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Underground mine stream crossing assessment: A multi-disciplinary approach

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ABSTRACT

Underground mine designs typically try to avoid extraction beneath streams and rivers of any significant size, especially when the overburden rock thickness between the stream bed and the mine is thin. Potential issues with mining beneath streams include excessive groundwater inflow to the mine, weak ground (roof, floor, and pillar) conditions, horizontal stress effects, as well as stream loss and other potential adverse environmental effects. However, there are times when crossing beneath a stream or river is necessary to move into a new area of mineral reserve without creating additional mine access points from the ground surface. Often, stream crossings are completed without thorough assessment, potentially resulting in increased costs, decreased safety, and, in some cases, failure to advance the mine. Selection of the most favorable location(s) to cross the stream must account for numerous factors and the associated assessment often requires a multi-disciplinary approach. Stream crossing investigations often require geological, hydrogeological, geotechnical, and geophysical expertise. Phases of stream crossing investigations include desktop evaluation of maps and aerial photography, stream bed observations, drilling, detailed rock core logging, downhole geophysical surveying, hydraulic conductivity testing (packer testing), geotechnical laboratory testing, assessment, and reporting. The deliverables from a stream crossing assessment typically include geological, geotechnical, and hydrogeological characterization of potential stream crossing locations, classification of favorable and unfavorable crossing locations, recommendations for entry design and pillar sizing, and recommendations for if, and how, to conduct pre-grouting activities. Examples of technical aspects of data collection and assessment are provided based on decades of industry experience conducting stream crossing assessments in various underground mining scenarios.

1. Introduction

Underground mining in areas with low overburden thicknesses often presents many challenges to operators. While weathered rock and low confining stresses associated with low cover depths are major contributors to underground mine problems, the presence of a stream or river on top of the thin overburden can significantly increase the risk to the mining operation. Mines attempting to cross beneath streams or rivers often encounter the Stress-Relief Zone, which is often called the Stress-Relief Aquifer Zone, as it tends to be one of the most significant aquifers in many areas with coal-bearing strata. Fig. 1 illustrates the Stress-Relief Aquifer Zone and the associated problems that may be encountered by mining. Characterization of this zone and the potential effects on mining is one of the main goals of a stream crossing evaluation.

Mining operations are often faced with making a stream crossing to efficiently access additional reserves, to avoid constructing additional box cuts or shafts, or to manage property control and mine access issues. Often, the geological, hydrogeological, and geotechnical characteristics of the desired location dictate the success or failure of the stream crossing attempt. A mine may have many potential locations to cross a stream, or the stream crossing may be limited to a single location. Regardless of the number of location choices, thorough assessment is recommended to select the most favorable location and complete the crossing in the most practical way. Without proper assessment, stream crossing attempts may result in unnecessary costs, failure to advance mining, or even danger to miners and equipment.

As with all scientific assessments, the results of the study are often limited by the available information. Thorough stream crossing assessments involve numerous evaluation techniques and activities, and are designed to look at all aspects of potential crossing locations. However, in practice it is not possible or practical to

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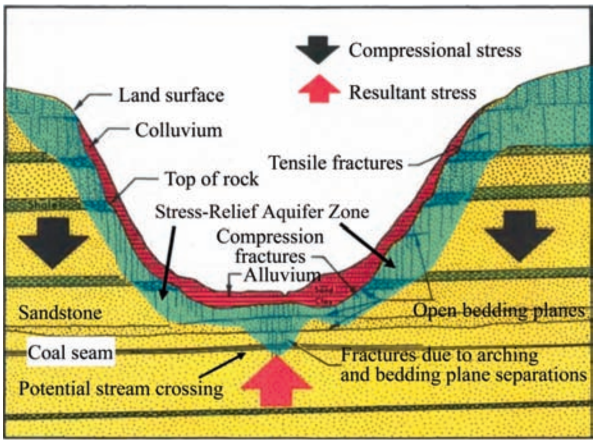


Fig. 1. Typical Stress-Relief Aquifer Zone (after [1]) and potential issues to be encountered by underground mine stream crossing.

evaluate every crossing in all available ways. The spectrum of possible scenarios may range from assessing multiple crossing sites with multiple holes on each side of the stream to testing one crossing site with a single hole. Extremely thorough assessment is often impractical due to budget and time, but a minimal approach increases the risk that the collected data is not representative of actual conditions. Each project must be evaluated separately and designed appropriately.

While stream crossing evaluations are often limited to some degree by budget, time, access, weather, and other factors, in some cases, evaluations are not conducted simply because mine operators are unaware or unfamiliar with available capabilities and techniques for assessment, or unsure of the benefits of such studies. This paper presents numerous components of stream crossing evaluations that are commonly used in the coal mining industry and briefly summarizes a series of case studies to demonstrate the variety of results and associated benefits. It is beyond the scope of this paper to provide extremely detailed descriptions of all field activities and assessment techniques.

2. Desktop evaluation

The initial step of any stream crossing evaluation must include review of all existing data for the site(s). This includes review of topographic mapping, surficial geology mapping, coal seam structure mapping, detailed mine maps and mine projections, mine roof and floor hazard mapping, coal reserve maps, lineament maps, aerial photography, existing mine inflow data, horizontal stress measurements, and any other existing information for the site. The desktop review of existing information allows for early identification of limiting factors that may significantly affect the selection of crossing sites before any field work is completed. Clear communication with the mine operator is also a key component of the desktop study, so that operational factors can be incorporated into the assessment. The desktop study is also essential for planning efficient drilling activities.

While most desktop study tasks are relatively self-explanatory, some approaches may be less known. Using only topography mapping, confinement ratios for the subject stream valley can be calculated to identify crossing locations along the stream that are expected to be less prone to mine roof falls. The methodology, described by Molinda et al. [2], is based on a significant correlation between mine roof falls and valley geometry. Confinement factor is the ratio of total valley relief to valley floor width, with valley floor width defined as the width of the valley at a height above the valley floor equal to 20% of the total relief (Fig. 2). The methodology is commonly referenced as the "R20 method". The research discussed by Molinda et al. [2] indicates that areas with confinement factors between 0.4 and 0.6 tend to be more susceptible to mine roof falls.

Lineament mapping is another desktop technique that often provides valuable insight for selection of stream crossing locations. A lineament is generally described as a naturally occurring, reasonably linear or slightly curved feature. The mapping uses Landsat Thematic Mapper data, side-looking airborne radar data, color-infrared photographs, topographic maps, and other sources (often available via federal and state government agencies) to identify topographic alignments that may be indicative of subsurface structural features that could adversely affect mining conditions. The aligned features may include fault scarps, fault traces, truncated geologic structures, unusually straight stream reaches, linear vegetation anomalies, aligned stream segments or depressions, soil anomalies, or other features. Care must be taken during the assessment to exclude cultural and man-made features. Identification of lineament features does not always correlate to the presence of underground mining issues, but the technique has been successful in many cases and is a relatively quick initial step. Lineaments are often classified into sets depending on their ability to be identified easily or in numerous data formats, and by their relative length and consistency. An example of a lineament map completed for an area along a stream is included in Fig. 3.

The ultimate goals of the desktop study are to identify the major features that may affect the desired stream crossing(s) and to design the field data collection phase of the project. Once a potential crossing location is identified, exploration drilling locations are planned. Ideally, hole locations should be placed to enable collection of data from all areas where the mining passes beneath the stream valley. Variable subsurface conditions from one side of a stream to the other are common. If available hole locations or the number of holes to be drilled are limited, it is usually best to place the hole(s) as close to the center of the stream valley as possible, as that is the location of greatest expected strata bedding plane separation and least overburden above the projected mining (presumably "worst-case"). The goal of the drilling plan is to accurately characterize the range of possible subsurface conditions to be encountered. Property issues, roads, railroads, and steep topography may complicate drilling designs, requiring special approaches including angled drilling.

3. Drilling and core logging

Core holes are most commonly drilled for stream crossing assessments, and it is best to use a triple-tube barrel assembly to ensure the highest core recovery possible. Rotary drilling is sometimes used to more economically increase the number of holes drilled, but the geotechnical data from rotary drilling is limited as compared to core drilling. While rotary drilling does not provide core for logging and testing, it does provide a hole in the ground in which geophysical logging and hydrogeologic packer testing can be conducted. Drilling activities define the thickness of the alluvium, the thickness of weathered bedrock, and the depth to competent

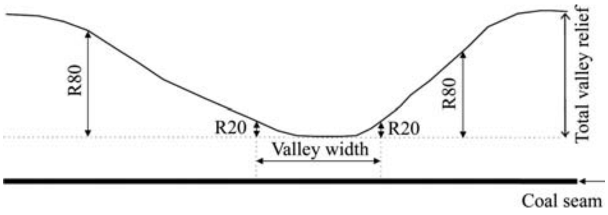
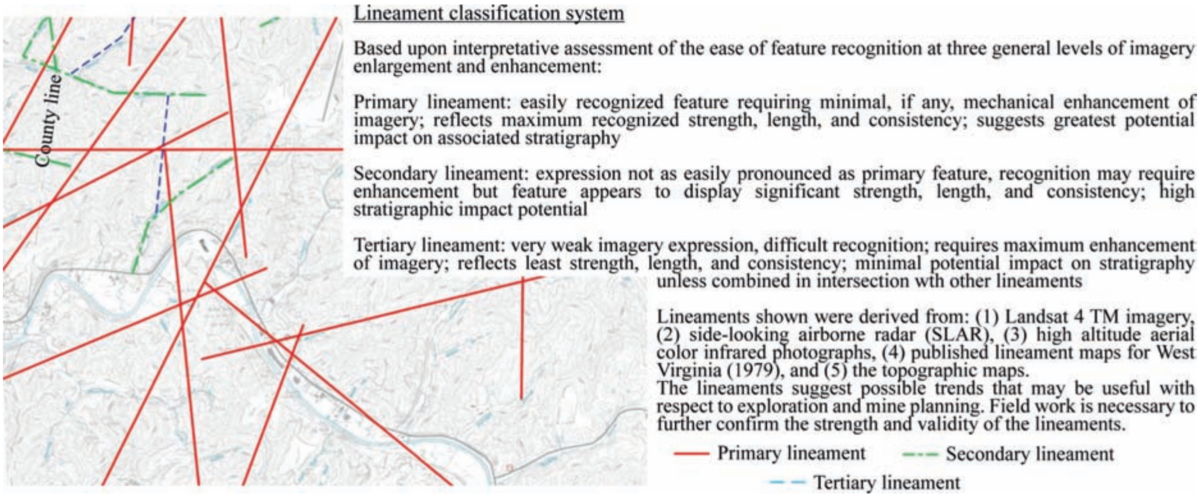


Fig. 2. Valley width defined for the "R20 method".



Lineament classification system

Based upon interpretative assessment of the ease of feature recognition at three general levels of imagery enlargement and enhancement:

Primary lineament: easily recognized feature requiring minimal, if any, mechanical enhancement of imagery; reflects maximum recognized strength, length, and consistency; suggests greatest potential impact on associated stratigraphy

Secondary lineament: expression not as easily pronounced as primary feature, recognition may require enhancement but feature appears to display significant strength, length, and consistency; high stratigraphic impact potential

Tertiary lineament: very weak imagery expression, difficult recognition; requires maximum enhancement of imagery; reflects least strength, length, and consistency; minimal potential impact on stratigraphy unless combined in intersection wth other lineaments

Lineaments shown were derived from: (1) Landsat 4 TM imagery, (2) side-looking airborne radar (SLAR), (3) high altitude aerial color infrared photographs, (4) published lineament maps for West Virginia (1979), and (5) the topographic maps. The lineaments suggest possible trends that may be useful with respect to exploration and mine planning. Field work is necessary to further confirm the strength and validity of the lineaments.

Fig. 3. Example of lineament mapping results with lineament classification system.

bedrock, as well as the overall geologic framework and geotechnical aspects of the strata.

Detailed geological and geotechnical core logging is best completed by an experienced geologist at the drill site as core is extracted from the core barrel to document the core recovery and as-drilled geotechnical conditions. Ideally, core drilled for geotechnical purposes should be pushed from the outer core barrel smoothly using water pressure while the barrel is lying horizontally. In practice, core is often pushed from the barrel using a long rod. Hammering on the core barrel, and especially extracting core from a vertically hanging core barrel, should be avoided. Transportation of core boxes prior to logging and long periods of time (months) between drilling and core logging activities can drastically affect the quality of geotechnical logging data and should be avoided. Geotechnical logging includes determination of rock quality designation (RQD), fracture descriptions, weathering observations, moisture sensitivity classification, relative fracture angles, and overall qualitative rock quality characterization. If oriented core drilling is part of the assessment, the associated fracture orientation measurements will also be collected during logging. Rock strata is divided into geotechnical units by the geologist based on a combination of both geological and geotechnical factors. Core logging data (lithology, strata defects, visual rock quality, RQD) is often organized and displayed graphically in combination with geotechnical laboratory results, geophysical logging data, and hydrogeologic test data. Graphical logs aid assessment by efficiently organizing all available data for a hole by depth below ground surface.

Core photography is completed in a systematic manner to preserve a record of the as-drilled appearance of the core for future reference. Fig. 4 is an example of core photography for a section of immediate roof rock including proper labeling, natural fracture marks, and geotechnical unit breaks. Drill site location descriptions and photographs are also collected; in particular, zones of visible bedrock in the creek and other stream features are documented.

Any holes drilled to assess the stream crossing must be fully grouted, from bottom to top, following completion of testing. Vertical connectivity of the stream and Stress-Relief Aquifer Zone to the mine horizon is to be avoided at all costs. It is the responsibility of the field geologist and the driller to ensure that all holes are completely backfilled. In addition to backfilling of all test holes used for an assessment, field personnel must identify and pursue backfilling of any additional water wells or other borings that may be encountered in the stream crossing area during the field investigation phase.

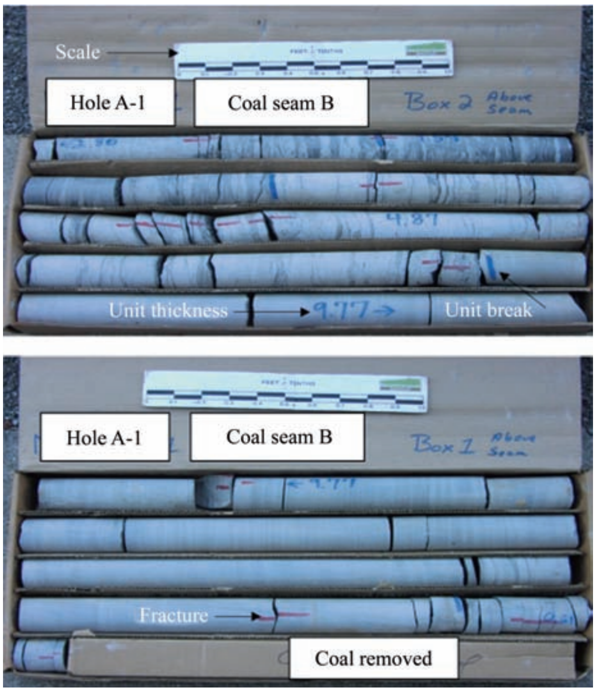


Fig. 4. Example of the core photography for immediate roof rock section.

4. Rock testing—laboratory work

Geotechnical rock core testing may include uniaxial compressive strength (UCS) with or without strain gauges, axial and diametral point load testing (PLT), Brazilian (indirect) tensile strength, density, triaxial compression, moisture sensitivity, and sometimes more specialized tests. The basic laboratory test suite typically includes UCS, Brazilian tensile, and density, with other test procedures determined based on the specific project factors. Core samples are typically collected in the field by a geologist and shipped to a third-party laboratory. Care must be taken to handle and package the samples carefully, preserve moisture content, and thoroughly document the hole numbers and depths from which the samples were collected. The laboratory must be contacted prior to start of drilling activities to ensure that the size of the samples collected is adequate and to ensure that the laboratory has the capability to complete the desired test suite.

It is important to consider that rock characteristics resulting from laboratory testing are based on samples of adequate size that were recoverable by the drilling, taken from discrete intervals. As such, laboratory test results tend to be inherently biased. As a simple example, if roof and floor rock for a coal seam are particularly weak and the only testable samples are intermittent, thin bands of sandstone, the laboratory results for the testable samples (sandstone only) may significantly overestimate the strength of the strata. Sampling for laboratory testing must always attempt to collect enough samples to accurately represent all of the relevant strata. If this is not possible, the test results must be heavily qualified and used very carefully. Geotechnical lab test results should always be reviewed in combination with geological, geotechnical, and geophysical logging results to ensure that the lab results are consistent with other technical data. Rather than attempting to achieve a specific standard deviation amongst samples within a given unit, it is often more practical to understand why there may be variability in test results. For example, coal-bearing rock is often classified with terms such as “sandstone with shale streaks” or “sandstone and shale interbedded”. In such cases, lab testing will often indicate noticeable variability in diametral point load testing (PLT) results due to the location of the tested interval relative to sandstone/shale boundaries within the unit. Too often, laboratory rock strength values are misinterpreted or trusted without question. It is important to remember that a laboratory rock strength result is representative of the intact rock strength of a discrete piece of rock and is not an automatic indication of expected mine roof conditions.

5. Geophysical logging

Conducting downhole geophysical logging for coal exploration activities and geotechnical studies is a standard practice that significantly enhances the amount and types of data that can be collected from test holes. The typical suite of geophysical testing for stream crossing investigations includes density and gamma log (standard logs for geologic interpretation), temperature log (detects changes in temperature indicative of flow zones in strata), resistivity log (detects changes in resistivity of the strata indicative of more permeable or conductive zones in strata), caliper log (identifies and measures larger fracture zones), acoustic televiewer log or ATV (accurately identifies fractures and their depth and orientation), sonic log (enhances fracture characterization and is indicative of relative changes in rock strength). In certain situations, a downhole camera may also be useful. When borehole conditions are stable, open-hole logging (as opposed to logging from within drill rods that are still in the hole) is strongly recommended, and many of the logs require open hole conditions.

Geophysical logging is used in combination with geological and geotechnical logging of core to plan hydrogeologic test intervals and to complete the overall stream crossing assessment. ATV logging data is very useful information to have for stream crossing assessment, as the logs graphically illustrate the frequency, orientation, and openness (aperture width) of in-situ fractures in the overburden above the proposed stream crossing. An example graphic from an ATV log is included as Fig. 5.

6. Hydrogeologic testing (packer testing)

Packer testing is done to test the horizontal hydraulic conductivity of strata. Straddle packer testing (implying two packers) uses an assembly attached to the drill rods or to water pipe extended from the drill that includes a perforated zone (usually 3.0 m or 10 ft long) of water pipe with inflatable packers above and below the perforated zone. A basic schematic diagram of the downhole portion of a packer testing assembly is included in Fig. 6.

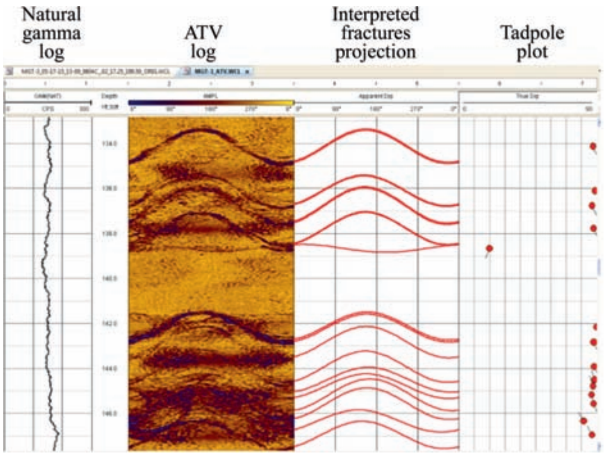


Fig. 5. Example of the ATV log with natural gamma and interpreted fractures.

The straddle packer assembly is used to isolate zones within the strata and determine the hydraulic conductivity of zones of open fractures, closed fractures, and intact rock. In coal bearing strata, hydraulic conductivity is most often fracture-controlled, and to a lesser extent dictated by lithology. It is standard practice to test adequate intervals of both the roof and floor rock for a particular coal seam, in addition to testing the coal itself. Single packer testing may also be conducted if conditions do not allow for straddle packer testing; however, the ability to isolate discrete horizons and fractures using two packers is often advantageous. Packer test results are used in combination with geological, geotechnical, and geophysical information to identify zones of potential water flow in the roof of the mine, which are often associated with more heavily fractured zones and/or weaker zones that are more likely to create adverse mining conditions and increase inflow of water to the mine.

To conduct a test, the packer assembly is positioned over a 3.0-m (10-ft) long interval at a selected depth, the packers are inflated (commonly with nitrogen gas) to isolate the selected zone from the rest of the hole, and water is pumped under pressure out of the perforated section of pipe and into the strata zone. Measurements of water pressure, nitrogen pressure in the packers, flow into the strata, and other measurements are recorded and used to calculate the hydraulic conductivity of each selected test zone. Packer testing concepts are straight-forward, but identifying, troubleshooting, and mitigating testing problems in the field often requires experienced personnel to avoid collection of erroneous data.

Observations of all hydrogeologic aspects of the drilling should be recorded, including transient and stabilized water levels in the test holes, any observed artesian conditions, gas detection in the holes, stream flow and streambed characteristics, and other relevant information.

7. Stream crossing assessment results and recommendations

The assessment phase of stream crossing evaluations incorporates all geological, geotechnical, and hydrogeological data in order to characterize the subject stream crossing zone, identify potential mining issues, and formulate mitigation approaches. The drilling results allow for creation of geological cross-sections through the area of the proposed crossing that are very useful for understand-

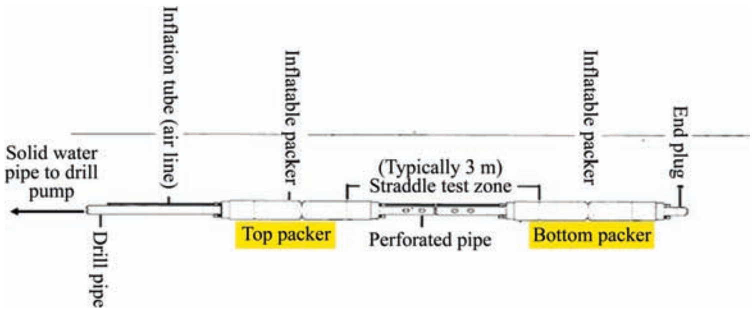


Fig. 6. Example of the straddle packer assembly (downhole portion).

ing the actual physical layout of the crossing. Fig. 7 is an example cross-section constructed from data collected for a stream crossing study. Fig. 7 includes a clear representation of the proximity of the alluvial material and weathered bedrock to the upper coal seam. Note the core loss within the coal zone in Hole 1.

The assessment phase identifies zones of geotechnical concern such as weak roof or floor, the presence of large or high angle fractures, excessive depth of weathering, excessive bedding plane separation, moisture sensitive roof or floor, potentially undersized pillars, poor projected mining orientations or layouts, and other potential adverse geotechnical conditions. Other adverse conditions in non-coal mine stream crossings may include karst conduits or sinkhole connections and large mud-infilled fractures. The geotechnical portion of the assessment may employ any number of tools and techniques common in the industry, including but not limited to Rock Mass Rating (RMR), Coal Mine Roof Rating (CMRR), Analysis of Coal Pillar Stability (ACPS), Fixed End Beam Theory, Analysis of Roof Bolting Systems (ARBS), Vesic-Gadde Floor Stability, LaModel, FLAC^{3D}, and many others. If multiple holes are involved, the assessment must include evaluation of geotechnical conditions both vertically in each hole and laterally between holes.

The hydrogeologic assessment portion of the evaluation involves determination of the hydrogeologic framework of the stream crossing area. This means defining the extent and character of the streambed alluvium, the Stress-Relief Fracture Zone, the weathered bedrock zone, major aquifers and aquitards in the overburden and in the mine floor, and the coal itself. The assessment also includes comparison of water levels in borings to the stream level to determine the potential for the stream to lose water to the underlying fracture zone aquifer.

The assessment portion of a stream crossing study is where all of the various types of data are combined. Data combinations often include correlation of weak roof and floor zones from core logging with ATV logging data, geotechnical laboratory results, and packer test results. Examples of ATV log sections combined with packer test results are provided in Fig. 8. In general, poorer rock quality correlates to higher hydraulic conductivity, but not always.

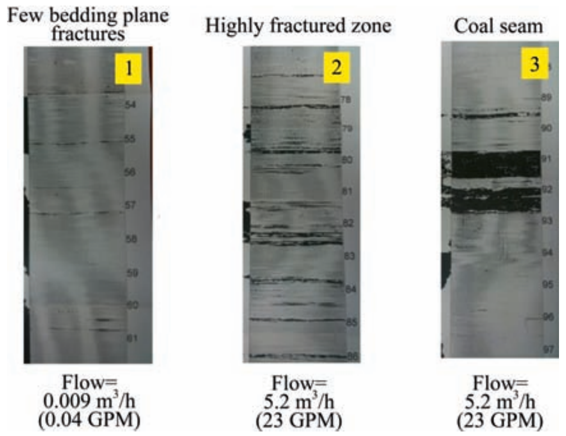


Fig. 8. Example of ATV logs combined with packer test results.

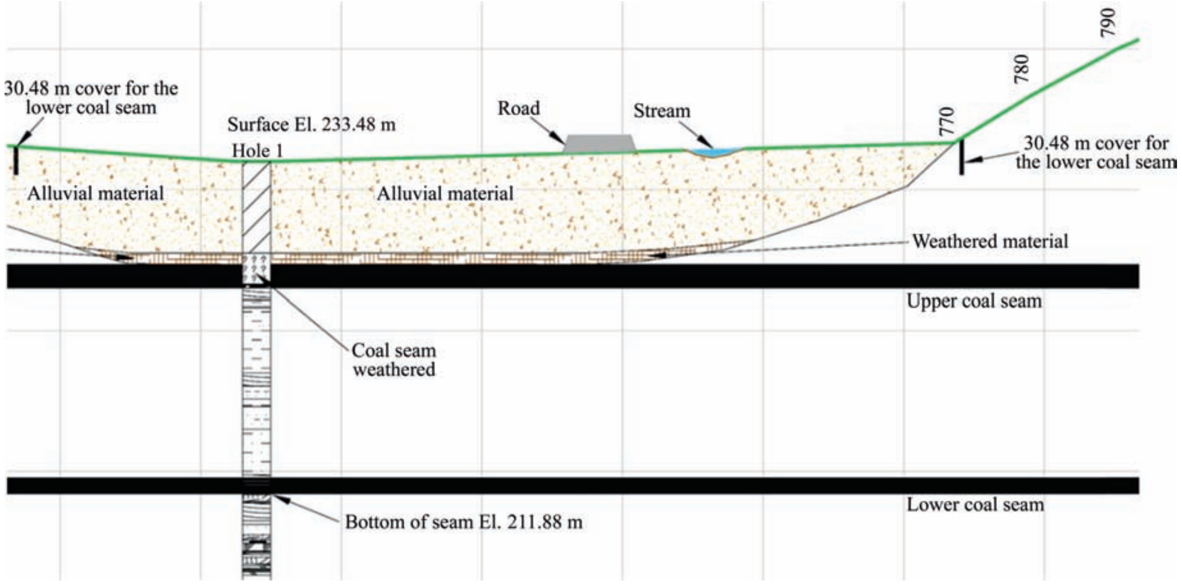


Fig. 7. Example of cross-section for stream crossing assessment.

Table 1
Case study summary.

Parameter	Case study				
	1	2	3	4	5
Holes drilled	3 holes, all on one side of creek	1 core hole, 1 rotary boring	3 core holes	4 core holes, 2 on each side of creek	5 core holes, 3 on one side of creek and 2 on other
Depth to bedrock (m)	6.1–9.1	3.0	6.4–15.2	3.9–7.0	6.1–7.6
Depth to top of coal seam (m)	15.8	25.9–30.4 (average), 18.2 (minimum)	44.2–48.7	16.7–18.2 in stream valley below stream bed, 15.2 (minimum)	33.5
Alluvial valley width (m)	39.6	91.4–137.1	152.4	60.9–76.2	91.4–152.4
R20 valley width (m)	304.8	182.8–274.3	274.3–350.5	219.4	259.0
Total valley relief (m)	155.4	176.7	213.3	192.9	109.7
Confinement factor	0.51 (more susceptible to roof falls)	0.97–0.72 (narrow)	0.78–0.61 (marginal)	0.88 (narrow)	0.42 (more susceptible to roof falls)
Roof and floor notes	Rock quality predominantly poor or very poor	80% of overburden fair to good and 20% somewhat poor to poor; no high angle fractures; poor immediate floor	Most roof rock is fair or good; floor is weak	Most immediate roof rock is good to fair, with poor zone 3.6 m above seam; floor rock varies from very good to very poor	Immediate roof is fair to poor; floor is weak and clay-rich
Hydraulic conductivity (*K*) notes	Ranged from 0.0003 m/day to 4.5720 m/day	0.0030 m/day in roof; 0.3658 m/day in coal; low in floor	0.0021–0.2134 m/day in coal; up to 2.7432 m/day in shallower overburden; low *K* in floor	0.0305–0.2591 m/day in coal; 0.0003–1.2497 m/day in roof with higher values due to bedding plane separations	0.0305–0.1524 m/day in coal; in rest of hole very low except at or above 18.2880 m deep
Notes	Tertiary lineament in crossing area	1 primary and 2 tertiary lineaments within 804 m—no effect	Found correlation between high angle fractures in core and ATV with lineament orientations and principal horizontal stress in area	Water levels in holes all lower than stream level implies downward gradient (losing stream)	Very few high angle fractures in core
Results	High water inflow potential; potential adverse effects to stream and aquifer	No significant water inflow expected	Below 36.5 m deep, *K* is low; water inflow not expected to be problem	Decent rock strength, but potential for significant adverse hydrogeologic conditions; numerous bedding plane separations with higher *K*, but lack of vertical fractures detected; eliminate 4-way intersections; limit cut depth	Rock strata below18.2 m is very low *K*; but strata are weak and must be well supported because small movement could induce large increase in inflow
Recommendations	Minimize number of entries; eliminate 4-way intersections; limit cut depth to 3.0 m or less; use mesh/screens; use fully grouted bolts and cable bolts; pre-grout from surface and in-mine grouting	Remove 0.3 m of immediate floor during mining; mine draw rock and rider coal to increase roof stability; use mesh/screens; use fully grouted bolts and cable bolts; reduce number of entries to 4; increase pillar size; eliminate 4-way intersections; no grouting necessary but have plan in place	Use mesh/screens; minimize number of entries, intersections, and cross-cuts; use fully grouted bolts; no grouting recommended but have plan in place	Use fully grouted bolts, cable bolts, and possibly steel sets or trusses; reduce bolt spacing; reduce entry width; use mesh/screens; apply sealant to deal with moisture sensitive strata; Intense grouting recommended (both pre-grouting from surface and in-mine)	Increase pillar size to assist with floor instability; reduce entry width; use fully grouted bolts and cable bolts; eliminate 4-way intersections; do not leave roof unsupported for any length of time; pre-grouting from surface not recommended (not practical due to low *K*); in-mine grouting recommended to strengthen weak strata

Reporting of assessment results summarizes geotechnical and hydrogeological characterization of the site(s) and highlights zones of expected instability and increased water inflow. Depending on the scope of a particular assessment, the results of a stream crossing study may include suggested pillar sizing and layout, roof bolt and other ground control specifications, suggestions for removing portions of the mine roof and floor strata during mining, and grouting recommendations.

One of the most common activities for mitigating potential stream crossing issues is grouting, both pre-grouting of the strata in the crossing area from the ground surface prior to mining advance, as well as in-mine grouting completed immediately in front of mining advance. Grouting has the potential to both increase the strength and cohesiveness of the rock and to decrease the hydraulic conductivity of the rock. The results of the stream crossing study are used to determine the zone of strata around the coal (roof and floor intervals) to be pre-grouted. In this way, the grouting can be done more efficiently, as opposed to attempting to grout blindly with no knowledge of the depth of the Stress-Relief Zone, the major fracture zones, or the low permeability zones. For example, injecting grout into the Stress-Relief Zone can lead to uncontrolled grout migration, damage to the stream, damage to any nearby water wells or septic fields, and loss of significant time and money. Often, grouting recommendations include avoiding grouting in shallow portions of the Stress-Relief Zone to allow shallow groundwater flow to continue downstream without causing a rise in the water table that can increase the head pressure trying to push water into the mine. Due to the potential adverse effects associated with grouting the subsurface near a stream, it is advisable to inventory water users and other entities in the area that could be affected, and to set up a monitoring system. The packer test results for highly fractured strata zones can be used as a guide for planning pressure grouting activities, to ensure that grouting does not adversely affect the strength of the rock mass. Another example of grouting without knowledge of the subsurface involves unsuccessfully attempting to grout very low-conductivity rock.

In-mine grouting often involves application of a polyurethane grout (or similar) and is conducted as part of the mining advance cycle in the stream crossing area. The in-mine grouting involves drilling and grouting via angled holes starting from the mining face and extending up into the roof strata in front of the mine. Mine advance through the stream crossing area should not extend beyond the limit of grouting.

8. Industry experiences

Table 1 summarizes the results of a series of stream crossing evaluations conducted for the coal mining industry in the United States. The results illustrate the potential variability that can be encountered and the range of recommendations that are produced from conducting stream crossing evaluations.

9. Conclusions

Due to the low cover depths, increased fracturing, and presence of significant water in stream valleys, mining is much more likely to encounter adverse conditions in these areas. Stream crossing studies are multi-disciplinary evaluations that are conducted to characterize the subsurface area through which a mine will attempt to advance, and to identify the potential issues before the mining occurs. The benefits of conducting a stream crossing study include increased miner safety, increased likelihood of a successful crossing attempt, decreased mining and ground control costs in the crossing area, and decreased potential for damage to the stream or nearby water wells. Mining conditions can change quickly under a valley and understanding the potential variability that may be encountered is important. In addition, activities such as pre-grouting should not be conducted without characterization of the subsurface so that unintended damage to streams, wells, basements, and septic fields can be avoided.

The individual tasks involved in a stream crossing evaluation are, for the most part, common activities within the coal mining industry. It is the necessary integration of several evaluation methodologies that is required to conduct a thorough stream crossing evaluation. The discussion of assessment techniques and case study results summarized in this paper are intended to inform mine operators of the key components and advantages of completing stream crossing evaluations.

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