mine Safety and Health Administration, 2001, *Report of Investigation: Noninjury Impoundment Failure/Mine Inundation Accident, October 11, 2000*: Mine Safety and Health Administration, Arlington, VA, 71 pp. plus appendices.

U.S. Office of Surface Mining Reclamation and Enforcement, 2011, *Technical Position Paper: Potential of Impounded-Coal-Waste-Slurry Breakthroughs into Underground Mines—Issues and Answers*: open file report, U.S. Office of Surface Mining Appalachian Region, Pittsburgh, PA, 25 pp. Available at: <http://www.techtransfer.osmre.gov/ARsite/arpublications.shtm>. [Accessed January 30, 2012]

U.S. Office of Surface Mining Reclamation and Enforcement, 2013, *Oversight Report: Coal Slurry Impoundment Breakthrough Potential (Phase III)*: open file report, U.S. Office of Surface Mining Charleston, WV Field Office, Charleston, WV, 10 pp. plus appendices. Available at: <http://odocs.osmre.gov/qdocs.aspx> (see record 1304, 2012).

Zeng, D., 2011, *Geotechnical Properties and Flow Behavior of Coal Refuse under Static and Impact Loading*: proposal submitted to the U.S. Office of Surface Mining, Case Western Reserve University, Cleveland, OH, 19 pp.