# ASDSO
# 2002 Southeast Regional Conference Proceedings

Published by:
Georgia Safe Dams Program and
Association of State Dam Safety Officials, Inc.
450 Old Vine Street
Lexington, KY 40507
859/257-5140

June 3 – 5, 2002

The Publishing of the Proceedings is Sponsored by:

**United Consulting**

# DANGERS ASSOCIATED WITH GOVERNMENT-COMMISSIONED REPORTS ON BREAKTHROUGHS OF SLURRY IMPOUNDMENTS INTO UNDERGROUND COAL MINES

*Barry K. Thacker, PE, Geo/Environmental Associates, Inc., Knoxville, TN 37909*

## Introduction

On 11 October 2000, the Big Branch Slurry Impoundment in Martin County, Kentucky, broke into an underground coal mine in the Coalburg seam. The Mine Safety and Health Administration (MSHA) conducted an investigation to determine the cause of the spill.[1] The National Research Council of the National Academies of Science and Engineering (NASE) conducted a study to evaluate the practice of coal processing waste disposal in slurry impoundments to reduce the potential for breakthroughs at other sites.[2]

As shown in Figure 1, a finite element model of the Big Branch site was developed using field and laboratory data contained in the government-commissioned studies to assess the conclusions and recommendations in those reports. Results of engineering analyses are presented to demonstrate that conclusions and recommendations in the MSHA and NASE reports may be wrong. Compliance with those documents may increase rather than decrease the risk of breakthroughs. Results of analyses and opinions are also presented to support the use of drained perimeter embankments as a means to reduce the breakthrough potential of coal slurry impoundments into underground coal mines.

## What Caused the Martin County Spill?

### *Piping?*

An investigation report prepared by MSHA contains a detailed description of the subsurface conditions and history of coal refuse disposal at the Big Branch site.[1] Generally, a relatively small spill occurred in 1994 when primarily water from the impoundment broke into mine works of the Coalburg coal seam. To reduce the potential for future breakthroughs, an embankment of well-graded mine spoil (i.e. silty, sandy, rockfill) was built around the perimeter of the slurry impoundment. The spoil embankment extended from about elevation 970 feet (i.e. top of the 10-foot thick Coalburg coal seam) to elevation 1080 feet.

The spill in October 2000 occurred when the slurry impoundment had achieved an elevation of 1060 feet and the level of the settled fine coal refuse was at elevation 1058 feet. At the breakthrough point, about 15 feet of unmined, unweathered coal and 55 feet of very stiff, natural cohesive soil overburden separated the deep mine from the slurry impoundment as measured along a horizontal projection of the mine floor.

According to an engineering report commissioned by MSHA, *"piping triggered the breakthrough. Over an extended period of time, groundwater and water seeping from the impoundment flowed through the weathered coal outcrop via fractures, joints, cleats, etc. commonly present in coal. Piping through the seepage barrier and natural ground likely occurred through zones of higher permeability within these layers. Although testing of* *undisturbed samples from these areas indicate relatively low permeabilities, these samples are likely not representative ....published data correlates to permeabilities on the order of $10^{-3}$ cm/sec."*

A finite element seepage analysis was performed using coefficients of permeability as shown in Table 1 to test the opinions regarding piping in the MSHA report.

**Table 1. Coefficients of Permeability (k) Input Data for Finite Element Modeling of the MSHA Piping Scenario at Big Branch**

| Material | $k_v$ saturated, ft/min | $k_v$ at -500 psf hydrostatic pressure, ft/min | $k_h/k_v$ |
|---|---|---|---|
| Spoil Fill, Coal, and Natural Soil Overburden | 2E-03 | 2E-04 | 9 |
| Bedrock | 5E-06 | 5E-07 | 9 |
| Fine Refuse | 1E-06 | 1E-07 | 100 |

Results of a seepage analysis in Figure 2 show that if the coal, spoil, and natural overburden had coefficients of permeability of $1\times10^{-3}$ cm/sec, then the spoil embankment at Big Branch would have been drained with relatively low hydrostatic pressures at the level of the natural outcrop barrier. Results shown in Figure 2 are academic. The model predicts that the total seepage rate through the 5200-foot long spoil embankment would have been 3700 acre-feet per year. A water balance shows that this seepage rate is greater than the combined rate of water being pumped to the Big Branch Slurry Impoundment by the owner and accumulated rainfall for the 176-acre Big Branch watershed (i.e. 2400 acre-feet per year). The impoundment would have remained essentially dewatered and two feet of water would not have been present above the settled fine refuse level at the time of the breakthrough. The piping theory presented in the MSHA report "won't hold water".

As an historical note, dam safety regulations in the United States were promulgated in response to catastrophic dam failures in the 1970's. One of those, the 1972 failure of Buffalo Creek Slurry Impoundment Dam 3, was initially attributed to piping.[3] Subsequent engineering analysis led investigators from the U.S. Bureau of Mines to conclude, "*there were earlier reports of piping. Neither field evidence nor engineering analysis substantiates this condition as the principal cause of the failure... the initial failure occurred in the downstream section. The oversteepened slope left by the initial failure became even more unstable. Progressive failure continued upstream until... the remaining section failed violently. Both the finite element and conventional methods (of seepage and stability analysis) predict failure*".[4]

### *Blow-in at the Outcrop?*

Two days after the October 2000 Big Branch breakthrough, a boring was drilled in the spoil embankment near the breakthrough location and encountered a phreatic level at elevation 1036 feet. MSHA began their investigative drilling 48 days after the breakthrough and encountered an initial phreatic level in the spoil as high as elevation 1023 feet. Each MSHA boring was cored into the mine, thereby providing drainage. Figure 3 summarizes the phreatic levels encountered in the spoil during drilling. A marked increase in the rate of dewatering is shown after additional drainage was provided by the MSHA cored holes. All cored holes were left open and then grouted at the completion of the MSHA drilling program.

Near the end of the MSHA drilling program, a weir was installed where the underlying Coalburg deep mine discharges. Flow rates from the deep mine varied from about 130 to 150 gallons per minute until August 2001 when the flow rate increased to between 200 and 250 gallons per minute for a several week period. The flow rate then declined to 80 gallons per minute by December 2001. A piezometer was installed at the breakthrough location in January 2002 and screened in the spoil. As shown in Figure 3, the phreatic level in the spoil had risen over 25 feet since the MSHA cored holes were grouted in January 2001. Unlike the MSHA piping theory, the spoil embankment at Big Branch does hold water.

Table 2 shows coefficients of permeability as judged from testing results included in the MSHA report for spoil, coal, and natural cohesive soil overburden. A seepage analysis was performed using these parameters to analyze for conditions that existed before the October 2000 breakthrough. The seepage analysis shown in Figure 4 predicts that the maximum hydrostatic pressure on the natural outcrop barrier prior to the breakthrough was approximately 4000 psf.

**Table 2. Coefficients of Permeability (k) Input Data for Finite Element Modeling Based on Results of Testing Included in the MSHA Report**

| **Material** | **$k_v$ saturated, ft/min** | **$k_v$ at -500 psf hydrostatic pressure, ft/min** | **$k_h/k_v$** |
|---|---|---|---|
| Spoil Fill | 1E-04 | 1E-05 | 9 |
| Coal | 1E-05 | 1E-06 | 9 |
| Natural Cohesive Soil Overburden | 5E-07 | 5E-08 | 9 |

Electrical geophysical data and field measurements presented in the MSHA report indicate that a near-vertical, stress-relief joint (i.e. hillseam) and near-vertical tension joints intersect at the point of breakthrough. The natural joints and the mine void appear to have created a block that was separated from the surrounding ground. Figure 5 summarizes the results of a shearing (blow-in) analysis. Using shearing resistance values of 4000 psf (i.e. cohesion) for the natural soil above coal seam level and 1125 psf (i.e. adhesion) for the interbedded coal/clayshale layers of the Coalburg seam and its residual soil, a factor of safety less than 1.0 is predicted.[5]

The failure analysis and site observations indicate that the natural outcrop barrier did not pipe, it broke instantaneously and without warning. When it broke, it was like pulling the plug out of a bathtub or flushing a toilet. Water that had accumulated in the pore space of the pervious spoil embankment prior to the breakthrough continued the flushing of fine refuse solids into the mine long after water had drained off the impoundment. The flushing of solids into the mine did not stop until the owner used bulldozers to push spoil into the breach.

## Lessons-Learned from the Martin County Spill

Figures 4 and 5 indicate that a build-up of hydrostatic pressure at the natural outcrop barrier caused the Martin County spill. Man-made drains can be installed in future perimeter embankments to reduce the potential for build-up of hydrostatic pressures.[6,7] Figure 6 shows the results of a seepage analysis for a partial-height, drained perimeter embankment (PHDPE) using the Big Branch model. Reduced hydrostatic pressures (i.e. 1000 psf for the PHDPE compared to 4000 psf for the undrained Big Branch embankment) are predicted by providing drainage. A calculated factor of safety of 4 would have been provided if a PHDPE had been built at Big Branch before the fine refuse reached the level of the Coalburg seam.

## NASE Recommendations to Reduce Future Breakthroughs

The NASE report concludes that concerns about water building up behind barriers or walls should be addressed by creating bigger undrained walls. No explanation is given as to how NASE can present recommendations for preventing breakthroughs without first performing engineering analyses to evaluate what causes breakthroughs. Engineering seepage analyses show that the problem is with the water, not the walls. Building bigger undrained walls increases risk because it allows higher hydrostatic heads to develop behind the walls. Experienced coal miners know that if you are concerned about the risk of water building up behind a wall, just drill weep holes through the wall so the water can't build up.

The wisdom of specific NASE recommendations is challenged in the following examples.

1. From the NASE report, "*The committee recommends that MSHA and the Office of Surface Mining (OSM) jointly pursue the issue of outcrop coal barrier width and overburden thickness and its competence and develop minimum standards for them.*" Figure 7 shows the results of a seepage analysis using the Big Branch model if the entire outcrop coal barrier had been removed by surface mining and replaced with drained engineered fill. A maximum hydrostatic pressure of only 60 psf is predicted showing that a PHDPE with NO outcrop coal barrier can provide a lower risk to breakthrough than by promulgating a minimum standard outcrop coal barrier width. Piezometers can be installed in the drained engineered fill to verify performance of the drain and the system. The results shown in Figure 7 suggest that if minimum outcrop coal barrier widths are promulgated, then the minimum widths should be "zero".

2. According to the NASE report, "*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. Furthermore, the bulkhead should be suitably anchored in competent, unfractured strata. If such an area is not available, pressure grouting may be needed. The size, integrity, and strength of the surrounding coal pillars, roof, and floor are critical to successful sealing.*" At most existing slurry impoundment sites, the deep mine beneath the impoundment is abandoned. Access is not available to coal outcrop barriers without risk to human life. Compliance with this recommendation requires that hydraulic bulkheads be built where the underlying deep mines discharge. Even if adequate bulkheads could be built at discharge locations, most underground workings were not mined

with the intent for hydraulic bulkheads to be built. Building hydraulic bulkheads for "successful sealing" will impound water in underground mines and increase the risk of blow-outs at coal outcrop barriers that may be miles away from the area where the bulkheads are built. In 1995, water built up in an abandoned mine in Virginia that was not associated with a slurry impoundment. The natural coal outcrop barrier failed, killing a resident who lived downstream.[8] Building hydraulic bulkheads at locations where abandoned deep mines discharge is akin to a doctor prescribing a cork as a treatment for diarrhea.

3. With regard to monitoring and evacuation, the NASE report recommends, "*If some crucial criteria are exceeded, visual or audible alarms can be triggered. Continuous monitoring could provide timely warning in case of impending failure of an embankment or basin. Its use with weirs, for example, is well established, and it can be used with other types of instrumentation. The committee recommends that MSHA and OSM consider requiring additional continuous monitoring in specific instances and evaluate automation of monitoring instrumentation.*"

The appropriate parameters need to be monitored to avoid triggering a false alarm. Reliance on the MSHA conclusion that excessive seepage and piping caused the Big Branch breakthrough and compliance with NASE recommendations for undrained barriers might mandate that increases in flow rates from deep mines be used to trigger evacuations. Engineering analysis of the Big Branch release shows that it occurred from too little drainage, not from too much seepage. Furthermore, flow rates fluctuate from deep mines in response to rainfall and local groundwater recharge even if they are not located beneath a slurry impoundment. Should fluctuations in flow rates from deep mines be used to trigger evacuations when real problems may exist due to a lack of seepage? If somebody gets injured during an unwarranted evacuation triggered by an increase in flow from a deep mine, will NASE, OSM, and MSHA accept responsibility because coal companies were required to follow the NASE recommendations? Will downstream residents listen during a real emergency if they are called out of their homes every time flows increase from a deep mine?

4. According to a news release that accompanied the NASE report [9], "*The committee found many of the alternatives to impoundments to be promising, but also costly and dependent on local geography. Two major studies are needed to determine the feasibility of alternatives to slurry impoundments, the committee said.*" After the Buffalo Creek failure, most coal companies began disposing of their coal processing wastes in alternative land disposal facilities called combined refuse fills. The problem with a combined refuse fill is that its stability depends on the fine refuse being dewatered with a machine. Fine refuse contains clay. Clay has low hydraulic conductivity and is difficult to dewater in a timely manner. Many coal companies found that an "impoundment" was still being created with the wet combined refuse fill, but no dam was being built to retain the saturated coal refuse. On 18 December 1981, a combined refuse fill failed in Harlan County, Kentucky, killing one person and demolishing several homes. Afterwards, most coal companies switched back to coal processing waste disposal in slurry impoundments.

Are two major studies really needed to determine the feasibility of alternatives to slurry impoundments? Most of the coal industry served as a full-scale study twenty years ago. The hydraulic conductivity characteristics of fine refuse have not changed since the early 1980's. Fine refuse is still difficult to dewater in a timely manner with a filter press or belt press. Does NASE really think it wise to go back to building structures with saturated coal refuse?

5. From the NASE 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*". Solutions to quality-of-life problems like drinking water supply, sewage treatment, education, abandoned mine drainage abatement, flooding, and dental/healthcare are needed in the Appalachian coal fields. There is no logic to taking tax dollars away from programs that support these basic human needs and giving this money to coal companies as incentive to switch to alternative refuse disposal methods. Since the promulgation of dam safety regulations, more people have died from failures of alternative coal refuse disposal facilities than from coal slurry impoundment failures.[2]

## Dangerous Consequences of Combining the MSHA and NASE Conclusions and Recommendations

### *General*

Government dam safety reviewers have been placed in an impossible position. So much hype has been placed on the NASE report that government agencies feel compelled to follow the NASE recommendations. They fear that if they do not follow those recommendations and another breakthrough occurs, then the agencies and the reviewers will be judged negligent. Conversely, if government regulatory agencies follow the NASE recommendations and another breakthrough occurs, then they will be in a defensible position because they merely followed the NASE recommendations. This situation is dangerous because it puts unjustified credence on cookbook standards and ignores site-specific engineering analysis and judgement.

### *Actual Example of Dangerous Consequences*

An actual example is presented where an owner, designer, and government dam safety agencies considered following the NASE and MSHA conclusions and recommendations. Specifically, a slurry impoundment was approaching the level of an underground mine. The example site had been deep mined and surface mined, leaving about 20 feet of coal outcrop barrier in some places. Using the MSHA conclusion that excessive seepage and piping caused the Big Branch breakthrough and the NASE recommendations regarding undrained barriers, attempts were made to design a "piping-resistant", undrained perimeter embankment. Figure 8 shows the results of a seepage analysis using the Big Branch model for the design being considered at the example site.

Cohesive soil fill and/or impervious synthetic liners were being considered for placement against the exposed coal seam and highwall. Reducing seepage was judged as a means to reduce piping potential. Coarse refuse was proposed as borrow to build the perimeter embankment with overcompaction as the method to reduce its piping potential. Using the values for shearing resistance assessed at Big Branch from Figure 5 and the hydrostatic pressures from Figure 8, a blow-in of the coal outcrop barrier is predicted for the model as shown in Figure 9.

The suggested method to reduce the risk of catastrophic breakthroughs from slurry impoundments is drainage. Figure 10 shows the results of a seepage analysis for a partial-height, drained perimeter embankment (PHDPE) at the example site using the Big Branch seepage model. Even with a depth of water of 21 feet above the settled fine refuse, a PHDPE maintains low hydrostatic pressures on the coal outcrop barrier.

## Conclusions

Engineering conclusions and recommendations should be justified by engineering analyses regardless of who offers them. MSHA and NASE should perform their own engineering analyses to assess the validity of their conclusions and recommendations and act based on their findings.

## References

1. Mine Safety and Health Administration (2001), *Report of Investigation: Big Branch Refuse Impoundment Failure/Mine Inundation Accident*, www.msha.gov.
2. National Research Council (2002), *Coal Waste Impoundments: Risks, Responses, and Alternatives*, National Academy Press, www.nas.edu.
3. West Virginia Governor's Ad Hoc Commission of Inquiry (1973), *The Buffalo Creek Flood and Disaster.*
4. Corp, E.L, R.L Schuster, and M.M McDonald (1975), *Elastic-Plastic Stability Analysis of Mine-Waste Embankments*, Bureau of Mines Report of Investigations 8069.
5. Thacker, B.K. (2002), *Big Branch Slurry Impoundment Breakthrough: Why It Happened and Lessons-Learned*, Proceedings: Tailings Dams 2002, Association of State Dam Safety Officials and U.S. Society on Dams.
6. Michalek, S. J., G.H. Gardner, and K.K. Wu (1997), *Accidental Releases of Slurry and Water from Coal Impoundments Through Abandoned Underground Coal Mines*, Dam Safety '97 Conference Proceedings, Pittsburgh, PA, Association of State Dam Safety Officials, p. 17.
7. Thacker, B.K. (2000), *Perimeter Embankments to Increase Capacity, Mitigate Subsidence Impacts, and Abandon Coal Refuse Disposal Impoundments*, Proceedings: Tailings Dams 2000, Association of State Dam Safety Officials and U.S. Committee on Large Dams.
8. Mine Safety and Health Administration (1995), *Blowouts of Impounded Water from Abandoned Underground Mines*, Program Information Bulletin No. P95-24.
9. The National Academies (2001), *FOR IMMEDIATE RELEASE New Federal Standards Needed for Storing Coal Waste*, The National Academies News, www.nas.edu.

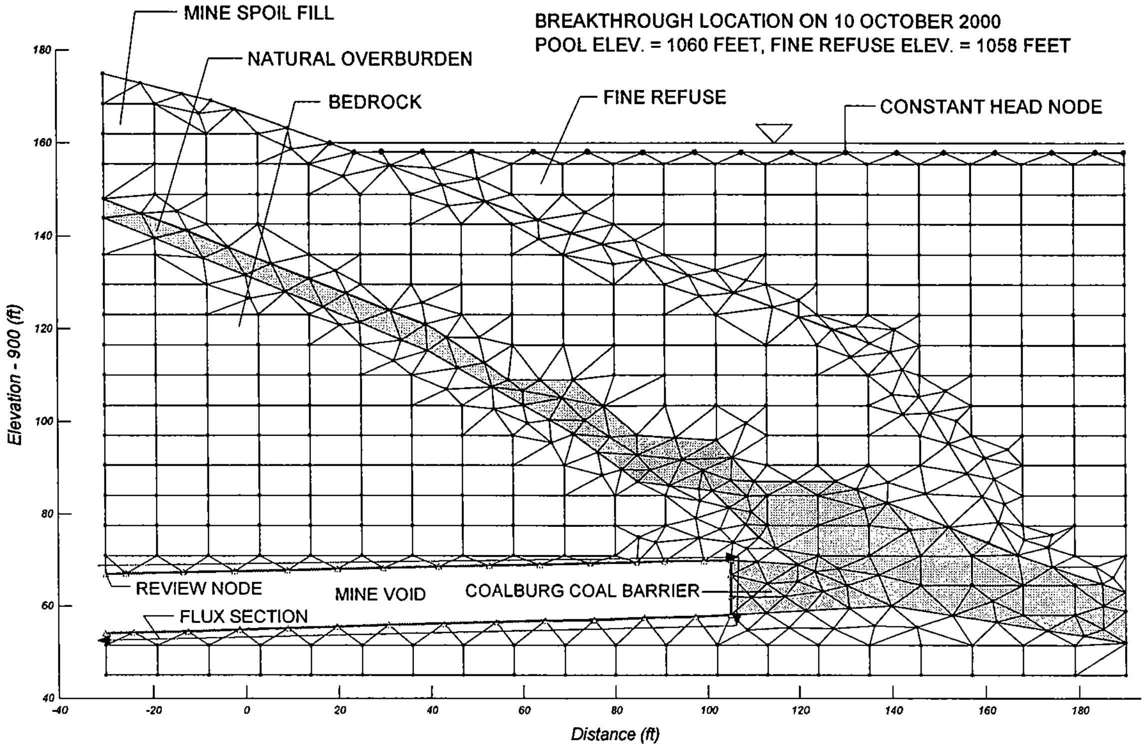


**Figure 1. Finite Element Seepage Analysis Grid used to Model the Big Branch Slurry Impoundment Breakthrough Location**

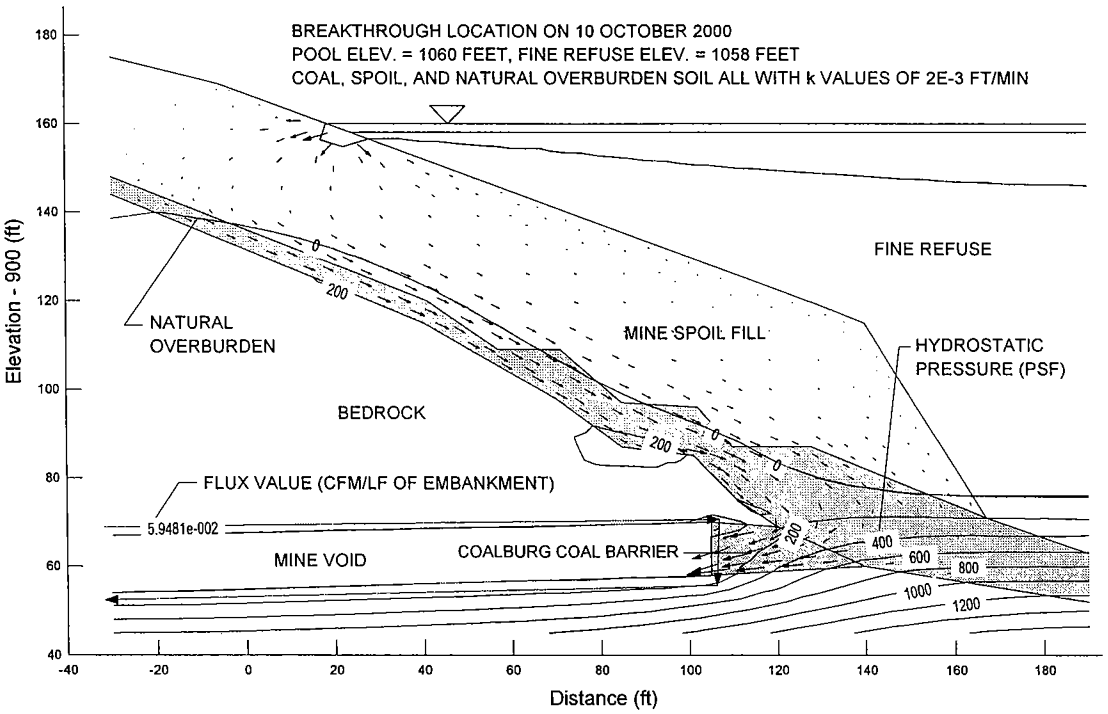
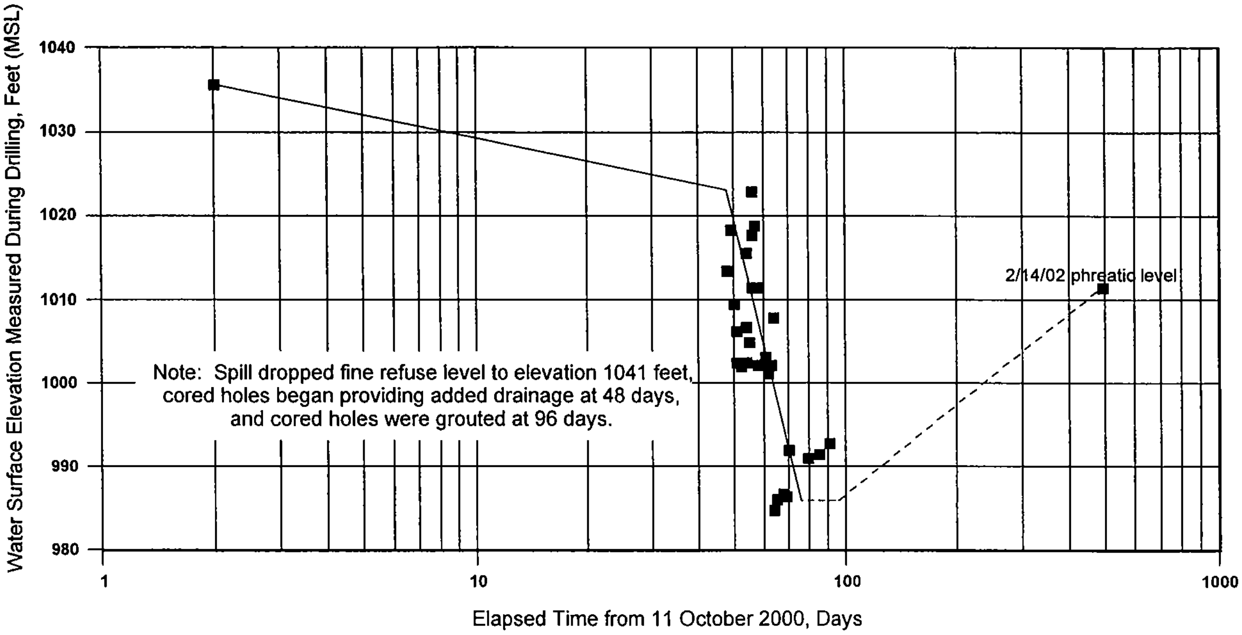


**Figure 2. Results of Seepage Analysis to Test the MSHA Piping Theory as to the Cause of the Big Branch Breakthrough (Maximum Hydrostatic Pressure = 600 psf on the Outcrop Barrier and Seepage Rate = 3700 Acre-Feet per Year)**



Note: Spill dropped fine refuse level to elevation 1041 feet, cored holes began providing added drainage at 48 days, and cored holes were grouted at 96 days.

**Figure 3. Relationship Between Elapsed Time Following the 11 October 2000 Breakthrough and Water Surface Elevation Measured in Spoil Embankment at Big Branch**

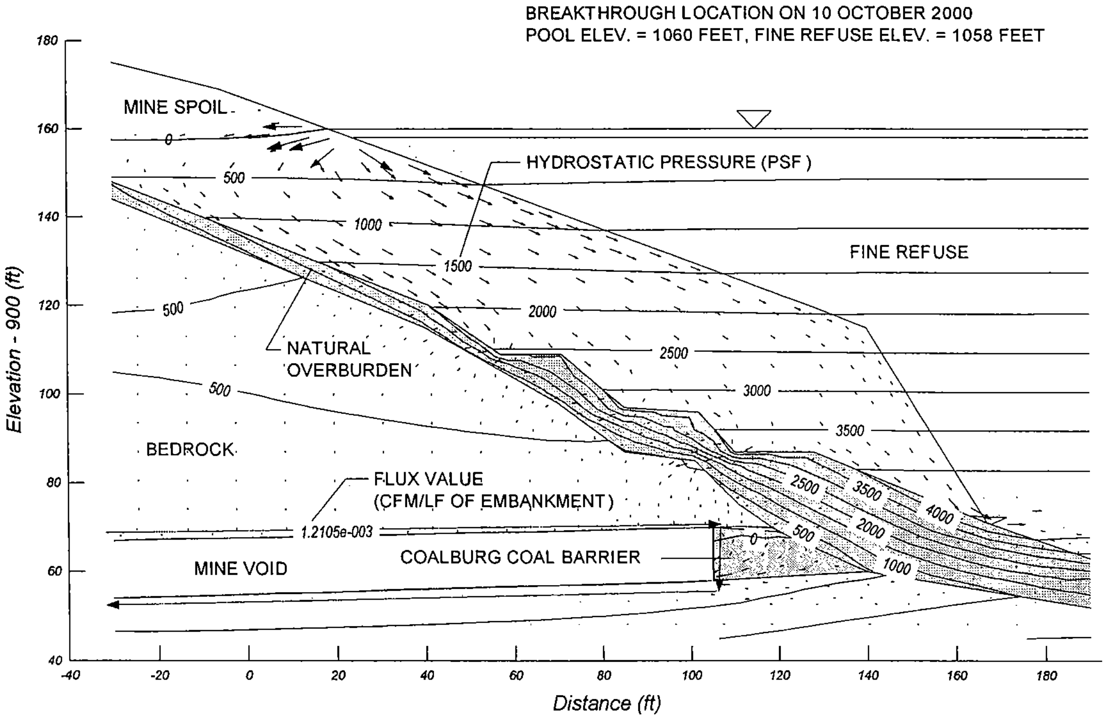
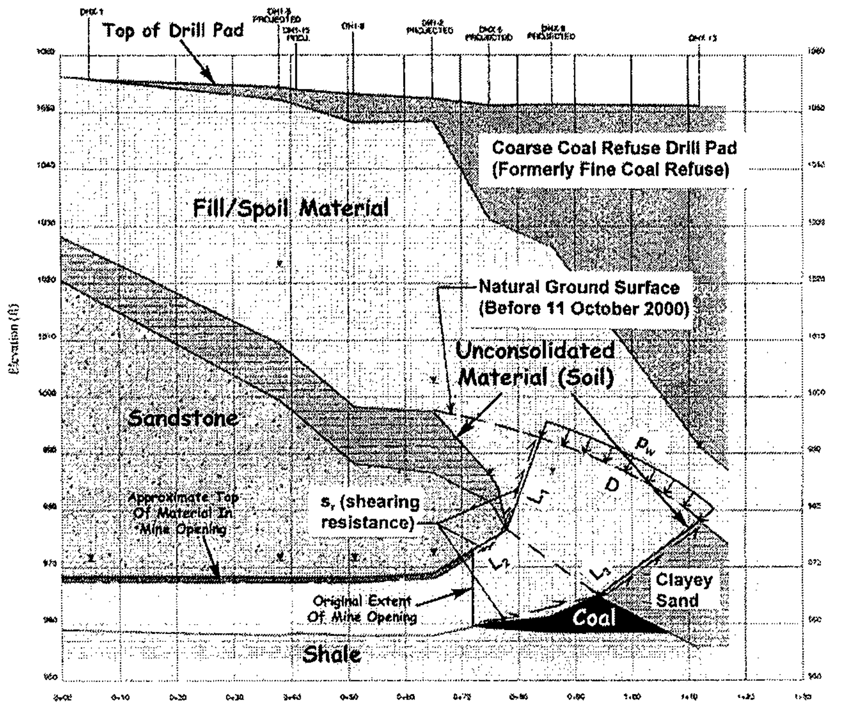


**Figure 4. Results of Seepage Analysis using Data from the MSHA Study to Assess the Cause of the Big Branch Breakthrough (Maximum Hydrostatic Pressure = 4000 psf on the Outcrop Barrier and Seepage Rate = 76 Acre-Feet per Year)**



$D = 32'$
$L_1 = 17'$
$L_2 = 7'$
$L_3 = 44'$
$s_{r1} = 4000$ psf
$s_{r2} = 1125$ psf
$s_{r3} = 1125$ psf
$p_w = 4000$ psf (hydrostatic pressure)

$$FS = \frac{(4000*17)+(1125*51)}{(4000*32)}$$

$$FS = 0.98$$

**Figure 5. Free-body Pressure Diagram and Shearing Calculations for the Big Branch Breakthrough Location (Adapted from Fig. 36 of MSHA Big Branch Investigation Report)**

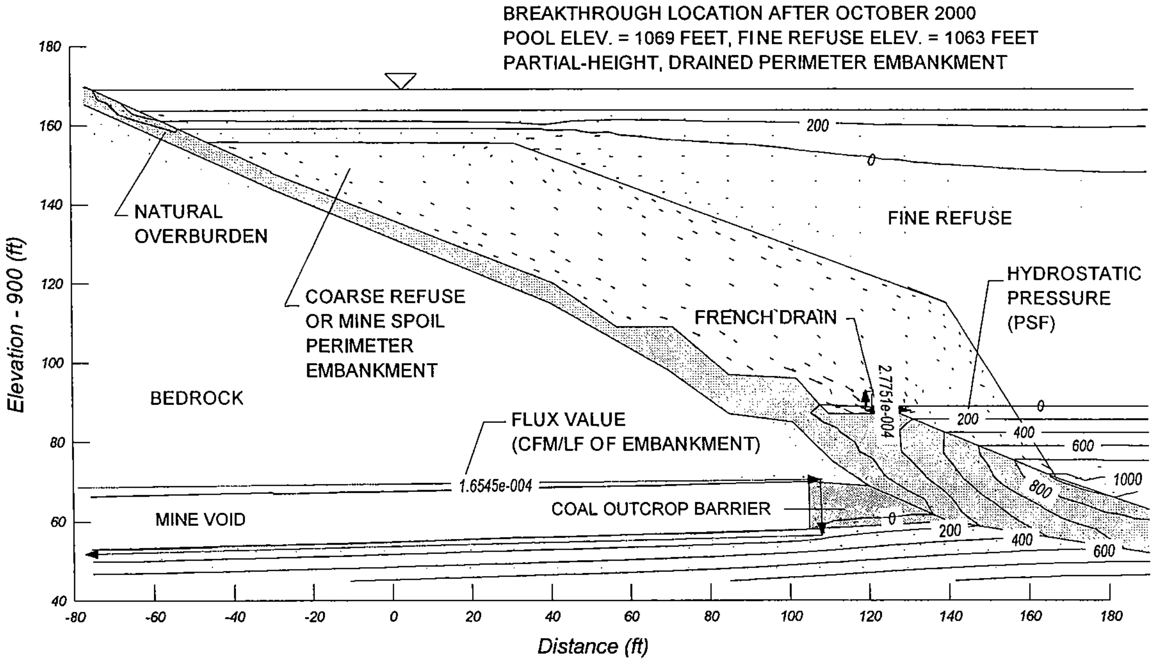


**Figure 6. Results of Seepage Analysis for a Partial-Height, Drained Perimeter Embankment Using the Big Branch Model (Maximum Hydrostatic Pressure = 1000 psf)**

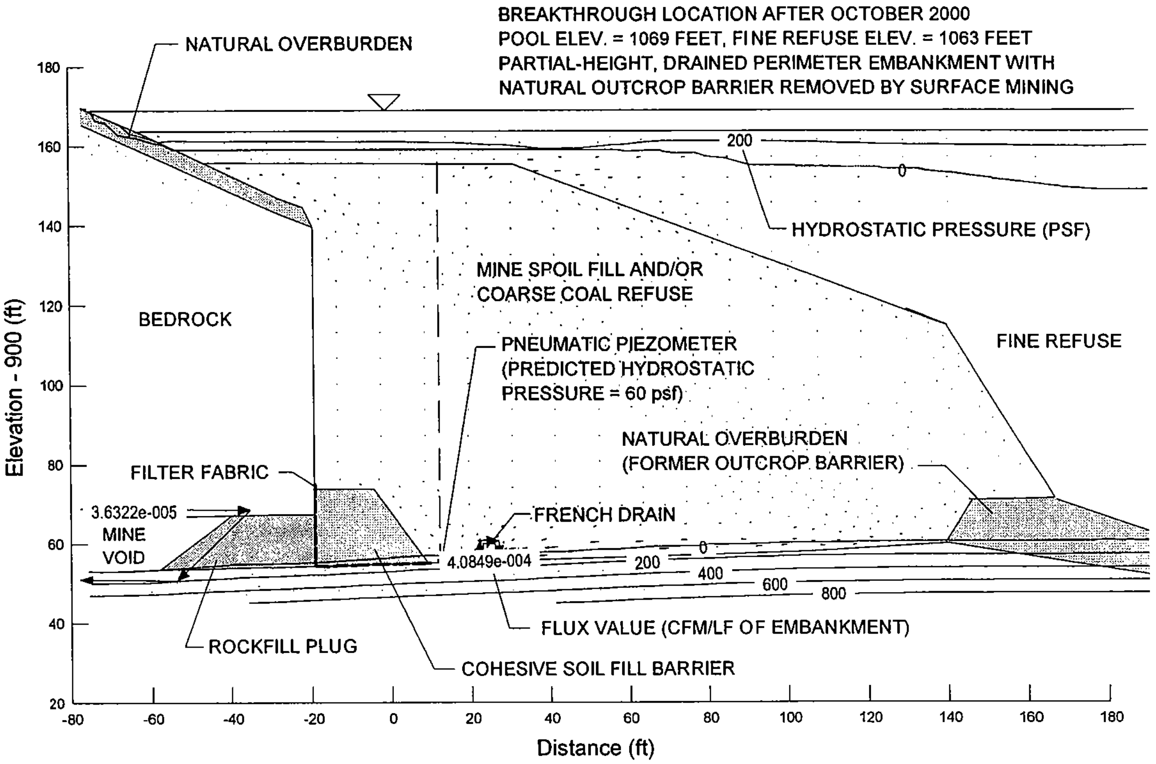


**Figure 7. Results of Seepage Analysis to Test NASE Minimum Coal Outcrop Barrier Width Recommendation Using the Big Branch Model (Maximum Hydrostatic Pressure = 60 psf with a PHDPE and No Coal Outcrop Barrier)**

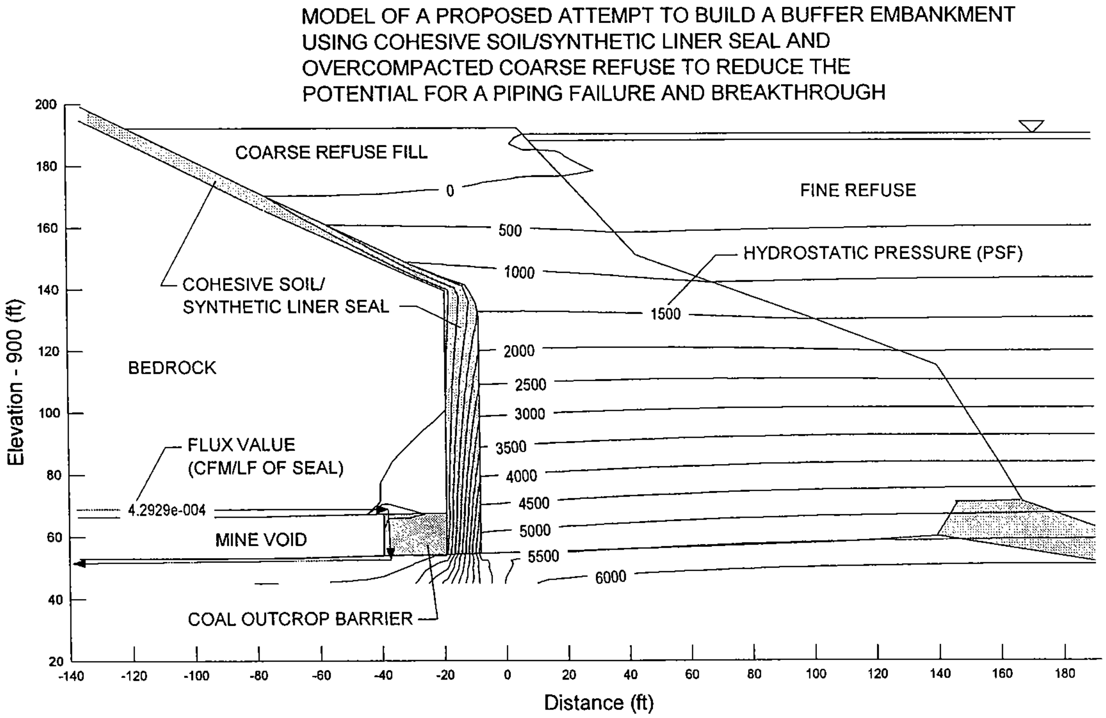
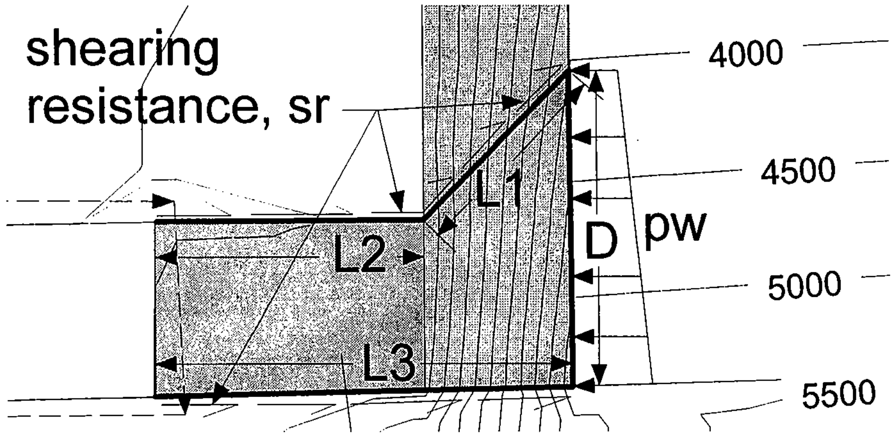


**Figure 8. Results of Seepage Analysis for a Design to Resist Piping Using the Big Branch Model (Maximum Hydrostatic Pressure = 5300 psf)**



$D = 25'$, $L_1 = 15'$
$L_2 = 20'$, $L_3 = 30'$
$s_{r1} = 4000$ psf
$s_{r2} = 1125$ psf
$s_{r3} = 1125$ psf
$p_w = 4700$ psf (hydrostatic pressure - average)

$$FS = \frac{(4000*15)+(1125*50)}{(4700*25)}$$

$$FS = 0.99$$

**Figure 9. Free-body Pressure Diagram and Calculations for a Design to Resist Piping Showing that a Breakthrough is Predicted due to Blow-in at the Outcrop (Values for Shearing Resistance Taken from Figure 5 and Average Hydrostatic Pressure Taken from Figure 8)**

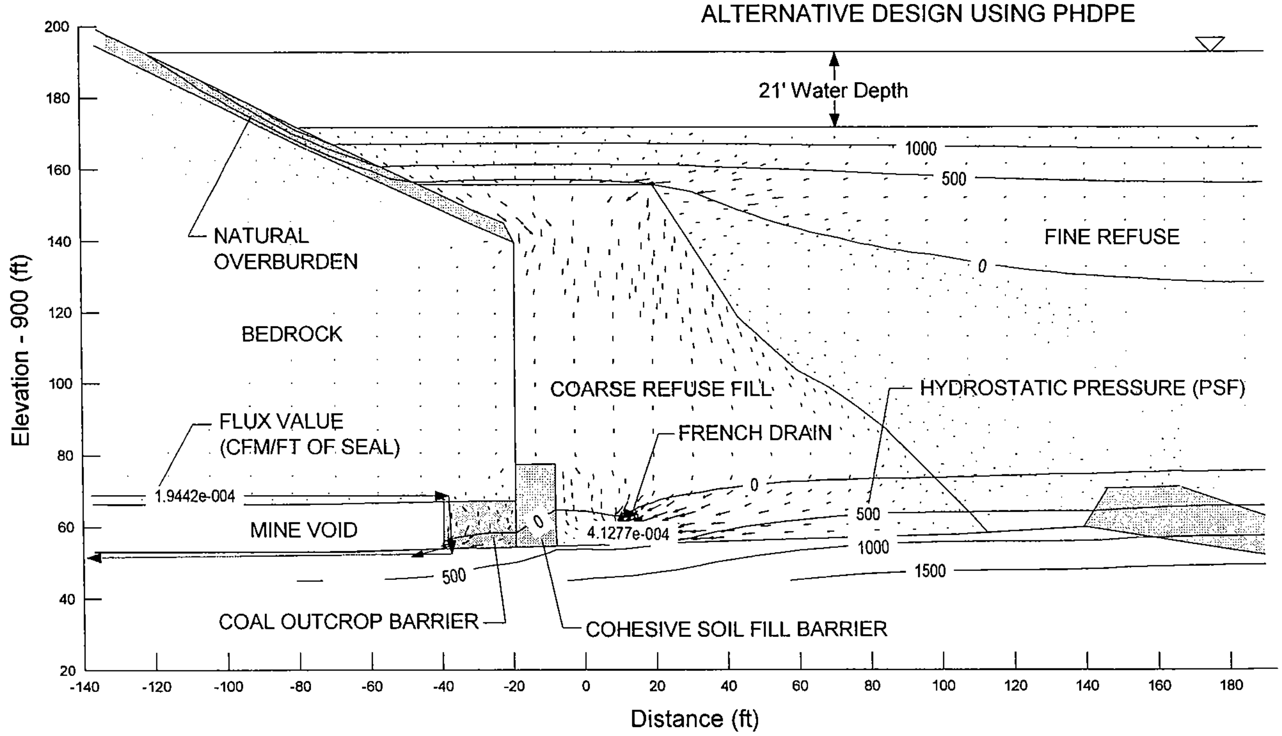


**Figure 10. Results of Seepage Analysis for a PHDPE Using the Big Branch Model as a Suggested Alternative for the Design to Resist Piping Shown in Figures 8 and 9 (Essentially No Hydrostatic Pressure Against the Coal Outcrop Barrier)**