MINE SEEPAGE PROBLEMS IN DRIFT MINE OPERATIONS

By

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Abstract. Extensive mining in the Eastern Kentucky Coal Region has occurred in coal deposits located above valley floors. Underground mines present unique stability problems resulting from the creation of mine pools in abandoned works. "Blowouts" occur when hydrostatic pressures result in the cataclysmic failure of an outcrop- barrier. Additionally, seepage from flooded works results in saturation of colluvium, which may ultimately mobilize as landslides. Several case studies of both landslides and blowouts illustrate that considerations should be taken into account to control or prevent these problems.

Underground mine maps and seepage conditions at the individual sites were examined to determine the mine layouts, outcrop-barrier widths, and structure of the mine floors. Discharge monitoring points were established in and near the landslides. These studies depict how mine layout, operation, and geology influence drainage conditions.

The authors suggest that mine designs should incorporate drainage control to insure long-term stability and limit liability. The goal of the post-mining drainage plan is control of the mine drainage, which will reduce the size of mine pools and lower the hydrostatic pressure. Recommendations are made as to several methods that may be useful in controlling mine drainage.

Additional Key Words: mine seepage, landslides, mine blowouts

Introduction

Extensive mining in the Eastern Kentucky Coal Region has occurred in coal deposits located above valley floors. These drift mines present unique stability problems resulting from the creation of mine pools. These pools can cause cataclysmic failure of outcrop-barriers, referred to as "blowouts". Another condition caused by mine pools is sudden increases in seepage from the mine works causing saturation of the colluvium, resulting in landslides. A recent blowout and two landslides were selected for case studies. These studies illustrate seepage problems encountered by drift mine operations, demonstrating the need for planned mine drainage. Recommendations are made as to several methods that may be useful in controlling mine drainage.

The groundwater flow of an undisturbed mountain in Eastern Kentucky is primarily through fractures and colluvium on the exterior portion of the mountain. This flow will recharge perched aquifers during wet seasons. The water stored in the aquifers will provide base flow to the

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mountain's exterior during the dry season. Wide distribution of stress-relief joints on the mountain, and the existence of perched aquifers help to keep the groundwater flow diffused. For additional study of groundwater flow in the area see Kipp and Dinger (1987) and Harlow and LeCain (1991).

The creation of a mine void will tend to concentrate groundwater, causing a change in groundwater flow patterns . This process is enhanced through fracturing caused by high-extraction techniques. Fractures created by mining provide better conduits into the mine void, draining overlying perched aquifers. Even installation of roof bolts may provide increased flow into the mine, if the drill holes penetrate a low hydraulic conductivity stratum in order to anchor into an overlying unit with a higher hydraulic conductivity. At the elevation of the mine works, groundwater flow changes from fracture-dominated to dip-controlled flow. Drainage into the mine will then be directed towards the mine pools, allowing a build-up of hydrostatic head and creating potential seepage areas when these pools intersect the joint system.

Concentration of Groundwater Flow

Case Study 1

Examination of a mine in Floyd County, Kentucky, is a good example of how a mine void concentrates diffuse groundwater flow. This study was based on an investigation of a slide that occurred in a small hillside drain in Southeastern Floyd County. At this site, two items were studied: a comparison of the volume of discharge from the slide area with the volume of measured rainfall, and a comparison of the discharge from the slide with flow from an undisturbed watershed (Figure 1).

Both the watershed of the slide and the control watershed have similar size and topography, and both were forested with little surface disturbance. The slide's watershed is 4.5 ha. (11 acres) and the control watershed is 5.5 ha. (13.5 acres). No known mining has occurred under the control watershed, but underground mining has occurred in the Amburgy coal seam to the ridge line behind the watershed. The underground works are approximately 305 meters west of the outcrop, and the nearest pillaring is 490 meters to the east. Underground mining in the Amburgy coal seam has occurred under the watershed of the slide. Mine works exist to within 60 meters of the crop line and the nearest pillaring is 80 meters from the crop line.

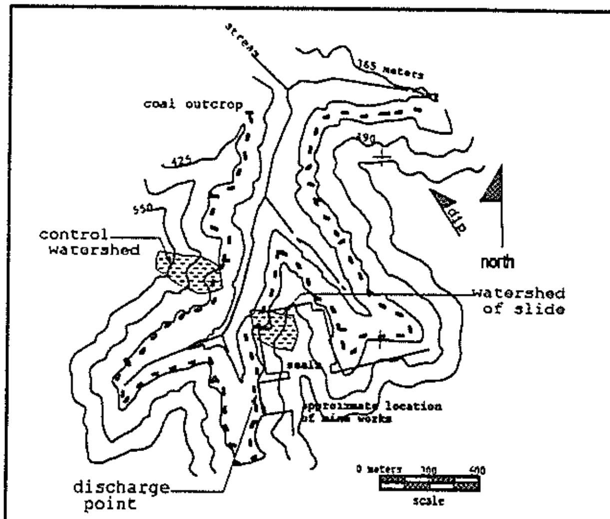

Figure 1. Area of watersheds at case study no. 1

Monitoring points were established and flow rates were monitored from August, 1994, to May, 1995. In the mine-affected watershed, three monitoring points were established near the base of the slide in order to measure the total discharge leaving the slide area. One monitoring point, that should have intercepted most of the drainage, was established in the control watershed.

During this study, the control watershed seldom flowed, with the only measured flow occurring on May 15,

1995. After establishing the monitoring point, a small point-discharge from the colluvium was discovered below the monitoring point. This point flowed for a few days at an estimated peak flow of 11 liters-per-minute during wet periods of the year, when the colluvium was saturated. Discharge from the point was observed only three times after heavy rainfall events in January, March, and May.

The affected watershed flowed constantly throughout the study, with flow rates ranging from 17.4 to 435.3 liters-per-minute. After one storm in January, 1995, the measured peak flow was 155.0 liters-per-minute, while the control watershed had a flow of less that 11.0 liters-per-minute. Four days after the storm, the flow rate in the affected watershed was 30.3 liters-per-minute, while the control watershed had stopped flowing.

The second item studied was a comparison of the volume of rainfall with the flow measured in the mine-affected watershed. Flow rates and on-site rain-gauge measurements were recorded from September, 1994, to January, 1995. A Belfort rain gauge (Model 5-780) recorded the amount and time of precipitation at the site. Flow was measured intermittently. Results of the volumetric calculations indicated that approximately 63 percent of the measured rainfall volume that fell in the watershed was measured at the monitoring points. This percentage of precipitation as flow is considered low, because the discrete monitoring probably did not always measure the peak flows. The monitoring points only measured a portion of the water coming from the mine void, with an unknown amount being discharged as subsurface flows.

The amount of groundwater coming from the slide area is considered high when compared to studies done by others. Analysis of stream flow hydrographs done in the watershed of Russell Fork near the Kentucky-Virginia border, estimated approximately 18 percent of precipitation was available for groundwater discharge. It was estimated that approximately 50 percent of the rainfall was lost to evapotranspriation (Larson and Powell 1986). This is in rough agreement to earlier estimates done at other large drainage basins in Eastern Kentucky showing approximately 67 percent of the rainfall lost to evapotranspriation (Price 1962). While direct comparison with these large watersheds may not be applicable, they do support the view that seepage seen in the study watershed was more than would be expected from the watershed.

Results from short-term monitoring of the two watersheds clearly showed that mining had affected groundwater flow in the slide area. The mine-affected watershed showed a constant flow that could vary greatly and produce large flow rates not noticed by the landowners before the mining operations. The mine pool feeding the seepage area had good storage, as evidenced by the constant flow rate and a total discharge volume of 222,202 cubic meters (18 acre-feet), from August 1994 to May 1995. High specific conductance measurements, often associated with mine drainage would also support the view that much of the water is coming from the mine. Comparison of the specific conductance taken in the control watershed would support this conclusion (Figure 2).

<u>Mine Blowouts</u>

The most drastic result of improper drainage control is the occurrence of mine blowouts from drift mines. These events can result in the sudden release of force that can endanger the public and cause substantial environmental damage in a few hours. From the spring of 1993 to the spring of 1994, five mine blowouts were studied. All the sites had one

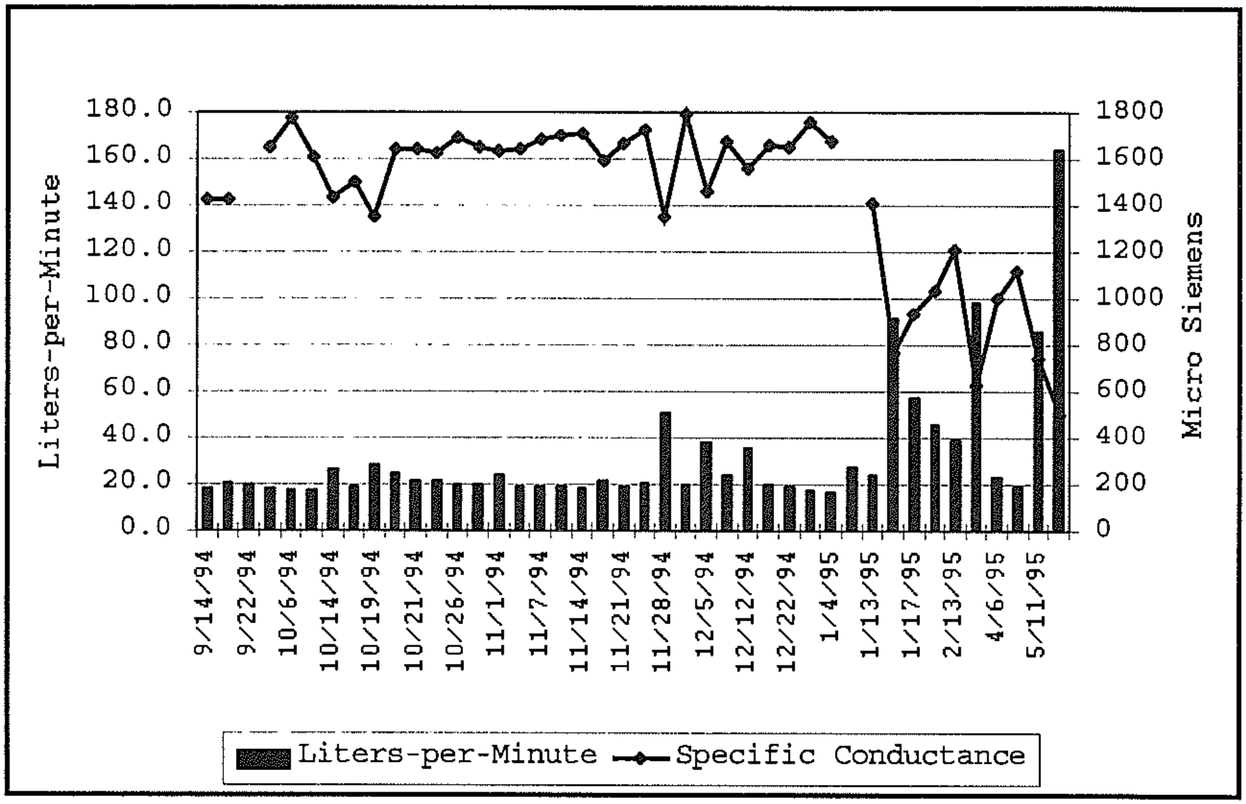

Figure 2. Discharge and Specific Conductance measurements for monitoring point No. 3, Case Study 1.

item in common: the events occurred at excessively weakened outcrop-barriers. These were either at extremely narrow outcrop-barriers or at intersections with small unknown mine works.

<u>Case Study 2</u>

At one study site, the blowout occurred where the outcrop-barrier was approximately 5 meters wide. The resulting blowout formed a gully in less than 3 hours and moved at least 3,600 cubic meters of colluvium. The effects of the sudden discharge blocked a stream, damaged several small bridges downstream, and blocked the road into a community over one mile away. The mine works associated with the blowout covered approximately 113 ha (280 acres) and had been active for approximately 3 years. The mining was completed in 1986, eight years before the blowout.

In addition to the blow out, there were two other small surface discharges located in the area. These were small discharges, one site had only diffused seepage in the area of the portals (no measurements taken). The second seep had a flow rate measured from 19 to 38 liters-per-minute, based on infrequent sampling done over the period from March, 1994, to March, 1996. The layout of the mine was such that almost all of the mine drained to the area of the blowout. The difference in elevation between the high and low points in the mine was almost 15 meters. The low point was located in the area of the seep (Figure 3) with the blowout occurring approximately 9 meters below the highest point of the mine. The two surface discharges were located close to each other and along with the configuration of the mine floor helped to reduce the water level in the mine pool during periods of low inflow, reducing the hydrostatic pressure in the area of blowout.

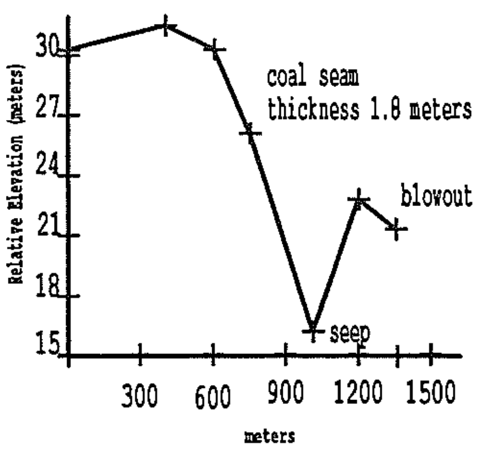

Figure no. 3. Profile of mine floor along drainage path in mine.

Measurements taken after the blowout showed a trend of reduced flow. While no attempt was made to account for the various factors influencing the flow from the blowout area, the measurements do indicate that a considable amount of water was stored in mine voids (Figure 4). Measurements over the period from February, 1994, to September, 1995, showed a downward trend indicating a reduction of storage in the mine. The main lessons to be learned from the study of this site were that control of the mine's outcrop-barrier and the size of the collection basin is necessary in order to lessen the chance and severity of the mine blowout.

Study of the dataset would also indicate that none of the mine blowouts occurred in areas where modest amounts of outcrop-barrier were maintained to resist the pressure. None of the cases examined indicated the Ashley or Mine Inspector Formula was invalid. This would support the use of the formula for the design of outcrop-barrier widths. However, the Ashley Formula only indicates the needed coal-pillar width (Chekan 1985). The coal seam may not be the structurally weakest member containing the mine pool, due to the topography of the hillside.

Mine Seepage Problems

The second stability problem associated with mine drainage is the saturation of outslopes resulting from seepage through outcrop-barriers. This problem is much harder to control than mine blowouts. Seepage from mine pools will result in saturation of colluvium on the outslope, sometimes resulting in landslides. Flow from mine pools to seepage areas is controlled by hydraulic conductivity along the outslopes. The greatest hydraulic conductivity is associated with the stress-relief joint-system. Studies have shown that hydraulic conductivity decreases greatly toward the center of mountains. Studies done in Virginia (Harlow and LeCain, 1991) have shown a large reduction of hydraulic conductivity within 31 meters for most rock strata, except coal, from the outcrop. Stress-relief joints are more open near the surface and close rapidly with increased overburden.

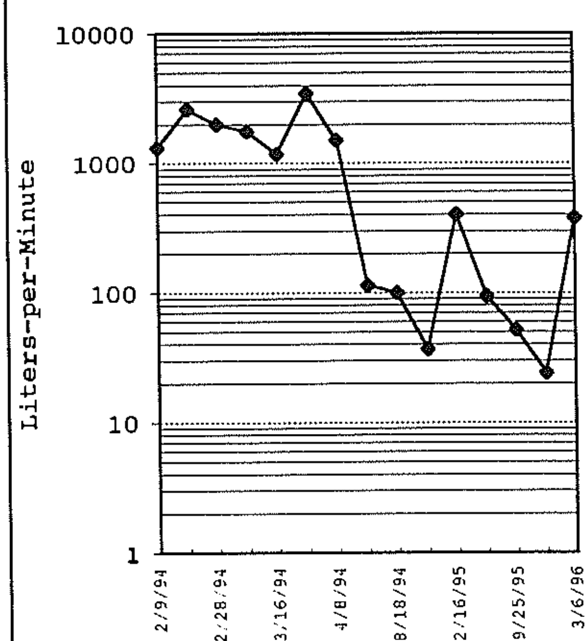

Figure 4. Flow Measurements From Blowout in Case Study No. 2.

A narrow outcrop-barrier will result in a better connection between the joint system and the mine pool. A chart showing a cumulative percentage curve of the width of the outcrop-barrier at the areas of the slides studied is shown in Figure 5. In these studies, the distance from the slide to the mine works has a mean of 45 meters, with a standard deviation of 8.5 meters. The study indicates that outcrop-barrier width is very important in the prevention of slides. However, maintenance of an outcrop-barrier alone will not always guarantee prevention of seepage problems. In case study number one, examination of the mine map indicates that a barrier of 60 meters was maintianed around the whole panel and mine pool. As suggested by Harlow and LeCain, 1991, hydraulic conductivity of the coal seam would decrease with increased barrier width due to the increased overburden depth. The decrease in hydraulic conductivity may allow a build up of the hydrostatic head, thereby increasing the flow through fractures that intersect the mine pool. Though increasing the outcrop-barrier will increase the head loss to the surface-seepage areas, resulting in a reduced flow, their use will not always assure prevention of seepage problems. If that area of the mine has enough inflow, the increase in depth may still provide enough hydrostatic head to cause seepage problems. While the use of increasing outcrop-barrier widths at sensitive areas may prove to be an effective tool, the main objective should be to control the size of the mine pools.

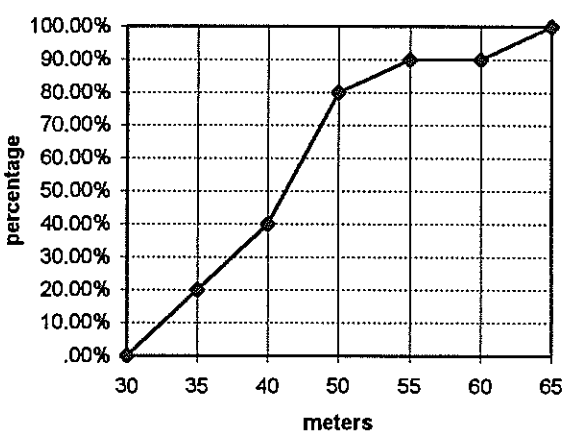

Figure 5. Cumulative Percentage Curve of Barrier Width at Landslides. Data set = 10.

From the case studies, it is clear that control of mine seepage must address both the maintenance of adequate outcrop-barriers width and control of the sizes of the mine pools. The control of the size of the mine pool can be either by planned drainage of the mine or by limiting the size of the drainage area, preventing most of the drainage from collecting into one large pool. Restricting the size of the mine drainage area should be a neccessary part of mine planning. The neglect of this has lead to serious seepage problems.

One method that can be used to control drainage is by planning the layout of barrier pillars in ways that divert drainage to various sections of the mine or to discharge points. While these pillars may allow considerable seepage, their use to divert flow to other areas is considered useful. Mine seals may also play an important part of the mine drainage plan. However, consideration needs to be given to ensure the long-term stability of these structures. Placement of the barrier pillars and mine seals along with the local dip of the coal seam could greatly aid in the control of mine drainage. A good example of this is demonstrated in Case Study 3, where seepage was observed on both sides of the of a small hollow.

__Case Study 3__

In Case Study 3 the mine map indicates two mine pools. One pool shows a possible collection basin of 40 ha (100 acres) and the other pool is basically limted to one panel, approximately 8 ha (20 acres), under the ridge. This panel is isolated by the barrier pillars and seals separating the sub-main from this panel. Sampling at several monitoring points was done to investigate seepage conditions. On the side of the large drainage area, the mine pool resulted in a slide and later a blowout. The seepage on the other side of the hollow, while not planned, has not resulted in a slope stability problem. Study of mine maps and monitoring points give some indications as to the differences in the problems seen at the two sides of the mountain.

Sampling was initially started at three sample points; however, one point was removed during stabilization of the slope. Two monitoring points remained allowing continued monitoring of the two mine pools. The most significant finding from the sampling was in the difference in the seasonal fluctuations of the two monitoring points and the reflection of the change of the flow rate at monitoring point 2 (Figure 6), which resulted from reduced hydraulic head caused by a blowout. Monitoring point 2, at the larger mine pool, showed less fluctuation of flow rate, except for one surge in flow due to precipitation. This surge in the flow showed large drops in specific conductance (Figure 7). This observation gives a good indication of how near surface groundwater (with lower specific conductance) affects the two seepage areas. Monitoring point 3 at the small drainage area shows a large downward trend in the flowrate during the dry time of the year. Results of the trends in the amount of seasonal fluctuation of the monitoring points indicated that the volumes of the mine pools are different as suggested by the mine map. The mine pool feeding monitoring point 2 showed less change in the hydraulic head as indicated by a more consistent flow rate, measured at the discharge point. Monitoring at sampling point 3 indicates a larger change in the hydrostatic head. The mine pool at monitoring point 3 is fluctuating more, presumably as a result of less storage capacity and/or lower inflow rates. In April, 1994, a blowout occurred in the area of monitoring point 2 reducing the flow measurements (Figure 6).

The Correlation Coefficient (r)

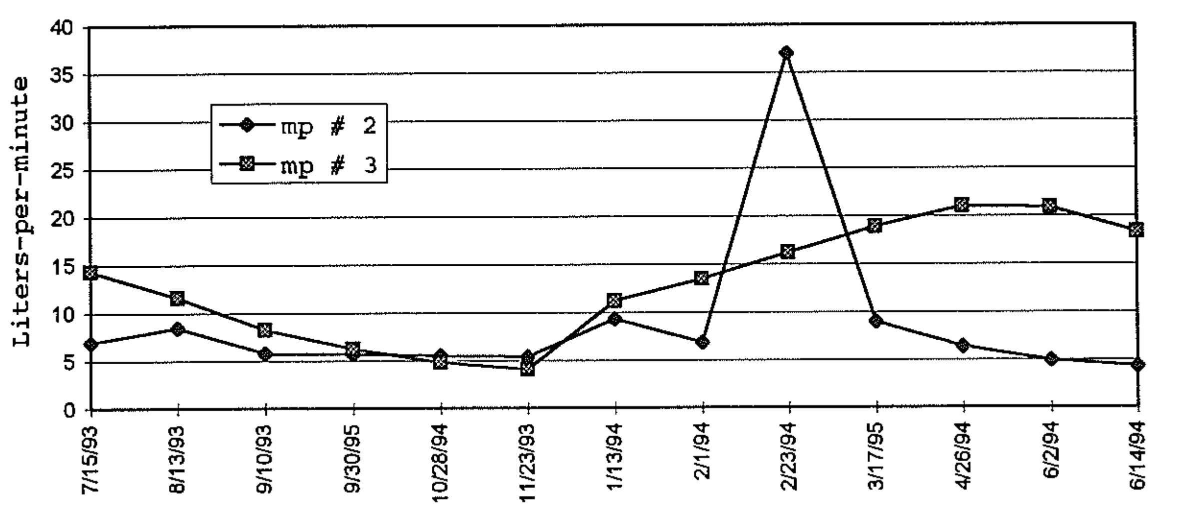

Figure 6. Comparison of Monitoring Points 2 and 3 in Case Study No. 3

was also calculated for the flow rates (the sample set on February 23, 1994, was not used because of the influence of the storm event). The r value for the data set before the blowout had a value of 0.75. The r value for all the data set had a value of 0.09. This change in the correlation of the two monitoring points would indicate that the blowout had affected a change in the hydrostatic head of the mine pool at monitoring point No.2. While the data set is limited and details of the actual drainage conditions and mine pool size are not available, this case study still demonstrates how control of mine drainage areas are important and that planning of the mine layout can reduce the size of the mine pools.

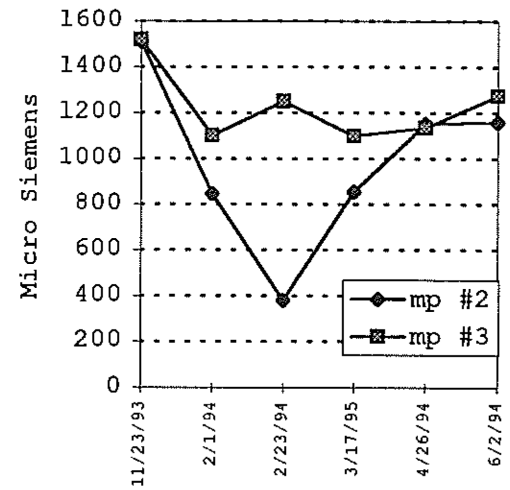

Figure 7. Specific Conductance Values for Case Study No. 3.

Conclusions and Recommendations

These case studies are not detailed investigations of mine drainage control; however the studies show the need to control mine drainage. The study indicates the need to have flexible systems that can take advanage of structural geology, outcrop-barrier width, and drainage points. Planning for drainage control must be flexiable enough to take advantage of the unique conditions that are present in each mine. In planning mine drainage the main concern is in limiting the hydrostatic pressure of the mine pool. Several tools are avialable for control of drainage both into and out of the mine pool. Specifically, the study has found:

*The mining operations will concentrate groundwater flow to specific areas of the mine. Failure to plan for the change in the groundwater flow can result in dangerous and costly environmental problems.

*Outcrop-barrier widths are important in the control of mine seepage. The outcrop-barrier widths seem useful in reducing the hydraulic gradient, causing less flow to specific areas at the outcrop. In areas where the mine pools develop close to the stress-relief fracture system seepage problems will increase. However, the use of a minimum barrier width will not assure prevention of landslides.

*Discharge points provide a method of reducing the volume and hydrostatic pressure at the mine pools. Possible discharge points should be considered where feasible to reduce the amount of water stored in the mine area. These discharge points can provide improvements to the landuse area when the water quality is adequate.

*Study of the mine maps and the flow measurements can give some indications of the mine pool conditions. While this data may be limited in detail on exact drainage areas and area and depth of the impoundment, useful information of the changing conditions of the mine pools can still be obtained. This information may be useful in planning of abandoned mine projects and assessment of potential hazards to the public, or when investigating the potential undermining of mine void.

*The use of barrier pillars and seals needs to be investigated as structures to reduce the size of the collection basin draining into the mine pool.

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