Underground Bulkhead Construction for Mine Discharge Control at Hardrock AML Sites

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Abstract

Reclamation of abandoned or inactive hardrock mine sites on public and private land in the western United States and Canada often involves developing a strategy for dealing with acid rock drainage (ARD) discharges. At many sites, there is no remaining reclamation responsibility or viable potentially responsible parties associated with the past mining operation. With continued absence of a Good Samaritan provision to limit liability under the Clean Water Act in the U.S., NGO watershed stakeholder groups and local Provincial and State governments are often reluctant or unable to implement ARD treatment to help clean up pollution problems they didn't create, even though they may have the funding and desire to do so.

For some mining sites, an alternative to traditional ARD treatment may be to institute source-controls within the hydrologic system to re-establish pre-mining groundwater pathways. This approach prevents rapid, continuous "pipe-flow" of groundwater into and through the open, oxygenated underground workings, significantly reducing the formation of ARD. This usually involves construction of a hydrologic bulkhead seal in the underground workings at a location designed to re-establish the pre-mining water-table elevation, establish anoxic conditions in the orebody, and eliminate direct discharge from the portal. An evaluation of the mine-groundwater system interaction is required to determine the feasibility of this strategy for each mine site.

This paper discusses the mine-site attributes most beneficial for a positive bulkhead feasibility determination, as well as optimizing success of the approach for specific site conditions. These include an understanding of the groundwater hydrogeology, reasonably good access to underground workings, sections of solid, competent rock (minimal faulting, jointing or bedding planes) preferably along cross-cut mine workings, an adequate overburden depth to hold the expected head pressure, no unknown workings, drill-holes, or other significant natural groundwater pathways connecting to surface or any adjacent mines, and the use of appropriate construction and grouting techniques.

Introduction

Many draining inactive or abandoned mines in the Rocky Mountain West may be amenable to a bulkhead-closure approach to eliminate or minimize ARD. The goal of a hydrologic mine bulkhead alternative is to return intercepted groundwater flow to pre-mining pathways, and re-establish the natural equilibrium in the groundwater system that was impacted by mining. Our experience with many recent underground bulkhead construction projects and examination of previously placed poorly-performing bulkheads has been used to develop a checklist of desirable site attributes when contemplating a bulkhead feasibility investigation at a given site. These attributes can be used help guide the subsequent hydrogeologic investigations and geotechnical work needed to assess the viability of a bulkhead ARD solution for each specific site.

Attributes for Bulkhead Success

A comparison of successful versus problematic bulkhead performance indicates there are several advantageous physical attributes of a given mine site that significantly decrease risk of bulkhead malfunction. These include aspects of the physical layout of the mine, as well as structural and geologic factors.

Reasonable Access to Underground Workings

One of the most important physical attributes for a bulkheading approach is reasonable access to the underground workings. A good preliminary assessment of the feasibility of a bulkhead approach can be made if the workings are reasonably accessible. Without underground access to the workings, structural bulkhead construction is not usually feasible, and an expensive and much riskier program of drilling and pressure-grouting "squeeze-plugs" into the underground workings may be the only alternative.

Many draining western hardock mines are either still accessible or reasonably accessible with some near surface rehabilitation work. In several successful bulkheading projects, existing portal collapses and minor near-surface cave-ins were successfully removed and sections of underground workings re-habilitated to allow access for feasibility investigations and construction of the bulkhead in the underground workings (Figure 1). Historic mine maps are the most important piece of information in determining if a reasonable chance for gaining access to the workings is feasible. If most other geologic and physical attributes appear favorable for a bulkheading approach, and mine maps and records suggest the mine workings should be reasonably intact beyond a portal collapse or near-surface cave-in, the bulkheading approach should not be abandoned until reasonable efforts to rehabilitate the underground access are made.

Figure 1. Rehabilitation of access for bulkhead construction in the Glengarry Mine crosscut, New World Reclamation Project, Montana.

Connections to Other Workings or Surface

A good understanding of the physical mine layout is needed before contemplating a bulkheading approach to ARD control. Mine maps should be available that illustrate all the internal mining connections and pathways that the impounded mine pool will occupy. It is particularly important to model the expected equilibrium elevation of the re-established groundwater system in relation to maps of mine workings to determine if groundwater re-filling the workings or natural structures penetrated by the workings (faults, veins, shear-zones etc.) will discharge at surface. Any underground connections or drill holes that lead to adjacent workings, or upper and lower levels of workings, need to be identified to determine if the bulkhead will be successful in impounding water without forcing it into adjacent workings, or into other nearby properties where it could unexpectedly discharge from interconnected adits or shafts. A groundwater discharge predicted from adjacent workings and addressed in the bulkheading approach (i.e. a planned second bulkhead) is part of the process, whereas an unexpected or surprise discharge from another mine opening is usually regarded as a failure of the project.

Crosscut Versus Drift Workings

In many western hardrock mines, long crosscut haulage and drain tunnels were driven to access the mineralized vein systems at later stages of the mining operation. Generally these crosscuts performed their intended purposes well, often having all of a mines discharge channeled into one outlet location. A bulkhead location in a long crosscut drainage or haulage tunnel at the lowest adit-level of a mine is the best, and generally has the highest chances for success. By being at the lowest level and not on-structure, the bulkhead can back up the mine pool with less chances of short-circuiting to lower mine levels through stopes or internal workings, or along the un-mined parts of the vein structure itself. Careful selection of a location along the crosscut away from faults and not on or near the mined vein or orebody gives fewer propensities for water to short-circuit around the bulkhead via structural geologic pathways.

It is difficult and very expensive, if possible at all, to hydraulically seal a mine heading that runs along and in, (drifts on), a water-transmitting geologic structure. In the mine these structures are often mineralized faults (veins) which almost always extend above and below the subject drift level. Bulkheads placed on drift workings usually fail because water simply moves around the plug location within and along the planar structure, moving above or below the bulkhead and flowing back into the workings downstream. Curtain grouting or attempting to seal off the structure itself is usually expensive, problematic, and often gives poor results due to the difficulties in getting adequate sealing along long and extensive lines of grout holes.

Adequate Overburden Thickness

An adequate overburden thickness is needed to hold the expected design head pressure on any bulkhead. Bulkheads placed too close to surface may fail if water pressure is high enough to jack joints and fractures open due to insufficient overburden pressure. This allows the head pressure to open or dilate the joint and fracture, and find a pathway around the bulkhead. The design of any bulkhead should include determining the maximum head pressure that will be developed, then using this number to determine a minimum depth of overburden needed above the bulkhead location. This often requires a location with several hundred feet of overlying rock; depending on surface topography, this might mean the bulkhead has to be placed hundreds of feet from the portal to ensure proper design performance (Figure 2).

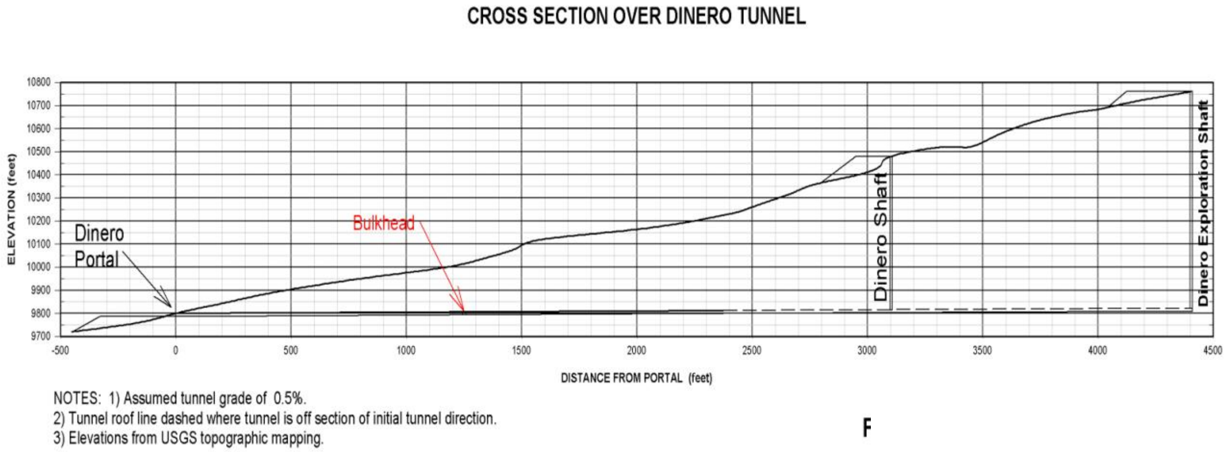


Figure 2. Cross section of the Dinero Tunnel bulkhead location, showing the selected bulkhead location and interconnected shaft workings, Sugarloaf Mining District, Colorado. From Dinero Bulkhead Design documents, J. Abel, 2007, used with permission.

A second problem with bulkheads placed too close to surface or too near the portal is mine-pool leakage through an interconnected near-surface fracture system that is often present. Fractures and joints are more numerous and more open in near-surface rock, due to weathering, structural unloading, and even freeze-thaw or glacial processes. With increasing depth from surface, fractures and open joints are generally fewer, tighter, and less likely to transmit groundwater. Bulkheads should always be sited deep enough underground to avoid leakage through the near-surface fracture system. Formation grouting (or "curtain grouting"), is expensive and difficult to perform near the surface where fractures are numerous and fairly open.

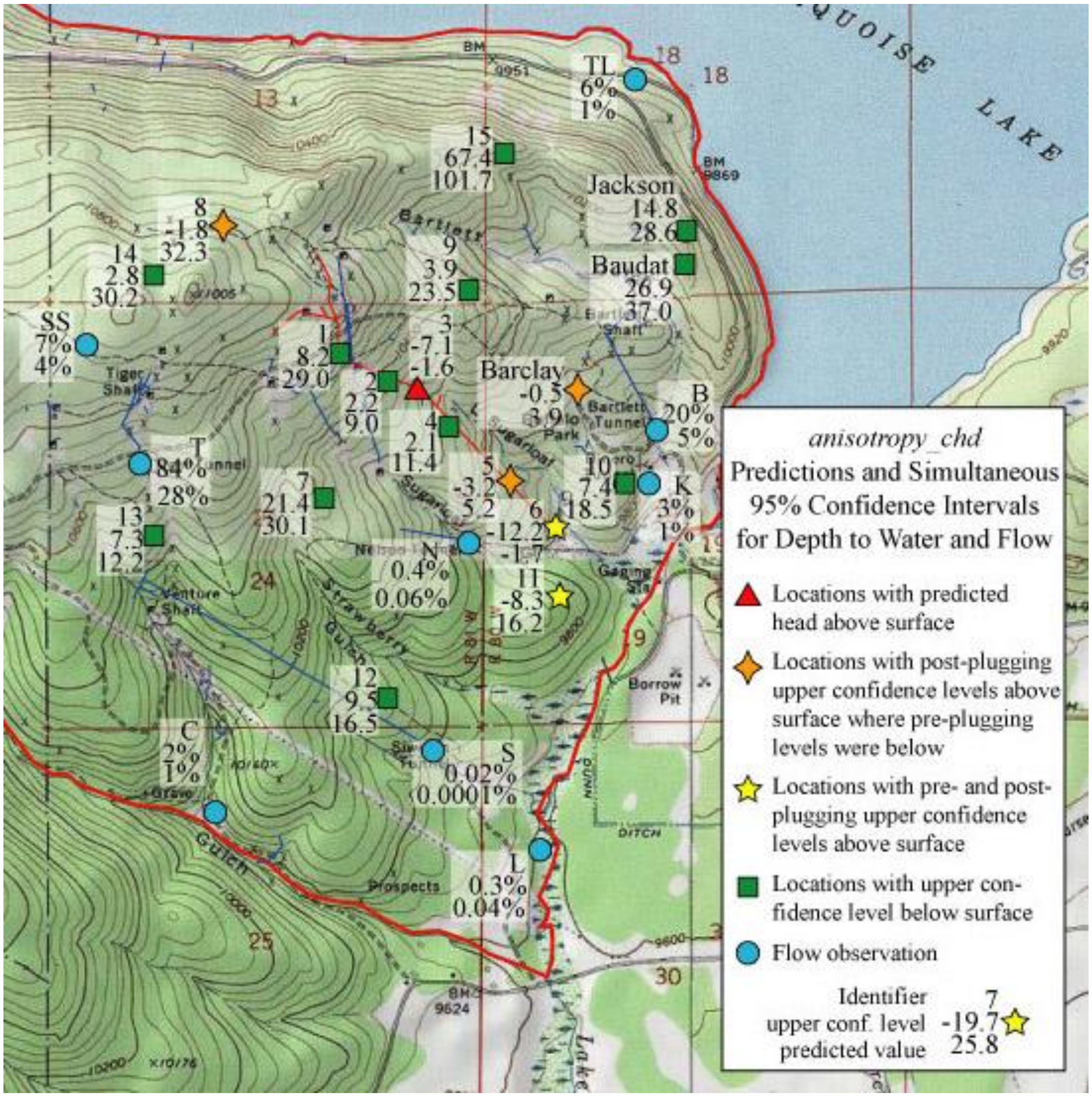
Favorable Geology

Geologic characteristics of the rock in which the bulkhead is constructed have a large bearing on bulkhead performance. Solid, competent rock with minimal water-transmitting discontinuities near the bulkhead location is an important attribute for success. Hard, competent igneous rock along a crosscut without major fractures or faulting is usually an ideal location for successful bulkhead construction. Locations should be selected to avoid faults, veins, and sheared or broken zones in proximity to the bulkhead. Rock strength is a critical component of the bulkhead design formula, so areas of significant faulting or soft, fissured, or hydrothermally-altered rock are less favorable and add to construction difficulties. Bulkheads sited in bedded sedimentary rock are often problematic to construct and seal adequately, unless the designed head pressures are kept low and extensive grouting is performed.

Groundwater Hydrogeology

Understanding what will happen to the local groundwater hydrogeology once the bulkhead is in place is of paramount importance in determining if the approach will be successful at a given site. It is important to remember that bulkheading a mine discharge does not stop water flow, but simply forces the flow to other pathways. A key attribute for any site is developing an understanding of where and at what flow rates the new pathways will conduct groundwater after bulkhead installation. Often these pathways my lead to groundwater discharges at pre-existing springs, or movement along natural structures that conducted groundwater prior to mining. Will groundwater reappear at surface locations nearby? Will it re-fill natural structural conduits that may connect to other mines or workings, creating undesirable effects at other sites?

It is important to develop an understanding of what the pre-mining groundwater system was like and what might be expected by bulkheading before moving forward with the approach. This can be accomplished through detailed water quality sampling, spring and seep surveys, installation of monitoring wells, and research of historical mining records for insights into where and to what extent groundwater was encountered during the mining operation. Information obtained from these sources should be used to conduct preliminary groundwater modeling (Figure 3). Prediction of what groundwater changes will occur once the bulkhead is installed must be developed before proceeding with a bulkhead control approach. Re-establishment of the pre-mining chemical and groundwater -gradient equilibriums should result in desirable effects, not unforeseen surprises or undesirable consequences.



<u>Figure 3.</u> Anisotropy Groundwater Model for the Dinero Tunnel Bulkhead Project, Sugarloaf Mining District, Colorado.

Proper Construction and Grouting Techniques

After favorable attributes and groundwater modeling indicate a bulkhead is the best management approach for the ARD site, proper bulkhead design and construction techniques are crucial to take advantage of the opportunity. Details of engineering practice and construction and grouting procedures and techniques necessary for successful bulkhead performance is beyond the scope of this paper. The following brief “to do lists” are intended to give an overview of the major items that need to be considered and addressed during bulkhead design and construction.

Every pressure-bulkhead should be designed by a registered mining engineer experienced in bulkhead design. The factor of safety for the bulkhead design should be the same as would be used for a dam or surface impoundment in the same location. The engineer should be involved in the planning and construction phases to assist in selection of the best location, and to inspect the work during construction.

Bulkhead design should include or address the following:

- Designed, reinforced and sized properly for maximum expected head pressure
- Overburden confining pressures and testing of rock strength values
- Earthquake factor of safety for the seismicity of the location
- Adequate design of forms and pipe and valve penetrations
- Concrete mix designed to meet critical compressive strength requirement as pumped/placed into the bulkhead forms
- Acidity and reactive chemistry of impounded mine pool in contact with the bulkhead and piping
- Post-grouting of construction shrinkage joint
- Design of any supplemental formation or curtain grouting
- Provisions for sampling and water pressure monitoring during mine pool filling and equilibrium
- Provisions for safe abandonment of all pipe penetrations within a specified time period after equilibrium and steady-state conditions are reached

The mining engineer should be available to make inspections of the bulkhead construction work as it proceeds. This includes inspection of the forms and the final cleaning and scaling of rock in the bulkhead interval, as well as the post-cure contact grouting of the construction joint (shrinkage–joint) along the top and sides of the placed concrete.

<u>Grouting Techniques</u>
Post-grouting the contact of the placed bulkhead concrete is critical to prevent leakage around the bulkhead itself along the construction shrinkage-joint. Using an experienced grouting contractor is crucial for successful post-placement contact grouting, as well as any required formation grouting.

An underground contact or formation grouting design must include the following:

- Structural mapping to determine the nature of any formation anisotropy due to preferential orientations of joints and fractures, the size of fractures, and the nature of any fracture fillings
- Size of grout holes and type of drilling allowed (percussion, rotary diamond drilling, etc).

- Location, angle and bearing and depths/lengths of each grout hole, and sequence of drilling and grouting (i.e. drilling of primary holes, then grouting, then drilling secondary infill holes, then tertiary holes, etc).

- A water testing method and procedure to determine permeability and expected grout take, prior to grouting

- Grouting procedures, including staging (up or down), recirculation system and equipment, allowable pressures, sizing and configuration of packers etc.

- Grouting materials, (Type-5 Portland cement, microfine cement, or chemical and hydro-activated foaming grouts that will perform in acidic conditions, or specific combinations of materials).

- Any warranted QA/QC or performance checks, such as drilling additional holes after grouting to check for grout coverage in joints, or a minimum amount of allowable remaining seepage.

Summary

Construction of an underground hydrologic bulkhead seal designed to re-establish the pre-mining water-table elevation, return near anoxic conditions within the orebody, and eliminate direct discharge from the workings can be an effective and long-term cost-effective best management practice for controlling ARD at some hardock mine sites. An evaluation of the geology, mine layout, condition of the mine workings, as well as the mine-groundwater system interaction is required to determine the feasibility of this strategy for a given ARD site. Attributes for bulkhead success include an understanding of the groundwater hydrogeology, reasonably good access to underground workings, sections of solid, competent rock (minimal faulting, jointing or bedding planes) preferably along cross-cut mine workings, an adequate overburden depth to hold the expected head pressure, no workings, drill-holes, or other significant natural groundwater pathways connecting to any adjacent mines, and the use of appropriate construction and grouting techniques during bulkhead installation. Follow-on formation grouting may also be necessary to achieve the bulkhead performance goals.

Source controls approaches such as bulkheading seek to control or reduce the driving reactions of ARD, as opposed to treatment alternatives that are resigned to address a perpetual discharge for the foreseeable future. Source controls approaches including bulkheading should always be considered and investigated for any draining hardrock mine site before committing that site to a perpetual treatment alternative. Although the up-front costs for investigations, underground rehabilitation of workings for access, and construction of underground bulkheads or other source controls can be very high, they are economical bargains in the long run when compared to the staggering accrual of costs through decades of operation and maintenance of perpetual “end of pipe” treatment approaches that do not control or eliminate the mechanisms of ARD formation.