

Report to Congress:
Responses to Recommendations
In the National Research Council's Report
Coal Waste Impoundments: Risks, Responses,
and Alternatives



August 15, 2003



Submitted by:



Mine Safety and Health Administration
U.S. Department of Labor

Office of Surface Mining
U.S. Department of the Interior

Report to Congress:
Responses to Recommendations
In the National Research Council's Report
Coal Waste Impoundments: Risks, Responses, and
Alternatives

August 15, 2003

Submitted by:

Mine Safety and Health Administration
U.S. Department of Labor

Office of Surface Mining
U.S. Department of the Interior

Table of Contents

Executive Summary.....	iii
Chapter I. Introduction.....	vi
Chapter II. Impoundment Plans and Permits: Administrative Issues..... (Three NRC Recommendations)	1
Chapter III. Impoundment Plans and Permits: Technical Review Issues... (Nine NRC Recommendations)	6
Chapter IV. Mapping and Surveying Related to Underground Mines and Impoundments..... (Ten NRC Recommendations)	15
Chapter V. Use of Geophysical Methods to Locate Mine Workings..... (One NRC Recommendation)	32
Chapter VI. Chemical Properties of Coal Waste (One Recommendation)...	34
Chapter VII. Alternative Methods of Coal Waste Disposal (Four NRC Recommendation).....	35
Chapter VIII. Summary of Actions Taken by MSHA and OSM Since the October 2000 Martin County Coal Corporation Breakthrough Incident.....	37
Chapter IX. Conclusions.....	41

Appendices

- Appendix A. List of Committee and Work-Group Members (5 pages)
- Appendix B. Copies of Memoranda of Understanding Between MSHA and various States (9 pages)
- Appendix C. Model Memorandum of Understanding (4 pages)
- Appendix D. “Guidance for Evaluating the Potential for Breakthroughs from Impoundments into Mine Workings and Breakthrough Prevention Measures” (54 pages)
- Appendix E. Survey of State Activities with Respect to Scanning And Storing Mine Maps (3 pages)
- Appendix F. Agenda for MSHA Symposium on “Geotechnical Methods For Mine Mapping Verification” (3 pages)
- Appendix G. Agenda and Members of Steering Committee for “Interactive Forum on Geophysical Technologies for Detecting Underground Mine Voids (5 pages)
- Appendix H. MSHA Solicitation for Projects to Demonstrate Technologies For Detecting Underground Mine Voids” (3 pages)

Executive Summary

On October 11, 2000, more than 300 million gallons of coal-waste slurry broke into an underground mine from the Big Branch Slurry Impoundment in Martin County, Kentucky. Slurry flowed through the mine to contaminate miles of creeks and rivers. This was the most notable of several incidents in which slurry from coal-waste impoundments has broken into underground mine workings in recent years. Such incidents have caused environmental damage and have the potential to endanger persons working in the underground mines or living in the affected areas.

Before constructing an impoundment of significant size, or one that can present a hazard, coal mining companies are required to obtain approval from the Mine Safety and Health Administration (MSHA) of the engineering plans and construction specifications. Permits for impoundment construction must also be obtained from the State regulatory authority or the Office of Surface Mining (OSM).

Investigators determined that the cause of the Martin County incident was the mine operator's failure to follow the approved plans. Nevertheless, MSHA and OSM also scrutinized their plan review processes following the Martin County incident and took several actions to help prevent similar occurrences in the future.

MSHA inspected 330 impoundments with breakthrough potential, required re-evaluations and revisions of plans for such impoundments, strengthened its own plan review process, and initiated an update of its impoundment review handbook. OSM inventoried impoundments within 500 feet of underground mine workings and, in close cooperation with the States, developed a strategy to prevent leaks from such impoundments.

Also following the incident in Martin County, Congress provided funding for the National Research Council (NRC) "to examine ways to reduce the potential for similar accidents in the future." The NRC appointed a Committee on Coal Waste Impoundments, which prepared a report entitled "Coal Waste Impoundments: Risks, Responses, and Alternatives."

In their report, the NRC does not specifically define the word "waste." They do, however, describe that the purpose for constructing coal refuse disposal impoundments is to dispose of any coal, rock, and related material removed from a coal mine in the process of mining. The report focuses on coal slurry impoundments and does not address valley fill coal disposal.

The NRC report included 28 recommendations organized in the following categories:

- Impoundment Plans and Permits: Administrative Issues
- Impoundment Plans and Permits: Technical Review Issues

- Mine Surveying and Mapping Issues
- Use of Geophysical Methods to Locate Mine Workings
- Chemical Properties of Coal Waste
- Alternative Coal Waste Disposal Methods

MSHA and OSM examined the NRC's recommendation to determine how the findings of the report could be used to further reduce the potential for impoundment breakthroughs. As requested by Congress as part of the FY 2003 Omnibus Spending Bill, this report addresses each of the NRC's recommendations and summarizes the actions MSHA and OSM have taken.

Among the significant findings reported by OSM and MSHA:

- MSHA and OSM have addressed several of the NRC committee's recommendations by jointly developing a technical report titled "Guidance for Evaluating the Potential for Breakthroughs from Impoundments into Mine Workings and Breakthrough Potential Measures." This document addresses issues concerning such aspects of design as outcrop coal barrier width; overburden thickness and competence; site evaluation; basin design, construction and operation; and bulkheads.
- OSM and MSHA believe that there is a need to update the existing publication, "Engineering and Design Manual for Coal Waste Disposal Facilities," originally issued in 1975. This comprehensive manual has assisted coal companies, engineering consultants, and government regulators in carrying out their responsibilities to help ensure that impoundments are designed and constructed safely. However, many significant changes have occurred in the field of mine waste disposal since 1975.
- Agreements need to be developed by OSM and the States in order to coordinate and enhance efforts to collect, store and scan mine maps.
- OSM's National Mine Map Repository (NMMR) is working through a five-year plan to improve its technical capability for electronic storage, copying, and information access.
- MSHA and OSM will work collaboratively with the States as they identify and address impediments to the collection and release of mine map information to the public and other Federal and State agencies.
- OSM and MSHA are working jointly on improving outreach to mine map owners. OSM also plans to continue its procedural agreement with MSHA that supplies the NMMR with closure maps submitted to MSHA.

- OSM and MSHA believe that surface topographic surveys along the coal outcrop should be performed by coal companies as part of their permit submittal, where practical and at critical locations. The surveys should be tied to either the U.S. Geological Survey or the U.S. Coast and Geodetic Survey benchmark system as used for the underground mine surveys. By using common benchmarks for the surface and underground surveys, appropriate vertical and horizontal control can be ensured.
- To ensure mapping accuracy, it is recommended that closed-loop surveys be used exclusively. At a minimum, a closed-loop traverse or equivalent should be conducted every 1,000 feet and at the last open crosscut. Extraction heights should be included on all maps.
- To ensure the accurate location of mine workings, it is recommended that all mine maps use the State plane coordinate system as the primary reference. Vertical control should be referenced to the North American Vertical Datum of 1988 to ensure accurate reporting of seam elevations. Floor elevations should be reported on the maps, along with mining heights, at regular intervals.
- At least two permanent survey monuments should be located on areas of mine property that will not be destroyed or disrupted during the life of the operation.
- Work is under way to develop and evaluate the use of geophysical and other remote sensing techniques through conferences and Federally supported research. Both MSHA and OSM are engaged in furthering this research.
- MSHA and OSM agree that further research would be valuable in several areas identified by the NRC committee that fall outside the two agencies' mandates: specifically, research to identify the constituents of coal waste, to characterize hydro-geologic conditions around impoundments, and to identify and evaluate alternative methods of coal mine waste disposal. Research on the chemical properties of coal waste would best be conducted by the Environmental Protection Agency (EPA) or the Department of Energy (DOE). Research on characterizing the hydro-geological conditions around impoundments would best be conducted by the United States Geological Survey (USGS). The NRC's recommendation for a study to identify technologies that will eliminate or reduce the need for slurry impoundments would best be done by universities or by the DOE. Examining the costs of alternatives would best be done by the mining industry itself or mining organizations. The environmental impacts of alternative methods of waste disposal could be evaluated by universities or the EPA. Exploring economic incentives to encourage the development of alternatives would best be done by university research or the DOE, perhaps within the mining industry program in the Office of Industrial Technologies in Industries of the Future.

I. Introduction

On October 11, 2000, an accident occurred in Martin County, Kentucky when over 300 million gallons of coal-waste slurry broke into an underground mine from the Big Branch Slurry Impoundment. Slurry flowed through and out of the mine and contaminated over 80 miles of creeks and rivers. This was the most notable of several incidents in recent years where slurry from coal-waste impoundments has broken into underground mine workings. These incidents have caused environmental damage, and have the potential to endanger persons working in the underground mines or living in the affected areas.

Following the accident in Martin County, Congress provided funding for the National Research Council (NRC) “to examine ways to reduce the potential for similar accidents in the future.” The NRC appointed a Committee on Coal Waste Impoundments, which prepared a report, entitled “Coal Waste Impoundments: Risks, Responses, and Alternatives.” The report, released in October 2001, contained twenty-eight recommendations, most of which were aimed at helping to prevent future breakthroughs. These recommendations fall into the following categories:

- Impoundment Plans and Permits: Administrative Issues (Three Recommendations)
- Impoundment Plans and Permits: Technical Review Issues (Nine Recommendations)
- Mine Surveying and Mapping Issues (Ten Recommendations)
- Use of Geophysical Methods to Locate Mine Workings (One Recommendation)
- Chemical Properties of Coal Waste (One Recommendation)
- Alternative Coal Waste Disposal Methods (Four Recommendations)

To determine how the NRC’s recommendations could be used to help reduce the potential for impoundment breakthroughs, MSHA and OSM formed a “Steering Committee.” The Steering Committee established joint work groups, consisting of representatives from MSHA, OSM, and State regulatory agencies, to examine and address the NRC’s recommendations. The members of the Steering Committee and the work groups are listed in Appendix A.

A work group was assigned to each of the recommendation categories indicated above. Chapters II through VII of this report correspond to the above categories and have been prepared based on the work groups’ findings. In addition, as requested by Congress, Chapter VIII summarizes the other actions that MSHA and OSM have taken since the October 2000 Martin County Coal Corporation slurry breakthrough accident.

II. Impoundment Plans and Permits: Administrative Issues

Coal companies are required to obtain approval from MSHA, and a permit from the State or OSM regulatory authority, before constructing an impoundment of significant size, or which can present a hazard. Plan or permit applications are reviewed by the agencies to determine whether the plans are consistent with accepted engineering practice, and to help ensure that the impoundment will not present a hazard to miners, the public, or the environment. As indicated in the NRC report, timely and thorough reviews are an essential component of an effective regulatory process.

The NRC report included three recommendations pertaining to the administrative review of plans and permit applications. These recommendations (shown in bold italics), and MSHA's and OSM's responses to them, are indicated below.

1. ***"The committee recommends that MSHA and OSM should have clear authority to review basin design."*** (See pages 3, 50, and 166 of NRC report.)

Response: Both MSHA and OSM agree that the existing statutory and regulatory framework provides clear authority to review impoundment designs. Neither MSHA nor OSM has encountered any situations where its authority to require or review basin designs, or the evaluation of breakthrough potential, has been an issue.

MSHA's authority to obtain the information needed to evaluate basin designs is found in 30 CFR 77.216. Section 77.216-2 indicates the items to be included in an impoundment plan that is submitted to MSHA for review and approval. These items include the following:

77.216-2(a)(5) - "A description of the physical and engineering properties of the foundation materials on which the structure is or will be constructed";

77.216-2(a)(7) - drawings showing, among other things, "information pertinent to the impoundment itself, including any identifiable natural or man made features which could affect the operation of the impoundment";

77.216-2(a)(14) - "The locations of surface and underground coal mine workings, including the depth and extent of such workings within the area 500 feet around the perimeter"; and

77.216-2(a)(18) - "Such other information pertaining to the stability of the impoundment and impounding structure which may be required by the District Manager."

These items have been used by MSHA to obtain the information needed to evaluate the potential impact of mining near an impoundment.

OSM's requirements related to evaluation of breakthrough potential are found in 30 CFR 780.25. This section sets design standards for various water control structures, including slurry impoundments. The standards incorporate by reference and cross-reference MSHA regulations at 30 CFR 77.216. Section 780.25(a)(1)(iv) requires that each plan contain a survey describing the potential effect on the structure from subsidence of the subsurface strata resulting from any underground mining. Section 780.25(e) addresses the design of coal waste dams and embankments. It requires that each plan comply with 30 CFR 816.81-816.84 and with 30 CFR 77.216-1 and 77.216-2. It also requires that applications for permits include "a geotechnical investigation of the proposed dam or embankment foundation area, to determine the structural competence of the foundation which will support the proposed dam or embankment structure and the *impounded material*" (emphasis added). This regulation goes on to specify the components of the geotechnical investigation, among which are "the character of the overburden and bedrock, the proposed abutment sites, and any adverse geotechnical conditions which may affect the particular dam, embankment, or *reservoir site*" (emphasis added).

2. *"The committee recommends that the review process for both new permits and existing permits be overhauled to include the following elements:*

- *A formal joint review that would coordinate the currently fragmented and inefficient collection of reviews into a single process.*
- *Sufficient staff for engineering and other reviews in the agencies that participate in the joint process so that the time required to complete the review can be reduced significantly."* (See pages 13, 50, and 172 of NRC report.)

Response on the issue of "formal joint reviews": MSHA and OSM believe that an overhaul of the existing system for reviewing plans or permits is not necessary and not practical. Coordination between MSHA and OSM and the State regulatory authority is provided in the regulations. Coordination is further enhanced by working arrangements, including memorandums of understanding (MOUs). MSHA, OSM and the States will continue to discuss ways to improve coordination and efficiency in the review process as specific issues arise. In addition, MSHA and OSM have drafted a model MOU for State regulatory agencies to consider.

In Kentucky, Virginia, and West Virginia, each MSHA District Office and the State Regulatory Authority have existing MOUs relating to Federal and State review and approval of the design and construction of impoundments. These MOUs describe each agency's jurisdictional role in the approval process. The purpose of each MOU is to

improve coordination among the agencies. The MOU between MSHA and West Virginia took effect on January 20, 1995. The MOU between MSHA and Kentucky took effect on December 11, 1997. The MOU between MSHA and Virginia took effect on October 1, 1998. Copies of these existing memorandums are provided in Appendix B.

To encourage the establishment of agreements between other State/Tribal regulatory authorities and MSHA districts, a model MOU was developed. The purpose of the model MOU is to:

- a. Improve communications and coordination of the review and inspection process on impoundments;
- b. Minimize duplication of review efforts;
- c. Identify and share coal companies' future abandonment plans;
- d. Present, provide, and coordinate training opportunities;
- e. Reduce the potential for conflicting standards and procedures during plan reviews and site inspections; and
- f. Provide understandable and consistently enforced standards for those applicants regulated by both agencies.

The model MOU can be modified to add or remove items in order to meet State/Tribal or MSHA specific requirements. The model MOU is provided in Appendix C.

Logistics alone make the use of formal joint reviews impractical. The locations where plans are reviewed are widely scattered. In MSHA, impoundment plans are reviewed either at the Pittsburgh Technical Support Center or in one of MSHA's eleven district offices. In OSM, while they have oversight responsibility, the impoundment plans are reviewed in the offices of the various state regulatory authorities. So the MSHA and state agency review personnel are in different locations. Another aspect is timing. Since the agencies have different responsibilities, which they attempt to handle with appropriate priorities, it would add a significant complication to attempt to coordinate reviews so that review personnel in both MSHA and the various states were handling the same plan at the same time. To illustrate the magnitude of this problem, as indicated in the report, nearly 1500 plans were submitted to MSHA for review from 1995 to 2001.

MSHA, OSM, and the States believe that an effective way to cooperate on impoundment plan reviews is to exchange information, as called for in the MOUs, rather than to conduct formal joint reviews. Plan reviewers, both in MSHA and in the States, typically have responsibilities for handling a variety of mine safety and/or environmental problems in addition to their plan review and other impoundment safety duties. Examples of other responsibilities include the investigation of accidents, and dealing with problems involving highwall stability, surge piles, roof control, blasting plans, and gas-well cut-throughs. These types of problems often require an

immediate response and interrupt plan review work. Nevertheless, this arrangement is necessary to most effectively use the resources and expertise within the agencies. Consider also that in the period from 1995 to 2001, nearly 1500 plans, to either construct new impoundments or modify existing structures, were submitted to MSHA for review. The combination of the varied and heavy workload handled by review personnel would complicate the agencies' abilities to coordinate formal reviews and would add time to the overall process. These factors make formal joint reviews impractical.

Response on the issue of "sufficient staffing": The NRC report recommends that sufficient staff be made available to reduce the amount of time to complete plan reviews. MSHA and OSM have agreed to complete an analysis of the current workload and projected staffing needs for the review of impoundment plans and permits. The issue of the adequacy of staffing for MSHA's impoundment safety program is currently under review within the agency. The staffing level, and the length of time required to complete plan reviews, were issues addressed in an internal investigation conducted within MSHA following the October 11, 2000 Martin County Coal slurry release accident. The "Internal Review of MSHA's Actions at the Big Branch Refuse Impoundment, Martin County Coal Corporation" was released on January 21, 2003. As a result of this investigation, MSHA has directed district offices to provide sufficient staff to review submittals for low-hazard-potential sites, and for minor modifications. The more complex plans are submitted to the Pittsburgh Technical Support Center for review. MSHA also has updated the computers and computer software used by Technical Support review engineers.

Another development within MSHA is that a committee has been formed to re-evaluate and re-write MSHA's Impoundment Inspection Handbook. This re-write will address minimum inspection frequencies and the issue of the qualifications and training required to review impoundment plans of different levels of complexity. The results of this effort will have a direct impact on defining the required staffing level within MSHA's impoundment program. MSHA's top management will monitor the progress made in the impoundment program to determine if additional measures, such as staffing increases within Technical Support, will be necessary. MSHA is committed to providing sufficient staff, based on the results of on-going evaluations, to perform sufficient inspections and review submitted impoundment plans in a reasonable time.

OSM will analyze workload through its oversight role in States where impoundments are located. This analysis will quantify the current workload, project future workload, and estimate staffing needs.

State workload will be analyzed through the oversight program for individual State regulatory authorities. The review will be included in the performance agreement negotiated between OSM and the States. This analysis will quantify the current workload, project future workload, and estimate staffing needs.

3. *“The committee recommends that MSHA work with OSM and State agencies to determine which mine permit documents should be retained, in what form, and for how long.”* (See pages 7, 83, and 168 of the NRC report.)

Response: The Federal government has a Files Maintenance and Records Disposition Program that is governed by the Records Disposal Act of 1943. The provisions of these laws place specific requirements upon the head of each Federal agency for the implementation and operation of an effective Files Maintenance and Records Disposition Program. Each responsible agency must review its Files Maintenance and Records Disposition Program and determine the final disposition of all documents relating to impoundments. In most instances, impoundment plans and maps for underground mines located in the immediate area of an impoundment, should be preserved permanently and not scheduled for destruction.

III. Impoundment Plans and Permits: Technical Review Issues

Before constructing an impoundment of significant size, or which, regardless of size, may present a hazard, a coal company must obtain approval from MSHA of the site's engineering plans and construction specifications (30 CFR 77.216). Permits for impoundment construction must also be obtained from the State regulatory authority, or OSM. Agency personnel review the submitted plans or permit applications to determine whether they are consistent with accepted engineering practice, and will provide adequate protection for miners, the public, and the environment.

Whenever there is underground mining near a proposed impoundment, the potential impact of the mining on the safety of the impoundment, and the potential for a breakthrough into the mine, is part of the technical review. Recent breakthrough incidents have caused coal company personnel, design consultants, and regulators to re-evaluate, and place greater emphasis on, the issue of breakthrough potential.

The NRC report included nine recommendations related to the technical review criteria for impoundment plans and permits. These recommendations (shown in bold italics), and MSHA's and OSM's responses to them, are shown below.

1. ***"The committee recommends that MSHA and OSM continue to adopt and promote the best available technology and practices with regard to the site evaluation, design, construction, and operation of impoundments."*** (See pages 4, 113, and 166 of NRC report.)

Response: MSHA and OSM attempt to promote the best available impoundment technology and practices through their technical reviews and inspection activities, and by sharing information via various guidance documents, such as handbooks. The agencies agree that this is an important function. Among Federal dam-safety regulators, MSHA and OSM are unique in that they must deal with dam construction practices that are only found, on a routine basis, in the mining industry. One example is the practice of increasing the height of dams by using upstream construction, where subsequent stages are constructed partially on hydraulically placed fine coal waste. Another prime example is that, in the mining industry, it is common to have underground mine workings near or under impoundment sites.

Since MSHA has commonly dealt with the issue of mining near impoundments, the agency worked with the former U.S. Bureau of Mines to have research projects devoted to this topic. This led to the Bureau's Information Circular 8741, "Results of Research to Develop Guidelines for Mining Near Surface and Underground Bodies of Water," and other research studies. The results of these studies have provided information that is

frequently drawn upon by impoundment designers, as well as MSHA, OSM, and State review personnel. Furthermore, MSHA, OSM, and the States routinely keep abreast of studies related to mine subsidence, and underground bulkhead design, for application to the potential problems involved when there are mine workings near impoundments. MSHA has published guidance in the form of technical papers, and Procedure Instruction Letters, to assist in informing the industry on this issue.

MSHA, OSM, and the States will continue these types of efforts and will apply the lessons from the breakthrough events that have occurred. As one example, in October 2002, MSHA organized a "Symposium on Geotechnical Methods for Mine Mapping Verification." This symposium brought together representatives from the mining industry and experts in the use of methods for locating mine workings, such as long-hole directional drilling and geophysics. Also, a report entitled "Guidance for Evaluating the Potential for Breakthroughs from Impoundments into Mine Workings and Breakthrough Potential Measures" has been prepared to assist review personnel in evaluating the design of impoundments that have potential for breakthroughs into mine workings. A copy of this report is attached in Appendix D.

The most effective action that MSHA and OSM could now take to promote best practices, in all aspects of impoundment design and construction, is to provide an updated "Engineering and Design Manual for Coal Waste Disposal Facilities". The present "Design Manual" was published in 1975 following a coal waste dam failure at Buffalo Creek, West Virginia. That failure resulted in 125 deaths and left over 4000 homeless. Prior to the Buffalo Creek failure, many coal waste dams were built without proper engineering designs and without adequate supervision of construction. The purpose of the "Design Manual" was to compile the available information on the design, construction, maintenance, and monitoring of coal waste impoundments, as no such compilation was previously available. The manual was prepared under contract to the Mining Enforcement and Safety Administration (MESA), the predecessor agency to MSHA. The manual provided a source of information that assisted all involved parties - coal companies, engineering consultants, and government regulators - in carrying out their responsibilities to help ensure that safe impoundments were designed and constructed. The original manual was sold by the Government Printing Office, but has not been available for many years.

Since the 1975 publication of the "Design Manual," many significant changes have occurred in the field of coal waste disposal. The changes have included:

- the occurrence of several incidents where impounded slurry has broken into underground mine workings (note that the research work cited above on mining near bodies of water was done after the "Design Manual" was published, and the subject is not covered in detail in the manual);

- general advances in technical knowledge for dam safety, combined with over 25 years of experience specific to the design and performance of coal waste impoundments;
- the availability of significantly more information on the engineering properties of coal waste materials; and,
- the use of construction products, such as geotextiles, synthetic drainage materials, and plastic pipes, that were used little, if at all, prior to 1975.

Given the issue of the breakthrough failures, combined with the significant changes that have occurred since the publication of the "Design Manual," an updating of the manual would require a significant effort. An updated manual would be highly beneficial to the coal industry, to engineering firms that design and monitor sites for the industry, and to government regulators. MSHA has allocated money in their FY05 budget proposal for updating of the "Design Manual."

2. *"The committee recommends that MSHA and OSM jointly pursue the issue of outcrop coal barrier width and overburden thickness and its competence and develop minimum standards for them."* (See pages 5, 118, and 167 of NRC report.)

Response: To address this recommendation, the joint work group has prepared a technical report entitled "Guidance for Evaluating the Potential for Breakthroughs from Impoundments into Mine Workings and Breakthrough Potential Measures", with an expected release date later this year. A copy of this report is attached as Appendix D. This report compiles the available technical information on how breakthrough failures can occur, the minimum standard engineering analyses that must be performed, and various prevention measures. The issues raised in the NRC committee's recommendation are addressed in the report's Chapter V, "Evaluation of Potential Breakthrough Failure Mechanisms," Chapter VI, "Basin Design Measures to Prevent Breakthroughs," and Chapter IX, "Evaluation Approach Versus Standards for Minimum Barrier Size."

The purpose of this document is to help ensure that a uniform and technically sound approach is taken by the agencies when evaluating the potential for a breakthrough, including the issues of outcrop barrier width and overburden thickness. The report incorporates lessons from the breakthroughs that have occurred. As indicated in the report, the best way to prevent breakthroughs is to locate impoundments a safe distance from mine workings. The alternative is to provide adequate engineering measures, such as mine backfilling, to account for the potential impact of any workings located close enough to affect the impoundment. MSHA's and OSM's goal is to ensure that, for any plan where the potential for a breakthrough exists, each potential failure mode is adequately evaluated and it is demonstrated that measures will be taken to provide an adequate margin of safety against such breakthrough.

The information contained in this guidance report is not mandatory, but the document does indicate the type and level of detail of the technical evaluations that plan reviewers are instructed to make sure are included, or otherwise accounted for, in an impoundment plan before the plan is recommended for approval. Since the required outcrop barrier width and overburden thickness depend heavily on the site-specific geologic conditions, the proposed loading to be applied, and on any mitigating design features, MSHA, OSM, and the States must continue to evaluate plans on a case-by-case basis. Since each site is unique, the “minimum standards” should be for the engineering evaluation performed to identify and prevent potential failure modes, rather than for universally applied practices or procedures that may be overly conservative in some cases and potentially unsafe in others.

MSHA has also previously distributed additional information concerning breakthrough potential. Program Information Bulletin P97-4, “Unintentional Release of Water or Slurry from Impoundments into Active or Abandoned Mines”, was issued on February 11, 1997. Procedure Instruction Letter I99-V-3, “Evaluating Breakthrough Potential and Impact of Protection - Unintentional Release of Water or Slurry from an Impoundment; District Response Procedures” was issued on December 1, 1997. These documents alerted the industry to the hazard of breakthroughs and provided District personnel with guidance for evaluating impoundments with breakthrough potential.

- 3. “The committee recommends that MSHA and OSM develop and promulgate guidelines for the site evaluation, design, construction, and operation of basins.”***
(See pages 5, 121, and 166 in the NRC report.)

Response: The plans for the construction of impoundments, including the “evaluation, design, construction and operation of basins,” are prepared by coal mining companies or their engineering consultants. The role of MSHA, OSM, or the State regulatory authority, is to review the plans for consistency with prudent engineering practice. As mentioned above, representatives from MSHA, OSM, and some State agencies prepared a document entitled “Guidance for Evaluating the Potential for Breakthroughs from Impoundments into Mine Workings and Breakthrough Potential Measures.” This report provides guidance for site evaluation (Chapter IV), design (Chapter VI), and construction and operation (Chapter VIII) of the basin portion of an impoundment. The work group envisions this report being used by review personnel and being shared with the mining industry. A copy of the report is attached in Appendix D.

In addition to the above referenced report, in July 2001, OSM issued a report entitled “Criteria for Evaluating the Potential for Impoundment Leaks into Underground Mines.” This report was prepared to provide regulatory authorities with criteria for evaluating impoundments to prevent breakthroughs.

4. *“The committee recommends that MSHA review its current practice and develop guidelines for the design of bulkheads intended to withstand hydraulic heads associated with slurry impoundments.”* (See pages 4, 121, and 166 of the NRC report.)

Response: Chapter VII of the previously mentioned report, “Guidance for Evaluating the Potential for Breakthroughs from Impoundments into Mine Workings and Breakthrough Potential Measures,” deals specifically with the design of bulkheads intended to withstand hydraulic heads associated with impoundments. This report will be used by review personnel and shared with the mining industry. As previously indicated, a copy of this report is attached as Appendix D.

The design of an underground bulkhead depends on several factors including the amount of head, the quality of the roof, rib, and floor anchorage, and the engineering properties of the material to be used to construct the bulkhead. The report covers the potential problems and the potential failure modes that need to be analyzed. Like the issue of outcrop barriers, MSHA, OSM, and the States find that bulkheads need to be designed and reviewed on a case-by-case basis because minimum standards cannot be established that will apply in all cases.

It has now become common for coal companies to propose using lightweight products, such as polyurethane foam, in the construction of underground bulkheads. These types of products can provide safety benefits by making it less labor intensive to construct a bulkhead. MSHA and OSM note, however, that it would be beneficial to have full-scale tests conducted on these types of bulkheads to verify their strength properties and their behavior under exposure to long-term, constant water pressure. Research studies addressing issues concerning the structural integrity of clay floor strata that have been suspected of failing due to hydraulic fracturing, or being “dispersive,” would also be beneficial. Research pertaining to the occurrence of hydraulic fracturing or the dispersive nature of clay floor strata would best be conducted by the Corps of Engineers, Bureau of Reclamation, NIOSH, or any other entity, be it public, private, or academic, with suitable geotechnical laboratory capabilities.

5. *“The committee recommends that:*

- 1) *MSHA and OSM review activities related to risk assessment for existing impoundments (including both embankments and basins) to ensure that they are consistent and that they distinguish appropriately between hazard and consequences assessment in the methodologies adopted; and*

2) MSHA and OSM establish a single, consistent system, which should be used to assign both embankments and basins to risk categories.” (See pages 12, 124, and 171 of the NRC report.)

Response: MSHA and OSM both use a potential-hazard-classification system that is consistent with the system advocated by the Interagency Committee on Dam Safety (ICODS), and contained in “Federal Guidelines for Dam Safety: Hazard Potential Classification Systems for Dams,” October, 1998. Impoundments are classified as having either high, significant (moderate), or low hazard potential, based on the consequences of their failure. OSM’s regulations specifically refer to the classification system found in “Earth Dams and Reservoirs,” or TR-60, a publication of the Soil Conservation Service.

If failure of the dam would likely cause loss of life or serious property damage, both MSHA and OSM classify the impoundment as having high-hazard potential, and require that it be designed to the highest dam-safety standards. This involves designing to safely handle extreme events like the probable maximum flood and the maximum credible earthquake, as well as all normal operating conditions. This also involves ensuring that the mining company has performed sufficient drilling and testing to adequately characterize the site conditions, and has conducted appropriate engineering analyses to show that each potential failure mode has an adequate factor of safety.

Impoundments whose failure would not likely cause loss of life or serious property damage can be designed to lesser standards. For example, an impoundment classified as having low-hazard potential would be designed to safely handle at least the 100-year frequency rainfall instead of the probable maximum flood. So a higher risk of the embankment possibly being overtopped and failing is accepted, based on a failure causing no serious consequences. This is standard practice in dam design. To design an impoundment for less than the highest standards, a mining company typically has to submit a conservative "breach analysis" that supports the low consequences of failure.

A similar approach is taken in evaluating impoundment plans when there is the potential for the reservoir to break into underground mine workings. That is, the potential consequences of a breakthrough are evaluated, and an attempt is made to ensure that mining companies perform an appropriate amount of investigation and analysis, commensurate with the hazard potential. Just as for the design of the dam itself, this involves ensuring that the mining company has performed sufficient drilling and testing to adequately characterize the site conditions, and has conducted appropriate engineering analyses to show that each potential failure mode has an adequate margin of safety. The goal is to ensure that either through investigation and analyses, or by the design of remedial measures, mine operators demonstrate that an acceptable level of protection has been provided against the chances of a breakthrough occurring.

Confusion may have resulted from the system that MSHA used to rank sites with respect to breakthrough potential. This system was developed after two breakthrough events in Virginia. The NRC report indicates that, "The purpose of this classification system is to evaluate whether the impoundment plan adequately addresses the breakthrough potential." This is not correct. The purpose of this system was simply to prioritize, on a one-time, nationwide basis, the order in which existing slurry impoundments would be re-evaluated for their breakthrough potential. These priorities were set by considering, at each site, the consequences of a breakthrough and how the site conditions compared with guidelines for mining under bodies of water, which had been developed under U.S. Bureau of Mines research contracts. Sites that did not meet the guidelines, and had higher consequences of failure, were given a higher rating (giving them a higher priority so that they would be re-evaluated before lower priority sites). The actual evaluation of whether a plan adequately addresses the breakthrough potential is based on examining the site-specific conditions, and determining whether the potential failure modes have been adequately considered and whether appropriate preventive measures have been included.

To summarize, MSHA and OSM each use a single, consistent system to determine the hazard-potential classification for an impoundment site. The methods are consistent with the system advocated by the ICODS, and contained in "Federal Guidelines for Dam Safety: Hazard Potential Classification Systems for Dams," October 1998. The hazard potential classification for a site is actually proposed by the designer (coal company or engineering consultant), and then either concurred with, or challenged, by the agencies. In this process, the agencies' goal is to ensure that the potential consequences of both failure of the embankment, and failure of the basin (breakthrough), are properly taken into account. MSHA's use of a separate classification system, which was focused strictly on breakthrough potential, was a one-time event, done for the purpose of prioritizing the order in which sites with breakthrough potential were to be re-evaluated following two breakthrough incidents in Virginia.

6. *"The committee also recommends that MSHA and OSM oversee a thorough assessment of potential mitigation measures for those impoundments that fall in the highest risk category and should determine which mitigation measures should be applied to reduce this risk to an acceptable level."* (See pages 13, 124, and 171 of the NRC report.)

Response: In accordance with a Procedure Instruction Letter issued by MSHA in 1997, mining companies with impoundments that have breakthrough potential were notified by MSHA and instructed to re-evaluate the safety of their situations and submit the results of their re-evaluation to MSHA. MSHA has reviewed all of these evaluations, and the measures proposed by mining companies to reduce the risk of breakthroughs,

for impoundments in the highest risk category. Where the information, or the proposed measures, was not considered adequate, MSHA is working with the coal companies, on a site-by-site basis, to get the situations corrected as expeditiously as is practical. As one example, at a site where MSHA's review identified an area of low cover under the impoundment where the potential for a breakthrough into abandoned mine workings was considered unacceptable, meetings were held with representatives of the coal company. A plan was then developed and approved to drill holes and backfill a portion of the underground mine workings. This action provided support to the strata and an adequate margin of safety against the occurrence of a breakthrough.

In OSM, each State regulatory agency has reviewed breakthrough potential plans and required mitigation measures. The Appalachian Region of OSM has prepared a plan for the oversight of slurry impoundments that includes breakthrough evaluations. A report entitled "Reviewing a State's Process for Evaluating the Potential for Impoundment Breakthrough into Underground Mine Workings," was issued by the Appalachian Regional Coordinating Center in May 2002.

7. *"To maximize the potential for risk reduction, the committee recommends that all impoundment designs be accompanied by a risk analysis utilizing qualitative methods."* (See pages 13, 125, and 172 of the NRC report.)

Response: Neither MSHA's nor OSM's regulations specifically require that a mining company submit a "risk analysis" in an impoundment plan or permit. MSHA, OSM, and the States will continue to reduce the risk of breakthroughs by requiring that plans or permits include the following:

- Identification of all reasonable potential-breakthrough failure modes;
- Adequate documentation of the conditions and engineering properties used in failure mode identification and analysis;
- Appropriate engineering analysis of each potential-failure mode to determine the margin of safety;
- Detailed engineering plans for any measures needed to reduce the risk of a breakthrough to appropriate levels;
- Provisions for monitoring key parameters related to the potential failure modes, so that action can be taken in the event the facility does not perform as expected;
- Provisions for inspections and certifications of facilities by qualified personnel, so that indications of potential problems are recognized and evaluated at early stages;
- Provisions for emergency action in the event a problem develops.

MSHA, OSM, and the States believe that these measures include the main elements of a qualitative risk analysis and maximize the potential for risk reduction. This approach is one of the goals of, and is already incorporated into, MSHA's and OSM's review process.

8. ***“The committee recommends that MSHA and OSM consider requiring additional continuous monitoring in specific instances and evaluate automation of monitoring instrumentation.”*** (See pages 6, 129, and 167 of the NRC report.)

Response: MSHA, OSM, and the States attempt to determine what type and frequency of monitoring is prudent based on the specific conditions involved at each impoundment. Typically, monitoring is performed during the inspections that qualified company personnel are required to make, per MSHA regulation, on a seven-day basis. When a potentially hazardous condition develops, the regulations require that instruments be monitored at least once every 8 hours, or more frequently if directed by an MSHA authorized representative. As recommended in the NRC report, where conditions warrant, MSHA, OSM, and the States will require more frequent, or automated continuous, monitoring.

9. ***“The committee recommends that coal seam names not be the sole basis for determining the vertical location of an abandoned mine.”*** (See pages 7, 84, and 168 of the NRC report.)

MSHA, OSM, and the States recognize that, in the technical review of a plan or permit, relying on the name of a coal seam to determine the vertical location of an abandoned mine is not prudent practice. Seam elevations are normally determined based on a mine survey or drilling logs.

IV. MAPPING AND SURVEYING RELATED TO UNDERGROUND MINES AND IMPOUNDMENTS

The NRC report identified several issues relating to adequacy and accuracy of mine maps and provided a number of recommendations for improvements in this area. A work group reviewed related regulations, policies, and procedures, analyzed the NRC recommendations, and identified those recommendations the group believed should be pursued to help eliminate incidents involving inaccurate or missing mine maps.

The NRC recommendations concerning mine mapping and surveying (shown in italics), and the work group's comments, are as follows:

1. *"The committee recommends that, adjacent to existing or proposed refuse impoundments, coal outcrop locations should be determined by aerial topographic measurements."* (See pages 7, 72, 85, and 167 of NRC report.)

Response: The surface topography maps submitted to MSHA, OSM, and the State Regulatory Authorities delineating coal outcrop locations are usually scaled at 500 feet to the inch or less. The maps are typically based on aerial photography or USGS mapping. Coal outcrop locations are usually a projection based on the structure of the coal and its intersection with the ground surface. The scale and accuracy of the map used, as well as the thickness of the pen line on the map, will impact the delineated coal outcrop location.

The steepness of the hillside, stress relief fracturing, weathering, hillside creep, landslides, and manmade disturbance all impact the coal that was originally at the projected outcrop location. These impacts, coupled with the possibility that the projected coal outcrop locations may be inaccurate because of local changes in coal structure, further complicate coal barrier analyses.

In some locations coal outcrops can be located because of surface mining activities, abandoned portals, outcrop sample areas, auger mining, highway cuts, house and building excavations, and house-coal openings. However, location of coal outcrops may be impractical in steep sloped areas because of difficult access to the outcrop areas and the necessity to excavate to locate the coal outcrop. Field efforts in Kentucky to determine actual coal outcrop locations were unsuccessful because of the steep hillsides and the presence of a colluvial and soil cover. Field location of outcrops can also be complicated by the presence of multiple seams in close proximity to each other. In addition, locating outcrops along hillsides requires excavation and results in considerable surface damage.

Drilling done after the October 2000 breakthrough at the Martin County Coal Company site documented the conditions of the material from the projected coal outcrop to the location of full thickness coal. The drilling confirmed that the delineations onto the aerial topographic map for the underground mined areas were accurate. It also confirmed that the projected coal outcrop location was correct in terms of surface topographic elevation. This projection indicated a 70-foot barrier from the face of the last entry to the outcrop. However, the drilling done after the October 2000 breakthrough found there was only 15 to 18 feet of full-seam thickness coal, while the remaining material to the projected outcrop location was thinning-coal and unconsolidated material.

The drilling done after the October 2000 breakthrough at the Martin County Coal Company site documented that there was about 50-foot barrier from the location of the projected coal outcrop at the ground surface to the location of full depth coal. This data generally supports the “rule of thumb” approach that has been used to establish coal outcrop barriers for flooded underground mines. These “rule of thumb” barriers are required to be at least 50 feet wide. The required barrier size is then increased by an amount equal to the anticipated water head in the abandoned underground mine. A review of the Martin County Coal Company breakthrough and other similar events also indicates that breakthroughs often occur through the material above the coal outcrop barrier. This is also the case with mine blowouts at or above drainage flooded underground mines.

When aerial topographic maps are used for permit preparation, coal operators have not always ensured that their submittals are compatible with the regulatory authority’s mapping database. Without coordination of the mapping databases, permit reviewers must spend excessive time transitioning from their database to the permit maps.

The NRC recommendation that coal outcrop locations be determined using aerial topographic measurements highlights one method of producing outcrop maps. However, when used properly, USGS topographic mapping and surface surveys are also acceptable. MSHA relies on the fact that surveyed surface maps are prepared and certified by a registered surveyor. The states have minimum requirements for registration which are intended to ensure that persons certifying maps are qualified to do so. The “surface maps” referred to in the report are maps made by surveyors using surveying instruments and working on the surface of the ground. Such maps would be expected to have greater accuracy than “aerial maps” and “surface topographical maps,” which are produced by a combination of aerial photography and surface surveying.

The NRC noted that underground mine maps are typically maintained to accuracies of a tenth or hundredth of a foot, while surface topographic maps may have much less accuracy. One of the key steps in properly delineating coal outcrop locations on surface

topographic maps is the coordination of survey control points. Common control points should be used for both the underground mine map and the surface topography map. The accuracy of each map generated from these common control points will then be controlled by the equipment or method used to create the elevations and contours.

We propose that, where practical, and at critical locations, the coal companies should do surface topographic surveys along the coal outcrop as part of their permit submittal. These surveys should fully document existing locations where the coal seam is already exposed due to natural or manmade activities. The surveys should be tied to either the United States Geological Survey or the United States Coast and Geodetic Survey benchmark system that are used for the underground mine surveys. By using common bench marks for the surface and underground surveys appropriate vertical and horizontal control can be ensured.

2./3. *“The committee recommends that MSHA work with OSM and State agencies to develop a coordinated and assertive approach for collecting and archiving mine maps and retaining permit documents. The committee also recommends that upon receipt of a mine map, the State or Federal agency should have it scanned into electronic data files.”* (See pages 7, 77, 85, and 168 of NRC report.)

Response: The Office of Surface Mining operates a National Mine Map Repository (NMMR) in Greentree (Pittsburgh), Pennsylvania. There are approximately 250,000 abandoned mine maps in its collection. Of those, about 82,000 have been scanned. The maps are from States throughout the country.

Prior to 1996, the NMMR concentrated its efforts on collecting mine maps only from eastern States. In April of 1996, due to the abolishment of the Bureau of Mines, OSM’s NMMR received mine maps that were formerly maintained by the Bureau in their repositories in Denver and Spokane. There is a large inventory of data that may contain other mine maps still archived in Denver.

The NMMR implemented their scanning program in 1998 with the scanning of mine maps from aperture cards. The NMMR currently scans about 5,000 maps a year.

The MSHA, through its Procedural Instruction Letter I-95 V-12, Procedures for Disposition of Mine “Closure” or “Final Maps,” provides the NMMR with closure maps of abandoned coal mines that are received from operators when mining is completed. These closure maps include the notes recorded concerning geologic conditions, water inflows, roof falls, etc. These mine maps are forwarded to OSM, catalogued, microfilmed, scanned, and then returned to the respective district office in MSHA. Returned maps bear the microfilm catalog numbers assigned by the NMMR.

The NMMR has arrangements with some States to scan their map collections, the largest collection being with the State of West Virginia. Others include Ohio and Illinois. Part of the OSM NMMR mission includes an assertive outreach program for the acquisition of maps for abandoned mines. However, the NMMR has not been able to collect and process all maps that have been made available by State agencies, mining companies, private individuals, universities, etc. In order to address this issue, as well as to redefine the NMMR's future, the NMMR this past year developed a five-year plan. This plan addresses the need for the NMMR to provide a more user-friendly product to the public and its other customers. The objectives of this plan coincide with several of the recommendations of this workgroup. They include: developing a plan to improve outreach to map owners; improving the NMMR's technical capability for electronic copying and storage of mine maps; and developing a web-based retrieval system for mine maps to improve information access by the public and other government agencies.

The National Mine Map Repository (NMMR) is funded as a part of OSM's base Technology Development and Transfer (TDT) business line. OSM spends money from its base funding to address the needs for updating the repository. While the internal budget documents for the TDT business line does include an increase for the NMMR in FY05, OSM anticipates that increase as being accommodated within the business line without an increase in the overall FY05 TDT request.

State agencies have established their own standards for collecting and cataloging maps, and the NMMR has developed a liaison with the States for the purpose of exchanging information on scanning technologies. Some State government agencies, such as Kentucky, had laws that placed restrictions on what information could be released pertaining to closure mine maps. Recently this restriction was eliminated through legislation. Other States that have confidentiality issues may want to consult with Kentucky for assistance.

A survey was conducted of the status of State efforts to electronically scan and store mine maps. The results are summarized in Appendix E. While these efforts by the States and the NMMR are planned to include all maps, some mine maps are being scanned as part of specific reclamation projects supported by the Abandoned Mine Lands Fund of SMCRA. These mine maps are scanned for isolated areas because they are needed to prepare the design drawings and specifications for an abandoned mine lands reclamation project. This map-scanning work, supported by the Abandoned Mine Lands Fund, is not done for areas outside the reclamation project limits. Except for this limited work, use of the Abandoned Mine Lands Fund for mine map scanning is generally not authorized.

All of the contacted States agreed that electronic storage of all mine maps is a highly desirable goal; however, only a few, Indiana, Ohio, Virginia, and to some degree Illinois, have actually been able to do so. These States have a relatively small number of

underground mines when compared to the historically large coal producers like Kentucky, West Virginia, and Pennsylvania. While the relationship between OSM and States has been one of cooperation (primarily providing scanned images on an as-needed basis for specific areas), there is a great need for OSM and the States to develop and enter into formal “MOUs,” similar to others now being used between OSM and MSHA, to ensure that all mine maps are digitally stored in a reasonable period of time.

Failure to develop a coordinated approach in the collection and storage of mine maps will result in duplication of effort at best, and a possibility that map collections may erroneously be believed to be all encompassing for a particular geographic area. This could result in future instances where human activities are planned near and over abandoned underground mines, with potentially disastrous consequences.

There also needs to be a concerted effort to develop and implement an outreach program to assure that other sources of maps, particularly older maps, are identified, collected, copied and properly stored. These maps are perhaps the most vulnerable to being lost forever.

Finally, there still appears to be a question as to the legal availability of mine maps to the public in some States. State and Federal officials need to inform lawmakers in those States that there is a need to assure that these resources (mine maps) are available to policymakers and others as a matter of public health and safety.

The following activities are either underway or proposed in response to the NRC recommendations:

- a. OSM’s NMMR proposes to work with each State in developing a plan for the collection, preparation, retention, and electronic storage of all available mine maps found in each State’s responsible agencies. In those States where it would be most advantageous for the NMMR to assume any of the tasks of collecting, preparing or storing the mine maps in an electronic format, a MOU should be developed and implemented outlining the specific responsibilities of each entity. In those instances where it is found to be most advantageous for the States to assume responsibility for all the tasks to assure that all mine maps are electronically stored, electronic copies should be made available to the NMMR for inclusion in a national database. It would also be advisable for those States to work closely with the NMMR to assure that technologies being used are compatible with the NMMR and other States where deemed necessary. OSM has begun outreach with States by discussing the scope and size of updating their mine map inventory into an electronic format. Discussions include options, resources, timetables, and areas of responsibility. Outcomes of such discussions will be documented through MOU’s, if desired by both parties. All States that

have abandoned mine maps will be contacted and any MOU's will be developed by early calendar year 2004.

- b. It is proposed to expand OSM's NMMR outreach efforts to include other agencies, universities, or any other party who may have abandoned mine maps in order to establish a coordinated effort for collecting and preserving all existing abandoned mine maps. Where needed, MOUs should be established to assure all responsibilities are clearly outlined. The NMMR has developed a plan and schedule for conducting this additional outreach to non-State sources that may have mine maps that are unavailable elsewhere. Implementation of this plan should begin early in calendar year 2004.
- c. It is proposed that OSM, MSHA and State agencies meet and develop an education plan, directed at policy makers and law makers, which emphasizes the need for abandoned map information to be readily available to the public, agencies and others involved in land development.
- d. OSM proposes to continue to improve the NMMR's technical capability to assure that it is capable of scanning and storing all mine maps that need to be scanned as well as to continue to develop the web-based data plan. OSM has developed a plan that identifies the technical needs of the NMMR in meeting its mission as it relates to its role in the electronic storage and retrieval of abandoned mine maps. OSM has recently developed several scenarios for accomplishing the above tasks. These scenarios include various approaches which allow both the NMMR and the States to devise the best approaches to assure that the scanning and electronic storage of mine map data is completed in the most efficient and timely manner, as well as provide the technical capability to assure that future mine maps are properly stored. Cost estimates for these scenarios range from 7 to 15 million dollars. OSM is also coordinating with MSHA on this effort. Since MSHA is a critical partner in the collection of maps that will, this coordination will help assure that all of these maps are collected and properly stored in an electronic format.
- e. It is recommended that State agencies revisit their laws/regulations (if any) on how mine map information is collected and disseminated, realizing the need to have this information available to the public, industry, regulatory agencies, and policymakers to assure that future development plans include the past mining information.
- f. OSM will continue to implement its five-year plan for the NMMR to assure that it is able to meet the obligations created by future MOUs, as well as to assure the implementation of future outreach programs. This plan will also enable the

NMMR to continue to develop a web-based program to improve access to mine maps through the Internet.

- g. OSM plans to continue its procedural agreement with MSHA that provides NMMR with closure maps of completed coal mines. This will ensure that the site-specific geologic information documented on the permit maps during mining will be retained permanently at the NMMR.

4. *“The committee recommends that MSHA set standards for minimum closure error for all underground closed-loop surveys and that a closed-loop survey be maintained within a standard distance (to be determined by MSHA).”* (See pages 7, 78, 85, and 168 of NRC report.)

Response: The Mine Safety and Health Administration, under 30 CFR §§ 75.1200-2, “Accuracy and scale of mine maps,” requires that mine traverses shall be advanced by closed loop methods of traversing, or other equally accurate methods of traversing. The regulations provide no standards pertaining to allowable closure error or how often the closed-loop surveys need to be performed. Title 30 CFR § 75.1201 requires that mine maps shall be made or certified by a registered engineer or registered surveyor of the State in which the mine is located. MSHA coal enforcement districts were provided an internal memorandum outlining common surveying practices. Following the advice of the memorandum, MSHA coal enforcement districts require closed-loop traverses. Desirable horizontal closure errors are on the order of 1:5,000. Vertical closure is not addressed. Records show that since 1990, MSHA has written 26 citations for violations of 30 CFR §§ 75.1200-2b.

Many coal-producing States require that mine maps be prepared by or under the supervision of a professional engineer or licensed land surveyor. Typical examples of this are the West Virginia Code under Chapter 22A, Article 2, and the Coal Mine Safety Laws of Virginia, Section 45.1-161.64. These State regulations do not specifically require closed-loop surveys are required.

Past informal reviews of survey practices by MSHA revealed that many mine surveyors performed closed-loop traverses at mines even before it was required. Respondents stated that the type of mining being performed dictated the accuracy. For instance, in longwall head and tailgate development, an accuracy of 1:20,000 is desired. For mains and panel entries, an accuracy of 1:10,000 and 1:5,000, respectively, is desired. Some operators have argued that information equivalent to that obtained by a closed-loop traverse can be obtained by conducting a “check survey.” These surveys consist of an open traverse with double angles and multiple distance measurements. Surveys conducted following these procedures are typically more accurate than single angle, single distance measurement traverses. The calculated coordinates of survey stations

common to the normal mine survey and the check survey are compared to give an error of closure.

Neither Federal nor State regulations address the issue of how often a closed-loop survey should be conducted. Many MSHA districts require all places to be surveyed by a closed-loop traverse prior to abandonment. In the industry, the time frame for conducting closed-loop surveys or check surveys appears to vary. While short-life panels may not be closed at all, long-term entries may be surveyed by a closed loop every 1,000 to 2,000 feet.

Virginia and West Virginia also have mapping requirements for surface coal mines. In Section 34.1-161.64 of the Coal Mine Safety Laws of Virginia, surface mine maps are required to be submitted if the mine may intersect underground workings or workings from auger, thin seam, or highwall mining operations. These maps must be certified. In Section 22-3-9 of the Surface Coal Mining and Reclamation Act of West Virginia, accurate maps must be submitted in the permit application. There are no specific surveying requirements for any of these maps.

The NRC recommended that standards be set for minimum closure error for all underground closed-loop surveys and that a closed-loop survey be maintained within a standard distance. In current practice, it was found that some mines perform what is termed a "check survey." This type of survey consists of an open traverse with double angles and multiple distance measurements running parallel to the original mine survey. Coordinates of survey stations common to the normal mine survey and the check survey are then compared. If the station coordinate values are close by both sets of calculations, the original mine survey is considered "acceptable." There are no uniform standards of closure. Further, although some consider this a form of closed-loop survey, it is questionable whether these check surveys are equivalent to a closed-loop traverse since the traverse does not tie back to itself and the original survey is not as precise. The practice of turning angles and measuring distances multiple times does increase the accuracy of the survey. However, unless the traverse is tied in to other accurately located control points, the probability of an acceptable closure ratio is less likely.

In place of closed-loop traverses, MSHA standard 75.1200-2(b) States that "other equally accurate methods of traversing" may be used. Some surveyors believe there are no methods as accurate as a closed-loop traverse while others believe a double angle, multiple distance measurement traverse is as accurate. It is reasonable to assume that having an accurately located control point at the start and end of the traverse would provide more confidence in the calculated closure. One surveying firm reported that they run two parallel double angle, multiple distance measurement surveys into the mine in different entries. At specified distances, the two surveys are tied together to

check the closure of the common points. This would be equivalent to a closed-loop traverse.

Accuracy can be measured on two levels: angular closure and linear (coordinate) closure. When a closed-loop traverse is completed, the theoretical sum of all interior angles is known and is equal to the value $(n-2)180^\circ$. If the actual sum of the angles does not equal the theoretical sum, there is an error of angular closure. The coordinates of survey stations are computed based on turned angles and measured distances between stations. A closed-loop traverse starts and ends at a point with known coordinates. If the calculated coordinates for the final station differ from the known coordinates, there is a linear (coordinate) closure error. The two errors are related since the coordinate values for a survey station are determined using the angles and distances measured during the traverse. Once the closure errors are known, corrections can be made to the angles throughout the traverse or to the calculated coordinate values. For non-surveyors, the coordinate closure error is more convenient.

True closed-loop surveys should be used exclusively. Agencies should define the types of surveys that are considered equivalent to a closed-loop survey. The linear (coordinate) closure accuracy should meet or exceed 1:10,000. The angular closure should not exceed 1 minute. Vertical controls should be carried through the mine to an accuracy of +/- 0.01 feet per 1,000 linear feet. As a minimum, a closed-loop traverse or equivalent should be conducted every one thousand feet and at the last open crosscut. Survey station coordinates should be corrected once the closure is determined. Along with the certified mine map that is required by regulators, operators should include documentation demonstrating how the above accuracy has been achieved. Finally, extraction heights should be included on all maps. If surveys are found to be inaccurate, the name of the certifying engineer or surveyor should be submitted to the appropriate State board of registration for possible disciplinary action.

Surveys to this degree of accuracy will require more time to conduct. To achieve this accuracy, specialized equipment may be required and some companies may need to hire additional surveying personnel or use contract surveyors for a longer period of time.

The accuracy of mine surveys would be very difficult for regulators to verify. Therefore, the burden should remain on the person certifying the mine map. Rather than a regulation change, MSHA believes the assurance of accurate surveys can be achieved through policy interpretations of the terms "accurate" and "certified" and a clear policy statement on the issue. Great latitude already exists in MSHA under 30 CFR § 75.1200(1), which allows the MSHA district manager to request "such other information as the Secretary may require", and lists the requirements for information that must be reported on a mine map. MSHA will use existing authority and will work with State agencies to adopt appropriate policy interpretations that will assure accurate

surveys. After conferring with the various mining states, it is anticipated that MSHA will specify details on surveying accuracy in a policy memorandum to all enforcement offices. MSHA believes a regulation could be too rigid and not allow flexibility in the standards if the surveying state-of-practice were to change. The policy changes related to mine survey accuracy would be issued as a directive through a "Program Policy Letter" (PPL). This PPL would be posted on the agency's web page and mailed to each of the Program Policy Manual holders, which includes MSHA personnel, the mining industry, labor, and other interested parties.

NOTE: At this time, MSHA has a committee looking into surveying practices with regard to mining near flooded workings.

5. *"The committee recommends that the mine foreman and surveyors be required to record the depth of last cut taken to a level of accuracy to be determined by MSHA. It is imperative that any not completely surveyed be noted as such."* (See pages 7, 80, 85, and 168 of NRC report.)

Response: The typical practice for recording the depth of last cut is for the section foreman to indicate on his working map the estimated distance from the last crosscut or other known location. This distance is generally not measured precisely using surveying instruments. The location of the face is transferred to the main mine map when the foreman turns in his map. Since the area is not surveyed to high precision, the area is often reported on the map with dashed lines.

The MSHA regulations at 30 CFR § 75.1200 require the operator of a coal mine to have "an accurate and up-to-date map" of the mine. Section 75.1200-1(k)(2) requires that the mine map show the elevations in the "last line of open crosscuts of each working section, and main and cross entries before such sections and main and cross entries are abandoned." In addition, Section 75.1202 requires that the mine map be kept up-to-date by temporary notations and revised and supplemented. The map kept at the mine must be re-certified every six months. Section 75.1204 requires that the map filed upon closure of the mine be "revised and supplemented to the date of closure." The latter standard also requires certification by a registered surveyor or engineer. MSHA considers the burden for verification of map data prior to certification to be on the certifying person.

The State of West Virginia has requirements similar to MSHA. It requires that the mine map show the last line of open crosscuts of each working section, and main and cross entries before such sections and main and cross entries are abandoned. Maps must be kept up-to-date with regard to each working face of each working place.

While the NRC recommended that the depth of the last cut taken should be recorded to some level of accuracy, it is uncertain how an engineer or surveyor can certify a map if

all data is not known. Such is the case when the depth of last cut is not measured precisely with surveying instruments. However, just because the area is not “surveyed” does not mean the foreman did not record and report an accurate depth of cut. The burden should remain on the person certifying the mine map. This person must assure regulators, either through documentation or qualification statements, that all data on the map is accurate and whether there are unknowns.

A key issue is how to prevent and detect inaccurate recording and reporting. It is unreasonable to require the area to be precisely located by a survey crew using surveying instruments. Often, the roof of the final cut is not bolted. Estimates of the distance by the foreman should be accurate to within a foot or two. The length of mining equipment is known or extendable survey rods can be used to obtain the last distance. The section foreman is responsible for recording and reporting accurate last depth-of-cut information. However, it ultimately is the decision of the person certifying the mine map whether the limit of mining is sufficiently known to merit a solid line on the mine map (accurately known) rather than a dashed line (not accurately known). However, none of these practices will be effective in deterring the fraudulent reporting of the amount of coal taken. Even personal observation by regulators would not guarantee that the operator did not come back in to take additional cuts.

It is proposed that the mine operator designate a qualified person(s) to be responsible for determining, recording, certifying, and reporting to the person responsible for certifying the mine map, the extent of mining in last cuts, along with the method used to determine the distance. The engineer/surveyor can then report the distance on the certified mine map. Elevations and mining heights should be reported at the last crosscut.

It is expected that mine operators would have to establish internal policies and guidelines to assure the certifying engineer/surveyor that the distances reported are indeed accurate. The burden for ensuring the mine map is accurate is on the certifying engineer/surveyor. This recommendation would result in very little change to current practices. MSHA will use existing authority and will work with State agencies to adopt appropriate policy interpretations that will assure accurate certification of mine maps showing the last cut.

On significant safety issues, MSHA and the States have worked together to ensure a uniform standard of safety. On the issue of recording the depth of last cut taken, it is anticipated that MSHA and the various mining states will hold joint meetings to discuss the issue. MSHA believes policy changes for recording the depth of last cut will be more effective than a regulation change. Title 30 CFR 75.1200 lists the requirements for information that must be reported on a mine map. Section (l) of the standard states “Such other information as the Secretary may require.” MSHA believes a regulation could be too rigid and not allow flexibility in the standards if the surveying state-of-

practice were to change. The policy changes related to recording the depth of the last cut would be issued as a directive through a "Program Policy Letter" (PPL). This PPL would be posted on the agency's web page and mailed to each of the Program Policy Manual holders, which includes MSHA personnel, the mining industry, labor, and other interested parties.

6. *"The committee recommends that State plane coordinates or latitude and longitude and bottom-of-seam elevations be used as the map based reference reporting of seam elevations."* (See pages 7, 80, 85, and 168 of NRC report.)

Response: MSHA regulations do not address the issue of coordinate systems for mine maps. State regulations do address the issue. For example, West Virginia's Code under Section 22A-2-1 States that "surveying calculations and mapping of underground coal mines . . . shall be done by the rectangular coordinate traversing method and meridians carried through and tied between at least two parallel entries of each development panel . . ." MSHA's experience is that present mine maps are tied to a common State-wide coordinate system. West Virginia has reported that all maps do not comply with their requirements. Kentucky reports that active mines are currently tied to a common coordinate system.

The MSHA regulation 30 CFR § 75.372 requires a mine map to show contour lines of the elevation of the coal bed being mined. The contour lines are not to exceed 10-foot elevation levels except when approved by MSHA in steeply pitching seams. In addition, § 75.1200 requires that elevations of all main and cross or side entries be provided on the mine map. Section 1201-1(k) specifies that mine floor elevations be to be provided. It appears many States have similar requirements for reporting seam elevations, but do not specify floor or roof.

The practical purpose for reporting mines on a common coordinate system is that adjacent mines can be located and positioned with little effort. The surveyor or engineer would simply align the common coordinate grids or points and would have confidence that the result is a true representation of the horizontal relationship between the mines.

The National Geodetic Survey has established a national network of horizontal and vertical control monuments that are available to any engineer or surveyor who desires to connect his work with the Federal system. This network is made available through the State coordinate systems computed for each State since the positions of these monuments are published in geographic and State plane coordinates. If only the latitude and longitude of a point are known, those coordinates can be converted to the corresponding State plane coordinate through available equations and tables.

The original horizontal control network for the United States was known as the Clarke Spheroid of 1866. From this, the North American Datum of 1927 (NAD 27) was developed. More recently, the North American Datum of 1983 (NAD 83) has been established. Many of the points from the NAD 27 survey have been given new coordinates as a result of the NAD 83 survey. With the addition of the newer and more accurate NAD 83, there are now two separate and distinct State plane coordinate systems (SPCS), namely, the SPCS 27 and the SPCS 83. There are subtle differences between the systems. One main difference is that NAD 83 coordinates are reported in meters. Two meter-to-foot conversions are available: the International foot and the U.S. Survey foot. Since most work in the U.S. is done in feet, States have adopted one of these two conversions as their official method. At this time, it is unknown whether all States have officially adopted the NAD 83. Therefore, both systems are still in use. Information is readily available telling which of the two projections described above have been used for each State under either State plane coordinate system.

With the advent of modern surveying equipment and computers, the task of converting local coordinate values into common coordinate system values has been greatly simplified. Presently, all surveyors need to do is enter the survey data into a computer program and the conversion into any desired coordinate system is performed. Most local construction projects do not reference their surveys to the State coordinate system or latitude and longitude. However, large projects such as highways do use the State plane coordinate systems. When survey results are being compared, it is critical that the same datum, adjustment year, and conversion method be used.

The historical reasoning for reporting floor rather than roof elevations is not so clear. Two possibilities seem reasonable: the floor elevation will not change appreciably with time, and it is possible to use this information for drainage control. However, since mine survey stations are typically located in the roof, additional calculations are required to obtain the floor elevation. This can introduce another source of error in reporting. Similar to the horizontal control system described above, the National Geodetic Survey has established a vertical control network. These monuments are typically the same as those used for the horizontal control network. All vertical controls should be referenced to the North American Vertical Datum of 1988 (NAVD 88).

It is proposed that all mine maps use the State plane coordinate system as the primary reference. It should be stated on the map whether the horizontal survey is based on NAD 27 or NAD 83, along with the adjustment year. If NAD 83 is used, the metric to foot conversion system should be reported. In addition, latitude and longitude coordinates should be provided for several key points on the map so that the mine can also be located on standard USGS topographic maps. It is further proposed that mine elevations be based on NAVD 88 and be reported on mine maps along with excavation heights. Floor elevations should be reported on the maps, along with mining heights, at

regular intervals. It should always be stated on the map which elevations are being reported.

All surveyors should already be aware of the different coordinate systems in use. Many mines are already using State plane coordinate systems. There should be very little cost associated with regulatory agencies implementing this requirement. In MSHA, this issue can be handled through policy and should not require a regulation change. The information can be obtained under 30 CFR § 75.1200(1), which states that a mine map shall show other information as the Secretary may require. Some States already have regulations in place to require the use of latitude and longitude. All States will need to address their specific situation. MSHA will use existing authority and will work with State agencies to adopt appropriate policy interpretations, which will assure accurate surveys and representations of locations on mine maps.

7./8. The committee recommends that: 1) " appropriate coordinate transformation equation(s) be listed on the map," and 2) " a qualifying statement accompany any coordinate transformation that is based upon the alignment of surface features."
(See pages 7, 82, 83, and 168 of NRC report.)

Response: No current mining regulations could be located that address the issue of coordinate transformation. Because the surface of the earth is curved, some compromise in position must be accepted when attempting to display the information on a plane surface, namely, a map sheet. Similarly, a State plane coordinate system must be a compromise since it represents a spheroid surface projected onto a curved surface (which may ultimately be developed onto a plane surface). These projections are handled nicely by appropriate computations.

Two types of projections are used in developing the State plane coordinate systems: the transverse Mercator projection and the Lambert conformal projection. Each projection method employs a different base surface, each of which results in distortions. The transverse Mercator projection is preferable for States with relatively short east-west dimensions. The Lambert conformal projection is preferable for States with relatively short north-south dimensions. States may be broken into "zones" which are then covered by one of the projection methods described earlier. Thus, a single State may require both projection methods to cover its unique area. The basis for selecting the appropriate system for each State or zone was to keep the maximum distortion at any point to about 1:10,000.

The original horizontal control network for the United States was known as the Clarke Spheroid of 1866. From this, the North American Datum of 1927 (NAD 27) was developed. More recently, the North American Datum of 1983 (NAD 83) has been established. Many of the points from the NAD 27 survey have been given new coordinates as a result of the NAD 83 survey. With the addition of the newer and more

accurate NAD 83, there now exist two separate and distinct State plane coordinate systems (SPCS), namely, the SPCS 27 and the SPCS 83. There are subtle differences between the systems. At this time, it is unknown whether all States have officially adopted the NAD 83. Therefore, both systems are most likely still in use. Information is readily available telling which of the two projections described above have been used for each State under either State plane coordinate system.

If no surveying data is available for a mine, the site cannot be readily transferred into another coordinate system. This is often the case with old abandoned mines. In these cases, it is common to scale the old map to match that of a new map and then overlay the two maps and align common geographical features or points. The location of the old mine can then be traced or digitized onto the newer map. Coordinates for the system employed for the newer map can then be applied to the old mine. When this is done in practice, the details of the procedure are rarely, if ever, reported.

The agencies recommend that mine surveys be based on the North American Datum of 1983. The projection method used to convert geographical coordinates into State plane coordinates should be based on the method chosen for the specific State and should not be altered by the mine surveyor or engineer. Persons certifying maps should provide sufficient documentation with the map to show how the coordinates were transformed (provide details on software used or detailed methodology), the adjustment year, and the meter-to-foot conversion used. When relative locations are obtained by overlaying and alignment, full details of the procedure used should be provided with the map.

MSHA will use existing authority and will work with State agencies to adopt appropriate policy interpretations, which will assure accurate surveys, however, the agencies do not believe there is a need for these equations to be listed. Since there are only two methods used for transforming the geographic coordinates into State plane coordinates, and these methods are well documented, it would be sufficient to simply list the method used. In the event that some method other than the two described in this paper is used, then full documentation should be provided.

9. *"The committee recommends that MSHA establish standards to improve and maintain the location of surface controls."* (See pages 7, 83, 85, and 168 of NRC report.)

Response: MSHA regulations require that surface controls be shown on the mine map (while the mine is active and during abandonment). No standard specifically requires that the points be maintained. The West Virginia Code under Chapter 22A Article 2A, Section 1, specifies that surveys originate from at least three permanent survey monuments on the surface of mine property. Further, these monuments are to be tied to either the United States Geological Survey or the United States Coast and Geodetic Survey bench mark system.

Mine surveys generally originate at nearby National Geodetic Survey control monuments. From these points, vertical and horizontal control is transferred to the mine property where at least two permanent monuments are typically located near the portal area. Construction of the monuments varies and could range from simple iron pins driven into the ground to sturdy concrete pedestals with protective fencing. These monuments may or may not be witnessed.

While a mine is operating, there appears to be more than adequate control over the quality of permanent survey monuments located on mine property. However, when the mine closes, the regulations protecting those monuments no longer apply. Land may be reclaimed and sold for development, resulting in the destruction of the monuments.

The subcommittee recommends that at least two permanent survey monuments be located on areas of mine property that will not be destroyed or disrupted during the life of the project. The monuments should be protected from vehicular traffic and ground instability. Information pertaining to the origin of the mine survey should be included on the mine map.

Since all mines must presently establish monuments, this issue is not expected to create problems. Regulators should provide information to mine operators relative to the long-term importance of monuments. MSHA will use existing authority and will work with State agencies to adopt appropriate policy interpretations that will assure accurate surveys.

10. *"The committee recommends that coal seam names not be the sole basis for determining the vertical location of an abandoned mine."* (See pages 7, 84, 85, and 168 of NRC report.)

Response: Mine maps currently being submitted have to meet the requirements of 30 CFR 75.1200. This regulation requires that mine maps show "Elevations of all main and cross or side entries," as well as "Contour lines of all elevations." Section 75-1200-1 requires that mine maps show "Contour lines passing through whole number elevations of the coalbed being mined. The spacing of such lines shall not exceed 10-foot elevation levels, except that a broader spacing of contour lines may be approved by the District Manager for steeply-pitching coalbeds."

State Regulatory Authorities require that similar information be included in mine maps to document the contours and elevations of the coal seam (coalbed) being mined. Coal seam names are also included on the mine maps, but they are not used to determine the vertical elevations and horizontal extent of the coal seam.

The name associated with a particular coal seam has historically been used as a method of nomenclature. Many older mine maps do not have contours and elevations for the coal seam. The maps may have notations of some surface features like roads or structures but typically do not have elevation information. These older maps will show the location of the mine entries and may project the coal seam outcrop locations.

The agencies agree with the NRC recommendation; however, this does not require any change in the current documentation of coal seam location relative to elevation and structure. MSHA and the State Regulatory Authorities already require this coal seam information. However, the recommendation is particularly relevant to the use of older maps of abandoned underground mines. They typically do not have coal seam elevation and structure information on the maps. Additional work should be done by OSM (NMMR) to coordinate local geologic drilling records, mine entry locations, and projected coal outcrop elevations. This additional information can be used to better document the vertical location and horizontal extent of the coal seam and any abandoned mines.

For older maps where coal seam elevations and structure are not included, the site cannot be readily transferred to a surface topography map. In these cases, it is recommended that the old mine map should be scaled to match the surface topography map. The two maps can then be aligned to match common geographical features or points. The location of the old mine can then be transferred onto the surface topography map.

While the agencies agree that coal seam names should not be the sole basis for determining the vertical location of an abandoned mine, it is recommended that the local coal seam names should still be included in the documentation of the location, elevations, mined areas, and contour mapping.

V. Use of Geophysical Methods to Locate Mine Workings

A critical task in the investigation of an impoundment site is the locating underground mine workings that could affect the safety of the facility. Experience has shown that mine maps are not always accurate or complete. Conventional exploratory drilling programs provide subsurface information, but have the limitation of only showing the conditions at discrete points. This can be a significant limitation given the large area that impoundments cover, and the long perimeter distance around them. Perimeters of a mile or more are common.

The use of well-planned and appropriate geophysical techniques can be used, in conjunction with drilling, to provide greater confidence that mine workings in the vicinity of an impoundment have been located. But it can be a problem for mine operators to determine which of the various geophysical techniques would be most effective for their particular conditions. The NRC study concluded that geophysical techniques have been underutilized in the coal-mining industry and that demonstration projects would be beneficial. This led to the following recommendation:

“The committee recommends that demonstration projects using modern geophysical techniques be funded, and that the results be widely conveyed to the mining industry and to government regulatory personnel through workshops and continuing education.”

Response: MSHA, OSM and the States agree that it would be beneficial if the capabilities of geophysical techniques, for use in the detection of mine voids, were demonstrated and the information conveyed to the mining industry. In addition to having application to the problem of impoundment breakthroughs, geophysical methods can also be used to detect workings ahead of mining, to help prevent accidents such as occurred in July 2002 at the Quecreek Mine in Pennsylvania. Other complementary projects, which could benefit from geophysics, include detecting potentially adverse geologic conditions, and detecting cracks and voids in the mine roof. Geophysical techniques are presently used to some extent, but their effectiveness is not well documented.

To promote the use of geophysical, and other remote sensing techniques, the following actions have been taken by MSHA, OSM, and the States:

- Symposium on Geophysical Methods: MSHA sponsored and organized a one-day symposium on “Geotechnical Methods for Mine Mapping Verification” which was held in Charleston, WV, on October 29, 2002. Vendors displayed some of the latest geophysical technologies. Industry experts, academia, and Federal and State government representatives (including West Virginia, Pennsylvania, Virginia, and Kentucky) made presentations on mine mapping and the use of geophysical

methods. Nearly 300 representatives of the mining industry attended the symposium. The agenda for this symposium, and a listing of the presentations, is provided in Appendix F.

- Interactive Forum on Geophysical Methods: OSM and MSHA have organized an “Interactive Forum on Geophysical Technologies for Detecting Underground Coal Mine Voids” which was held July 29-30, 2003, in Lexington, Kentucky. The forum is intended to encourage technology transfer and provide case studies on the use of geophysical technologies to identify coal mine voids for consideration in siting and constructing coal mine waste impoundments. Administrative support for the forum was contracted with the University of Kentucky’s College of Engineering. Listings of the agenda, and the members of the steering committee, for the interactive forum are included in Appendix G.
- Geophysical Demonstration Projects: Congress had appropriated funds to MSHA for the dual purpose of digitizing mine maps and for funding projects to demonstrate the use of geophysical methods for void detection. MSHA published a solicitation notice on May 8, 2003. Contract awardees will be required to demonstrate their proposed technology at a coal mine and to document the results. The results of all projects will be shared with the mining industry. A copy of the solicitation is included in Appendix H.
- National Energy Technology Laboratory Project: The Department of Energy’s National Energy Technology Laboratory (NETL), the State of Virginia, and OSM are conducting a project to evaluate the combined application of airborne and ground-based geophysical technologies and geographical information system (GIS) technology as tools for delineating underground coal mine workings, mapping groundwater flow paths, and targeting potential impoundment failures. In collaboration with the State of Virginia, a small demonstration site (approximately 10 square miles) was selected in Wise County, Virginia. Results of the study will be made available to the industry through written publications at appropriate conferences.

VI. Chemical Properties of Coal Waste

The NRC report included the following recommendation involving the environmental impact of coal waste:

“The committee recommends that research be performed to identify the chemical constituents contained in the liquid and solid fractions of coal waste, and to characterize the hydrogeologic conditions around impoundments.” (See Page 173 of the NRC report).

Response: OSM and MSHA agree that these are important areas of research. Neither agency has the resources to undertake these projects at this time. Further, the recent industry practices in coal processing have been changing (e.g., the move away from diesel fuel as a reagent in coal flotation) and there are new chemicals being introduced regularly. We believe that universities and other agencies may have the knowledge of the field, and that funding is needed to investigate the composition of past and present coal slurry impoundments. We believe that research on the chemical properties of coal waste would best be conducted by the Environmental Protection Agency (EPA) or the Department of Energy (DOE). The NRC report discusses the EPA’s involvement through the Clean Water Act.

As to hydrogeologic conditions around impoundments, some site-specific investigations are required as an integral part of hydrologic analyses for SMCRA permitting. However the long-term changes to local hydrogeology from older fills should be investigated.

VII. Alternative Methods of Coal Waste Disposal

Concerning alternative methods for the disposal of coal mine waste, the NRC report contains the following recommendations:

- *“The committee recommends that a screening study be conducted that:*
 1. *Establishes ranges of costs applicable to alternative disposal options;*
 2. *Identifies best candidates for demonstration of alternative technologies for coal waste impoundments, and*
 3. *Identifies specific technologies for which research is warranted.*

Input from MSHA and OSM regarding regulatory issues will be valuable to such a study.” (See Page 170 of the NRC report.)

- *“The committee recommends that the total system of mining, preparation, transportation, and utilization of coal and the associated environmental and economic issues, be studied in a comprehensive manner to identify the appropriate technologies for each component that will eliminate or reduce the need for slurry impoundments while optimizing the performance objectives of the system.”* (Page 169 of NRC report.)
- *“The committee recommends incorporating life-cycle assessment of the costs and environmental impacts of the alternatives to evaluate them on a more objective, comprehensive basis. In addition, a detailed analysis of the economic and environmental impact of the various policy alternatives should be performed.”* (Page 169 of NRC report.)
- *“The committee recommends that the use of economic incentives be explored as a way of encouraging the development and implementation of alternatives to slurry impoundments.”* (Page 170 of NRC report.)

The NRC report does not address overburden fill material from mountaintop mining.

Response: OSM and MSHA agree that these recommendations are worthwhile endeavors. Determining costs and identifying research alternatives are outside of their statutory and regulatory mandates. However, both agencies would appreciate the opportunity to add our technical expertise to these studies and to cooperate in developing a plan for investigation that incorporates the appropriate health and safety and environmental considerations.

The agencies note that in the 1970s, various methods for de-watering fine coal waste – to eliminate the need for impoundments - were attempted. Instead of pumping slurry into an impoundment, the idea was to de-water the fines and mix them with coarse coal refuse so that the “combined” waste product could be disposed of as a compacted fill. The de-watering efforts generally resulted in a “combined” material that was difficult to handle and compact because of its high water content. There also were economic issues with providing sufficient de-watering capacity to keep up with increasing coal production rates. Due to these problems, the issue wasn’t resolved and there was a general move back to impoundments.

One coal waste disposal alternative that MSHA, OSM, and the States are exploring is pumping fine coal waste back into underground mine workings. SMCRA requires approval by OSM, with concurrence by MSHA, of mine operator’s plans to discharge slurry, water, or other coal mining waste into active, inactive, or abandoned underground mine workings. The plans are reviewed to ensure that they adequately address the health and safety of coal miners. Procedure Instruction Letter (PIL) No. I03-V-4, dated April 11, 2003, extends the responsibility for MSHA’s concurrence with such plans to the District Managers. We would also note that the NRC Board on Earth Resources held a meeting in November 2002, to discuss the need for coal mining research and make recommendations. The areas identified in these recommendations are ones that are in need of new research that in the past may have been studied by the now-defunct Bureau of Mines. We believe any follow up studies conducted by the NRC, based on the input it received in that meeting, should consider the appropriate Federal entity and funding mechanism for addressing these types of research needs, including the necessary cost-benefit analyses for possible new economic incentives.

The NRC’s recommendation for a study to identify technologies that will eliminate or reduce the need for slurry impoundments would best be done by universities or by the DOE. Examining the costs of alternatives would best be done by the mining industry itself, or mining organizations. The environmental impacts of alternative methods of waste disposal could be evaluated by universities or the EPA. Exploring economic incentives to encourage the development of alternatives would best be done by university research or the DOE, or perhaps within the mining industry program in the Office of Industrial Technologies in Industries of the Future.

Summary of Actions Taken by MSHA and OSM Since the October 2000 Martin County Coal Corporation Breakthrough Incident

Actions Taken by MSHA: Following the slurry release at the Big Branch Slurry Impoundment of Martin County Coal Company, the Mine Safety and Health Administration took the following actions to help prevent a similar occurrence at other facilities.

- The Agency issued a directive that all sites classified as having a high potential for a breakthrough were to be immediately inspected to collect field data needed to assess each site's actual breakthrough potential. Eventually, all sites that had any potential for a breakthrough were inspected. Over 330 individual sites were inspected with many sites receiving multiple inspections. District personnel conducted these inspections with assistance from the Agency's Technical Support office. After the sites were inspected and it was deemed necessary, additional plans were requested and the plans were evaluated. Corrective actions were taken at sites while others were abandoned or converted into non-impounding structures.
- The Agency issued a directive that all coal enforcement offices were immediately to contact owners of sites classified as having high breakthrough potential to request a study to assess the site's actual breakthrough potential. A plan was to be submitted addressing the safety issues and providing remedies to prevent a breakthrough.
- The Agency decided that all plans submitted pertaining to the breakthrough potential for impoundments would be evaluated by engineers from the Agency's Technical Support office. Technical Support engineers were sent directly to several enforcement offices to conduct site evaluations and plan reviews.
- The Agency conducted an internal review of its entire impoundment safety program. The review panel was composed of high-level managers and engineers from various branches of the Agency. All aspects of the impoundment plan review and inspection program were evaluated. The results are contained in "Internal Review of MSHA's Actions At the Big Branch Refuse Impoundment, Martin County Coal Corporation, Inez, Martin County, Kentucky," dated January 21, 2003.
- The Agency developed training programs to ensure that all personnel involved in evaluating the potential for impoundment breakthroughs are properly trained, and that this issue is emphasized during reviews of impoundment plans. Training was conducted during annual Impoundment Specialist retraining seminars held at the National Mine Health and Safety Academy.

- The Agency formed a committee to evaluate and update the “Coal Mine Impoundment Inspection Procedures” handbook used by enforcement personnel. The revised handbook will address breakthrough potential issues in greater detail and will provide for more uniform procedures with respect to impoundment inspections and plan reviews. The deadline for preparation of the revised handbook is March 2004.
- MSHA identified the preparation of a fully updated “Engineering and Design Manual for Coal Refuse Disposal Facilities” as an important element in preventing future breakthrough incidents, as well as other types of impoundment failures. MSHA is currently seeking sources of funding for this effort, which is expected to cost several hundred thousand dollars.

OSM Actions: Following the Big Branch slurry impoundment breakthrough in October 2000, OSM developed a strategy to prevent leaks from impoundments into underground mines. This strategy includes a major initiative to assess and mitigate the potential for impounded water, slurry, water treatment sludge, coal combustion byproducts or other materials to drain in an uncontrolled manner into subjacent or underground mines. Because the geologic setting for having impoundments in proximity to underground mines is more common in the eastern U.S., OSM’s Appalachian Region was the primary location for these activities. OSM field offices and the Appalachian Regional Coordinating Center in Pittsburgh worked with the State regulatory authorities to evaluate impoundments within the States.

Background: OSM, working with the State of Virginia during 1997, developed draft guidelines to provide a basic framework for regulatory authorities to use for independent and timely reviews of structures. The Virginia Division of Mined Land Reclamation (VADMLR) developed a checklist incorporating elements of the guidelines and evaluated 24 impoundments. Permit revisions and remedial work were required where high potential for leaks was evident. OSM also provided technical assistance to VADMLR in the review of these remedial plans. OSM provided the guidelines used in Virginia to other Appalachian Region States. Moreover, OSM provided to all States the December 1, 1997, MSHA Procedure Instruction Letter (PIL) for classification of leak potential and subsequent impacts which was issued as a result MSHA’s initiative to classify the breakthrough potential of impoundments following the 1996 incidents in Virginia. OSM believes other regulatory authorities have initiated various other types of reviews for which procedures may be available for consideration. This accumulated data and experience will be used for re-evaluating the safety of all impoundments associated with underlying or adjacent mine workings.

OSM will take the following actions in Federal program States as well as primacy States. In primacy States, OSM will work with the States through oversight and technical assistance to address the following topics:

- OSM will coordinate with MSHA and the regulatory authorities to determine priorities for technical review and minimize duplication of effort.
- OSM will work with the States to ensure the maintenance of an inventory of existing permitted impoundments containing 20 acre-feet or more of storage, and the identification of those known to be within 500 feet of underground mines. OSM will issue basic guidelines to assist regulatory authorities in completing this initiative, i.e., reviewing existing and proposed impoundments for breakthrough potential and catastrophic discharge potential.
- OSM will continue to evaluate the implementation of State program requirements for design, construction, and operation of impoundments to ensure the approved State program is no less effective than the Federal regulations.
- OSM will assess the procedures used by regulatory authorities (RA) for the requisite approval of surface mining activities within 500 feet of underground mine works (per State analogs to 30 CFR 816.79) and for the evaluation of the foundation of disposal facilities (per State analogs to 30 CFR 816.81(d)).
- OSM and the States will assess the potential threat and impact on the downstream life, property, and environment that exist from an impoundment breakthrough. The oversight of RA review and approval of impoundments will determine whether independent technical reviews were completed to fulfill SMCRA responsibilities, and the degree to which the RA relied on MSHA evaluations and approvals of the impoundment. A collaborative effort will be conducted to review the various guidelines, PILs, checklists, and to expand them as necessary to provide more-detailed information on what should be included/considered in assessing breakthrough potential as well as remedial measures which may be taken to prevent breakthroughs. In cases where the potential for failure exists, the RA may require permit revisions and remedial actions. Examples of technical reviews include: evaluating methods to verify the extent of mine workings through drilling, geophysical, mapping or other techniques; evaluating the types of analyses that are useful in assessing the permeability and effectiveness of seals and barriers; evaluating methods to determine mine roof, floor, pillar, and outcrop stability; evaluating the effectiveness of using Surface Deformation Prediction System (SDPS) analyses; and evaluating the benefit of considering hydrostatic pressure on subsidence or natural fractures connecting the mine and surface.
- OSM will evaluate the adequacy of information used by the RA in making engineering judgments on the impoundment foundation (e.g., existence and accuracy of maps of underground works, etc.). If disposal facility foundation

characterization and breakthrough potential reviews have not been routinely conducted as a part of the permitting process, RAs should undertake review initiatives as soon as possible. The RAs should draw on the expertise of other States, MSHA, and OSM to ensure that impoundments do not present a hazard to the health and safety of the general public and the environment, as well as to the coal miners.

This approach will ensure development of specific permit information requirements and evaluation procedures that companies must address for all States where underground workings are near proposed impoundments.

IX. Conclusions

Recent breakthrough incidents, especially the one at Big Branch Impoundment near Inez, Kentucky, on October 11, 2000, have made impoundment designers and regulators re-evaluate, and place additional emphasis on, the issue of breakthrough potential. MSHA, OSM, and the State have considered the recommendations provided in the NRC report, and have re-evaluated their programs with respect to the prevention of breakthrough incidents. This re-evaluation has led to the following conclusions.

Administrative Issues:

- MSHA and OSM recognize that a comprehensive impoundment safety program requires both thorough plan reviews and effective field inspections. MSHA is committed to providing sufficient staff, based on the results of on-going evaluations, to both perform sufficient impoundment inspections and review submitted impoundment plans in a reasonable time.
- OSM, MSHA and the States have developed a model Memorandum of Understanding (MOU) to improve coordination and sharing of information between MSHA and State regulatory authorities. MOUs are in place between MSHA and the States of West Virginia, Virginia, and Kentucky. MSHA, OSM, and the States will continue to work together to improve coordination.

Technical Review Issues:

- MSHA, OSM, and the States are placing increased emphasis on breakthrough potential in reviews of impoundment plans. To assist in this effort, a report entitled "Guidance for Evaluating the Potential for Breakthroughs from Impoundments into Mine Workings and Breakthrough Potential Measures" was prepared. This report explains each way that a breakthrough can occur and advises reviewers on how to take adequate prevention measures.
- MSHA, OSM, and the States will continue to reduce the risk of breakthroughs by ensuring, during the review process, that plans or permits include the following:
 - Identification of all reasonable potential-breakthrough failure modes;
 - Adequate documentation of the conditions and engineering properties used in failure mode identification and analysis;
 - Appropriate engineering analysis of each potential-failure mode to determine the margin of safety;

- Detailed engineering plans for any measures needed to reduce the risk of a breakthrough to acceptable levels;
 - Provisions for monitoring key parameters related to the potential failure modes, so that action can be taken in the event the facility does not perform as expected;
 - Provisions for inspections and certifications of facilities by qualified personnel, so that indications of potential problems are recognized and evaluated at early stages; and,
 - Provisions for emergency action in the event a problem develops.
- MSHA and OSM agree with the NRC recommendation that they need to continue to promote the best available technology and practice in impoundment design and construction. The best way to accomplish this goal is to update the “Engineering and Design Manual: Coal Waste Disposal Facilities.” This manual was published in 1975 following the Buffalo Creek failure. Several critical components of the design and operation of a coal waste impoundment, such as breakthrough potential, are not covered by the current manual. The agencies are attempting to locate funding (the cost will likely be several hundred thousand dollars) to have a qualified geotechnical-engineering firm to update the manual. Consistent use of the best available technology and practices would help expedite the review and approval process and assist all parties in carrying out their responsibilities to ensure that the impoundments constructed by the coal mining industry are safe.
- As recommended by the NRC report, MSHA uses a single system to assign both embankment and basins to hazard potential categories. The system is consistent with the system promoted by the Interagency Committee on Dam Safety (ICODS) and the Federal Guidelines for Dam Safety. The breakthrough-potential-rating system was used on a one-time basis, simply to prioritize the review of breakthrough evaluation plans.
- As recommended by the NRC report, MSHA, OSM, and the States are in the process of re-evaluating all sites with a significant risk of breakthrough potential. Where the information, or the proposed measures, was not considered adequate, MSHA, OSM, and the States have worked with the coal companies, on a site-by-site basis, to get mitigation measures implemented to reduce the risk to an acceptable level.
- MSHA, OSM, and the States are placing increased emphasis during plan reviews on ensuring that sites with breakthrough potential have appropriate monitoring provisions. The goal is to determine critical parameters, such as seepage or piezometric levels, for the potential failure modes and then monitor those parameters to check whether the plan is performing as intended.

Mine Surveying and Mapping Issues:

- MSHA and OSM are working with the States on new initiatives to improve the collection, digitizing, and archiving of underground mine maps. MSHA received additional funding in its FY 2003 appropriation to begin this process. OSM is continuing to survey the State regulatory authorities and State geological surveys to find out what mine map information is available and what uses there are or may be for that information. The efforts of MSHA, OSM, and the States are being coordinated to ensure that they are complimentary and that the resulting products can be integrated. In addition, OSM's National Mine Map Repository (NMMR) will continue to implement its five-year plan, which includes improving coordination with States on the development of a national electronic database of mine maps.
- The agencies find that current mine surveying practices include many of the recommendations included in the NRC report. MSHA will use existing authority and will work with State agencies to adopt appropriate policy interpretations that will help ensure accurate surveys. In addition, MSHA has an internal committee looking into surveying practices near flooded workings.
- The agencies find that aerial topographic measurements are only one way to attempt to locate coal outcrops. Accurate land surveys and the use of accurate topographic maps are other acceptable ways of locating the coal outcrop. The agencies recommend that surface topographic surveys along the coal outcrop, should be done by the coal companies as part of a permit submittal. The surveys should be tied to either the United States Geological Survey or the United States Coast and Geodetic Survey bench mark system that are used for the underground mine surveys. By using common bench marks for the surface and underground surveys appropriate vertical and horizontal control can be ensured.
- The agencies believe that the use of either the North American Datum (NAD) 27 or NAD 83 plane coordinates (which serve as the bases for State plane coordinates) and the NAVD 88 for mine elevations is appropriate. MSHA will use existing authority and will work with State agencies to adopt appropriate policy interpretations that will help ensure accurate surveys and representations of locations on mine maps.
- The agencies believe that mine surveys should be based on the NAD 83 and that the map documentation should show how the coordinates were transformed, including details of the software used or the detailed methodology employed. Listing transformation equations is not considered necessary since only two methods exist. The agencies believe simply identifying which of these methods was employed is sufficient. However, if another methodology is used, full documentation should be provided.

- The agencies believe that the use of either the North American Datum (NAD) 27 or NAD 83 plane coordinates (which serve as the bases for State plane coordinates) and the NAVD 88 for mine elevations is appropriate. MSHA will use existing authority and will work with State agencies to adopt appropriate policy interpretations that will help ensure accurate surveys and representations of locations on mine maps.
- The agencies believe that mine surveys should be based on the NAD 83 and that the map documentation should show how the coordinates were transformed, including details of the software used or the detailed methodology employed. Listing transformation equations is not considered necessary since only two methods exist. The agencies believe simply identifying which of these methods was employed is sufficient. However, if another methodology is used, full documentation should be provided.
- The agencies believe that two permanent survey monuments should be established on areas of the mine property that will not be disturbed. The agencies believe that current practices are compatible with this recommendation. MSHA will use existing authority and will work with State agencies to adopt appropriate policy interpretations that will assure accurate surveys.

Use of Geophysical Methods to Locate Mine Workings:

- The agencies agree that more needs to be done to disseminate information to the mining industry on the potential uses of geophysical methods for mine void detection. MSHA sponsored a one-day symposium on Geotechnical Methods for Mine Mapping Verification in Charleston, West Virginia. OSM and MSHA are jointly sponsoring a forum on geophysical technologies in July 2003, in Lexington, Kentucky.
- The agencies agree on the benefits of demonstrating the uses of geophysical methods to the coal mining industry and documenting the results of such demonstrations. Congress has allocated funds to MSHA for this purpose. MSHA has solicited proposals for the demonstration of void detection technology.

As indicated above, a number of actions have been taken within MSHA, OSM, and the States, and additional evaluations are ongoing, with respect to the prevention of breakthrough incidents. MSHA, OSM, and the States recognize that additional emphasis must be placed on ensuring that the impoundments constructed by the mining industry do not present a hazard to miners, the public, or the environment, from breaking into underground mine workings.

Appendix A

Committee and Work-Group Members

Steering Committee

Kelvin K. Wu, Ph.D., PE	Chief, Mine Waste and Geotechnical Engineering Division, Pittsburgh Technical Support, MSHA Dam Safety Officer, Department of Labor
John R. Craynon, PE	Chief, Division of Technical Support, Office of Surface Mining, Washington, DC

Work Group on Administrative Issues

Bill Kovacic	Work-Group Chairman Field Office Director, Office of Surface Mining, Lexington, KY
Roger Schmidt	Safety Division, Coal Mine Safety and Health, MSHA, Arlington, VA
Donald Kirkwood, PE	Supervisory Civil Engineer, Mine Waste and Geotechnical Engineering Division, Pittsburgh Technical Support, MSHA
Allen Luttrell	Deputy Commissioner, Department for Surface Mining Reclamation and Enforcement, Kentucky
Charlie Sturey	Manager of Program Development, West Virginia Department of Environmental Protection
William Plassio	District Mining Manager, McMurray District Mining Office, PA Department of Environmental Protection
Daniel Ross	Surface Mining Reclamation Specialist, Office of Surface Mining, Lexington, KY

Work Group on Technical Review Issues

John W. Fredland, PE	Work-Group Chairman Civil Engineer, Mine Waste and Geotechnical Engineering Division, Pittsburgh Technical Support, MSHA
Harold L. Owens, PE	Supervisory Civil Engineer, Coal Mine Safety and Health, District 4, MSHA, Mt. Hope, WV
Terence M. Taylor, PE	Senior Civil Engineer, Mine Waste and Geotechnical Engineering Division, Pittsburgh Technical Support, MSHA
Lawrence J. Trainor, P.E.	Mine Engineer, Division of Technical Support, Office of Surface Mining, Washington, DC
Donald E. Stump, P.E.	Civil Engineer, Office of Surface Mining, Greentree, PA
Michael Rosenthal	Mining Engineer, Office of Surface Mining, Denver, CO
Gary Gilliam	Mining Engineer, Kentucky Department for Surface Mining Reclamation and Enforcement
Charlie Sturey,	Manager of Program Development, West Virginia Department of Environmental Protection, Nitro, WV
Gerald D. Collins, P.E.	Technical Services Manager, Division of Mined Land Reclamation, Virginia Department of Mines, Minerals and Energy
Joel Koricich, P.E.	Engineer Supervisor, Pennsylvania Department of Environmental Protection

Work Group on Mine Maps and Mine Surveying Issues

Buck Miller	Work-Group Chairman Director, Knoxville Field Office, Office of Surface Mining, Knoxville, TN
Stan Michalek, P.E.	Supervisory Civil Engineer, Mine Waste and Geotechnical Engineering Division, Pittsburgh Technical Support, MSHA
Charles Grace, P.E., P.L.S.	Assistant District Manager, MSHA, Coal Mine Safety and Health District 7, Barbourville, KY
Darren Blank, P.E.	Civil Engineer, Mine Waste and Geotechnical Engineering Division, Pittsburgh Technical Support, MSHA
Tim Dieringer	Chief, Division of Federal Reclamation Program, Appalachian Regional Coordinating Center, Pittsburgh, PA
Donald Stump, P.E.	Civil Engineer, Office of Surface Mining, Greentree, PA
Greig Robertson	Program Specialist, Division of Federal Reclamation Program, Appalachian Regional Coordinating Center, Pittsburgh, PA
Pam Carew, P.G.	Environmental Scientist, Department for Surface Mining Reclamation and Enforcement, Frankfort, KY
Dalip Sarin	Department of Environmental Protection, Nitro, West Virginia
Bill Bookshar, P.E.	Chief, Engineering Services, Pennsylvania Bureau of Deep Mine Safety
Les Vincent, P.E.	Customer Services Unit Manager, Virginia Department of Mines, Minerals and Energy

Work Group on Geophysical Methods

Bill Kovacic	Work-Group Chairman Director, Lexington Field Office, Office of Surface Mining, Lexington, KY
George Gardner, P.E.	Senior Civil Engineer, Mine Waste and Geotechnical Engineering Division, Pittsburgh Technical Support, MSHA
Hank Bellamy	Mining Engineer, Coal Mine Safety and Health District 6, MSHA, Pikeville, KY
Alice Perry	Mining Engineer, Office of Surface Mining, Lexington Field Office, Lexington, KY

Work Group on Chemical Properties of Coal Waste

John R. Craynon, P.E.	Chief, Division of Technical Support, Office of Surface Mining, Washington, DC
-----------------------	--

Work Group on Alternative Coal Waste Disposal Methods

John R. Craynon, P.E.	Chief, Division of Technical Support, Office of Surface Mining, Washington, DC
Kelvin K. Wu, Ph.D., P.E.	Chief, Mine Waste and Geotechnical Engineering Division, Pittsburgh Technical Support, MSHA Dam Safety Officer, Department of Labor

APPENDIX B.

**Existing Memoranda of Understanding
Between MSHA and the States of
Virginia, West Virginia, and Kentucky
Concerning Impoundment Plan Reviews**

MEMORANDUM OF UNDERSTANDING
Between the
KENTUCKY NATURAL RESOURCES AND ENVIRONMENTAL PROTECTION CABINET
DEPARTMENT FOR SURFACE MINING RECLAMATION AND ENFORCEMENT
and the
UNITED STATES DEPARTMENT OF LABOR
MINE SAFETY AND HEALTH ADMINISTRATION
DISTRICT 6 (PIKEVILLE), DISTRICT 7 (BARBOURVILLE) & DISTRICT 10 (MADISONVILLE)

I. Introduction

This Memorandum of Understanding relates to federal and state review and approval of the design and construction of coal refuse piles and impoundments at coal mining and processing operations in Kentucky.

The U. S. Mine Safety and Health Administration (MSHA) has jurisdiction over coal refuse piles and impoundments under the federal Coal Mine Health and Safety Act of 1969 and federal regulations at 30 CFR Part 77.214-217. The Kentucky Department for Surface Mining Reclamation and Enforcement (DSMRE) has jurisdiction over coal refuse piles and impoundments under KRS Chapter 350 and administrative regulations at 405 KAR Chapters 7-24. These jurisdictions overlap each other under the federal Surface Mining Control and Reclamation Act of 1977 and implementing regulations at 30 CFR Parts 780.25, 784.16, 816.79-87 and 817.81-87.

II. Purposes

The purposes of this Memorandum of Understanding are:

- A. To improve communication and the coordination of review of coal refuse piles and impoundments by MSHA and DSMRE
- B. To minimize duplication of review efforts
- C. To reduce the potential for conflicting review determinations
- D. To provide certainty and consistency to those applicants who must obtain the approval of both agencies

III. Procedures

MSHA shall provide the following:

- A. After a plan for a coal refuse pile or impoundment has been approved by MSHA, the MSHA District Manager will provide copies of the location acknowledgment letters, plan review letters, and plan approval letters, to the Director of DSMRE's Division of Permits (DSMRE Permits Director) or his authorized representatives.

DSMRE shall require and provide the following:

- A. Once the applicant receives plan approval from MSHA, it will be the applicant's responsibility to submit to DSMRE a copy of the final approved plan and the plan review letters by MSHA (including all the extra technical support documents which were requested by MSHA during their review process) with a certified letter from the applicant indicating that "This is a copy of the final approved plan by MSHA containing a description of the material reviewed by MSHA."
- B. After the final MSHA approved plan and its attachments are received from the applicant, DSMRE will include them as part of the permit application, and then, DSMRE will do its review responsibilities which are not covered by 30 CFR.

IV. Understanding

The following is understood by both parties:

- A. The coal mine waste dams and embankments shall be designed to comply with the requirements of MSHA, 30 CFR 77.216-1 and 77.216-2.
- B. If a citation issued by MSHA will require a plan change, then MSHA will send DSMRE a copy of the violation.

V. Effective Date

This Memorandum of Understanding shall take effect on 12-11-99 and shall remain in effect until modified or terminated.

VI. Deviations

This Memorandum of Understanding may be modified at any time by joint agreement of the parties hereto.

This Memorandum of Understanding may be terminated at any time by joint agreement of the parties hereto, or by any party upon giving the other parties thirty (30) days written notice.

Carl E. Campbell 12/11/97
Carl E. Campbell, Commissioner (date)
Department for Surface Mining
Reclamation and Enforcement

Carl E. Boone II 12-2-97
Carl E. Boone, II, Dist. Manager (date)
MSHA District 6 (Pikeville)

Joseph W. Pavlovich 12-2-97
Joseph W. Pavlovich, Dist. Manager (date)
MSHA District 7 (Barbourville)

Paul D. DeHart for Rexford Music
Rexford Music, Dist. Manager (date) 12-2-97
MSHA District 10 (Madisonville)

MEMORANDUM OF UNDERSTANDING
VIRGINIA DEPARTMENT OF MINES, MINERALS AND ENERGY
DIVISION OF MINED LAND RECLAMATION

NSN 7540-01-317-7268 5099-101 GENERAL SERVICES ADMINISTRATION

and the

UNITED STATES DEPARTMENT OF LABOR
MINE SAFETY AND HEALTH ADMINISTRATION
DISTRICT 5 NORTON, VIRGINIA

I. Introduction

This Memorandum of Understanding addresses federal and state review and approval of the design and construction of coal refuse piles and impoundments at coal mining and processing operations in Virginia.

The U.S. Mine Safety and Health Administration (MSHA) has jurisdiction over coal refuse piles and impoundments under the federal Coal Mine Safety and Health Act of 1969 and federal regulations, 30 CFR, Part 77.214-217. The Division of Mined Land Reclamation (DMLR) of the Virginia Department of Mines, Minerals and Energy (DMME) has jurisdiction over coal refuse piles and impoundments under 4 VAC 25-130-700.1 et seq. These jurisdictions overlap each other under the federal Surface Mining Control and Reclamation Act of 1977 and implementing regulations at 30 CFR, Parts 780.25, 784.16, 816.79-87 and 817.81-87.

II. Purposes

The purposes of this Memorandum of Understanding are:

- A. To improve communication and the coordination of the review process of coal refuse piles and impoundments by MSHA and DMLR;
- B. To minimize duplication of review efforts;
- C. To reduce the potential for conflicting review determinations; and
- D. To provide certainty and consistency of those applicants who must obtain the approval from both agencies

III. Procedures

MSHA shall provide the following:

A. After a plan for a coal refuse pile or impoundment has been approved by MSHA, the MSHA District Manager will provide copies of the location acknowledgment letters, ~~plan~~ ^{NET} review letters, and plan approval letters, to the Director of DMLR or his Authorized Representatives. ^{Deputy}

^{DMML} DMLR shall require and provide the following:

- A. Once the ^{DMME} applicant receives plan approval from MSHA, it will be the applicant's responsibility to submit to DMLR a copy of the final approved plan and the plan review letters by MSHA (including all the extra technical support documents which were requested by MSHA during their review process) with a certified letter from the applicant indicating that "This is a copy of the final approved plan by MSHA containing a description of the material reviewed by MSHA."
- B. After the final MSHA approved plan and its attachments are received from the applicant, DMLR will include them as part of the permit application, and then, DMLR will do its review responsibilities which are not covered by 30 CFR.
- C.

IV. Understanding

The following is understood by both parties:

- A. MSHA will review only plans for coal refuse piles and impoundments submitted for approval in compliance with 30 CFR, Part 77.214-217;
- B. The coal mine waste dams and embankments shall be designed to comply with the requirements of MSHA, 30 CFR, 77.216-1 and 77.216-2,
- C. If a citation issued by MSHA requires a plan change, MSHA will send DMLR a copy of the citation.
- D. If a citation issued by DMLR requires a plan change, DMLR will send MSHA a copy of the citation.

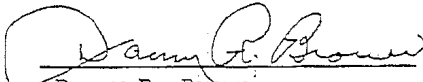
V. Effective Date

This Memorandum of Understanding shall take effect on October 1, 1998 and shall remain in effect until modified or terminated.

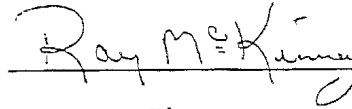
VI. Deviations

This Memorandum of Understanding may be modified at any time by joint agreement of the parties hereto.

This Memorandum of Understanding may be terminated at any time by joint agreement of the parties hereto, or by any party upon giving the other parties thirty (30) days written notice.



Danny R. Brown
Director Division of Mined
Land Reclamation



Ray McKinney
District Manager

10/01/98

Date

10/1/98


Date

WMJ:mc

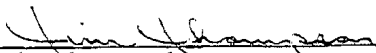
MEMORANDUM OF UNDERSTANDING
BETWEEN THE
WEST VIRGINIA DIVISION OF ENVIRONMENTAL PROTECTION
AND THE
MINE SAFETY AND HEALTH ADMINISTRATION
DISTRICT 3

This Memorandum of Understanding defines procedures to be used to facilitate communication between the West Virginia Division of Environmental Protection (WVDEP) and the Mine Safety and Health Administration (MSHA), District 3, concerning implementation of the Coal Refuse Disposal provisions of Article 1, Chapter 22, and Article 3, Chapter 22, of the Code of West Virginia; Title 38, Series 2, Section 22, of the West Virginia Surface Mining and Reclamation Regulations; and 30 CFR 77.214 through 77.217.

1. The Director, West Virginia Division of Environmental Protection or his authorized representative, will provide the District Manager, MSHA District 3, with copies of WVDEP plan review comments, plan modifications comments, Certificates of Approval, and bond releases for refuse piles and impoundments.
2. The District Manager, MSHA District 3, will provide the Director, WVDEP or his authorized representative, with copies of refuse pile and impoundment location acknowledgement letters, plan approval letters, plan review letters, plan approval letters, plan modification approval letters, and site abandonment letters.
3. Inspectors and engineers from WVDEP, Office of Mining and Reclamation and MSHA District 3 will communicate with each other and coordinate the resolution of conflicts and problems concerning approved plans, permits and conditions which have an adverse impact on safety.
4. This Memorandum may be terminated at any time by the joint agreement of the parties hereto, or by either party upon giving the other party written notice.

 1/20/95

David C. Callaghan
Director
WV Division of Environmental Protection

 2/3/95

Timothy J. Thompson
District Manager, District 3
Mine Safety and Health Administration

MEMORANDUM OF UNDERSTANDING
BETWEEN THE
WEST VIRGINIA DIVISION OF ENVIRONMENTAL PROTECTION
AND THE
MINE SAFETY AND HEALTH ADMINISTRATION
DISTRICT 4

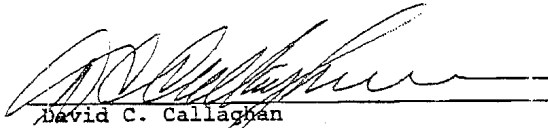
RECEIVED
Headquarters OMR

JAN 13 1995


Permitting

This Memorandum of Understanding defines procedures to be used to facilitate communication between the West Virginia Division of Environmental Protection (WVDEP) and the Mine Safety and Health Administration (MSHA), District 4, concerning implementation of the Coal Refuse Disposal provisions of Article 1, Chapter 22, and Article 3, Chapter 22, of the Code of West Virginia; Title 38, Series 2, Section 22, of the West Virginia Surface Mining and Reclamation Regulations; and 30 CFR 77.214 through 77.217.

1. The director, WVDEP or his authorized representative, will provide the District Manager, MSHA District 4, with copies of WVDEP plan review comments, Certificates of Approval, and bond releases for refuse piles and impoundments.
2. The District Manager, MSHA District 4, will provide the Director, WVDEP or his authorized representative, with copies of refuse pile and impoundment location acknowledgment letters, plan review letters, plan approval letters, and site abandonment letters.
3. Inspectors and engineers from WVDEP, Office of Mining and Reclamation and MSHA District 4 will communicate with each other and coordinate the resolution of conflicts and problems concerning approved plans, permits and conditions which could have an adverse impact on safety.
4. This Memorandum may be terminated at any time by the joint agreement of the parties hereto, or by either party upon giving the other party ninety (90) days written notice.



David C. Callaghan
Director
WV Division of Environmental Protection



Michael Lawless
District Manager, District 4
Mine Safety and Health Administration

APPENDIX C

Model Memorandum of Understanding

Between MSHA and the States

FRAMEWORK FOR A MOU BETWEEN MSHA AND STATES
DRAFT - 11/05/02

(Note that a final MOU with MSHA requires Department of Labor clearance.)

MEMORANDUM OF UNDERSTANDING

Between the

INSERT STATE MINING AUTHORITY NAME

And the

UNITED STATES DEPARTMENT OF LABOR
MINE SAFETY AND HEALTH ADMINISTRATION (MSHA)
INSERT APPROPRIATE DISTRICT NUMBER

INTRODUCTION

This Memorandum of Understanding (MOU) addresses federal and state review and approval of the design and construction of coal refuse impoundments at coal mining and processing operations in **INSERT STATE NAME**, and outlines procedures for joint inspections of these facilities between the respective agencies.

The US Mine Safety and Health Administration (MSHA) has jurisdiction over coal refuse impoundments under the Federal Mine Safety and Health Act of 1977, and federal regulations at 30 CFR, Part 77.214 through .217.

The **INSERT STATE NAME** has jurisdiction over coal refuse impoundments under **INSERT STATE LAW AND REGS**. These jurisdictions overlap under the Federal Surface Mining Control and Reclamation Act of 1977, and implementing federal regulations at 30 CFR, Parts 780.25, 784.16, 816.79-87 and 817.81-87.

PURPOSE

The purposes of this Memorandum of Understanding are:

- A. To improve communication and coordination of the review and inspection process of coal refuse piles and impoundments by MSHA and **INSERT STATE NAME**;
- B. To minimize duplication of the review efforts;
- C. To identify and share Coal Companies' future abandonment plans;

- D. To present, provide and participate in training opportunities
- E. To reduce the potential for conflicting standards and procedures during plan reviews and site inspections; and
- F. To provide understandable and consistently enforced standards for those applicants being regulated by both agencies.

III. PROCEDURE

MSHA shall provide the following:

After a plan for a coal refuse impoundment has been submitted to MSHA by a coal company, the District Manager will provide a copy of the location acknowledgment letter, the plan review letter, and the eventual plan approval letter to the **INSERT APPROPRIATE STATE OFFICIAL'S TITLE** or his authorized Representatives. If a coal company has submitted an abandonment plan, MSHA will provide a copy of the abandonment-plan acknowledgement letter to the **INSERT APPROPRIATE STATE OFFICIAL'S TITLE** or his authorized Representatives.

INSERT STATE NAME shall provide the following:

IDENTIFY THE PERMIT APPROVAL AND REVIEW ITEMS THAT THE STATE IS WILLING TO PROVIDE TO MSHA.

Coordination between MSHA and **INSERT STATE NAME**

An annual coordinated site evaluation (**will or may**) be conducted by MSHA and **INSERT STATE NAME**. The scheduling of site evaluations will be triggered by mutual agreement of time and site **IDENTIFY A SUITABLE TRIGGER AND WHO SHOULD BE INCLUDED IN THE INSPECTION**.

MSHA will correspond and invite **INSERT STATE NAME** personnel to annual training seminars. **INSERT STATE NAME** personnel may be requested to provide training material for the annual development of the training sessions or present case studies during the seminar.

IV. UNDERSTANDING

The following is understood by both parties:

- A. MSHA will only review plans for coal refuse piles and impoundments submitted for approval in compliance with 30 CFR, Parts 77.214 - .217.

- B. Coal mine waste impoundments and other dams on Coal Company property shall be designed to comply with the requirements of MSHA regulations 30 CFR, Parts 77.216.
- C. If a citation, issued by MSHA, requires a plan change, MSHA will notify and provide a copy of the citation to **INSERT STATE NAME**.
- D. If a citation, issued by **INSERT STATE NAME**, requires a plan change, **INSERT STATE NAME** will notify and provide a copy of the citation to MSHA.

V. EFFECTIVE DATE

This Memorandum of Understanding shall take effect on _____, and shall remain in effect until modified or terminated.

VI. DEVIATIONS

This Memorandum of Understanding may be modified at any time by joint agreement between the two regulatory authorities.

This Memorandum of Understanding may be terminated at any time by joint agreement between the two regulatory authorities, or by any one party upon giving the other party a thirty (30) day written notice.

This Memorandum of Understanding supersedes any other Memoranda of Understanding that pertain to the enforcement of the federal regulations addressed in 30 CFR, 77.214 - 77.217.

**INSERT STATE OFFICIAL'S
 NAME AND TITLE**

 MSHA District Manager (s)

 Date

 Date

APPENDIX D

**“Guidance for Evaluating the
Potential for Breakthroughs from Impoundments
Into Underground Mine Workings
And
Breakthrough Prevention Measures”**

**Guidance for Evaluating the
Potential for Breakthroughs from Impoundments into Mine Workings
and
Breakthrough Prevention Measures**

December 18, 2002
(Revised May 15, 2003)

Prepared by a Joint Work-Group with Representatives From:
Mine Safety and Health Administration, U. S. Department of Labor
Office of Surface Mining, U. S. Department of the Interior
Kentucky Department of Surface Mine Reclamation and Enforcement
Pennsylvania Department of Environmental Protection
Virginia Department of Mines, Minerals and Energy
West Virginia Department of Environmental Protection

Table of Contents

<u>Chapter</u>		<u>Page</u>
I.	Introduction and Background	3
II.	Impoundment Breakthrough History: Circumstances and Lessons.....	5
III.	Mine Blowouts.....	10
IV.	Impoundment Basins: Guidelines for Site Evaluations.....	11
	Accuracy of Mine Maps.....	11
	Coal Seam “Outcrop Line” Location.....	12
	Preliminary Investigation.....	13
	On-site reconnaissance.....	14
	Direct / Detailed Investigation.....	14
	Geophysical Methods.....	15
	Long-Hole Directional Drilling.....	15
	Conventional Drilling and Sampling.....	16
	Information Related to the Consequences of a Breakthrough.....	18
V.	Evaluation of Potential Breakthrough Failure Mechanisms.....	19
	Potential Failure Mechanisms.....	19
	Sinkholes.....	19
	Pillar Failure.....	21
	Pillar Punching, or Floor Failure.....	21
	Outcrop Barrier Failure by Shear or Punching.....	22
	Internal Erosion.....	22
	Bulkhead Failure.....	24
	Trough Subsidence and Subsidence Cracks.....	24
	Failures Related to Auger Mining.....	25
	Hillside Movement or Disturbance.....	26
	Note on Seepage Analyses.....	26
	Potential Failure Evaluations.....	26

VI.	Basin Design Measures to Prevent Breakthroughs.....	28
	Use of Safety Zones.....	28
	Mine Backfilling.....	28
	Stowing of Mine Openings in Basin Area.....	29
	Construction of Bulkheads.....	30
	Construction of Compacted Earthen Barriers on the Surface.....	30
	Conversion to Slurry Cells.....	33
	Sealing Sources of Leakage.....	34
	Stabilization of Fines.....	34
	Induced Subsidence.....	35
	Monitoring Provisions.....	37
VII.	Bulkhead Seals in Mine Entries or in Mine Openings at Coal Seam Outcrops.....	37
	Site Preparation.....	37
	Bulkhead Types.....	38
	Design Loads.....	40
	Structural Resistance.....	41
	Flexural Design of Reinforced Concrete Bulkheads.....	42
	Thick Concrete Bulkhead Plugs.....	43
	Shear Design of Reinforced Concrete Bulkheads.....	44
	Safety Monitoring Provisions.....	45
VIII.	Basin Construction, Operation and Monitoring.....	47
	Pre-Construction Planning.....	47
	Basin Construction.....	48
	Basin Operation.....	48
	Breakthrough-Potential Related Monitoring.....	49
IX.	Evaluation Approach Versus Standard for Minimum Barrier Size.....	51
	Appendix – Listing of Work Group Members.....	52

I. Introduction and Background

The construction of impoundments, for the purposes of coal waste disposal and water supply, is an integral part of most coal mining operations. However, in many coal mining areas, it is difficult to find a site for impoundment construction that has not been undermined to some extent, especially near the coal preparation plants that the impoundments serve. Thus, it is not unusual for the impoundments constructed by the coal industry to be located in the vicinity of underground mine workings.

On October 11, 2000, an accident occurred near Inez, Kentucky when over 300 million gallons of coal-waste slurry broke into an underground mine from the Big Branch Slurry Impoundment. The slurry flowed through and out of the mine and contaminated over 80 miles of creeks and rivers. This was the most notable of several incidents in recent years where slurry from coal-waste impoundments has broken into underground mine workings. These incidents have caused considerable environmental damage, and have the potential to endanger persons working in the underground mines or living in the affected areas.

When there is mining in the vicinity of an impoundment, measures need to be taken to evaluate the potential impact of the mining not only on the safety of the dam, but also on the integrity of the reservoir or basin. The dam itself forms only a small part of the reservoir containment, and to ensure the adequacy of the entire reservoir, it is necessary to locate and evaluate all possible breakthrough locations. Evaluating the potential for a breakthrough can be a difficult problem because of uncertainties with the location of the mining, and problems with characterizing and analyzing the engineering behavior of the overburden. In dealing with these conditions, the industry is often compelled to approach the threshold between safe and stable containment, and the risk of a breakthrough. Accordingly, it is important that mine operators take the necessary steps to accurately assess breakthrough potential, and provide sufficiently conservative preventive measures. (Note that the terms basin, reservoir, impoundment and pool are sometimes used interchangeably. In the context of this report, they all refer to the area in which water or slurry is impounded or contained on the surface.)

After the October, 2000 accident in Kentucky, Congress provided funding for the National Research Council (NRC) “to examine ways to reduce the potential for similar accidents in the future.” The NRC appointed a Committee on Coal Waste Impoundments which prepared a report entitled “Coal Waste Impoundments: Risks, Responses, and Alternatives.” The report, which was released in October, 2001, contains the following recommendations:

“The committee recommends that MSHA and OSM develop and promulgate guidelines for the site evaluation, design, construction, and operation of basins.”

“The committee recommends that MSHA and OSM jointly pursue the issue of outcrop coal barrier width and overburden thickness and its competence and develop minimum standards for them.”

“The committee recommends that MSHA review its current practice and develop guidelines for the design of bulkheads intended to withstand hydraulic heads associated with slurry impoundments.”

This document has been prepared in response to these recommendations. It is intended to provide guidance for designers and reviewers in determining the potential for a breakthrough to occur from an impoundment into underground mine workings, and in evaluating the adequacy of breakthrough prevention measures. It was prepared by a joint work group consisting of representatives of MSHA, OSM, and State regulatory agencies in Kentucky, Pennsylvania, Virginia, and West Virginia.

II. Impoundment Breakthrough History: Circumstances and Lessons

Reportedly, the first documented breakthrough from a coal-waste slurry impoundment occurred in 1956, in Virginia. A number of other breakthrough incidents have occurred since then, for example:

- In the mid-70s, slurry discharged through unsealed auger holes at an impoundment in Nicholas County, West Virginia. The slurry discharged into Muddlety Creek, disrupting the domestic water supply for the city of Summersville, West Virginia.
- In 1980, in Mercer County, West Virginia, water and fines from an inactive impoundment broke into an entry of an abandoned mine in the Pocahontas No. 6 seam. The entry was about 35 feet below the slurry surface and had not been sealed. Most of the slurry was contained in the mine and no damage was reported.
- In 1981, in Boone County, West Virginia, clear water broke through a hillside into an inactive mine at an area where the cover was shallow. The breakthrough occurred behind a 33-foot long grouted rock mine seal. The discharge flowed out the mine drift, lowering the pool by 4 to 5 feet, but no damage was reported.
- A breakthrough occurred in Floyd County, Kentucky, in 1987, in which approximately 7.5 million gallons of water and slurry broke into abandoned mine workings from an impoundment. The material flowed approximately a mile underground before discharging through a portal that had been backfilled. The failure occurred through a mine opening under the impoundment, and 55 feet below the pool level, that had been sealed with earthen material. Reportedly, some years prior to the incident, mining had been conducted in a seam only 30 feet below the abandoned mine workings.

It wasn't until three breakthroughs occurred within a span of four months in 1996 that significant attention was directed to this problem. Some of the more recent breakthrough incidents, and some lessons to be learned from them, are summarized below.

A. Big Branch Slurry Impoundment, Martin County, Kentucky - May, 1994

On May 22, 1994, a breakthrough occurred into underground mine workings from the Big Branch Impoundment. An estimated 343 acre-feet, or 112 million gallons, of water, with some fine coal waste, discharged from the impoundment, lowering the impoundment level by approximately 6 feet. Prior to the breakthrough, the impoundment level was approximately 24 feet above the elevation of the top of the coal seam.

In the area of the breakthrough, the mine map indicated that an entry had been driven to within approximately 52 feet (horizontally) of the original hillside. This left a minimum thickness of cover above the mining of 18 feet. An approximated cross-section of the hillside at the point of the breakthrough is shown in Figure 2-1. No information is available on how much of the 18 feet was soil and how much was rock. The breakthrough was thought to have been caused by

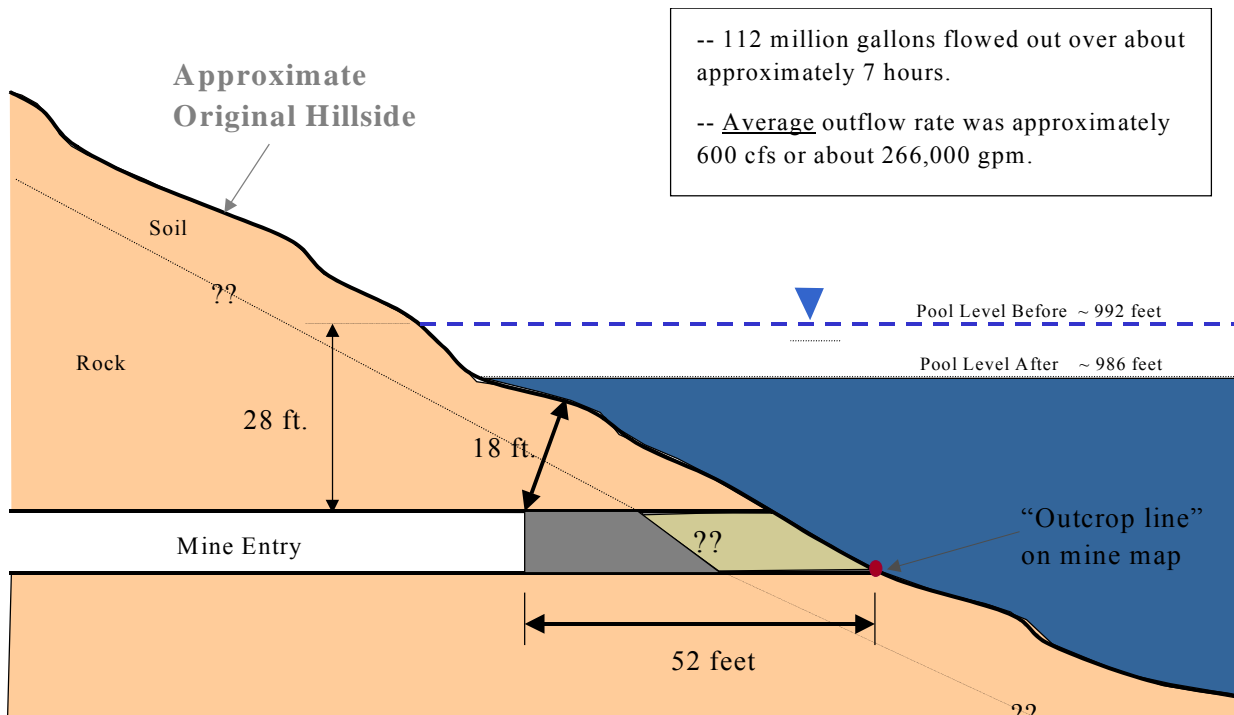


Figure 2-1. Approximate cross-section of hillside at location of May 1994 breakthrough at Big Branch Impoundment.

collapse of the shallow cover. The proximity of the mine workings to the impoundment had not been verified.

Lesson: Whenever there are shallow mine workings in the vicinity of an impoundment, the potential for sinkhole development needs to be investigated. Where sinkhole potential exists in the vicinity of an impoundment, measures need to be taken to prevent them from developing, or to locate the impoundment a safe distance away.

B. Turkeypen Branch Slurry Impoundment, Harlan County, KY - September, 1994

An incident occurred at the Turkeypen Branch Slurry Impoundment, on September 22, 1994, releasing over 14 million gallons of slurry and water into underground mine workings. The incident was discovered when a portion of the underground mine was found to be flooded during a pre-shift examination. As a result of this incident, the impoundment level, which had been approximately 30 feet above the elevation of the mine workings, dropped 7 feet.

The failure occurred near a portal opening that had been sealed. The seal design called for material to extend 30 feet into the mine opening. The seal did not fail, but the breakthrough occurred at a point 60 feet back into the mine, in an area where the overburden was shallow. The pillars had been second mined in the area. The breakthrough was attributed to either a roof fall extending to the surface, or possibly internal erosion. The elevation of the coal seam had been mistakenly reported in the impoundment plans as being at a higher level than the crest of the dam. This may have affected the amount of attention given to the potential for a breakthrough.

Lesson: The presence of mine workings in the vicinity of an impoundment need to be thoroughly investigated. Where the potential for sinkhole development exists, measures need to be taken to prevent their development, or the impoundment needs to be located a safe distance away.

C. Miller's Cove Slurry Impoundment, Lee County, Virginia - August 1996

In August of 1996, a release of slurry occurred at the Miller's Cove Slurry Impoundment located near St. Charles, Virginia. The slurry broke into underground mine workings in the Darby seam, flowed through the mine workings, and discharged into the adjacent watershed. The breakthrough occurred at a point where the mine map indicated a 25-foot wide outcrop barrier pillar. The pool level was only one foot higher than the elevation of the top of the four-foot thick coal seam when the breakthrough occurred. After the incident, the barrier was found to be only 2 feet thick.

Lesson: Mine maps can be inaccurate or incomplete and the extent of mining should be verified in critical locations, such as in the vicinity of an impoundment.

D. Miller's Cove Slurry Impoundment, Lee County, Virginia - October 1996

On October 24, 1996, a second breakthrough occurred at the Miller's Cove Slurry Impoundment. This time, the pool level was approximately 23 feet above the elevation of the top of the coal seam. The discharge again went through the underground mine works and discharged in the adjacent watershed. The slurry then flowed for a distance of 11 miles before entering the North Fork of the Powell River, discoloring the river for more than 40 miles, and killing an estimated 11,500 fish.

The October breakthrough occurred in an area that was upstream of a compacted earthen liner that had been constructed after the August breakthrough. The failure occurred at a point where a mine opening had been sealed. The opening had been treated by pushing and packing shot rock into it, then covering the area with filter material and a layer of compacted fill. However, a subsidence crack was found approximately 25 feet above the sealed mine opening. The breakthrough had occurred through the subsidence crack.

Lesson: Where there are mine workings in the vicinity of an impoundment, the potential for ground disturbance due to subsidence needs to be investigated. Measures need to be taken to prevent or minimize ground movement over shallow workings.

E. Buchanan Mine Slurry Impoundment, Buchanan County, Virginia - November 1996

A breakthrough occurred at the Buchanan Mine Slurry Impoundment in Virginia on November 26, 1996. The impoundment had been started in the early 1980s. Prior to impoundment construction, surface mining of the Kennedy coal seam, which outcrops in the impoundment and embankment areas, had taken place. Some auger mining also was conducted. After the highwall had been backfilled and reclaimed, room and pillar mining took place in the vicinity of the impoundment. The presence of the auger mining was not addressed in the impoundment plan.

When the breakthrough occurred, slurry discharged from the impoundment into the underground mine workings in the Kennedy seam, which by then had been abandoned. The slurry flowed approximately 1000 feet through the mine workings and exited into an adjacent watershed through two reclaimed portals. The peak discharge from the portals was estimated at 1000 gallons per minute. It was estimated that over 20,000 fish were killed over a length of 18 miles of waterways, and evidence of the discharge was found 30 miles downstream.

Prior to the breakthrough there was little free water in the impoundment, and the fines were at an elevation of approximately 1988 feet. The breakthrough occurred at the level of the reclaimed surface mine bench, which was at elevation 1975 feet, or 13 feet below the pool level. The exit point from the underground mine was at elevation 1938, or 50 feet below the pool level.

When the area of the breakthrough was excavated, three drift openings and at least 50 auger holes were uncovered. The breakthrough occurred through either a drift opening, or through the auger holes, which may have connected, or come close to, the underground mine workings. Other than the backfilling that had occurred after the surface mining, no work had been done, in association with the impoundment construction, to treat the drift openings or the auger holes.

Lesson: Previous mining in the vicinity of an impoundment needs to be thoroughly investigated to determine the potential impact of the mine workings on the stability of the foundation and basin. The potential impact of auger holes, in providing a connection with, or close to, underground mine workings, needs to be investigated and analyzed.

F. Big Branch Slurry Impoundment, Martin County, Kentucky - October, 2000

On October 11, 2000, a second breakthrough occurred at the Big Branch Slurry Impoundment in Martin County, Kentucky. After the breakthrough in May of 1994, the coal company had constructed a “seepage barrier” around the inside of the reservoir. The “seepage barrier” was constructed using overburden from surface mining a coal seam around the perimeter of the reservoir area.

As a result of the breakthrough, 306 million gallons of slurry discharged from the impoundment into underground mine workings. The slurry exited from two mine portals and discharged down two separate watersheds polluting over 80 miles of waterways. No downstream residents were injured, but slurry was deposited on a number of properties. The release destroyed a significant amount of aquatic life, water intakes had to be shut off, and water supplies were affected in a 10 county area. The governor of Kentucky declared a state of emergency.

The breakthrough occurred when the impoundment level had risen to approximately 100 feet above the elevation of the underground mine workings. The failure occurred at a point where a 50-foot long entry had been driven to within 70 feet (horizontally) of the outcrop line. At the end of this entry, the minimum overburden distance, measured diagonally, was 27 feet. Ten feet of this distance was weathered sandstone, with the remainder being sandy soil. A cross-section of the original hillside at the point where the failure occurred (without the “seepage barrier” or impoundment depicted) is shown in Figure 2-2.

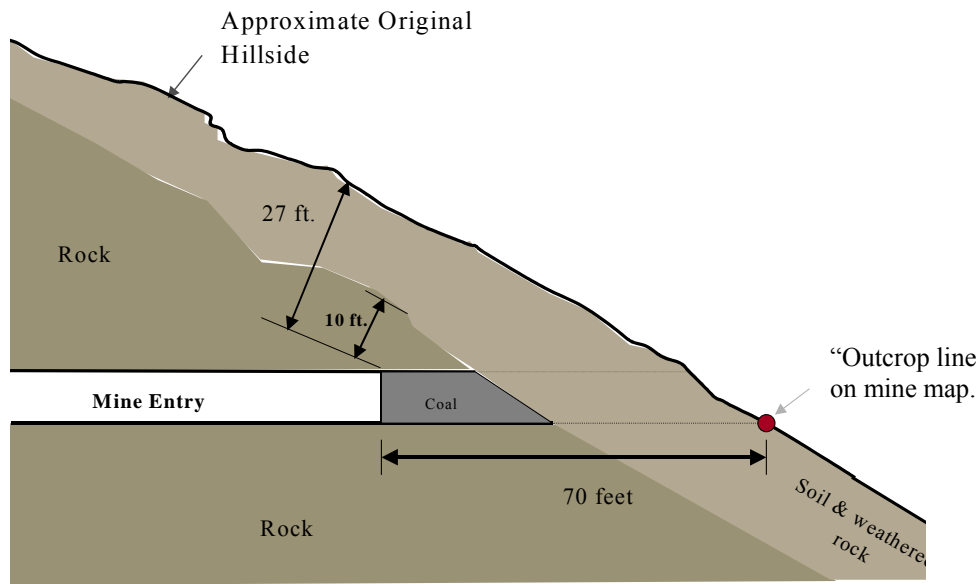


Figure 2-2. Approximate cross-section of original hillside (“seepage barrier” not illustrated) at location of October 2000 breakthrough at Big Branch Impoundment, Martin County, KY.

Drilling conducted following the failure indicated that a sinkhole mechanism had not occurred. The likely failure mechanism was either progressive internal erosion, or a partial “blow-in” type shear failure followed by internal erosion, at the end of the 50-foot entry. A main factor in the failure was the hydrostatic pressure in the shot rock “seepage barrier.” The barrier had not been provided with a drainage outlet, and the surface of the barrier had not been sealed with relatively impermeable material.

Lessons: In preparing impoundment plans, the designer should thoroughly investigate and document the nature and engineering characteristics of all materials separating the underground mines and the impoundment pool. Remedial measures taken to prevent a breakthrough need to account for the effects of water pressure and seepage.

(Note that the term “outcrop” may be used in different ways. As used in this report, “outcrop” is the area where a coal seam appears at the surface, or, if the seam is not exposed on the surface, the point where the seam projects to the surface. “Outcrop” has also been used to describe the point, as the seam approaches the surface, where the solid coal ends and weathered material begins. The “outcrop barrier” is the coal and other material between the mine workings and the surface.)

III. Mine “Blowouts”

A “blowout” occurs when water impounded in an underground mine breaks out through either a sealed mine opening or a thin section of the coal outcrop barrier. A “blowout” may be a secondary consequence of an impoundment breaking into an underground mine. Mine blowouts have caused loss of life and environmental damage. Consider these examples:

1. In the fall of 1968, a blowout occurred at a road construction site in Montgomery, West Virginia. A cut was being made into a hillside for road construction. At 7:00 pm, the pressure from the accumulation of water in an adjacent underground mine caused the outcrop barrier to fail, flooding the town with acidic/iron water. There was no loss of life.
2. In the summer of 1972, an auger mining operation mined into an abandoned coal mine near Page, West Virginia, resulting in the release of large quantities of acidic water into the local stream. There was no loss of life but there was environmental damage.
3. In May, 1995, there was a blowout from an abandoned underground coal mine in Buchanan County, Virginia. This blowout released a large quantity of impounded mine water and resulted in the death of a person and environmental damage. The pressure from the water in the mine caused the outcrop barrier to fail. There was no mining related or other activity that precipitated this event.
4. An opening into an abandoned underground coal mine near Yocum Creek, Kentucky, had been sealed with a concrete block wall, with a pipe to discharge the mine water. When the pipe became clogged, the block seal failed and discharged a large quantity of acid/iron water. There were no active mines in the area and liability had been released long ago.

Closing off drift openings with a seal constructed of a single row of concrete blocks, with a drain pipe, was a common practice from the 1940s to the 1970s. Since a single row of concrete block does not have sufficient strength to resist a significant buildup of water pressure, blockage of the drain, or a sudden large inflow of water into the mine, can potentially cause a blowout in these situations. Similarly, a blowout can occur if mining occurred close to the outcrop, leaving only a thin outcrop barrier. Impoundment designers should investigate the potential for blowouts in the watershed basin above an impoundment. Such an event could cause a significant amount of water to discharge into the pool area and potentially affect the safety of the impoundment.

Information about the strength of mine seals is provided in a later section of this report. A reference for the evaluation of outcrop barriers is “Outcrop Barrier Design Guidelines for Appalachian Coal Mines,” 1981, prepared under Bureau of Mines contract by Dames & Moore.

IV. Impoundment Basins: Guidelines for Site Evaluation

In general, there are no hard and fast rules that can be applied to the question of how much exploration, sampling and testing should be done to adequately evaluate a reservoir or basin area for breakthrough potential. As with most geotechnical projects, the amount of site evaluation work depends on the complexity of the conditions, the degree of uncertainty, and the level of potential hazard or impacts. The site evaluation program must be determined by a qualified engineer or engineering geologist, with experience in subsurface investigations. The process involves collecting and reviewing all of the available information, establishing a preliminary evaluation plan, and then adjusting the plan as the investigation progresses.

The distance around the perimeter of a reservoir can be a couple of miles, and a distance of at least a mile is common. With the large area to cover, the site exploration program must be carefully planned to ensure that all areas with the potential for a breakthrough are identified and analyzed.

Accuracy of mine maps

In evaluating breakthrough potential, mine mapping is obviously a key element. The accuracy and completeness of the information found on mine maps can vary widely. There may be mining that was not mapped at all, mining that is accurately reflected on mine maps, or anything in between.

Many accidents have occurred where an active mine broke into old mine workings that either had not been shown on a map, or were shown as being hundreds of feet from their actual location. In fact, in one case the mine maps showed that an abandoned mine was 1000 feet away when it was cut into. In another case the map was said to be off by 300 feet. MSHA records indicate that 79 water inundation accidents occurred from cutting into old coal mine workings in the period from 1995 through May, 2002. These incidents may have occurred because coal was mined and the full workings not surveyed, or the area was surveyed, but the survey was in error. Problems can also occur when maps for adjacent mines are not referenced to a common coordinate system, or when a map is improperly transposed from one coordinate system to another. Many potential problems could be avoided by accurately referencing all maps to the state plane coordinate system.

When mining occurs near an outcrop, the conditions may make problems with mine map accuracy more likely. It is not uncommon for roof conditions to deteriorate as the outcrop is approached. This occurs as the mining encounters lower cover, more weathered roof strata, more frequent jointing, and possibly "hillseams" ("hillseam" is a term used by miners for highly weathered joints that may be found near an outcrop). Furthermore, the last cut made toward an outcrop would typically not be provided with roof support. Since surveyors could not have access to the unsupported entry, its depth would be estimated rather than directly surveyed. If a roof fall occurs, or an area is dangered-off after mining, it may not be accurately surveyed. This may be more likely to occur near an outcrop. Dashed lines on a map indicate that the area was not surveyed, but was estimated based on the best available information, which may have been the section foreman's map.

As an example of inaccuracies in mine maps, drilling was performed, in 2001, at an impoundment site in Kentucky to check the accuracy of the mine map. A 46-inch thick seam had been surface mined in the impoundment area in the 1970s, leaving a highwall. Room-and-pillar mining, with second mining of the pillars, was then performed from 1985 to 1995. Twenty-six horizontal holes were drilled from the highwall location to verify the mine map. The holes were drilled to the maximum capacity of the drill, which was 100 feet. In eleven of the holes, the drill steel veered out of the coal seam, typically after about 50 to 80 feet of penetration. Twenty-one of the holes were in areas where the distance to the void (based on the mine map) was expected to be in excess of 100 feet (in some cases the mines were more than 300 feet away based on the maps), so these were not expected to encounter mines, and they did not. The other 5 holes encountered mine voids as shown in Table 1.

Expected horizontal distance to mine workings from highwall, <u>based on mine map</u> , feet.	Actual horizontal distance to mine workings from highwall, <u>based on drilling</u> , feet.	Discrepancy, that is, workings were actually this much closer or farther from highwall than shown on mine map.
40	37.5	2.5 feet closer
122	92	30 feet closer
137	89	48 feet closer
27	67	40 feet farther
67	41	26 feet closer

Discrepancies like this between the “mapped” and “actual” amount of barrier width could have serious implications to the safety of the site against a breakthrough. This example points out the need to verify mine maps - even more recent maps - when performing a site evaluation.

Coal seam “outcrop line” location

The “outcrop” is generally taken to mean the point where a coal seam intersects the surface. Normally, however, if one were to dig in from the surface, they would encounter anywhere from a few feet, to several tens of feet, of weathered material at the level of the coal seam before hard coal is reached. In the case of the October 2000 breakthrough in Martin County, Kentucky, for example, drilling after the accident revealed that, at the floor level, there was a distance of 70 feet from the face of the last entry to the hillside. However, only 15 to 18 feet of this distance was full-seam solid coal. As the seam thinned out, it ended approximately 36 feet back from the projected outcrop location, with the remaining distance consisting of weathered and unconsolidated material.

It is common to represent the coal “outcrop line” on contour maps. Since the actual coal seam is generally not visible at the surface, the outcrop line is commonly located as a contour corresponding to the bottom elevation of the coal seam in that area. As more definite information becomes available, such as from face-ups, or coal prospecting, the outcrop line is

located more accurately. In considering the question of breakthrough potential, outcrop lines that are located based on projecting the elevation of the coal seam, should not be relied on for anything more than preliminary information.

Preliminary Investigation

Evaluating a basin area for breakthrough potential should begin with a thorough and intensive review of all available information on the presence and extent of mining in the area of the impoundment. This review should include the following:

- A search should be made for all available mine maps for the area. The local mining companies should be contacted. Other potential sources of mine maps include OSM's National Mine Map Repository, museums, mining schools, and state agencies that deal with mine safety, or mine reclamation.

(OSM's National Mine Map Repository is located in Pittsburgh, PA. There are approximately 250,000 abandoned mine maps in its collection. When a mine closes, MSHA forwards the final mine map to the repository for cataloging and microfilming. The address of the National Mine Map Repository is 3 Parkway Center, Pittsburgh, PA 15220. The telephone number is 412-937-3001. Additional information on the repository can be found at OSM's web site at <http://mmr.osmre.gov>.)

- Where there are multiple coal seams, the mine maps for each seam should be obtained.
- Any available aerial photos of the area should be checked for indications of mine openings, auger mining, other types of surface disturbance, or the presence of mining facilities.
- Topographic maps should be checked for indications of mine openings or mine facilities.
- Geologic maps and cross-sections should be checked for the presence of coal seams in the area.
- Available information on the condition of, and any surface disturbance to, the outcrop barrier and overburden should be collected and reviewed. This would include geologic maps, aerial photographs, publications available from government agencies, and any previous engineering reports, plans, or permits pertaining to the area.
- A search should be made for any boring logs from drill holes in the area. This could be holes drilled for any reason, such as for coal or gas exploration.
- Collect and review any available information on the mining conditions, and practices, for workings under or near the site. Include information on: roof falls; roof support measures, especially any supplemental support used near the outcrop or under shallow cover; pillar stability, particularly any information on second mining of pillars; and floor conditions, especially information on punching or heaving.
- Miners, especially older or retired miners who worked in the area, should be asked about the mining conditions, including the roof, pillar, floor, and water conditions; the practices

used when mining near the outcrop; and whether the available mine maps reflect their knowledge of the mining that took place.

- Mine surveyors who may have worked in the area should be asked about their knowledge of mining in the basin and surrounding area.
- The search should include any available information on auger mining. Often the depth of auger holes are not shown on the mine map, or only approximate depths are indicated.
- Production records can be compared to the dates of mine maps to verify that additional mining did not occur after the mine map was produced.

On-site reconnaissance

- The entire basin area should be walked and examined, by a geotechnical engineer, mining engineer, engineering geologist, or other person knowledgeable and experienced in mining and geotechnical matters. The area should be examined for signs of mine openings, auger mining, old mine facilities, subsidence, hillside movement, hill seams or other geologic features, springs, water seepage, and any unusual or suspicious conditions.
- Any activity in the basin area that has affected the natural hillside, and possibly reduced the thickness of the overburden or barrier, such as road or ditch construction, should be noted and investigated for its potential impact on breakthrough potential.
- Areas above the seam elevation where the ground surface is naturally benched, or slopes at a shallower angle, should be investigated. This effect may reduce the amount of overburden over mine workings.
- The use of exploration test pits should also be considered. Test pits can be used to locate the coal seam outcrop, and to investigate suspicious areas. Permits should be obtained, as required, for the excavation of test pits, and proper safety precautions should be taken when working in any trench or test pit.

Direct / Detailed Investigation

Once all of the above information has been collected and evaluated, the designer needs to determine the reliability and completeness of the available information. Experience has shown that some mining is not shown on a mine map, or a map may be missing. Also, as indicated by the examples mentioned previously, the location of workings that are depicted on a map may be grossly in error.

At this point, the designer may be able to judge with confidence that there is no mining in the area of the basin that would present the opportunity for a breakthrough from the impoundment. More likely, however, there will be less than 100% certainty that there is no mining in a critical area, or there will be evidence that there is mining. A site evaluation program will need to be conducted in these cases to confirm whether mining is present, to delineate the extent of the mining, and to determine the thickness and characteristics of the barrier and overburden between the impoundment and the mine workings.

Geophysical Methods

Where there is uncertainty about whether all of the mining that may have taken place is shown on mine maps, or whether the workings shown on the map are accurately depicted, a logical first step for the site evaluation may be the use of geophysical methods to investigate the area in question. Methods that have been used for locating mine workings include seismic and electrical resistivity techniques. The obvious advantage of geophysical methods is that a large area can be investigated, versus the limited, single-points of information obtained by drilling boreholes. Geophysical investigations should be planned, carried out, and interpreted, only by persons experienced in this specialty field.

Geophysical methods, by indicating the presence of anomalies, can indicate whether mine workings are present, and whether the mine workings generally correspond to the available mine maps. Geophysical results should always be confirmed by drilling or other known data.

There are numerous references that cover the use of geophysical methods. The following references discuss geophysical methods in the context of their use for locating mine workings.

- “Coal Waste Impoundments: Risks, Responses, and Alternatives”, National Research Council, 2002
- “Geophysical Methods for Detection of Underground Mine Workings,” Johnson and Snow, Tailings Dams 2002, Las Vegas, Nevada, April 29-May 1, 2002.

Long-hole Directional Drilling

Advances in directional, long-hole drilling have added a technique that can be used to locate mine workings, or show the absence of workings. Directional holes have been drilled for horizontal distances of over 4000 feet. The position of the end of the hole is determined from a surveying tool that is an integral part of the drilling system. The hole can be guided or steered from underground mine workings, or from the outcrop on the surface, to investigate whether there are mine workings in a particular area. This technique could also be used to advance a hole roughly parallel to a coal-outcrop line to establish the thickness of solid outcrop barrier around an impoundment site. Reportedly, long-hole drilling can achieve accuracies of better than plus or minus one degree of azimuth and plus or minus 0.25 degrees of inclination.

Information on directional, long-hole drilling was provided in the following presentations at the MSHA sponsored “Symposium on Geotechnical Methods for Mine Mapping Verification,” held in Charleston, WV in October, 2002.

- “Proven Benefits of Target Drilling, Inc.’s In-Mine Directional Drilling Technology for Abandoned Mine Verification,” by Stephen Kravits.
- “Directional Drilling of Methane Drainage and Exploration in Advance of Mining: Recent Advances and Applications,” by Daniel Brunner and Jeff Schwoebel.

Another directional drilling reference is “Directional Drilling Techniques for Exploration In Advance of Mining,” by Kravits and Schwoebel, World Mining Equipment, January, 1994.

Conventional Borehole Drilling and Sampling

Drilling boreholes is probably the best method for determining the nature of subsurface conditions at particular points. The issues with drilling boreholes are where should they be located, and how many are needed to adequately characterize the site.

In designing a normal earthen dam, borings are made primarily to provide design information on the engineering properties of the foundation. Typically they are taken across the axis of the dam, up and down the valley, and at the location of spillway and decant structures. The number and spacing depends on the uniformity of the conditions disclosed. Typically, borings may be at a spacing of 100 feet, but for uniform conditions the spacing may be doubled, while for irregular conditions the spacing would be reduced. It is impossible to determine the number and location of borings before the investigation begins, because the spacing depends upon the uniformity of the conditions that are found. Numerous textbooks and references in geotechnical engineering are available to assist the designer on this subject.

Geotechnical exploration for an impoundment site becomes much more complicated when there is underground mining in the area. Additional borings are then necessary to adequately characterize the basin conditions, as well as the conditions near the dam, and this can increase the number of borings significantly. Not only does the accuracy of the mine maps need to be determined, but the nature and variability of the overburden need to be defined, as well. An advantage of using geophysical methods as a preliminary step in the basin investigation is that the results may allow the designer to optimize the number and location of boreholes. In general, sufficient drilling needs to be performed to check the accuracy of the mapping information, and identify all geologic, soil, and water conditions needed to evaluate the adequacy of the barrier and overburden with respect to breakthrough potential. The following points relate to the drilling program conducted to collect information relative to breakthrough potential.

1. The accuracy of the mine map should be checked by first identifying the locations under the reservoir, and around the perimeter of the reservoir, where the conditions appear to be most critical. This should be based not only on the locations where the mine map, or the geophysics, indicates that the total amount of cover, or the outcrop barrier width, is at a minimum, but needs to take into account other locations where the competent rock portion of the overburden may be reduced due to a deeper soil layer, or other reasons. For example, there may be significant differences between the thickness of the soil layer lower in a valley versus near a ridge. Or, roads or diversion ditches could have been constructed which removed original hillside material.
 2. Several of these critical locations should be investigated either by drilling, or test pits. The number of locations investigated will depend on how far the mining is supposed to be from the impoundment, the level of uncertainty, the results that are found, and the degree of conservatism to be used by the designer on any remedial measures.
- In an outcrop barrier situation, main concerns are to verify how close to the surface the mining has occurred, determine whether the pillars have been first-mined only, and establish whether auger mining has reduced the size of the barrier. It is recommended that several of the more critical areas be investigated

to verify the extent of mining and determine the cover conditions. If the mapping is found to be inaccurate in any of those areas, then additional areas will need to be checked. Any other areas where there is reason to suspect that more mining may have occurred than is depicted on the mine map should also be investigated.

- Where mining has occurred below the level of the bottom of the reservoir, the main concern will be to confirm the depth to mining, the extent of mining, the characteristics of the overburden, and the size and condition of the pillars. Whether or not the pillars have been second-mined, or “robbed,” is a critical piece of information to evaluating the subsidence and sinkhole potential.
3. Where possible, borings that are drilled for other purposes, such as foundation investigation, should be extended to seam level to provide additional points to confirm whether or not mining has occurred.
 4. For each area investigated, sufficient information on the geologic conditions (rock quality, joints, hillseams, weathering, etc.), and the engineering properties of the materials, should be obtained to evaluate the degree of safety of the outcrop barrier and the overburden against failure.
 5. With drilling vertical holes, sufficient holes should be drilled at each critical location to bracket the farthest extent of the mining. It may be effective to drill horizontal holes, within the coal seam, to better pinpoint the location of the coal face and its distance from the outcrop.
 6. It may be helpful to drill some holes at an angle. The advantage of angle drilling is that features such as hillseams can be more readily intercepted and mapped.
 7. In determining where holes should be drilled, the designer should consider that the surface area that may be affected by subsidence can be larger than the area directly over the mining workings. This larger area is defined by the draw angle. So an impoundment that is near, but not directly over, mine workings can still be affected by the strata disturbance induced by the mining.
 8. The designer should determine whether multiple seam mining has occurred in the area. If so, information should be collected on the mining in the other seams including mine map overlays and the nature of the inter-burden between the seams.
 9. Where auger holes are located, it may be important to know whether the back of the holes intercept mine workings, or the width of the remaining barrier. The extent of augering is usually not accurately documented.
 10. Borehole cameras, with video taping, can be used to obtain additional information about the conditions at mine level, such as the amount of subsidence or collapse that has occurred, as well as provide more information on the conditions at discontinuities intersected by the borehole.

Information Related to the Consequences of a Breakthrough

Where the potential for a breakthrough exists, the site evaluation should include collecting sufficient information to determine the consequences of a breakthrough. The designer should consider all possible scenarios, including the following:

- Could a breakthrough occur directly into an active mine?
- Is there an active mine that could be affected in a seam below the level of the seam where the breakthrough could occur?
- Could a breakthrough occur into an abandoned mine and cause hydrostatic pressure to build-up on a barrier or bulkhead adjacent to an active mine?
- If a breakthrough occurred into a mine, which direction does the coal dip and where would the inflow end up?
- What is the potential for injury or death to miners?
- Could the inflow discharge out of a mine opening, or break through an outcrop barrier or bulkhead?
- How much hydrostatic pressure have any bulkheads been designed to withstand?
- What is the potential for injury or death to the general public?
- Could the discharge from a breakthrough affect another impoundment?
- How would a discharge impact the drinking water supply for the residents in the area?
- How would a discharge effect the environment?

Answers to these questions are needed to determine the adequacy of the breakthrough-potential evaluation. The more serious the consequences of a breakthrough, then the higher the level of confidence that must be provided in the adequacy of the investigation and the design of any preventive measures.

Summary

It is the responsibility of the designer and operator of impoundments to ensure that they do not fail, do not result in death or injury to miners or the general public, and do not cause environmental damage. The information presented above is intended to assist designers and reviewers in ensuring that impoundment sites are adequately investigated to identify and properly address the potential for a breakthrough. The overriding factor, however, is that obtaining the information that will give an accurate picture of underground conditions is an engineering problem requiring the efforts of resourceful, knowledgeable personnel trained in the principles of mining, geology and geotechnical engineering.

V. Evaluation of Potential Breakthrough Failure Mechanisms

A breakthrough is a sudden, uncontrolled release of water and/or fine coal refuse/waste (slurry) from an impoundment into an underground coal mine. For this to occur an opening must exist or develop between the impoundment area and the underground mine. Such an opening can form when the intervening material fails suddenly, or the material may gradually weaken over time.

The ability of coal outcrop barriers, the surrounding strata, and mine bulkheads, to prevent breakthroughs depends on many factors. These factors include: the width and integrity of the outcrop coal barrier; the thickness and integrity of the material above and below the coal barrier; the permeability of the coal and surrounding strata; the size and location of mine voids; the hydrostatic and earth pressures; the water and fine coal refuse levels; the flowability of the fine coal refuse; the presence and orientation of stress relief fractures, rock discontinuities, and hillseam fractures; and the impacts of any physical disturbance (landslides, road cuts, auger mining, etc.) to the material in the outcrop area.

Each of the potential breakthrough failure mechanisms needs to be evaluated based on the site evaluation information collected. Additional site information may have to be collected during the course of an analysis, depending on site-specific conditions, or to minimize the need to make assumptions about important failure-mechanism parameters. It should be noted that after a slurry impoundment is no longer in use, there may still be the potential for a breakthrough if the buried fines remain in a loose, saturated condition.

Potential Failure Mechanisms

There are several potential failure mechanisms that are associated with breakthroughs. The driving force for a breakthrough is the pressure gradient between the basin and the underground mine workings. The failure mechanisms that can cause a breakthrough include sinkhole development from subsidence, pillar crushing, pillar punching, internal erosion or “piping,” outcrop barrier failure, hillside movement and disturbance, mine seal failure, or soil and rock decomposition. These failure mechanisms are frequently interrelated, and should all be considered when analyzing for breakthrough potential.

Sinkholes: A sinkhole is a depression or opening in the ground surface above an underground mine void where the mine roof has fractured and fallen. Especially when the cover is shallow, the fracturing of the roof material can eventually extend high enough that an opening, or at least a weakened area, is created at the ground surface. A sinkhole can provide a direct conduit from an impoundment to underground mine workings. The factors contributing to sinkhole development include the presence of a mine void, mine roof material that isn’t strong enough or durable enough to span the mine opening, fractures in the mine roof, unconsolidated soil and weathered rock above the mine roof, and pressure exerted by the slurry or water above the area.

A sinkhole will not develop if the strata above the mine openings is either strong enough to span the opening without collapsing, or the strata above the mine is thick enough that an arch forms over the mine opening before collapsed material can work its way close to the surface. One study in Pennsylvania found that 81% of sinkholes occurred where there was less than 100 feet of cover, with most occurring at 50 to 60 feet of cover. There have been, however, unusual

cases, such as a sinkhole in Illinois where the cover was 160 feet (which may have included a significant thickness of unconsolidated material).

Analyzing the immediate roof strata to determine if it will span the entries indefinitely is difficult because the tensile or bending strength of the rock is not easily defined, and the impact of joints on the integrity of the roof, especially at shallow depths, adds considerable uncertainty. For these reasons, the adequacy of the overburden to prevent sinkhole development is commonly assessed by certain “rule-of-thumb” type guidelines that have been developed based on experience. These guidelines are contained in Bureau of Mines Information Circular 8741, “Results of Research to Develop Guidelines for Mining Near Surface and Underground Bodies of Water,” (1977).

For first mining only, the guidelines recommend, with respect to sinkholes, that the amount of “solid strata” should be equal to at least 5 times the entry width, or 10 times the mining height, whichever is the greater distance. These guidelines are consistent with the findings that compression arches are normally stable within the overburden if the mining width is limited to one-half to one-fourth of the overburden height. In other words, the arch is typically stable, depending on the strength of the strata, if the thickness of the strata above the mining is from 2 times (strong strata) to 4 times (weaker strata) the entry width. Adding a margin of safety, the “rule-of-thumb” is 5 times the entry width. Similarly, the criterion related to the mining height is based on adding a margin of safety to the observation that the height of collapse above a mine entry generally does not exceed 3 to 5 times the mining height.

A key point in the use of these guidelines is that the strata thickness refers to “solid strata.” Soil, weathered rock, or weak rock, should not be included in the “solid strata” thickness since it will not provide the strength needed to resist sinkhole development.

Note that the guidelines in IC 8741 suggest that a lesser strata thickness may be acceptable where it can be demonstrated that there is a “competent” layer of rock (“competent bed of sandstone or similar material”) with a thickness of at least 1.75 times the entry width. This is normally taken to mean a homogeneous, “massive” layer of sandstone or limestone. This guideline is based on analyses of the roof beam using a minimum tensile strength (20 psi). Any intact piece of rock will likely have a tensile strength of over 20 psi (typical intact rock tensile strengths might range from about 300 to 2000 psi), but the question is, how will any joints affect the “effective” strength of the “beam.” Since the potential impact of joints and weathering, especially near the outcrop, can’t be modeled with confidence, this approach should normally not be relied on for a critical breakthrough situation. Furthermore, in a breakthrough situation, there is the potential for the strength of the strata to deteriorate over time due to seepage and weathering, especially as the pool level rises.

In summary, any area where the cover over a mine entry is less than 100 feet of solid strata is a concern for sinkhole development. This is especially true near the outcrop where additional weathering and stress relief has occurred. If sinkhole development cannot be reasonably ruled out, then conservative preventive measures, as discussed in a later section of this report, need to be taken.

Pillar Failure: Loss of support due to coal pillar failure allows the mine roof to sag or collapse. This can create or open fractures in the overburden. These fractures may cause a roof fall and subsequent sinkholes or the fractures may create zones where internal erosion can begin. Furthermore, failure of one pillar transfers the load to other pillars, and may lead to progressive pillar failure (sudden or gradual) over a larger area.

Pillar crushing occurs when the load on the pillar exceeds its strength. This can be caused by existing loads, additional loading from impounded slurry and/or water, loss of strength in the coal from chemical decomposition, and loss of buoyant pressure from a lowered mine pool.

A number of formulas have been developed to analyze the strength of a pillar, and computer programs are now available for pillar analyses. One example is a program called “Analysis of Retreat Mining Pillar Stability” or “ARMPS,” which was developed by Chris Mark and Frank Chase at the National Institute for Occupational Safety and Health (NIOSH). This program uses the Mark-Bieniawski formula for pillar strength, and has the capability to account for loadings on barriers and abutment pressures.

In breakthrough potential situations, analyses must show that pillars have a conservative margin of safety against crushing. The factor of safety should be at least 2.0 for the long-term support of critical areas. Lower factors of safety should only be considered where there is clear evidence that pillars with factors of safety less than 2.0 have proven to provide satisfactory long-term support under similar mining, geologic and loading conditions in the same seam. The additional loading from the weight of the impoundment material needs to be included in the pillar strength analysis.

Conservative coal strengths based on field experience should be used, or tests should be conducted to verify the strength of the coal. There are considerable differences of opinion relative to the merits of representing coal pillar strength based on the strength of small laboratory samples. In any analysis of pillar stability, it is best if the method being used is calibrated to the conditions in the particular mine. That is, the model should be applied to different areas of the mine to determine how well it reflects the actual condition or performance of the pillars. If an analysis indicates a factor of safety of 2.0 for the pillars in a certain section of the mine, for example, then those pillars should be highly stable, with no signs of pillar instability. If they are not, then the coal strength may need to be adjusted, or a different method of analysis may need to be used.

Pillar analysis becomes more complicated when multiple seams are mined. In these cases, the loading conditions become much more complex due to load transfer and the potential for stress concentrations. Analytical models, such as a program called “Lamodel,” are available to assist in this type of evaluation. Higher pillar factors of safety should be used in multiple seam cases to account for the additional uncertainty. “Lamodel” and “ARMPS” are both available on NIOSH’s web site at www.cdc.gov/niosh/mining/groundcontrol..

Pillar Punching (Floor Failure): Just as the pillars need to be strong enough to support the mine roof, the mine floor needs to provide the foundation for the pillars. Pillar punching occurs when a pillar pushes down into the mine floor allowing the roof to sag. This sagging can create fractures and/or open existing joints in the overburden. If the punching occurs over a large area,

the surface will be affected similar to a situation where total extraction of a thinner seam has occurred.

Pillar punching occurs when the load on the pillar exceeds the bearing capacity of the mine floor beneath the pillar. This can be caused by existing loads, saturation of the floor material causing loss of strength, additional loading from impounded slurry and/or water, and loss of buoyant pressure from a lowered mine pool.

One factor to consider in evaluating the tendency for pillar punching is the experience elsewhere in the mine. Has there been a problem with floor heave? Has the floor been susceptible to softening in wet conditions? There are techniques available to analyze the bearing capacity of the floor using foundation design methods. Floor strength needs to be modeled using the reduced strength that would apply under wet conditions.

Reference information on floor heave problems can be found in “A Geotechnical Study of the Squeeze Problem Associated with the Underground Mining of Coal,” by Harold Ganow, Doctoral Thesis, University of Illinois at Urbana-Champaign, 1975, and in “Ground Control in Bedded Formations,” L. Adler and M. Sun, Bulletin 28, Virginia Polytechnic Institute, 1968.

Outcrop Barrier Failure by Shear or Punching: In an outcrop barrier situation, a potential failure mode that must be considered is whether the pressure from the water and/or slurry in the impoundment may become high enough to overcome the shear strength that is holding in place the “plug” of material separating the impoundment from the mine works. Failure could occur through the coal seam itself, through the strata above the coal (especially as this strata may represent the shortest thickness of material between the impoundment and the mine entry), or along the interface of different materials.

Analysis of this failure mode involves comparing the force tending to push the plug into the mine, versus the available resisting force, as provided by the shear strength around the outer edges of the plug. The pressure acting on the plug is normally taken as the hydrostatic head from the impoundment pool level, plus any applicable lateral earth pressure, such as from settled fines. A major factor with this type of analysis is judging what to use for the shear strengths along the top, bottom and sides of the plug. Here factors such as the presence of weathered joints, the cleats in the coal, the softening of the floor from saturation, and the difficulty of sampling and testing these materials, can make the available shear strength highly uncertain. Furthermore, as seepage occurs into the mine, the strength along potential shearing surfaces may degrade over time, and if sloughing or a roof fall occurs in the mine, the length of the shear plug may be reduced. Given these problems, any shear-type failure analysis should use conservative values for the available shear strength, as well as a conservative factor of safety of at least 2.0.

Internal Erosion: Internal erosion, or “piping,” is the movement of material as the result of seepage forces. Seeping water creates a drag force on the material that it is seeping through or around. If this drag force is greater than the frictional or cohesive forces holding particles in place, the particles will be moved by the seeping water. As smaller particles are carried away, more flow can occur, increasing the drag force, and dislodging larger particles. The process can continue until a “pipe” is formed back to the source of the seepage. In a breakthrough situation, where the source of the seepage is the impoundment and internal erosion occurs through the

material between the pool and the mine workings, the “pipe” can gradually enlarge to the point where a significant discharge can occur into the mine.

In dam design, one technique to prevent internal erosion is to incorporate “filter” layers, or material with grain-size distributions that prevent particles from moving along the seepage path as flow occurs from one material into another. At unrestrained surfaces, the method of preventing internal erosion is to limit the drag forces, by limiting the hydraulic gradient of the exiting seepage flow. The gradient is the rate at which head is lost along any flow path, and is represented, between two points, by the head loss divided by the flow distance. The drag force imparted on material by seeping water is proportional to the gradient. The gradient can be reduced by using lower permeability layers along the upstream portion of the seepage path, that causes head loss before the water reaches a critical area. Excess water pressure also can be controlled by providing drainage that bleeds off the pressure at a point where it can do no harm, such as in an internal drain which is protected by properly designed filters.

In breakthrough situations, seepage can occur into an underground mine through the roof, floor, or coal seam. If the material at the point where the seepage exits is weathered or fine-grained, or loosened as the coal may be along a face or rib, then the force of the seeping water may carry particles away. Over time, this can cause the area to weaken, slough, or progressively deteriorate. This is especially a concern near the outcrop, where the internal erosion could cause the ground to give way or a “pipe” to form through the weathered material. Either case could lead to a connection between the impoundment and the mine workings.

Whenever seepage is flowing upward at an unrestrained surface, as it may be near the toe of a dam, the value of the critical gradient with respect to piping is approximately one. That’s because under that condition, for a typical soil, the upward seepage force is then about equal to the submerged unit weight of the soil. In this case the weight of the soil is acting against the upward seepage force. When the seepage is horizontal, such as coming through a rib, or downward, such as coming through the mine roof, internal erosion can develop from very small gradients. In the case of seepage through the roof, for example, the seepage forces are then acting with, instead of against, the force of gravity.

Obviously, analyzing the potential for internal erosion is difficult. Determining the hydraulic gradient requires accurately characterizing the permeability of the materials between the impoundment and the mine. Near the outcrop, the seepage may be governed by flow along weathered joints, and be difficult to characterize. The gradients could be estimated by drawing flow nets or by using a finite-element seepage program. Once a gradient is estimated, then the impact of the seepage force on the seepage medium would have to be determined. The seepage force, per unit volume of seepage medium, is equal to the product of the gradient and the unit weight of water. So for a gradient of two, the seepage force acting on a cubic foot of seepage medium would be 2 times 62.4, or approximately 125 pounds. Whether the medium material would be dislodged by the combination of seepage and gravity forces depends on the amount of friction and cohesion that exists.

Cohesionless soils, particularly silts and fine sands, are most susceptible to piping. Clays are more resistant to piping because the cohesive bonds help prevent the particles from being carried away, however, they are not immune. Soft rocks such as poorly cemented sandstones have been

known to exhibit piping failures. Even shales, usually considered to be resistant, have developed piping under conditions of very high gradients (see, for example, “Introductory Soil Mechanics and Foundations,” Sowers and Sowers, 1970).

Because of the uncertainties of analyzing the potential for internal erosion based on comparing seepage forces to restraining forces, combined with the fact that it only takes one area of erodible material to cause a problem, such analyses should generally not be relied upon. Impoundments should be designed with suitable filters and drains so that seepage is collected and released in a controlled fashion; or with properly located seepage barriers so that pressures are minimized; or, preferably, with some combination of the two methods.

Bulkhead Failure: If a mine opening exists in a potential breakthrough area, then a failure of the bulkhead used to block the mine opening must be considered. Depending on their thickness and shape, bulkheads can fail when the pressure acting on them causes the bending or shear strength of the bulkhead material to be exceeded. Bulkheads can also fail if the material they are anchored into is not strong enough to resist the pressures applied to the bulkhead, and the pressures applied from water seeping around the bulkhead. More details on bulkhead design are provided in a separate section of this report.

Trough Subsidence and Subsidence Cracks: If old workings are found near the footprint of an impoundment, and if either longwall mining or second mining of pillars has occurred, an analysis of the potential impact of trough subsidence needs to be made. In this situation, zones of tension or deformation will be created which can extend from the surface to the mine workings. The area affected by total extraction mining is larger than the mined area, as defined by a draw angle. The draw angle used should be consistent with the local subsidence experience associated with the coal seam, the topography, and the mining method. If mining is approaching an impoundment, the potential effects of ground deformations need to be fully considered. In this situation, best practice would be to stop the mining at a point, corresponding to a conservative draw angle, where the ground deformation will not affect the impoundment.

For total extraction mining (longwalls or second mining of pillars) that occurs completely underneath an impoundment, the guidelines in IC 8741 recommend that the amount of cover should be at least 60 times the mining height. This guideline was based on studies that looked at disturbance of the strata, and the change in the permeability of the strata, above mined areas. The data indicated that the chances of the strata above total extraction being disturbed for more than 25 to 35 times the mining height were small. This thickness guideline is based on the concept of a constrained zone. That is, when total extraction occurs, cracks and joints open at the surface and at immediate roof, but if overburden is thick enough, then natural restraint prevents the intermediate overburden from fracturing, that is, the induced stress is absorbed or resisted without fracturing taking place.

Based on additional data, another USBM research study, titled “Criteria for Determining When a Body of Surface Water Constitutes a Hazard to Mining” (Engineer’s International, 1979), recommends thicknesses of cover greater than 60 times the mining height when the mining height is less than 7.5 feet. For example, this report recommends that the thickness should be 71, 80, 95, and 117 times the mining height for mining heights of 6, 5, 4, and 3 feet, respectively. This report also recommends that, where inflow can be tolerated, the thickness of cover could be

reduced if certain types of strata are present, such as claystone or shales, which are less prone to cracking and of low permeability. The report should be consulted for additional details.

There are a number of subsidence prediction models available, such as “Surface Deformation Prediction System (SDPS, Virginia Polytechnic Institute and State University), and “Comprehensive & Integrated Subsidence Prediction Model (CISPM, West Virginia University). Such programs can be used to estimate the amount of surface subsidence and ground strain induced by mining. Two cautions are offered concerning the use of these types of programs. First, they should only be used for the type of topography and mining conditions that they are based on; and secondly, the strains indicated by these programs typically represent average values and do not account for strain concentration along one or more existing discontinuities. Concerning the second point, studies have shown that topography may have a substantial effect on the development of horizontal strain. Furthermore, where there is less confinement, such as on hillsides, and highly weathered and fractured material, as may be found with mining at shallow depths, the strain that is induced by the mining may be more likely to accumulate on one or more of the joints, rather than being more evenly distributed. This could be significant in a breakthrough potential case where open joints can provide paths for seepage.

Experience has shown that there can be cases where subsidence cracks connect to the surface even when mining is relatively deep. In Utah, there was a case where with 900 feet of overburden, surface tension cracks were found to connect to the mine workings. This case involved massive sandstone and the mining was located near a cliff. Designers should consider the potential for cracks to connect to the mining, especially where there is a high percentage of sandstone in the overburden, and where zones of high tensile strain are created, such as where pillars are split or removed adjacent to coal barrier pillars, or where, as in the Utah case, there is significant topographic relief.

In summary, when total extraction mining is conducted, the strata above the mining and the surface are affected, regardless of the mining depth. The impact of tensile strains and strata disturbance on breakthrough potential needs to be considered. Guidelines are available for the thickness of strata needed to minimize the chances for a significant, direct connection between the surface and the mine workings. Subsidence prediction models should be used with caution.

Failures Related to Auger Mining: A situation that must be considered is whether a breakthrough can occur through auger holes, through the coal left at the end of auger holes, or as a result of the collapse of auger holes. The importance of locating auger holes, during the site investigation phase, cannot be overemphasized. The holes may be hidden if the area that was augered was backfilled. If auger holes are not discovered and taken into account in the impoundment design, then seepage pressures can cause backfill to fail into the auger hole. If the auger holes are connected to the mine, then a direct path for a breakthrough would exist. Or, the back end of auger holes may come close enough to the mine workings that the remaining coal may fail in a shear or punch-type failure. Finally, the thin webs of coal between auger holes may be marginally stable, and may collapse and cause ground deformations that could lead to a breakthrough. All of these scenarios must be considered, and accounted for, when there is auger mining near a site.

Hillside Movement or Disturbance: Hillside movement and disturbance (landslide, creep, or human impacts) are the natural or man-induced impacts on the surface soil and rock at and above the coal outcrop. Weathering reduces the strength of the surface soils and rocks while gravity provides a driving force to move the soil and rock down the hillside. Man can accelerate the process considerably by removing soil and rock from the hillside, causing landslides. Or man can excavate material from a hillside to create a roadbed or diversion ditch. Any movement or removal of soil and rock from the hillside can reduce and/or disturb the coal outcrop and rock barriers between the underground mine and the impounded slurry and/or water. They can contribute to the occurrence of a sinkhole, internal erosion, or shear-type failure.

Note on Seepage Analyses

Seepage forces and water pressures are normally critical factors in determining the potential for a breakthrough. Finite-element programs are available to assist in the analysis of seepage from impoundments into barriers and mine workings. This type of seepage analysis can be a valuable tool in showing the potential for seepage flow, gradients and hydrostatic pressure. However, the results should be used with caution because they can be extremely sensitive to the input parameters, such as permeability. Permeability values are difficult to determine with confidence from small-scale samples and limited field testing. Also, a false sense of confidence may be gained from the simplified or idealized models, whereas in the actual case, even a limited zone of differing permeability could result in a significantly more critical condition. The designer should keep in mind that only one area of weakness in the material separating the mine works from the impoundment basin can lead to a progressive failure and the loss of a substantial amount of the basin contents into the mine workings.

Construction of an impoundment over or adjacent to underground mine works will result in seepage of additional water into the mine works in virtually every case, no matter what steps might be taken to seal the basin. Each situation should be evaluated to determine if the additional water introduced into the mine will cause harm, such as from coal outcrop blowouts, mine discharges of unacceptable water quality; or the unacceptable buildup of water against ventilation seals, bulkheads, or barrier pillars.

Potential-failure evaluations

Each of the failure mechanisms discussed above should be evaluated. The site investigation should provide the information for the evaluations. The individual factors for each failure mechanism should be used to identify critical areas and cross-sections for specific analysis (i.e. shallowest overburden depth, smallest outcrop barrier, deepest soil zone, road-cuts, etc.). Historic conditions in the underground mines relative to roof falls, fractures, faults, hillseam fractures, floor heave, secondary mining, subsidence areas, planned subsidence areas, etc. should be highlighted and incorporated into the evaluation. All efforts should be made to determine the critical parameters, and conservative assumptions should be made for any information that can't be determine with a high level of confidence. The professional engineer performing the evaluation needs to be familiar with the concepts of geotechnical engineering including dam safety, subsidence, seepage, piping, rock mechanics, pillar strength, etc.

References

Gray, R.E., Bruhn, R.W., and Turka, R.J., "Study and Analysis of Surface Subsidence Over the Mine Pittsburgh Coalbed," U.S. Bureau of Mines Contract No. JO366047, 1977.

Kendorski, F.S., Khosla, I., and Singh, M.M., "Criteria for Determining When a Body of Surface Water Constitutes a Hazard to Mining," U.S. Bureau of Mines Contract No. JO285011, 1979.

U.S. Bureau of Mines, "Results of Research to Develop Guidelines for Mining Near Surface and Underground Bodies of Water," Information Circular 8741, 1977.

U.S. Bureau of Mines, "Hillseam Geology and Roof Instability Near Outcrop in Eastern Kentucky Drift Mines," Report of Investigation 9267, 1989.

VI. Basin Design Measures to Prevent Breakthroughs

Where the site investigation has indicated that mine workings are located in the vicinity of the impoundment, engineering analyses must be conducted to evaluate whether or not an adequate margin of safety exists against a breakthrough. If, considering the level of uncertainty about the information, the margin of safety is considered inadequate, then compensating or remedial measures need to be designed, or an alternative site found. Prevention measures could include some combination of the following: providing a “safety zone” around the impoundment; providing support by backfilling portions of the mine; improving the in-situ materials by grouting; constructing an engineered barrier; isolating the reservoir from the area of influence of the mining; constructing secondary defense measures, such as bulkheads, to contain a breakthrough within the mine, and other engineered measures that would control seepage and reduce pressures in the areas of potential breakthroughs. The main prevention measures are discussed below.

Use of “Safety Zones”: Obviously the best way to prevent a breakthrough is to keep any mine workings located far enough away from the impoundment that any mining-induced ground disturbance cannot cause a breakthrough. That is, to leave an unmined “safety zone” around the impoundment. Or, if mine workings are already close enough to potentially cause a problem, to backfill these workings to re-establish a “safety zone” and minimize adverse effects. As previously mentioned, guidelines on the size of “safety zones” around impoundments are provided in “Results of Research to Develop Guidelines for Mining Near Surface and Underground Bodies of Water,” (USBM IC 8741). Additional information can be found in the report “Criteria for Determining When a Body of Surface Water Constitutes a Hazard to Mining.” The plans for all existing and future impoundments need to include limits on future mining near the impoundment, such that the potential for a breakthrough is not created or increased.

Mine Backfilling: Filling previously-mined areas with grout or other stowing material may be a necessary remedy when the thickness and characteristics of the overburden or barrier cannot be relied on to prevent a sinkhole, subsidence cracks, or other breakthrough failure mechanism. In such cases additional support can be provided by backfilling the critical areas.

The grout, or other backfill material, must have the needed strength to support the weight of the overburden, including the impoundment loading, plus any transfer of loads from previous mining in overlying coal seams. The extent of the backfilled or stowed areas must be sufficient to support the overburden or hillside to be inundated by the impoundment pool, or to protect an existing or planned mine seepage barrier from adverse subsidence effects. The mine openings should be totally filled and boreholes should be used to determine if the program was successful. The boreholes can be used to obtain grout samples from the mine for strength testing, to secondary grout to fill voids due to grout shrinkage, or to provide access for borehole cameras to evaluate the success of stowing programs.

When backfilling is proposed, subsidence and/or pillar analyses need to be conducted to substantiate that the backfill strength and area will be adequate. The angle-of-draw needs to be considered so that support is provided to all critical areas. The design needs to specify the

strength of the backfill material; the area to be backfilled; and the methods to check that the design intentions for strength and area of backfilling are met.

Stowing Mine Openings in Basin Area: It has been common practice in the past to seal mine entries into the basin by stowing them with competent rock or other fill, in conjunction with constructing an earth or coarse coal refuse embankment on the outside against the openings. This approach can also be used with auger holes. The openings should be filled far enough back into the mine to prevent adverse subsidence or sinkholes from developing to the surface in the basin. The outside embankment must be protected by appropriate geotextile or graded filters to prevent piping into the mine, open joints, and the stowing material. Drains should be installed as needed to reduce the hydrostatic pressure in the area. The system of the stowed material and outside embankment must be designed to have sufficient strength and extent to resist a shear or “punching” failure into the mine by hydraulic and earth-load forces. It must also be of sufficient size and material gradation to provide a seepage resistance path that will prevent failure of the embankment, stowed material, or adjoining strata by piping or hydraulic fracturing into the mine. If a coarse coal refuse embankment is to be constructed over top of a sealed opening, the exposed coal seam must first be covered with clay, or other inert material, to provide a fire barrier. If water drains out of the mine from an opening that is to be sealed, it may be necessary to provide a drain to prevent water from building up in the mine. In such cases, the designer must take special care to install a drainage system that will release the mine water while preventing hydrostatic pressures from causing problems with saturation, piping, or instability of the impounding structure.

Impervious membranes have been used in conjunction with mine opening seals, by incorporating either solid plastic or rubber liners into a zone of fill material. If used, the membranes should extend a sufficient distance on all sides of the opening to provide an effective barrier. Such membranes should be surrounded by a layer of finer-grained, cushioning material to prevent puncture by sharp rocks that may be present in the embankment or highwall.

If the openings are accessible to workers, or can be rehabilitated so that they can be safely accessed, form-work or bulkheads can be constructed in the mine to contain the stowed material to the desired depth in the mine. Workers can enter the mine to install grout pipes or do other needed work. This approach has successfully been used for both the pneumatic stowing of gravel, followed by grouting of the gravel, or the installation of a grouted rock plug. If the mine opening is not made accessible to workers, rams mounted on heavy construction equipment have been used to pack the stowing material into the openings.

In addition to filling the mine opening, hillside fill should be placed adjacent to and in the vicinity of where the outcrop barrier is narrow or where the overburden above the openings is inadequate. Ideally, the hillside fill should consist of a non-dispersive clay material. Between the original ground and the hillside fill, an internal drain should be installed. The drain should consist of a gravel-type material wrapped in a permeable geotextile or surrounded by a graded filter. The purpose of the drain is to minimize hydraulic pressures against the hillside. When using a geotextile for a filter layer, the fabric must retain the protected soil to prevent piping, have sufficient permeability to prevent a build-up of water pressure, not become clogged, and have sufficient strength to survive the construction procedures. In general, a geotextile should be selected with the largest opening size (maximum flow capacity), that still meets the

soil retention requirements. Likewise, if a graded filter drain is used in lieu of a geotextile, it must be specified with a material sized to prevent migration of the base soil into the filter layer and provide adequate permeability.

When evaluating earthen seals, the integrity of the seal is also a function of its ability to resist soil piping, or the migration of particles with the seepage water. Such internal erosion can lead to a blowout of the seal. A piping evaluation involves a comparison between the expected hydraulic gradient (head losses per unit length) and the critical gradient, or the gradient that would cause particles to be displaced with the flow. In a situation involving an earthen dam, it is common practice to provide a factor of safety of at least three against a piping type failure. Added precautions may be needed in an earthen seal application, where the material can be more prone to piping, because the seepage forces may be horizontal, and the seal material, at the point where the seepage exits, may be in a loose condition.

Construction of Bulkheads: Construction of bulkheads, inside the mine or at mine portals to the outside, may be a feature of a breakthrough prevention program. They are designed to withstand fluid and/or earth pressures. They may be relatively thin structures made of concrete reinforced by structural steel, a relatively thick plug of concrete, or made of other plug materials such as grouted gravel or polyurethane foam.

In certain situations, such as where there is uncertainty about the level of breakthrough protection that otherwise is provided, bulkheads may be constructed as a secondary line of defense against the discharge of water or slurry out of a mine. Designers need to consider, however, that impounding water or slurry in a mine creates the potential for a blowout of an outcrop barrier or bulkhead, and that risk needs to be considered and evaluated. Further information on bulkheads is provided in a separate section of this report.

Construction of compacted earthen barriers on the surface: One design measure that has been used, in breakthrough potential situations, is to construct a barrier of compacted earthen fill around the inside of the reservoir area. A fill barrier can provide additional bulk between the impoundment and the mine workings, and, when provided with properly designed internal drainage, can lower the water pressure against the outcrop barrier. The water pressure can be reduced if internal drains act to draw down the saturation level in the fill and provide a place for the seepage to discharge to a safe place, in a controlled fashion. Compacted earthen barriers can be placed, and raised as the impoundment level rises, to keep the impoundment pool from ever being above or within a draw angle, of the mine workings.

One precaution is that where the combination of cover and overburden characteristics indicate the potential for a sinkhole, construction of a surface barrier should normally not be considered to take the place of measures to prevent sinkhole development. That is, the approach of placing fill material on the surface above the potential sinkhole, with the idea that the fill will collapse into and choke off the sinkhole should it develop, should normally not be relied upon. If a sinkhole does form, there is no way to guarantee that the fill material above it will not just be eroded away and allow the contents of the impoundment to discharge into the mine.

There are a couple of approaches that can be used for constructing a compacted barrier as a breakthrough prevention measure. One approach is to surface mine any seam in the reservoir

vicinity that is known or suspected to have mine voids. In this approach, the operation would often be looking to “daylight” the mine voids and expose any known or unknown workings near the outcrop. This method also serves to ensure that the earthen barrier is founded on a competent rock bench and may provide competent rock for underdrains, for diversion ditch channel linings, and other construction purposes. Any weathered or fractured strata near the coal seam outcrop are removed through the surface mining process prior to constructing the earthen barrier.

The second approach is to construct the barrier over the existing coal seam outcrop without surface mining the seam. In this case, there may be exposed highwall if the coal seam has previously been surface-mined, augered or highwall-mined, or there may be an undisturbed outcrop that has not been affected by surface mining. The following points relate to the construction of compacted barriers.

1. Material Properties

The barrier should be designed using the same principles as embankment dam construction, with the configuration depending on the shear strength and permeability properties of the available materials. The available material is normally either coarse coal refuse, or spoil. Typically, a relatively impervious material should be used for the fill, or a zone of less permeable material should be incorporated, like is done in earth dam design, with either an upstream impermeable liner, or an internal impermeable core. Just as with the design of embankment dams, internal drain materials need to be durable and free-draining.

Designers should consider the option of incorporating flyash or bentonite to create a zone of low permeability. Flyash could be used as a zone within the fill, or mixed with other material. The type of flyash that “sets up” should be used to provide strength and piping resistance. Bentonite has been mixed with coarse coal refuse to create low permeability zones in barriers embankments. If the coal seam has underground workings, the potential for the impervious seal to be affected by subsidence would have to be taken into consideration.

The fine coal refuse deposited in a slurry impoundment typically has a relatively low permeability and will tend to seal the bottom of the reservoir as it accumulates. However, since there is typically a pool of water above the level of the settled fines, the fines should not be relied on, by themselves, to limit seepage into a compacted barrier. Plans which rely on the distribution of the fines for seepage control should be viewed with caution, and more positive means of primary seepage control should be provided.

2. Foundation Preparation

Vegetation and other unsuitable material should be removed so that compacted barriers are constructed on a firm foundation. Consideration should be given to stripping the foundation to bedrock so that pre-existing subsidence cracks, or open joints, can be discovered and filled by grouting. Stripping the foundation may also have the benefit of removing soils that have the potential to pipe into subsidence cracks, or open joints, that may develop in the future.

Some consultants have used geogrids in conjunction with the construction of seepage barrier embankments in the impoundment basin. The geogrids have a geotextile attached to them,

and can be placed over the foundation of the embankment to bridge potential future subsidence cracks. A detailed subsidence analysis is needed in order to select a geogrid which has the ability to bridge the predicted crack widths under the maximum embankment loading, and to withstand the predicted strains with a conservative safety factor. An important design consideration is that the slope and physical characteristics of the foundation upon which the geogrid will be placed should be prepared to meet the manufacturer's recommendations. Proper foundation preparation and placement of a geogrid can be very difficult on steep slopes.

3. Internal Drainage Provisions

Drains in compacted earthen barriers should be designed and constructed with the same type of specifications as used for the internal drains of embankment dams. That is, analyses should be provided to show that the drain is adequately sized and sloped to handle the discharge, and to demonstrate that filter criteria is met wherever flow occurs from one material into another. Due to the possibility of partial clogging, and the uncertainty associated with permeability measurements and seepage estimates, it is good practice to design internal drains to handle at least 10 times their anticipated flow rate.

The construction of the internal drainage within the impoundment basin is critical in keeping the phreatic surface from building up within the barrier, causing increased pressure on the mine seal. The internal drain network is generally constructed of competent rock obtained on-site, sized according to its filtering capability and flow capacity. Some drains consist solely of rock wrapped with a geotextile or other filter material, while other drains may incorporate a perforated plastic pipe, surrounded by the rock. Additional internal drains are added, as necessary to reduce the water pressures, as the barrier is increased in height. The drains need to discharge into an open channel spillway or diversion ditch, thus routing the drainage away from the embankment.

4. Stability of the Compacted Barrier

Stability analyses should demonstrate that compacted barriers have adequate factors of safety. Good practice is to provide factors of safety of at least 1.5 for static stability and 1.2 for pseudo-static stability. Where liquefaction may cause a barrier to become unstable, such as if a portion of the barrier is founded on settled fines, seismic stability should be investigated. For safety of construction personnel, the stability of barrier out-slopes, under the anticipated surcharge loading of construction equipment, should also be considered. If the barrier is founded on settled fines, the rate of construction may need to be closely controlled to prevent excess pore pressures from causing stability problems.

5. Construction Specifications

In constructing a barrier on the surface, complete construction specifications should be provided, just as would be required for an earthen dam. These include the following:

- a. Lift thickness – the earthen material placed around the inside of the reservoir should be placed in lifts that are thin enough to allow adequate compaction to be achieved. Lifts

should be horizontal and should be placed going from the lowest to the highest elevation. For structural portions of a barrier, typical good practice is to compact fine-grained material in lifts no thicker than 8-inches, and coarse refuse in lifts no thicker than one foot. Rockfill may be placed in thicker lifts, depending on the circumstances.

b. Compaction specifications should be provided. Compaction specifications typically call for a maximum dry density of at least 95 percent of the maximum Standard Proctor dry density. Moisture content is typically specified as in the range of -2% to +3% of optimum Standard Proctor moisture.

c. Underdrain material – The type of rock and the gradation would need to be specified, as well as the filter layer, or geotextile, used to prevent piping into the drain material. Provisions for the outlets of the drains to discharge to a safe place, in a controlled fashion, need to be provided.

d. The extent of the primary sealing material would need to be delineated, as well as the lateral extent of the seal along the coal seam outcrop, and the cross-sectional width and the depth of the seal above the coal seam elevation.

e. Provisions for the quality control, to ensure that the barrier is constructed as intended by the designer, should be spelled out in the specifications.

f. This approach should always include a monitoring plan with provisions for recording the outflow from the drain and with a sufficient number of piezometers to verify that the drainage network is working as intended.

Note on Surface Mining Through Abandoned Mines: Contour surface mining along the basin through abandoned or active underground mines can be considered to achieve the following: create a bench to be used as a competent foundation to construct a seepage barrier embankment, expose the underground mine so that the extent of the mining adjacent to the basin can be established and suitable measures designed, and create a highwall of competent rock of sufficient height to prevent undesirable mine subsidence or sinkhole development. However, a hazard to miners due to highwall instability can exist, when using this method, if mine entries which parallel the highwall are encountered when making the contour cut. In this case, there could be an entry running parallel to, and either at, or only a few feet behind, the face of the highwall, meaning that the toe of the highwall would either be cantilevered over the entry, or only be supported by a thin section of coal. In either case, there would be a significant potential for the highwall to be unstable.

Conversion to Slurry Cells: An approach that may be taken to reduce the breakthrough hazard is to convert from a full slurry impoundment into a slurry cell configuration. Small, individual cells are created using compacted coarse refuse. The number of cells that can be active (not capped with backfill) at any given time is usually limited in size and volume to the amount of storage that will result in a low-hazard potential classification for the facility. The benefit is that the coarse refuse dikes and covering layers, combined with the thin layers of fines, allow the fines to dewater and consolidate, making the total mass less flowable. Furthermore, with the fines compartmentalized, a problem at one location is less likely to affect the entire facility.

It has been common practice to design a “structural shell” as the downstream containment structure for the cells. The structural shell is designed much in the same manner as a dam with the required width, slopes, benches, internal drainage system, and embankment-material strengths, to achieve the required safety factors for slope stability. Slurry cells seem to work most efficiently when the depth of fines in the cells is kept relatively shallow, preferably to five feet or less. At this depth, the fines can usually drain and dry out enough that they can be efficiently covered with coarse refuse.

Some disadvantages of cells are: frequent construction of diversion ditches, new cells, and cell spillways is necessary as the site increases in height; a relatively large ratio of coarse refuse to fine refuse is required; and close planning and supervision of the site is needed to ensure that the construction, filling, and backfilling of cells is accomplished in the proper sequence to make the system work as intended. Also, once a slurry cell site is large enough that it is classified as having high-hazard potential, then the facility’s spillways would need to be designed to handle the runoff from the probable maximum flood.

Sealing Sources of Leakage: Open joints or cracks in the foundation of a dam, or in the basin area, should always be grouted or otherwise treated to prevent them from transmitting high hydrostatic pressures, and to eliminate potential paths for internal erosion. A measure that can be taken to provide additional protection against leakage is to deposit fine coal waste (slurry) in a manner that it provides another layer of material between the pool and potential seepage-problem areas. This technique has been used successfully to reduce leakage through abutment areas or along the perimeter of the pool. The long-term benefit of this secondary measure is limited to situations where the bedding planes or joints are relatively small and the sand-sized portion of the slurry is sufficient to result in the gradual formation of a natural filter in the openings and the eventual sealing of the openings by the clay and silt-sized particles. If a seepage problem develops after an impoundment is constructed and the technique of distributing the slurry upstream of the seepage area doesn’t correct the problem, then grouting, construction of an impervious liner, or other measures, need to be taken.

Stabilization of Fines: The potential for a breakthrough of the contents of a slurry impoundment into mine works could be lessened significantly by stabilizing the fine refuse. That is, treating the fines to increase their strength and/or reduce their water content. Thickening of coal-waste fines has sometimes been accomplished, for example, by the addition of Portland cement. Work is currently being done to develop other stabilizer additives. Some information on additive development is provided in “Design Alternatives for Refuse Disposal”, by Steve Fiscor, Coal Age, May, 2002.

Although not for the purpose of breakthrough mitigation, a portion of a slurry impoundment in Pennsylvania was stabilized in place by shallow and deep mixing with flyash and cement grout. The stabilized fines were then used as the foundation for a highway embankment that crossed the rear end of the impoundment. The volume of stabilized material, in this case, was approximately 200 acre-feet. For additional information, see “In-Place Solidification of Coal Tailings for Expressway Subgrade,” Bazan-Arias, Michalski, Glogowski, and Howard, Tailings Dams 2002, Association of State Dam Safety Officials.

An approach that might be proposed, for an existing impoundment, is to show that the settled fines have consolidated and gained strength to the point where they will not flow. Whether settled fines will flow depends on such factors as its degree of consolidation and cohesive strength, the state of the pore-water pressures, the potential for excess pore-water pressures to be induced, and the size of the opening available to it. Just because a soil is shown to be at or below its liquid limit does not, in itself, demonstrate that the material will not flow. The liquid limit is simply the water content corresponding to an arbitrary boundary between the “liquid” and “plastic” states of a soil. It indicates nothing about how the soil will behave when bridging an opening with the pressure of the contents of an impoundment above it, or when excess pore-water pressures are induced. A change in conditions within the impoundment, such as additional water due to a large storm, could help liquefy the fines and result in an unplanned release of slurry and water through underlying or adjacent mine works. Additionally, if a subsidence event occurred under saturated, hydraulically placed fines, the sudden increase in shear stress in the fines would induce increases in pore-water pressure that could trigger “static liquefaction” and cause the fines to flow. For these reasons, this approach would be difficult to justify. The potential for static liquefaction may, however, be reduced if the fine coal refuse can be drained. Partially saturated fine refuse would be more apt to densify under load, and would be more resistant to liquefaction. (For additional information on “static liquefaction,” see “Static Liquefaction of Tailings - Fundamentals and Case Histories,” by Michael Davies, Todd Martin, and Ed McRoberts, Tailing Dams 2002, Association of State Dam Safety Officials, May, 2002, Las Vegas, NV.)

Induced Subsidence: In some cases, the presence of old, unmapped, or poorly mapped, underground mine works may require consideration of collapsing the area by controlled blasting. This could prevent future mine subsidence from inducing cracks or sinkholes, or compromising planned mine seepage barriers. Not all rock strata are suitable for this approach. To determine if this technique could be applied to a particular site, a geologic investigation should be conducted to determine the character of the strata and to obtain samples to test for rock soundness and resistance to degradation over time.

If this approach is considered, a representative test area should be blasted, and the area should be excavated to determine if the blasting design parameters achieved the desired effect. The area treated by this approach will result in a zone of fractured and blasted rock between the basin and the remainder of the mine which should be required to meet standard gradation criteria to prevent piping or erosion of the fill into the mine. The resultant rockfill should be protected by an overlying layer of finer-grained fill underlain by any required graded filters, or geotextiles, to minimize the amount of seepage that can enter the rockfill and the mine. This approach can eliminate or reduce the extent of mine areas requiring grouting or stowing, the need to surface mine through the area to obtain a highwall of competent material sufficient to prevent subsidence, or the need to try to seal mine openings of unknown extent.

Safety precautions need to be taken such as gas sampling in the mine to insure that a mine explosion will not occur as a result of the blasting. A thorough study needs to be conducted to ensure that the blasting will not have detrimental effects on adjacent underground mines or surface facilities. Obviously, this approach should only be taken with a great deal of caution and should only be considered with the advice of persons with expertise and experience in dam safety, explosives, and the blasting characteristics of the local materials.

A reference on this subject is “Blasting as an AML Reclamation Method,” by J. L. Workman and P. C. Satchwell, September, 1987. This two-volume report was prepared under contract to the Office of Surface Mining, Department of the Interior.

Monitoring Provisions

Wherever the potential for a breakthrough exists, critical parameters should be identified and a monitoring program should be put in place that will show whether or not the barrier /overburden is performing as anticipated. Monitoring could include piezometric levels, discharge rates from mine workings, discharge rates from drains, seepage quantity and quality, water levels in the mine, ground movement, rainfall, etc. The acceptable range, and warning or action levels, should be established for all monitored values. Monitoring programs should include requirements to have the data plotted and evaluated, in a timely manner, by an engineer familiar with the design of the facility. It is good practice to plot monitored parameters on the same graph to check whether the trends over time make sense, and to allow for unusual conditions or trends to be recognized.

VII. Bulkhead Seals in Mine Entries or in Mine Openings at Coal Seam Outcrops

Bulkheads, also known as hydraulic seals, may be installed across mine entries underground, or in mine openings at coal seam outcrops, for a variety of reasons. Normally, bulkheads are installed across mine entries underground to control groundwater in abandoned workings, to prevent rapid inundation of active mine areas in the event of a breakthrough, or to serve as a retention dam in an underground disposal system for fine coal waste. At coal seam outcrops, bulkheads have typically been used to prevent access and to control acid mine drainage. Bulkheads have also been installed at outcrop openings located within the footprint of an embankment dam, or within the reservoir of an impoundment, to prevent stored water or slurry waste from flowing into active or inactive underground mine workings.

Even seals that are designed with drainage pipes, to prevent water buildup, may become bulkheads when the pipes become blocked or clogged, or when inflow rates exceed outflow rates. Also, when coal barriers are deemed to be too narrow, bulkheads may be added on the mine side of the barrier to enhance the safety of the condition.

The hazards associated with constructing bulkheads across mine entries or openings should be carefully considered. Design considerations should include: site preparation, seal type selection, design load assessment, structural resistance (of both the bulkhead and surrounding strata), and safety monitoring provisions

Site Preparation

As problems with bulkheads are often associated with seepage along the bulkhead and rock interface, or through the surrounding strata, the nature of the rock at the bulkhead location is important. To the extent practical, bulkheads should be located in the most competent and least fractured area (normally away from pillar corners), so that these types of problems can be minimized. When investigating the strata at a bulkhead location, the information gathered should include the type and strength of the rock in the immediate roof and floor, as well as the strength of the coal ribs. Any information related to roof falls, pillar punching, floor heave, pillar burst, or any other unusual conditions in the area where the bulkheads are to be installed, should be evaluated. The coal pillars adjacent to the bulkheads should have a high factor of safety against failure taking into account all loading factors, such as the transfer stress due to overlying or underlying mining.

The investigation should also attempt to locate fractures or joints in the surrounding rock. One means, other than visual, is the use of geophysical techniques to locate rock discontinuities. Subsidence and potential sinkhole formation over the entry should also be investigated. If joints, fractures, or subsidence cracks are present, then chemical or cement-based grouting measures will need to be taken to minimize seepage pathways that could lead to piping problems or deterioration of the strata. To maintain the integrity of a bulkhead, a complete grout curtain should be constructed around its perimeter. In addition to grouting, any loose, cracked, and weak floor, roof, and rib should be removed. Regardless of the bulkhead type, if the surrounding material consists of weathered or soft rock, then piping (internal erosion) and hydro-fracturing of that material should be considered.

It is common for the mine floor to be a claystone or fireclay material. When subjected to water, this material breaks down from a rock-like material to a soft soil. On a micro-level, the presence of water molecules causes the clay's electrostatic charge to break down. This results in dispersion of the clay, which is a loss of its cohesive strength. The dispersed clay particles can then be eroded away by seeping water. For this reason, it is imperative that claystone and fireclay floors be removed beneath the footprint of a bulkhead. Trenches should be extended down to a hard competent rock. While trenching can minimize a floor failure directly beneath the bulkhead, it will not protect against water seeping under the adjacent pillars. One means of adding protection for the clay under the adjacent pillars is to excavate floor trenches through the fireclay or claystone layer along the edges of the pillars on the downstream (outby) side of the bulkhead. These floor trenches should then be filled with a seepage-resistant material, such as a cement-based or polyurethane foam product.

Hydraulic fracturing is also a concern with maintaining the integrity of a bulkhead system. This type of fracturing can occur when pressure from seeping water is great enough to cause strata cracks to widen and grow. When coal is mined to create an entry, the stress relief can cause stress fractures to occur, or natural discontinuities to open in the mine roof, ribs, and floor. In particular, the floor heaves upward in some mines. This opening up of the strata makes it particularly susceptible to additional hydraulic fracturing when seepage pressures become elevated. Strata grouting, and sufficient hitching into competent material, are means of mitigating the potential for hydraulic fracturing.

Prior to construction, additional roof support should be provided near the bulkhead location, both inby and outby. This would include additional roof bolting, posts, and especially cribbing. Soft floor should be removed before installing posts and cribbing. Notching of the bulkhead into the surrounding strata is recommended. The notch will provide a longer flow path for any seepage, and will increase the resistance to a contact failure between the bulkhead and strata. In addition, notching will (in most cases) place the bulkhead in contact with a more competent material, when the loose material has been removed. When roof notching is not feasible, a strong, steel structural-angle section member can be bolted to the roof on the outby side of the bulkhead to provide lateral support. The surrounding strata can also be treated with a low permeable-type coating, such as shotcrete, to increase seepage resistance.

Bulkhead Types

Several types of materials and physical arrangements have been used in bulkhead construction. The materials include: plain concrete, cementitious foam, reinforced concrete, composite concrete and masonry, masonry with pilasters, polyurethane foams, compacted earthen materials, and grouted rock (Figure 7-1). Seal arrangements vary and typically are either long mass plugs with a straight or tapered length, or thin walls with a straight or arched shape (Figure 7-2). Each different type of construction has its own advantages and disadvantages. In general, the longer the bulkhead, the more resistance there will be to seepage and piping around the perimeter.

When cement-based products are used to construct long plugs, consideration should be given to the possibility of heat build-up within the mass (Figure 7-3). This is termed the heat of hydration, and if not considered, the heat can lead to internal cracking within the plug during the

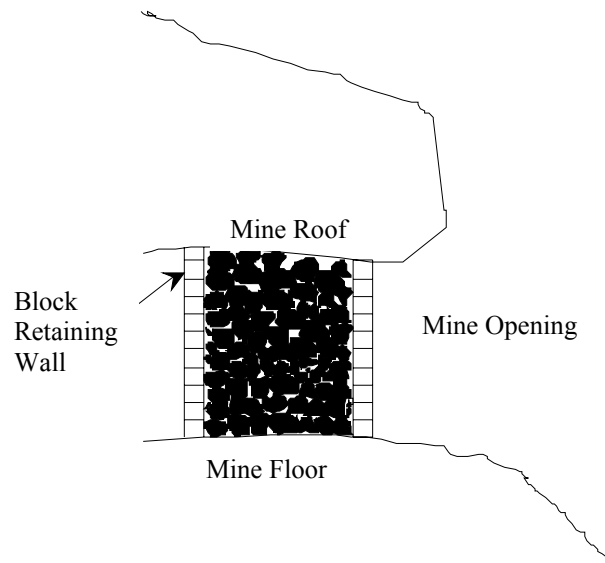
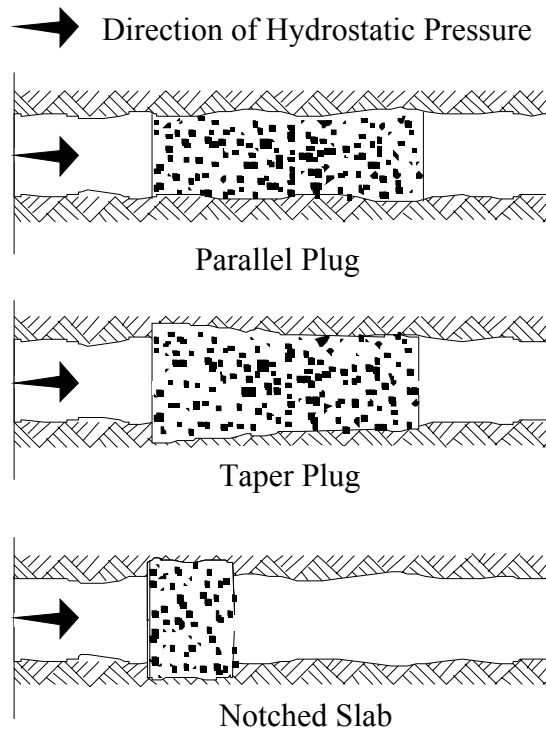


Figure 7-1. Grouted Rock Hydraulic Seal at a Mine Opening



NOT TO SCALE

Figure 7-2. Various Seal Configurations (W.S. Garrett and L.T. Campbell Pitt, 1958)

curing period. Measures can be taken to minimize hydration by using low-heat cements and cooling the mix water. Whatever type of material is selected for the bulkhead, the resistance of that material to deterioration from acid mine water should also be considered. For example, the sulfates in ground water have been known to deteriorate or spall certain types of cements, which are not inherently resistant to sulfate attack.

When formwork is used in bulkhead construction, it should be adequately braced, and vents should be installed at the top of the formwork to release entrapped air and prevent the formation of voids. Further, cement upon final curing can shrink and provisions should be made to use contact grouting, after setting, to fill the void between the strata and the bulkhead.

In selecting the type of bulkhead to be used, consideration should also be given to the likelihood of roof convergence. Some types of materials can accommodate this type of deformation without cracking. For example, low-density cementitious foams, lightweight concretes, and polyurethane foams have some ability to strain or deform before cracking.

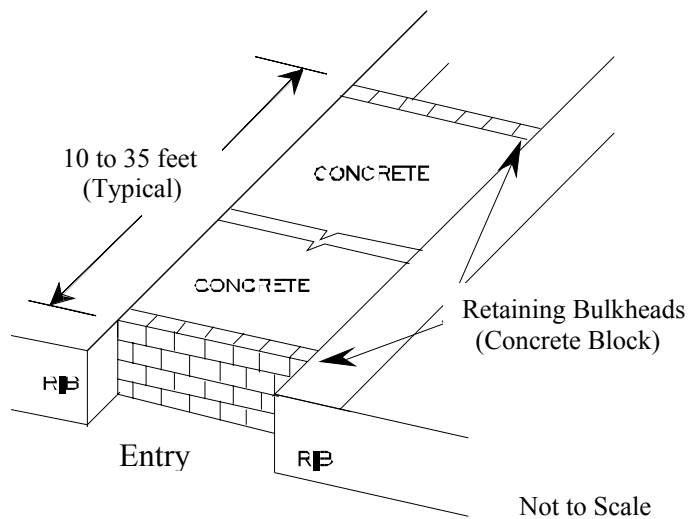


Figure 7-3. Seal Configuration Showing Retaining Walls and Concrete Center (Chekan, 1985).

Design Loads

As with barrier pillars, it is important to accurately predict the maximum design loads on the bulkhead. The hydraulic pressure is governed by the projected head of water behind the bulkhead. This level may be limited by such factors as: other mine drift openings, shaft or borehole openings, flooded overlying mines, flooded adjacent mines with inadequate barrier

pillars, partial height seals located up-dip that act as a spillway weir and divert the water elsewhere in the mine, changes in the mine floor slope which divert water into other parts of the mine, maximum seasonal groundwater levels, or the maximum design storm water level in an overlying impoundment.

The potential water level in flooded overlying mines is a concern if cracks develop in the strata. There have also been instances where flooded mines located beneath the subject seam could dip such that the flood water levels in the seam below are at a higher elevation than the elevation of the bulkhead in the overlying mine opening or entry. In this case, if cracks are present in the strata, then the water level in the underlying mine could control the design head. The inlet elevation of drainage pipes extending through up dip ventilation seals is normally not considered the limiting design water pool level, as it is possible that such pipes could clog. It is important to have an accurate, up-to-date contoured mine map for predicting the design pool level.

In addition to static hydraulic loads, seismic loads may need to be considered if a seal is located in a seismically active area. In this event, the design should consider both the inertial and the hydrodynamic forces that result from an earthquake. Hydrodynamic forces are related to the increase in static pressure caused by accelerating the water mass behind the seal.

As mentioned above, the roof in an entry can exert a compressive load on the top of the seal. This compressive force should be estimated based on experience from convergence, or from the stress that could result from the zone of material within the pressure arch over the entry.

Structural Resistance

Considering the above types of loading, the bulkhead should be designed to have the structural capacity to resist the forces acting on it with a factor of safety consistent with the degree of uncertainty and the consequences of failure. The bulkhead must be able to resist the shear and bending stresses caused by the pressures acting on the face of the seal. The bending stresses in both directions (roof-to-floor and rib-to-rib) can be calculated based on the edge restraints of a plate or slab, and the relative dimensions of width and length (Timoshenko and Woinowsky-Krieger 1959, Young 1989). For thick members relative to span, Young provides guidance on stress multipliers for deep members. In addition to resisting the lateral loads, the seal should have the capacity to resist the vertical bearing loads caused by the mine roof convergence and stress transfer.

For thin bulkheads installed in typical openings with a cross sectional width at least two times greater than the height of the opening, if adequate edge connections are provided at the mine roof and floor, the bulkheads can be designed as a one-way slab spanning between the roof and the floor. Reinforcement to account for temperature and shrinkage stresses would still be necessary in the rib-to-rib direction. Alternatively, and more conservatively, if there is concern that either the roof or floor may not provide adequate resistance, then reinforcing steel in the horizontal and vertical directions could each be sized to independently carry the full bending moment. However, regardless of the width to height ratio, diagonal reinforcement steel should be placed in the bulkhead corners to control cracking from twisting moments. Further, designers are cautioned that despite the load path direction assumed, if the mine roof, floor, and ribs are properly notched, or if the steel bar reinforcing mats near the inby and outby faces are adequately

doweled into the surrounding strata, then it is possible to develop negative moment bending stresses at the edges of the restrained bulkhead slab. The negative steel (that is the steel bars near the inby “wetside” face) should be sized to resist the negative moment bending stresses.

Reinforced concrete structures should be designed in accordance with the most recent version of the American Concrete Institute (ACI) Building Code 318. The code is based on ultimate strength design, which entails applying uncertainty factors to the loads and strength reduction factors to the capacity of the structure. The design strength of the member must be greater than the required strength to ensure a safe design. For fluid pressure, the load factor is 1.4 when the maximum height of the water or slurry is controllable or conservatively estimated.

Flexural Design of Reinforced Concrete Bulkheads

The flexural design strength of a conventional/standard reinforced concrete member is given by the following expression:

$$M_d = \Phi A_s f_y \left(d - \frac{a}{2} \right)$$

where: M_d = flexural design strength, (pound-inches)

Φ = 0.9, strength reduction factor

A_s = area of tension reinforcement (in.²) per unit foot

f_y = yield strength of the reinforcing steel, (psi)

d = distance from extreme compression fiber to centroid of the tension reinforcement, (in.)

a = depth of rectangular stress block at failure, (in.)

$$a = \frac{A_s f_y}{0.85 f'_c b}$$

f'_c = specified compressive strength of concrete, (psi)

b = width of compression face of member, normally taken as 12" for slabs, (in.)

For thicker bulkheads, the above capacity should be modified to reflect deep flexural member behavior. Thicker members have low span to thickness ratios, so the simple theory of linear stress distribution is no longer valid. According to Park and Pauley, for simply supported members with span to depth (thickness) ratios less than or equal to two, the internal lever arm can be calculated as:

$$z = 0.2(l + 2h) \quad \text{when} \quad 1 \leq \frac{l}{h} \leq 2$$

$$z = 0.6l \quad \text{when} \quad \frac{l}{h} < 1$$

where: l = span distance centerline-to-centerline of two bearing points or 1.15 times the clear span, whichever is smaller (in.)
 h = thickness of the bulkhead (in.)
 z = internal lever arm (in.)

Applying the revised lever arm value to the above standard flexural equation, the capacity can be estimated as:

$$M_d = \Phi A_s f_y z$$

The value of “ z ” should not be taken as greater than $[d - (a/2)]$. In addition, if the designer assumes the end supports to be fixed, rather than simply supported, “ z ” values should be further adjusted (see Park and Pauley). Winter recommends that tension steel in a deep flexural member should be distributed over the bottom third of the member depth.

Thick Concrete Bulkhead Plugs

The shear resistance may be governed by the strength of the seal, the strength of the surrounding strata, or by the contact interface between the two. In cases where there is no notching, the interface resistance may be governed by adhesion or friction. The South African plug formulas, which are based on the shear strength and bearing capacity of the bulkhead material and surrounding strata, are often used to evaluate the required length of thick bulkheads (Garret and Campbell Pitt 1961).

$$l = \frac{pab}{2(a+b)f_s}$$

$$l = \frac{pab}{(a+b)f_c}$$

where: l = length of the bulkhead, (ft.)
 p = hydraulic pressure on the bulkhead, (psi)
 a = width of the entry, (ft.)
 b = height of the entry, (ft.)
 f_s = minimum allowable shear strength of the strata or concrete, whichever is lesser, (psi)
 f_c = minimum allowable compressive strength of the strata rock or concrete, whichever is the lesser, (psi)

The designer should consider that the values of f_c and f_s obtained from sampling may not conservatively represent the strength of the de-stressed edges of the coal pillars. Further, the designer should select a required length based on the larger of the values obtained from these two equations. The South African equations are most applicable to high head situations, where the

resulting bulkhead acts as a massive plug. If they indicate a relatively narrow bulkhead, then the bulkhead would need to be checked for adequate flexural strength.

Methods of increasing the resistance along the interface include notching the bulkheads into the surrounding strata, tapering the plug, and/or installing epoxy coated (corrosion resistant) dowel rods into the strata and allowing the rods to protrude into the bulkhead material. The dowel rods should have an embedded length into the strata and into the bulkhead sufficient to develop the strength of the dowel rod without having a bond failure. For size number 11 bars and smaller, the minimum required development length in concrete can be calculated as:

$$l_d = \frac{0.04 A_b f_y}{\sqrt{f'_c}} \text{ but } \geq 0.0004 d_b f_y$$

where: l_d = required development (or embedment) length of bar, (in.)
 A_b = area of the reinforcing bar, (in.²)
 d_b = diameter of reinforcing bar, (in.)

It should be noted that large mass concrete plugs should have some minimal temperature and shrinkage steel placed in all three dimensions: length, width, and depth (thickness).

Shear Design of Reinforced Concrete Bulkheads

While the above equations can be used to evaluate the shear strength of long bulkhead plugs, for thinner reinforced concrete bulkheads, the following expressions can be used to calculate the concrete's design shear strength:

$$V_c = \phi 2 \sqrt{f'_c} b_w d$$

where: V_c = shear strength of the concrete bulkhead per unit width (pounds)
 ϕ = shear strength reduction factor is 0.85
 b_w = unit width of bulkhead (12 inches)

If the above expression indicates inadequate concrete shear strength, there is a more rigorous and exact expression found in the ACI section 11.3. In addition, the contribution of steel reinforcement, ACI section 11.5, could be added to the value obtained for the concrete to get a combined strength of the member.

For thick reinforced concrete bulkheads where the ratio of the clear span distance (l_n , in.) to the depth (d , in.) from the water-side of the bulkhead to the centroid of the tensile steel reinforcement is less than five, section 11.8 of ACI should be applied. As indicated above, it should be noted that the span-to-depth ratios are different for shear design than they are for flexural design.

If lightweight concrete with densities of 100 to 110 pounds per cubic foot are used, the values of V_c obtained using $\sqrt{f_c}$ in the expression should be multiplied by 0.75 for “all-lightweight” concrete and by 0.85 for “sand-lightweight” concrete, as per section 11.2 of ACI.

Safety Monitoring Provisions

Certain precautions can be taken to enhance the safety of a bulkhead. The designer should monitor the construction of the bulkhead to ensure that the field conditions are consistent with the conditions considered in the design, and that the bulkhead is built according to the construction specifications. For example, in preparing an area for a bulkhead, it may be that a couple of feet of loose roof strata has to be removed, making height of the bulkhead greater than designed for in the plan. If the in-mine conditions are found to differ significantly from what was anticipated in the design, then appropriate design modifications need to be made. In addition, for quality control, field samples of the bulkhead construction material should be obtained and tested to ensure that it meets the minimum strength assumptions in the design.

Once an entry has been sealed, no additional pillaring should be permitted near the structure. Additional pillaring could cause redistributions of the overburden stress and/or fracturing of the strata around the bulkhead, opening up seepage pathways. Along with mining near the bulkhead, potential impacts of additional mining in lower or upper seams need to be considered.

The water level behind the bulkhead should be monitored using a pressure gauge so that the actual water level can be compared to the design level. Warning levels should be established which would warrant drawing down the pool or initiating a downstream evacuation. To draw-down the water level, a corrosion-resistant pipe should be installed through the bulkhead with a “U-trap” and a pressure relief valve on the downstream end, and provisions to prevent clogging, such as a riser and trash rack, on the upstream end. The decant pipe should be sized to have adequate capacity to draw-down the water faster than it can build up. Pipes extending through a bulkhead should be equipped with external collars to cut off seepage and prevent a pipe blowout.

One safety measure for regulating the maximum hydraulic pressure is to install an additional pipe through the bulkhead with a rupture disk attached to the downstream end. If the hydraulic pressure reaches the rupture strength of the disk, it will fail and therefore limit the head on the bulkhead. The outlet end of the pipe should project downward to prevent injuries to anyone near the pipe if the disk were to rupture suddenly.

A final safety measure would include establishing an inspection schedule for long-term monitoring of the bulkhead and having an evacuation contingency plan if problems are encountered with the integrity of the bulkhead or surrounding strata.

Summary

The failure of a bulkhead, or the strata around it, can have hazardous downstream consequences, both to the environment and to human safety, not to mention the economic impact. Therefore, it is imperative that a bulkhead be strong enough to resist the anticipated loads, durable to withstand exposure to acid mine water, resistant to seepage, and adequately constructed with all safety measures considered. Due to the inherent uncertainties and potential downstream consequences, it is recommended that bulkhead designers check multiple methods when

designing a bulkhead and select the method that gives the most conservative results. All bulkheads should be designed by a registered professional engineer knowledgeable in the design and placement of fluid retention structures in a mine environment.

References

- American Concrete Institute 1995, "Building Code Requirements for Reinforced Concrete (ACI 318-95) and Commentary (ACI 318R-95)," Detroit, Michigan, 369 pp.
- Auld, F.A. 1983, "Design of Underground Plugs," International Journal of Mining Engineering, 1, pp. 189-228.
- Chekan, G.J. 1985, "Design of Bulkheads for Controlling Water in Underground Mines," U.S. Bureau of Mines Info. Cir. 9021, Washington, 36 pp.
- Dames & Moore 1981, "Outcrop Barrier Design Guidelines for Appalachian Coal Mines," Prepared for U.S. Bureau of Mines, Contract JO 395069, Feb., pp. 26-36.
- Djahanguiri, F., and Abel, Jr., J.F. 1997, "Design and construction of a bulkhead for a simulated underground leaching stope," Mining Engineering, Jan., pp. 57-64.
- Fuenkajorn, K., and Daemen, J.J.K. 1997, "Mine sealing: Design guidelines and considerations," Tailing and Mine Waste '97, Balkema, Rotterdam, ISBN 90 5410 857 6, pp. 59-68.
- Garret, W.S., and Campbell Pitt, L.T. 1958, "Tests on an experimental underground bulkhead for high pressures," J.S. African Institute of Mining and Metallurgy, Oct., pp. 123-143.
- Garret, W.S., and Campbell Pitt, L.T. 1961, "Design and Construction of Underground Bulkheads and Water Barriers," Transactions, 7th Commonwealth Mining and Metallurgical Congress, South African Institute of Mining and Metallurgy, pp. 1283-1301.
- Gray, T.A., and Gray, R.E. 1992, "Mine closure, sealing, and abandonment," SME Mining Engineering Handbook, Littleton: SME, Vol. 1, pp. 659-674.
- Masser, K.R., Kingery, D.S., and Hoadley, D. 1975, "Design of Reusable Explosion-Proof Bulkhead for a Crosscut Refuge Chamber," Bureau of Mines OFR 48-76, Nov., 197 pp.
- The Masonry Standards Joint Committee: American Concrete Institute, American Society of Civil Engineers, The Masonry Society 1992, "Building Code Requirements for Masonry Structures and Commentary," ACI 530-92/ASCE 5-92/TMS 402-92. Also, "Specifications for Masonry Structures and Commentary," ACI 530.1-92/ASCE 6-92/TMS 602-92.
- Park, R., and Paulay, T. 1975, Reinforced Concrete Structures, John Wiley & Sons, 1st Edition.
- Timoshenko, S., and Woinowsky-Krieger, S. 1968, Theory of Plates and Shells, McGraw-Hill Book Company, 2nd Ed., pp. 580.
- Winter, G., Nilson, A. 1979, Design of Concrete Structures, McGraw-Hill Book Company, 9th Edition, pp. 647.
- Young, W., 1989, Roark's Formulas for Stress and Strain, McGraw-Hill, Inc., 6th Ed., pp 763.

VIII. Basin Construction, Operation, and Monitoring

Pre-construction Planning

Perhaps the most important step in the new construction on an impoundment is the pre-construction meeting and preparation. During this period, the operator's personnel, design engineer, regulatory representative, and the contractor in charge of construction, meet to review the plans and specifications. Such planning is especially important with breakthrough potential plans, because the work may involve unusual construction features.

The design engineer is a professional engineer and has been involved with the project throughout the permitting process. Permit applications are lengthy and complex. The design engineer obtaining the permits is informed of critical regulatory requirements from the State Regulatory Authority (RA) or Mine Safety and Health Administration (MSHA) reviewers. The regulatory requirements cover a wide range of technical and administrative topics. Utilizing a different engineer to manage the construction of the impoundment can result in these critical topics being overlooked or ignored.

To ensure design compliance during basin construction, the requirements of the approved plan or permit dealing with Construction Quality Control / Construction Quality Assurance (CQC/CQA), should be reviewed and discussed at the pre-construction meeting. The quality control and assurance aspects of an impoundment plan should be developed during the permitting or approval process in conjunction with the design engineer, mine operator, and the appropriate regulatory agencies. The CQC/CQA plan is defined as follows:

CQC – A planned system of inspections that is used to directly monitor and control the quality of a construction project (EPA, 1986).

CQA –A planned system of activities that provides the owner and permitting agency assurance that the facility was constructed as specified in the design (EPA, 1986).

Integral to the quality control and assurance plan is the defined responsibility of the certifying/design engineer and the basin-construction certification requirements. This component of the CQC/CQA plan must be emphasized during the pre-construction meeting. The certifying/design engineer should check and certify phases of construction as they are completed, and, since basin construction can span decades, annual certification of basin development and operation should be performed, through facility abandonment. The annual certification required by MSHA should address inspection and monitoring of the basin portion of the impoundment in addition to the embankment dam.

At a minimum, basin components that should be certified include:

- Foundation preparation (which can include abandoned or active deep mine stabilization and/or isolation by earthen barriers);
- Erosion and Sedimentation Controls;

- Embankment construction, including internal drainage and seepage control features; and
- Spillway/Drainage Structures.

During the pre-construction meeting as well as throughout construction, detail notes and records should be kept. Detail notes and records will aid both the present operator of the impoundment, and any future operator, if changes need to be made or the impoundment modified. Establishing a report format that is both practical and functional for all parties is also achieved during the pre-construction phase.

It is also very important during the pre-construction meeting that lines of communication are established between all parties. The construction foreman, for example, needs to have the phone number of the engineer-in-charge so that questions that arise during critical construction phases can be properly addressed. What may seem very clear in a permit design may be foreign to a construction foreman or a dozer operator. The reverse is also true that the construction foreman may have an idea that will be more efficient, or provide a greater level of safety.

Basin Construction

Typically, in the past, construction within the basin or reservoir area of an impoundment consisted mainly of clearing trees and brush. However, the breakthrough failure of Martin County Coal Company's Big Branch Slurry Impoundment, and the other recent breakthroughs, have placed a greater focus on construction within the basin area. Mitigative measures may need to be constructed in the basin to provide a prudent level of safety against a breakthrough. As discussed previously, such measures may include construction of barriers around the basin, installation of drains, backfilling of mine workings, or construction of bulkheads in mine openings. Generally, the specifications for any of this work should be prepared to the same detail as for earth dam construction. During construction, the designer, or his qualified representative, should monitor that construction is according to the approved plan and should ensure that approval is obtained for any needed modifications to the design requirements. Documenting the construction provides information that can be extremely important in evaluating problems that might arise during the life of the facility.

Basin Operation

The manner in which an impoundment is operated can affect the breakthrough potential. Measures should be taken, for example, to design and operate the impoundment in a manner that minimizes the amount of free water in the pool. This means that decant raises should be staged to provide incremental rises in the water level. Pumping can also be used to help minimize the amount of water in the impoundment. Mine personnel who work on or around the impoundment should be cognizant of the features of the plan, especially of any unusual operational requirements.

Impoundment designs should not rely on operational procedures, such as the distribution of the slurry, to provide a seepage barrier. Operational requirements that place an extra burden on the preparation plant workforce, may not get the priority that the designer intends, or the design requires.

Breakthrough-Potential Related Monitoring

A site-specific monitoring plan should be developed with respect to breakthrough prevention measures. Monitoring involves both collecting information from the visual inspection of the impoundment and from instrumentation. Coal company personnel who routinely inspect the impoundment, or routinely work on or around the impoundment, should be trained to keep an eye out for potential signs of trouble with respect to a breakthrough. Such personnel should be aware of where underground mining has occurred and where to look for cracks or other evidence of subsidence. Other signs that they should look for include unusual drops in the pool level, the presence of a whirlpool or bubbles in the pool, unusual readings in piezometers; changes in seepage conditions, and changes in water discharges from mine openings, backfilled mine openings, or outcrop areas.

In determining what instrumentation should be installed and monitored, the designer should consider which parameters will be indicative of how the site is performing with respect to the potential failure modes. This way, action can be taken in the event the facility does not perform as expected. The following items should be considered in developing a monitoring plan:

1. Seepage: Seepage from the impoundment should be monitored. This includes seepage through the embankment, through any internal drainage measures, and through underground mines that receive seepage from the impoundment. Weirs should be installed so that flow rates can be easily and consistently measured. If other measures are used, such as measuring flow through a pipe, then the procedure should be standardized so that all measurements, regardless of who takes them, are comparable. Preferably, the same person, or persons following the exact same procedures, should take the measurements.

Monitor both changes in water quantity and quality from seeps and discharges (including mine/pump discharges) that are hydraulically connected to the impoundment pool. It may be especially important to monitor seepage for the presence of fines, that may be an indicator of piping. Note, however, that if water flows through underground mine workings, sediment may drop in pools within the mine.

2. Water Levels: The pool level in the impoundment, as well as water levels in underground mines should be monitored. Changes in these levels that do not “make sense” would be indications of possible problems that should be investigated. If there are bulkheads in the mine, the water pressure against them should be monitored.

Where conditions with respect to breakthrough potential are uncertain, instrumentation should be installed to provide an alarm in the event of a sudden drop in the water level of the impoundment. The alarm can alert mine personnel to check on the situation, and allow for early warning, and emergency response, in the event of a breakthrough failure.

3. Piezometric Levels: Saturation levels and water pressures within the embankment dam, as well as within any earthen barriers, should be monitored to determine whether hydrostatic pressures are within design values, and whether the changes or trends are reasonable. It is good practice to use piezometers that isolate a zone in which the water

pressure is to be monitored, versus using an “observation well.” The disadvantage of an “observation well” is that the measured water level represents the contribution from all layers intersected by the borehole. Thus, it is not possible to distinguish between water pressures occurring at different elevations throughout the borehole, as can be done with a properly designed open-standpipe piezometer, or a closed-system piezometer. In situations where it is critical to be able to measure a rapid or sudden change in pore water pressure, a closed system, such as a vibrating-wire piezometer, should be used.

4. Rainfall Data: It is good practice to install a rain gauge in the vicinity of an impoundment, but it is especially important in a situation where there is breakthrough potential, and discharges from a mine are related to seepage from the impoundment. Rainfall data should be routinely collected in such cases so that it can be determined whether changes in the water flow, or water level, data correlates to rainfall, or may be occurring for other reasons.

5. Ground Movement: Where the potential for subsidence exists in the vicinity of an impoundment, the ground should be monitored for movement. Both horizontal and vertical movement should be measured. Monitoring may be done with surface monuments, settlement instruments, rock strain gauges, inclinometers, or a combination of methods. Surface monuments should be installed deep enough that they are not affected by freeze-thaw action.

The type and frequency of monitoring that is prudent depends on the particular conditions involved at each impoundment. Typically, monitoring is performed during the inspections that qualified company personnel are required to make, per MSHA regulation, on a seven-day basis. When a potentially hazardous condition develops, the MSHA’s regulations require that instruments be monitored at least once every 8 hours, or more frequently if directed by an MSHA authorized representative. Where conditions warrant, more frequent, or even automated continuous, monitoring, should be performed.

Monitoring data is meaningless if it is not plotted and analyzed by a person who is knowledgeable about the significance of the information. Plotting the data is important to enable trends in the data to be detected. It is useful to plot related data on the same graph, and over the same period, to allow the trends of the data to be effectively compared. Plans should include procedures for plotting and evaluating monitoring data in a timely manner.

IX. Evaluation Approach Versus Standard for Minimum Barrier Size

The evaluation and design of impoundments above and adjacent to underground mine workings must take into account various geologic, hydrologic, operational, engineering, and unknown factors. These factors vary from site to site, and as discussed in this report, there are a number of ways that a breakthrough can occur. Furthermore, there are often difficulties with breakthrough analyses because of lack of confidence in how accurately critical parameters can be known. While mine owners and managers, impoundment designers, and regulatory reviewers, all share the same goal of preventing impoundments from breaking into underground mine workings, the mine owner must consider the practicality and economic impact of any breakthrough prevention plan. These circumstances can lead to dilemmas between the various parties on how conservative a breakthrough prevention plan must be.

One approach to this dilemma is to establish conservative minimums for barrier widths and overburden thicknesses, which would be applied in all cases. The problem with this approach is that to cover all circumstances, the selected minimum distances would end up being overly conservative in many cases. So the approach that is recommended is either to use established, conservative “guidelines,” such as those contained in IC 8741, or to show through engineering analyses that each of the potential failure modes have been considered and adequately designed against. In the latter approach, differences in perceptions of the level of confidence or conservatism can lead to differences of opinion as to the adequacy of a proposed design. One way to deal with this problem is for designers to include redundancy in breakthrough prevention plans. That is, the plan should provide multiple levels of protection so that the development of a problem with one aspect of the plan will not cause a failure. In dealing with hydrostatic pressure, for example, a combination of impervious zones to limit seepage, and drainage provisions to collect and discharge seepage under controlled and filtered conditions, is recommended. If breakthroughs are to be prevented, designers need to fully consider the uncertainties and take this type of conservative design approach.

Appendix – Listing of Work-Group Members

John W. Fredland, P.E. Work-Group Chairman
Civil Engineer, Pittsburgh Safety and Health Technology Center,
MSHA, Pittsburgh, PA

Harold L. Owens, P.E. Supervisory Civil Engineer, Coal Mine Safety and Health District
4, MSHA, Mount Hope, WV

Terence M. Taylor, P.E. Senior Civil Engineer, Pittsburgh Safety and Health Technology
Center, MSHA, Pittsburgh, PA

Lawrence J. Trainor, Jr., P.E. Mine Engineer, Division of Technical Support, Office of Surface
Mining, Washington, DC

Donald E. Stump, Jr., P.E. Civil Engineer, Office of Surface Mining, Greentree, PA

Michael Rosenthal Mining Engineer, Office of Surface Mining, Denver, CO

Gary Gilliam Mining Engineer, Kentucky Department for Surface Mining
Reclamation and Enforcement

Charlie Sturey Manager of Program Development, West Virginia Department of
Environmental Protection

Gerald D. Collins, P.E. Technical Services Manager, Division of Mined Land
Reclamation, Virginia Department of Mines, Minerals and Energy

Joel Koricich, P.E. Engineer Supervisor, Pennsylvania Department of Environmental
Protection

Steering Committee

Kelvin K. Wu, Ph.D., P.E. Chief, Mine Waste and Geotechnical Engineering Division,
Pittsburgh Technical Support, MSHA

 Dam Safety Officer, Department of Labor

John R. Craynon, P.E. Chief, Division of Technical Support, Office of Surface
Mining, Washington, DC

Appendix E

Survey of State Activities

With Respect to Scanning and Storing

Mine Maps

The following is a review of the status of State activities with respect to the electronic scanning and storage of mine maps.

ALABAMA: Alabama has approximately 600 underground coal mine maps, none of which have been scanned. (Contact John W. Sandlin, Chief Mine Inspector, Alabama Department of Industrial Relations)

ARKANSAS: The Surface Mining and Reclamation Division, Arkansas Department of Environmental Quality is responsible for the maintenance of coal and non-coal maps. They have about 360 coal maps and an unknown number of non-coal maps. All collected coal maps are on microfilm and have been scanned by the NMMR. (Contact: James F. Stephens)

COLOADO: Colorado has thousands of coal and non-coal underground mine maps, few of which are scanned. (Contact: Jim Cappa, Colorado Geologic Survey)

ILLINOIS: Illinois currently has about 2000 coal mine maps and about 350 non-coal mine maps. All of the maps were microfilmed and scanned by the NMMR in 1999. (Contact Robert Gibson, AML Division for Abandoned Mines)

INDIANA: The Indiana Geological Survey stated that all of their mine maps have been scanned. They have about 4900 coal maps. This represents about 95% of the known abandoned coalmines in the state. They have a few underground non-coal mine maps. (Contact Lisa Webber)

IOWA: Iowa has approximately 2700 underground coal mine maps and 50 non-coal maps. These maps represent about half of the known underground mines in the state. None of these maps have been scanned.

KANSAS: Kansas has about 1100 coal maps on file, all of which have been scanned. This represents about 90% of the known mine maps in the state. (Contact: Mickey Center, Larry Spahn)

KENTUCKY: The KY Dept. of Mines and Minerals in Frankfort indicated that they have over 160,000 abandoned mine maps in hard copy and on microfilm. Only a small percentage have be scanned. Kentucky has also recently passed legislation to permit the release of mine maps to the public. Kentucky's map collection is the largest collection of maps outside the NMMR. (Contact: John Hiatt, Kentucky Department of Mines and Minerals)

LOUISIANA: The Louisiana Geological Survey stated that they have no abandoned mine maps. (Contact: Dale Bergguist, Louisiana Office of Conservation)

MARYLAND: Maryland has about 450 underground coal mine maps, all of which need to be scanned. (Contact: Maryland Bureau of Mines)

MISSOURI: Missouri has about 500 abandoned underground coal maps and 2000 underground non-coal maps. This represents about 10% of the state's abandoned mines. About 10% of the maps have been scanned. (Contacts: David Smith for coal, and Cheryl Seeger for non-coal, Missouri Geological Survey and Resource Assessment Center.)

OHIO: The NMMR recently scanned all of Ohio's 2700 + underground coal mine maps. This represents about 94% of all abandoned underground coal mines. Ohio also has about 1700 non-coal mine maps, which represent about 6% of the known abandoned non-coal mines. (Contact Doug Crowell, Chief, Ohio Geological Survey)

OKLAHOMA: The Oklahoma Dept. of Mines has about 500 underground mine maps. These are original paper or linen maps. None of these maps have been microfilmed or scanned. (Contact Darrell Shults, Oklahoma Department of Mines)

PENNSYLVANIA: Pennsylvania has about 16,000 underground coal mine maps and over 43,000 non-coal mine maps. It is uncertain as to how many underground mines may exist in the state. While most of the coal mine maps have been microfilmed, few have been scanned. (Contacts: Bureau of District Mining Operations, Bill Plassio, Mc Murray; and Bureau of Deep Mine Safety, Bill Bookshar, Uniontown, and Paul Hummel, Pottsville)

TENNESSEE: The State of Tennessee and the Office of Surface Mining have about 950 underground coalmine maps, which represent about 50% of the known coalmines in the state. Few if any of these maps have been scanned. (Contact: Bill Card, OSM Knoxville Office, Barry Miller, Tennessee Dept. of Environmental and Conservation)

UTAH: Utah has about 280 underground coal mine maps and 250 non-coal mine maps. This represents a small percentage of the total number of mines in the state. Few of the abandoned mine maps have been digitized. (Contact: Susan White, Utah Geological Survey)

VIRGINIA: The Virginia Dept. of Mines and Minerals has over 19, 000 abandoned underground coal mines which represents about 40% of the known mines. They also have about 75 non-coal mine maps. About 60% of their maps have been scanned. (Contact: Roger Williams, Division of Mined Land Reclamation, Department of Mines and Minerals)

WEST VIRGINIA: West Virginia has about 49,000 underground coal mine maps which represents about 40% of the known mines. Nearly all of the known maps have been scanned. (Contact: J.D. Higginbotham, National Mine Health and Safety Academy; Nick Fedorko, WV Geological and Economic Survey).

APPENDIX F

Agenda for MSHA Symposium on “Geotechnical Methods For Mine Mapping Verification”



October 29, 2002

Charleston, West Virginia

Agenda - Geotechnical Methods for Mine Mapping Verification

9:00 - 9:30 am	Welcome / Introduction	John Correll MSHA, Deputy Assistant Secretary
	Scope of the Problem	Ray McKinney MSHA, Administrator for Coal Mine Safety and Health
9:30 - 10:30 am	Questions & Answers	Ray McKinney
10:45-11:00 am	West Virginia's Program	Mr. Doug Conaway
11:05-11:20 am	Pennsylvania's Program	Mr. Richard Stickler
11:25-11:40 am	Virginia's Program	Mr. Frank Linkous
11:45-12:00 pm	Kentucky's Program	Mr. Frank Delzer
1:00 - 4:00 pm	Technical Sessions (Dual Concurrent Tracks)	

Track 1 - Moderator - Michael Miano, Chief of Safety, MSHA Coal Mine Safety and Health, Arlington, VA

1:00-1:25	"Horizontal Drilling for Advance Exploration in Underground Mines", Dr. Pramod Thakur, Consol Energy Incorporated (in Conjunction with J.H. Fletcher Company)
1:30-1:55	"Application of True Reflective Tomography and 2-D and 3-D Seismic Tomographic Imaging to Location of Mine Works", Timothy Ross, NSA Engineering
2:00-2:25	"Proven Benefits of Target Drilling, Inc.'s In-Mine Directional Drilling Technology for Abandoned Mine Verification", Stephen J. Kravits, Target Drilling, Incorporated
2:30-2:55	"Directional Drilling - It's What's Up Front that Counts", Jeff Schwoebel, REI Drilling, Incorporated
3:00-3:25	"Surface Geophysical Methods for Detection of Underground Mine Workings", William J. Johnson, PG, D'Appolonia Engineering Div., Ground Technology, Inc.

3:30-3:55 A Horizon Sensing and Radio Imaging Method (RIMJ) for Detecting and Imaging Underground Barrier Pillars, Mine Voids, and Water", Dr. Larry Stolarczyk, Stolar Horizon Inc.

Track 2 Moderator: Edward Miller, Chief, Pittsburgh Safety and Health Technology Center, MSHA Technical Support, Pittsburgh, PA

1:00-1:25 "Robotic Mine Mapping", Dr. William "Red" Whittaker, The Robotics Institute, Carnegie Mellon University

1:30-1:55 "Current Research in Mining Geophysics at Virginia Tech", Dr. Eric Westman, Virginia Polytechnic Institute

2:00-2:25 "A Protocol for Selecting Appropriate Geophysical Surveying Tools based on Geotechnical Objective and Site Characteristics", Dr. Neil Anderson, Professor of Applied Geophysics, University of Missouri Rolla

2:30-2:55 "Radio Imaging Method (RIM™) for Detecting and Imaging Underground Barrier Pillars, Mine Voids, and Water", Dr. Syd Peng, West Virginia University

3:00-3:25 "The National Institute for Occupational Safety and Health (NIOSH) Research Program for Detection of Abandoned Mines and Mine Voids", Thomas Mucho, Dr. Peter Swanson, National Institute of Occupational Safety and Health (NIOSH)

3:30-3:55 "Using Geographic Information Systems to Map and Model Underground Mines", Michael J. Price, ESRI, Mining and Earth Sciences Solutions

4:00-4:45 **Panel Discussion** - **Moderator:** Dr. Kelvin Wu, Chief of the Mine Waste and Geotechnical Division, MSHA Pittsburgh Safety and Health Technology Center, Pittsburgh, PA.

Panel of all Presenters - "Most Promising Current Technology And Research Needs relative to Detecting Abandoned Mine Voids using Geophysical Techniques".

4:45 Concluding Remarks

John Correll

APPENDIX G

Agenda and Members of Steering Committee For “Interactive Forum on Geophysical Technologies For Detecting Underground Coal Mine Voids”

Geophysical Technologies for Detecting Underground Coal Mine Voids: An Interactive Forum

July 28-30, 2003, Hyatt Regency Lexington - Lexington, Kentucky

Purpose: The purpose of the interactive forum, sponsored by the Mine Safety and Health Administration and the Office of Surface Mining, is to evaluate the applicability and effectiveness of available geophysical technologies for detecting, locating, and delineating active and inactive underground mine workings.

Tuesday, July 29, 2003 Day One: BASICS

8:30 a.m. **Introduction and Purpose of Forum**, *William Kovacic, Lexington Field Office Director, Office of Surface Mining*

8:45 a.m. **Featured MSHA Speaker**, *Dave Lauriski, Assistant Secretary, MSHA (invited)*

Session Moderator: *Vann Weaver, Chief, Technology & Support Group, Office of Surface Mining*

9:15 a.m. **Technology Opportunities for Coal Mining**, *Richard Sweigard, Chairman, Department of Mining Engineering, University of Kentucky*

10:30 a.m. **DOE's Program on The Mining Industry of the Future**, *Roy Tiley, Research Analyst, BCS, Inc.*

11:00 a.m. **OSM Perspective**, *John Craynon, Chief, Division of Technical Support Office of Surface Mining*

11:30 a.m. **MSHA Perspective**, *Kelvin Wu, Chief, Mine Waste and Geotechnical Engineering Division, MSHA*

12:00 Noon **Featured OSM Speaker**, *Jeffrey Jarrett, Director Office of Surface Mining (invited)*

Session Moderator: *Kelvin Wu, Chief, Mine Waste and Geotechnical Engineering Division, MSHA*

1:30 p.m. **Overview of Geophysical Methods**, *Don Steeples, Professor of Geology University of Kansas*

2:30 p.m. **Selection of Geophysical Methods**, *Neil Anderson, Professor of Geology University of Missouri-Rolla*

3:30 p.m. **Quality Control**, *Gary Olhoeft, Professor of Geophysics Colorado School of Mines*

4:00 p.m. **Panel Discussion**, *Neil Anderson, John Craynon, Gary Olhoeft, Don Steeples, Richard Sweigard, Roy Tiley, and Kelvin Wu*

Wednesday, July 30, 2003 Day Two: SPECIFICS

Session Moderator: *Doug Conaway, Director, WV Miner's Health Safety and Training*

- 8:30 a.m. **Surface Seismic Methods**, *Lawrence Gochioco, GX Technology Corporation*
9:00 a.m. **Electrical Resistivity**, *William Johnson, D'Appolonia Engineering*
9:30 a.m. **Ground Penetrating Radar**, *Mike Trevits, Research Physical Scientist, National Institute of Occupational Safety and Health*

Session Moderator: *Gary Slagel, Director, Governmental Affairs Consol Energy, Inc.*

- 10:30 a.m. **Tomographic Methods**, *Ernest Majer, Deputy Director, Earth Sciences Division, Lawrence Berkeley National Laboratory*
11:00 a.m. **Electromagnetic Methods and Radio Imaging Methods for Detecting Coal Mine Voids**, *Larry Stolarczyk, President & Chief Technology Officer, Stolar Horizon Research Corporatio, and Syd Peng, Chairman, Department of Mining Engineering West Virginia University*
11:30 a.m. **Airborne Electromagnetic Surveys**, *Richard Hammack, NETL*

Session Moderator: *Benny Wampler, Deputy Director, VA Department of Mines Minerals and Energy*

- 1:00 p.m. **Microgravity**, *Richard Benson, President, Technos, Inc.*
1:30 p.m. **Directional Drilling**, *John Wood, Vice-President, Marketing Target Drilling, Inc.*
2:00 p.m. **Quecreek Surface Seismic**, *James Acker, SEISPROS*
2:30 p.m. **Panel Discussion - James Acker, Richard Benson, Lawrence Gochioco, Richard Hammack, William Johnson, Steven Kravits, Ernest Majer, Syd Peng, Larry Stolarczyk, Mike Trevits and John Wood**

Session Moderator: *James Cobb, State Geologist and Director, Kentucky Geological Survey*

- 3:30 p.m. **Forum Summary**, *Dwain Butler, Senior Research Geophysicist (Retired) U.S. Army Engineering Research & Development Center*
4:30 p.m. **What's the Next Step?** *Greg Conrad, John Craynon, and Kelvin Wu*
5:00 p.m. **Adjournment**

Steering Committee for “Interactive Forum on Geophysical Technologies For Detecting Underground Mine Voids”

Bill Kovacic, Field Office Director
Lexington Field Office
Office of Surface Mining
Lexington, Kentucky 40503

Alice Perry, Mining Engineer
Lexington Field Office
Office of Surface Mining
Lexington, Kentucky 40503

Joe Blackburn, Program Manager (Field Support)
Lexington Field Office
Office of Surface Mining
Lexington, Kentucky 40503

Ralph Blumer, Mining Engineer
Lexington Field Office
Office of Surface Mining
Lexington, Kentucky 40503

Vann Weaver, Chief
Program Support Division
Appalachian Regional Coordinating Center
Office of Surface Mining
Pittsburgh, Pennsylvania 15220

Peter Michael, Geologist
Appalachian Regional Coordinating Center
Office of Surface Mining
Pittsburgh, Pennsylvania 15220

Kim Vories, Natural Resources Specialist, Mid-Continent Regional Coordinating Center,
Office of Surface Mining
Alton, Illinois

George H. Gardner, Jr., P.E., Senior Civil Engineer
Mine Waste and Geotechnical Engineering Division
Pittsburgh Safety Technical Center
Mine Safety and Health Administration
Pittsburgh, Pennsylvania 15236

Kyle Bohnensteil, Physical Scientist
Western Regional Coordinating Center
Office of Surface Mining
Denver, Colorado 80202

Robert H. (Hank) Bellamy, Mining Engineer
District 6 Field Office
Mine Safety and Health Administration
Pikeville, Kentucky

Neil Anderson, Professor of Geophysics
University of Missouri
Rolla, Missouri 65401

Donald W. Steeples, Professor of Geophysics
Department of Geology
University of Kansas
Lawrence, Kansas

Terry E. Ackman, Clean Water Team Leader (Tentative)
Environmental Science and Technology Division
U.S. Department of Energy
National Energy Technology Laboratory
Pittsburgh, Pennsylvania

Richard Hammack, Geologist
Clean Water Team
Nation Energy Technology Laboratory
U.S. Department of Energy
Pittsburgh, Pennsylvania

John W. Lane, Chief
Branch of Geophysics
U.S. Geological Survey
University of Connecticut
Storrs Mansfield, Connecticut

Alan Witten, Ph.D.
School of Geology and Geophysics
The University of Oklahoma
Norman, Oklahoma

Barry C. Berkovitz, P.E., Senior
Geotechnical Engineer
Federal Highway Administration
(FHWA)
Southern Resource Center
Atlanta, Georgia

Dwain K. Butler, Ph.D., P.G., Senior
Geophysicist
US Army Engineer Research and
Development Center
Corps of Engineers
Vicksburg, Mississippi

Troy R. Brosten, Research Geophysicist
US Army Engineer Research and
Development Center
Corps of Engineers
Vicksburg, Mississippi 39180-6199

Larry D. Adams, Director
Division of Permits
Department for Surface Mining
Reclamation and Enforcement
Frankfort, Kentucky

Dalip Sarin, Engineer
Department of Environmental
Protection
West Virginia Division of Mining and
Reclamation
Nitro, West Virginia

Bradley Lambert, Policy and Planning
Analyst II
Department of Mines and Minerals
Division of Mined Land Reclamation
Big Stone Gap, Virginia

Thomas Lefchik, Structural Engineer
Federal Highway Administration
Ohio Division Office
Columbus, Ohio

Thomas Mucho, Supervisory Physical
Scientist
DHHS/CDC/NIOSH/PRL
Bruceton, Pennsylvania

Joseph Schueck, Chief
Division of Acid Mine Drainage
Abatement
Department of Environmental
Protection
Harrisburg, Pennsylvania

Les Vincent, Customer Services
Manager
Department of Mines, Minerals and
Energy
Division of Mined Land Reclamation
Big Stone Gap, Virginia

APPENDIX H

MSHA Solicitation for Projects to Demonstrate Technologies for Detecting Underground Mine Voids



B -- Technology in detecting underground mine voids

- [Synopsis](#) - Posted on May 08, 2003

General Information

Document Type:	Modification to a Previous Presolicitation Notice
Solicitation Number:	B2532516
Posted Date:	May 08, 2003
Original Response Date:	May 22, 2003
Current Response Date:	May 22, 2003
Original Archive Date:	Jun 06, 2003
Current Archive Date:	Jun 06, 2003
Classification Code:	B -- Special studies and analysis - not R&D

Contracting Office Address

Department of Labor, Mine Safety and Health Administration, Acquisition Management Branch (WV), 1301 Airport Road, Beaver, WV, 25813-9426

Description

The United States Department of labor, Mine Safety and Health Administration (MSHA) is seeking sources to conduct demonstration projects for advancing the current state of technology in detecting underground mine voids. MSHA envisions the use of modification of geo-technical and geo-physical detection methods, but any proposed technology or method, or combination of technology and methods, will be considered. Methods may include, but are not limited to, long-hole directional drilling, seismic reflection/refraction, ground penetrating radar, subterranean robotics, and electromagnetic methods.

On July 24, 2002 , a nonfatal entrapment accident occurred at Quecreek #1 Mine, Black Wolf Coal Company. This incident brought national attention to a common problem in the coal mining industry. In the United States, there have been more than 100 incidents since 1995 where miners

have inadvertently broken into abandoned underground mines. Unavailable, inaccurate or incomplete mapping of abandoned mines is typically responsible.

MSHA intends to issue a solicitation that will result in the award of one, or more contracts for field demonstration of the detection methods and technology that can be certified as acceptable standard industry practice by the mining industry. MSHA wants to examine the capabilities of any geo-technical or geo-physical methods that can be confidently and practically applied to detect voids and prevent inundation hazards.

The ultimate objective in support of the MSHA mission is to accurately identify mine voids in advance of mining. These voids may present potential hazards to miners from water or gas inundation. For example, identifying voids and hazards can be accomplished by locating mine voids over a broad area well in advance of mining, by verifying the boundaries of adjacent mines, and/or by locating voids a safe distance ahead of the advancing face. Offerors who are selected to demonstrate their proposed methodology and technology will be required to document the results of the field demonstration that will be attended by MSHA personnel. The awardee is responsible for making arrangements for location and resources needed to conduct the demonstration at the conclusion of the selection process. Offerors who are interested in being included on the solicitation mailing list must submit a written request to: Darrell A. Cooper, CPCM Director, Acquisition Management Division Room 2132 Mine Safety and Health Administration 1100 Wilson Blvd. Arlington, VA 22209 (202)693-9831 cooper-darrell@msha.gov. Phone request will not be accepted. Offerors are not being asked to submit corporate capability statements as part of this announcement. All responses should be received within 14 days of this notice.

Original Point of Contact

William Och, Supv Contract Specialist, Phone (304) 256-3388, Fax (304) 256-3350, Email och-william@msha.gov - Katheryn Hampton, Contract Specialist, Phone (304) 256-3367, Fax (304) 256-3350, Email hampton-katheryn@msha.gov

Current Point of Contact

William Och, Supv Contract Specialist, Phone (304) 256-3388, Fax (304) 256-3350, Email och-william@msha.gov - Katheryn Hampton, Contract Specialist, Phone (304) 256-3367, Fax (304) 256-3350, Email hampton-katheryn@msha.gov

Place of Performance

Address: Mine Safety and Health Administration 1100 Wilson Blvd. Arlington, VA 22209