SME Annual Meeting
Feb. 15 - 18, 2015, Denver, CO

Preprint 15-127

PREVENTING COAL WASTE IMPOUNDMENT BREAKTHROUGHS INTO UNDERGROUND MINES: HOW WELL ARE WE DOING?

P. R. Michael, OSMRE, Pittsburgh, PA
M. W. Richmond, OSMRE, Pittsburgh, PA
S. J. Self, OSMRE, Pittsburgh, PA
J. M. Shapaka, OSMRE, Pittsburgh, PA
J. F. Mack, OSMRE, Harrisburg, PA

ABSTRACT

On October 11, 2000, an estimated 306 million gallons of water and coal waste 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 (OSMRE) commissioned an oversight study that evaluates how well state and federal regulatory programs established under the Surface Mining Control and Enforcement Act are ensuring that impoundment operators are minimizing the potential for impoundment-basin breakthroughs. The study focuses on slurry impoundments constructed in the hollows of Appalachia where numerous coal seams and steep topography combine to result in a large number of mined seams intersecting and underlying impounding facilities. Factors under consideration include: (1) full accounting of all mineable coal seams intersecting and underlying the impoundment; (2) identification and accurate location of underground mines close enough to the impoundment to potentially affect its stability; (3) assessment of the stability of coal barriers between the impoundment basin and adjacent mines, and stability of roof rock and pillars in mines subjacent to the structure; (4) determination of the flowability of the impounded slurry when expanding or undermining the facility are being considered; and (5) measures undertaken to reduce breakthrough potential when necessary. The oversight study began in 2012 after program-evaluation criteria were defined in an OSMRE technical position paper. The study is scheduled to be completed in 2017.

BACKGROUND

The Surface Mining Control and Reclamation Act (SMCRA) authorizes the disposal of coal mine waste by constructing a coarse coal mine waste embankment across a valley and pumping the fine coal mine waste (slurry) into the resulting 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: the potential for slurry "breakthroughs" into mine works and subsequent breakouts into the surface waterways (Figure 2).

On October 11, 2000 a combination of coal refuse 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. The location of the point of breakthrough, pathways of slurry/water flow within the mine workings, and two points where the liquid exited the mine are shown in Figure 3. An estimated 306 million gallons of water and coal refuse slurry drained from the impoundment into the adjacent underground mine. Approximately 230 million gallons subsequently discharged from the underground mine at two portals.

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 2000 breakthrough. However, the water-slurry mixture affected over 75 miles of stream in Kentucky and West Virginia. At some locations, the water-slurry mixture spilled over the banks and deposited fine coal mine waste onto adjacent property. Six public water intakes were adversely affected and alternative water supplies had to be arranged. It was reported that the cost to clean up the waterways and affected lands exceeded 56 million dollars.

Figure 1. Example of a coal waste slurry impoundment in steep-slope topography in West Virginia.

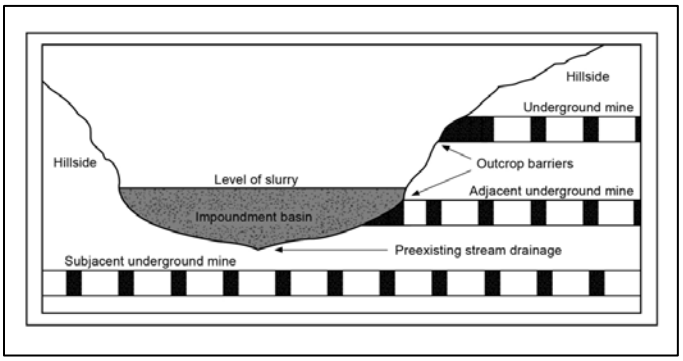

Figure 2. Schematic cross section of an impoundment basin and adjacent and subjacent underground mines in the bituminous Appalachian coal fields (modified from the NRC, 2002).

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 refuse impoundments; explored ways to improve underground mine location relative to the impoundments; and evaluated alternative technologies that could reduce the amount of coal refuse 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), and OSMRE. Both evaluated on-site conditions, and problems with construction and regulation-enforcement practices that led to the failure.

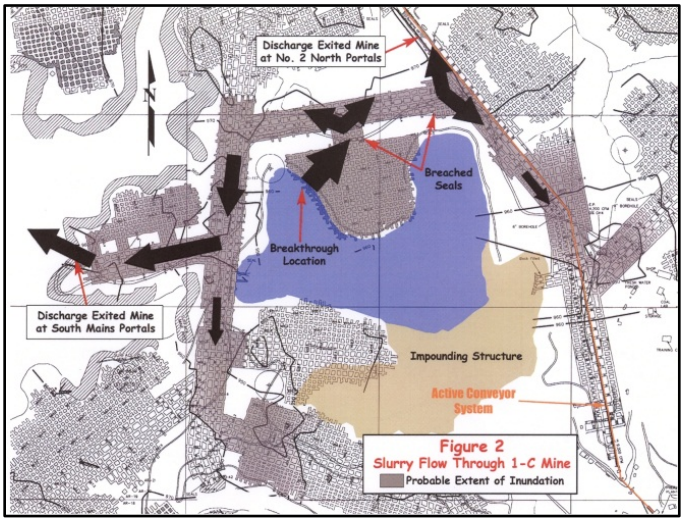

Figure 3. Illustration of the October 11, 200 breakthrough at the Big Branch coal waste slurry impoundment in Martin County, KY (modified from MSHA, 2001).

Since 2005, OSMRE has also published four technical papers relating to slurry impoundments: The Flowability of Impounded Coal Refuse (Michael et al., 2005); Environmental Risks Associated with Coal Refuse Impoundment Reclamation (Michael et al., 2008); Potential of Breakthroughs of Impounded Coal Refuse Slurry into Underground Mines (Michael et al., 2010); and Potential of Impounded-Fine-Coal-Refuse Breakthroughs into Underground Mines: Issues and Answers (OSMRE, 2011). These papers are available on the OSMRE Technology Transfer Website (Appalachian Region): http://www.techtransfer.osmrere.gov/ARsite/arpublications.shtm

In 2001, OSMRE's Appalachian Office initiated a regional oversight review of how well state regulatory programs and the Tennessee Federal program were implementing the requirements of SMCRA in relation to determinations for potential breakthrough into underground works. Oversight and technical assistance efforts in this area were accomplished at various levels of detail in each state. In 2009, each OSMRE office was asked again to review its actions of the past and determine if the agency was being consistent in its overview of each state. The offices were also asked to identify problems that were systemic to the programs, as distinguished from those more site-specific.

During opening discussions at the OSMRE Field Office in Charleston, West Virginia, staff members assigned to the review teams were identifying some technical concerns that were not emphasized in the previous oversight study in that state. Consequently, OSMRE management temporarily diverted the team from the oversight work and asked that they develop a technical, peer-reviewed position paper (or "white paper") on the best science on issues that were not only potentially noted in West Virginia but were also known to the reviewers from their multi-state general experience.

The position paper identifies issues and methods for addressing whether: (a) there is a sufficient accounting for all minable coal seams cropping out within and underlying slurry impoundments; (b) mine maps are sufficiently definitive in delineating the extent of previous mining and the thickness of barriers between underground mines and the impoundment footprint; and (c) appropriate information is available to determine slurry flowability when impoundments are either expanded in size or "eliminated,"—i.e., capped to eliminate impoundment storage, and no longer considered impoundments. The paper provides technical justifications in support of the OSMRE's recently completed West Virginia Oversight Study entitled "Coal Slurry Impoundment Breakthrough Potential (Phase III)" and ongoing and future oversight studies of the other regulatory programs in the Appalachian Region. It poses the following issues and provides findings and recommendations for each of them:

Issue 1: What is a mineable seam? To be certain that all coal seams in the vicinity of major impoundments are included in a breakthrough analysis, seams with a reported or known thickness equal or greater than 24 inches should be investigated.

Issue 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. Investigations into the presence of underground mines and assessments of the competence of mine barriers should never rely solely on information provided by mine maps. Nor should the absence of mine maps be accepted as proof that mining has not occurred.

Issue 3: How can we determine whether minable seams have been mined? Interviews with experienced miners and local residents; research of historical documents such as tax records, landownership records, and media archives; 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.

Issue 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? 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.

Issue 5: How can we test the impounded slurry for its flow characteristics? Capping of an impoundment does not eliminate the potential for breakthrough into underground mine works. Prior to impoundment closure or expansion, the properties of the impounded slurry should be tested to ensure its properties preclude potential for flowing into underground mine works. One method to determine flowability is to compare the moisture content (MC) of sampled slurry with its liquid limit (LL). 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 tests are performed on the same sample.

Issue 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 this document. 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. Whereas special studies would provide a better understanding of the magnitude of the breakthrough-potential problem and of factors affecting slurry flowability, 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.

Issue 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. Even if a discharge does not occur, the breakthrough of the slurry may contaminate local aquifers hydraulically connected with the coal seam.

It is important to note that the answers OSMRE provides to several of the issues are not universally shared. For example, the recommendation under Issue 5 that the MC of impounded coal waste slurry be compared to its LL to determine flowability has been objected to on the grounds that the approach is too conservative. The position of OSMRE is that that the comparison is indeed conservative but appropriately so. The agency does support the recommendation for a "parametric study" comparing slurry moisture content with flow-related properties of the material as determined by other test methods. In fact, OSMRE has made clear several times in its disposition of peer-review comments that the agency is willing to consider alternatives to or enhancements of the MC/LL protocol that are already available or that may result from future research. Currently, there is an OSMRE-funded Applied Science project under way at Case Western Reserve University in Cleveland, Ohio that compares several standard engineering properties of slurry, including MC, with its flow characteristics. A final report is scheduled for release in 2015.

Another concern relates to Issue 3, under which OSMRE lists several techniques which an impoundment permittee should use to determine whether minable coal seams adjacent or subjacent to the proposed structure have been mined. The application of those methods is considered to be potentially cost-prohibitive and unnecessary. In response OSMRE has clarified that it does not propose that all of the techniques should be applied to every impoundment. The amount of effort needed for the exploration for proximate underground mines depends on site-specific conditions and the quality of existing information, and must be determined using sound (and clearly documented) professional judgment. It is emphasized that simple reliance on mine maps, or their absence, will never suffice.

THE APPALACHIAN REGION OVERSIGHT STUDY

The initial technical evaluation of fifteen impoundments in West Virginia has been completed and documented. The evaluation of the ten Ohio impoundments has also been completed and its report nearly finalized. The assessment of ten Virginia facilities is well underway. Planning for the Kentucky phase of the study will begin in December 2014. The evaluation of the Kentucky program will be followed by evaluations in Pennsylvania, Maryland, and the Federal program in Tennessee. The regional study is expected to be completed in 2017.

Each Appalachian Region regulatory program is being evaluated by a team comprised of technical and program staff from the regional office in Pittsburgh, Pennsylvania and OSMRE field offices. The study focuses on the review of pertinent documents, information, and data in the coal waste impoundment permit-application and inspection-and-enforcement files. On-site reviews are also conducted to assess field conditions at the facility, and conformity with the conditions of the approved permit. The evaluation team utilizes standard review guidelines to ensure a consistent approach to each program. However, the guidelines are partly modified to reflect regulations and documented policies pertaining to impoundment-breakthrough prevention that are unique to each program. The review team works with the staff of each State or Federal program to develop an accurate and current inventory of coal waste impoundment facilities. From the inventory the team selects specific impoundment facilities to be assessed. The sample size will be based on the population of active and recently abandoned large coal waste impoundments in the state. "Recently abandoned" is defined as closed within the past five years. A minimum of 10 percent of the population or ten impoundments (whichever is greater) is randomly chosen for review. If the total population of impoundments in any state is less than ten, all impoundments are selected for review. A report of findings is written for each reviewed impoundment. Those reports are then assembled in an appendix behind a summary report on the program.

For each sampled impoundment, the review team is charged with determining whether the following investigative and engineering-design measures have been taken: (1) identification of all mineable coal seams; (2) identification of all underground mines near to (e.g. within a ten-mile radius of) the impoundment; (3) identification of all underground mines close enough to the impoundment basin to present a breakthrough risk; (4) assessment of the stability of coal barriers to adjacent mines and roof and pillars of subjacent mine workings; (5) construction or enhancement of mine barriers when necessary using prudent engineering practices; (6) assessment of impounded slurry flowability when the occurrence of proximate mines or stability of barriers are uncertain; and (7) professional engineer certifications that required and approved breakthrough-prevention measures have been taken.

For each impoundment the review procedure also entails the application of the MSHA Procedure Instruction Letter 199-V-3 (Lawless et al., 1997) to categorize the level of risk of slurry breakthrough into underground mines, and the potential impacts to the public, infrastructure and the environment should such a breakthrough occur. The review team also evaluates the breakthrough potential of the impoundment based on the US Bureau of Mines Information Circular, IC 8741 (Babcock et al., 1977) and other guidelines that may be used by the regulatory program. IC 8741 includes definitions of safety zones in the proximity of the impoundment in which mine voids are either prohibited entirely (embankment safety zone), or allowed under defined conditions (basin safety zone). The safety zones are depicted in Figure 4. The team is to use alternative guidelines developed by the evaluated program instead of the IC if the evaluated program has been approved by OSMRE. If there are alternative guidelines under a state program that have not been officially approved by OSMRE, but that are acceptable to the review team, the team evaluates the impoundment using both guidelines. An example of the latter case is the West Virginia Coal Related Dam Safety Rules (WVDEP, 2003). Those rules include definitions of embankment and basin safety zones similar to those described in IC 8741; however, mining is permitted within the embankment safety zones, if pillar strength and strain criteria are satisfied, and definition of the basin safety zone was simplified. The basin safety zone is defined as the area within a perimeter 200 feet outside of the impoundment high water mark, to a depth that will provide a minimum of 100 vertical feet thickness of solid strata between the basin floor and any underground voids. Those safety zones are depicted in Figure 5.

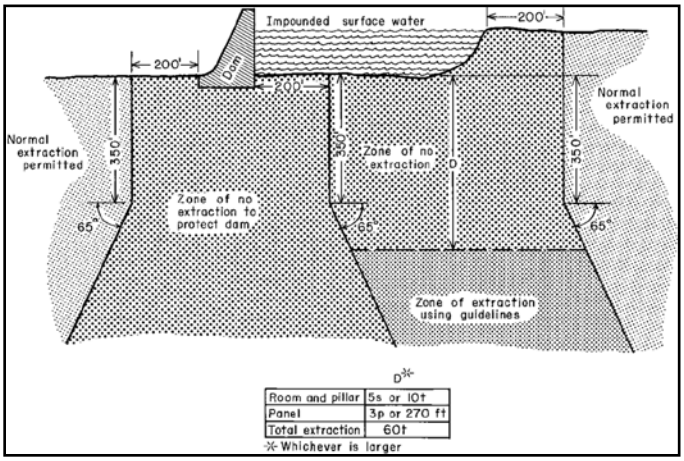

Figure 4. Embankment and basin safety zones of an impoundment (Babcock et al., 1977).

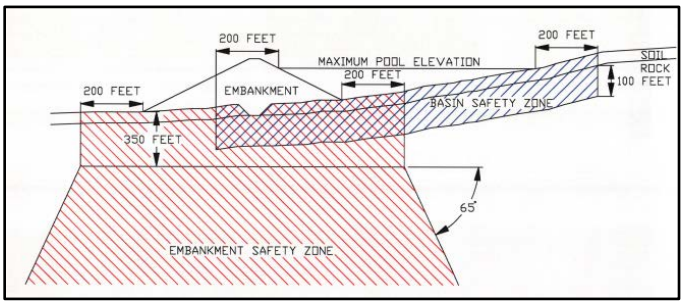

Figure 5. Schematic of impoundment embankment and basin safety zones delineated in the West Virginia dam safety regulations.

With respect to the basin safety zone it is noted that both the IC guidelines and the West Virginia rules are applicable to impoundments containing water as well as slurried waste. The minimum of 100 vertical feet in the State rules is to ensure that the effect of mine roof failure will not reach to bottom of the basin, or if it does, will not result in an open sinkhole due to bulking of solid rock fragments. The allowance for the potential subsidence cracks that may form from pillar failure in deeper mines assumes that the cracks would not wide enough for more than negligible transmission of fluids from the basin bottom into the mine. The OSMRE technical review team finds those premises plausible for coal waste slurry impoundments owing to the viscosity of the slurry at and near the bottom of the pool.

SUMMARY OF FINDINGS TO-DATE

As previously stated, the West Virginia evaluation has been finalized. The permit reviews and site visits for the Ohio evaluation have been completed and the state report is close to finalization. Since the Virginia evaluation is still in process and the other Appalachian states have not yet been evaluated, the comments below focus on the West Virginia and Ohio programs.

Based on the contents of the permit files and discussions with staff of the state regulatory authorities it is clear that there is keen awareness of the need to ensure against coal waste impoundment basin breakthroughs into underground mines. This has been the case since shortly after the 2000 Martin County breakthrough in particular; and is reflected in the programs' approach known underground mines close to the facilities, e.g. requirements for breakthrough-potential analyses, preventative measures, monitoring of underground-mine effluent and ground movement, and emergency action plans. A common opportunity for improvement entails the full accounting of: (1) all coal seams that intersect or underlay an impoundment; (2) which coal seams are mineable; (3) which seams have been mined in the proximate to the facility; and (4) whether the mine workings of those coal seams are near enough to the facility to present a breakthrough risk.

As one might expect, there are differences between the states in terms of their regulatory programs and the physiographic settings the programs contend with. In both of them, however, significant programmatic changes were made in response to the Martin County, Kentucky breakthrough. In 2001, the Director of the West Virginia Department of Environmental Protection, Division of Mining and Reclamation issued an order (Director's Order) requiring operators of slurry impoundments to evaluate their impoundments in accordance with the IC 8741 and to submit reports for review. In June of 2003, the WVDEP implemented their Coal Related Dam Safety Rules. In addition to delineating the safety zones discussed above, these rules required all operators to submit an "Assessment of Hazards and Consequences of Failure" (AHCF) with each new application. A memorandum was issued concurrently, requiring any operator of a previously permitted impoundment to submit an AHCF with the next annual update of the Emergency Action Plan. The WVDEP review of the AHCF reports resulted in the closure of several impoundments. There was no like documentation in the Ohio program. However, it was clear during OSMRE's scrutiny of the contents of permit applications and letter requests for additional information or preventative action plans from the regulatory authority to the applicant that the awareness of the danger of impoundment basin breakthrough has intensified since 2001 in that state as well. In both West Virginia and Ohio this awareness is reflected in the treatment of known underground mines close to an impounding facility, i.e. requirements for breakthrough potential analyses, breakthrough preventative measures, monitoring for subsidence-related ground movements and increased discharge or turbidity of mine opening effluent; and emergency action plans to protect the public and mitigate environmental damages.

As stated, the regulatory programs can be improved with more thorough accounts of underground mines that may intersect or underlay an impoundment. This concern is more critical in West Virginia but not because its program is less effective than Ohio's. Coal mining and coal waste slurry impoundment construction in the former state occurs in rugged topography in which coarse refuse embankments are constructed at the mouth of a hollow and fine refuse slurry is pumped upstream from the embankment into the formed impoundment basin. Figure 6 illustrates an impoundment that was closed and converted to layers of slurry cells in response to breakthrough concerns. It demonstrates how impoundment construction in this environment frequently results in numerous coal seams intersecting the slurry basin as well underlying the facility. The potential of a breakthrough occurring in Ohio may be relatively less because of the state's gentler topography.

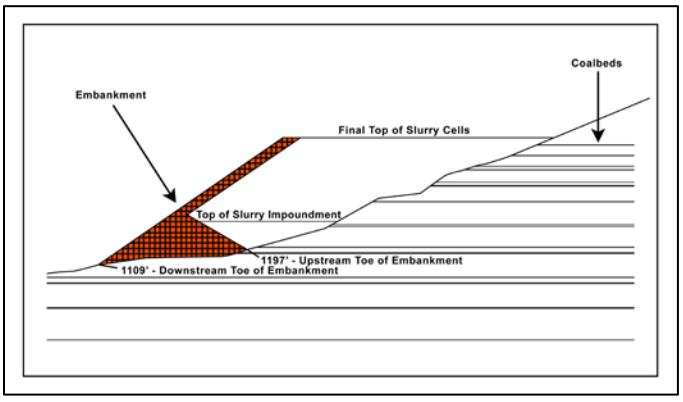

Figure 6. Schematic longitudinal profile of an impoundment in West Virginia showing multiple coal seams adjacent as well as subjacent to the facility.

FUTURE WORK

As stated, OSMRE oversight evaluations of the regulatory programs in the Appalachian coal fields with respect to impoundment basin breakthrough prevention will continue over the next several years. Thus far indications are that the programs' more aggressive approach to breakthrough prevention has significantly reduced the

danger over the last decade and a half. However, it is important to emphasize that the potential cost of a breakthrough to public safety and the environment remains just as high as before and, consequently, that continued vigilance is imperative.

This paper does not do justice to the rich variety of challenges faced by the impoundment operator and regulators as they confront the possibility of basin breakthrough at specific impoundment sites. Future papers on this subject will focus on case studies. Developments pertaining to the topic of impounded coal waste slurry flowability will also be presented.

REFERENCES

Babcock, C. and V. Hooker, 1977, *Results of Research to Develop Guidelines for Mining Near Surface and Underground Bodies of Water*: U.S. Bureau of Mines Information Circular 8741, U.S. Department of Interior Library, Washington, DC, 17 pp.

Lawless, M. and R. Elam, 1997, *Evaluating Breakthrough Potential and Impact of an Unintentional Release of Water or Slurry from an Impoundment*: U.S. Mine Safety and Health Administration Procedure Instruction Letter No. I99-V3, Arlington, VA, 6 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. [Accessed December 3, 2014].

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. [Accessed December 3, 2014].

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/arpublications.shtm. [Accessed December 3, 2014].

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 (MSHA), 2001, *Report of Investigation: Noninjury Impoundment Failure/Mine Inundation Accident, October 11, 2000*: Mine Safety and Health Administration, Arlington, VA, 71 p., 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 December 3, 2014].

West Virginia Department of Environmental Protection (WVDEP), 2003, *Coal Related Dam Safety Rule*: Title 38, Series 4 of the Code of State Regulations, WVDEP, Charleston, WV.