# Innovative Systems for Mine Closure at the Haile Gold Mine

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**Abstract** Mine closure is an important part of the mine life cycle. The management of acid rock drainage (ARD) is a major consideration for closure at mining properties that contain sulfide-bearing materials. The use of innovative engineering designs that include passive systems for prevention and long-term management of ARD is often a good option. The Haile Gold Mine closure project implemented in about 2000 to 2005 used several innovative engineering solutions that incorporated passive systems. The goals of the closure systems were to minimize the potential for ARD generation, eliminate the need for long-term active treatment, and require minimal long-term maintenance.

**Keywords** mine closure, mine water management, water balance, passive treatment, ARD

## Introduction

The best options for mine closure systems vary depending on the mine facilities, ore body, site conditions, and climate. Selecting the right closure system involves defining closure goals and criteria, assessing viable options for the mine site, defining a strategy to meet regulatory requirement, and balancing costs and benefits with risks and feasibility. The following items should be considered when developing the criteria for closure systems at a mine site:

- Understanding the site conditions that will affect the closure system including environmental and social constraints
- Defining the corporate goals and expectations of the mining company for closure
- Defining what performance measures will be used to determine success
- Evaluating the technical feasibility of the closure system
- Evaluating the regulatory feasibility of the closure system
- Understanding prior experience, including failures and successes
- Incorporating industry standards (*e.g.* MEND guidelines for ARD (Gilles and Hogan 2001))

At the Haile Mine, a careful evaluation of potential closure options was conducted that considered the following elements that are generally applicable to all mines:

- Maximize the use of natural conditions
  - In arid climates consider dry disposal and evaporative systems
  - In wet climates submergence is commonly used
  - Consider options for natural attenuation
  - Consider options for passive treatment systems
- Minimize long-term water treatment
- Utilize passive treatment measures to reduce long-term costs
- Evaluate cost/benefit of up-front closure work versus long-term operation and maintenance
- Educate regulators and other stakeholders to achieve buy-in to the innovative concepts in the closure plan
- Provide flexibility in design, construction, and operation
- Manage financial assurance and bond release
- Evaluate costs based on water quality goals and criteria
  - Focus on activities that will reduce or

  eliminate active water treatment
  - Minimize contact water volumes that require treatment
  - Segregate waters to keep clean water clean
- Build closure systems that can be sustained with low operation and maintenance costs
- Understand public and regulatory perceptions and limitations

## Haile Gold Mine

The Haile Gold Mine is located at the eastern edge of the Piedmont Province in South Carolina, USA. The mine property is in the Haile Gold Mine Creek (HGMC) watershed, which is characterized by moderate topography and is mostly covered with pine forest. Climate is sub-tropical with high rainfall (mean annual total of about 122 cm) and relatively high evaporation (mean annual total open water evaporation of about 107 cm).

The property is located within the Carolina Slate Belt. Metasedimentary bedrock units in the HGMC watershed include Pre-Cambrian argillites, subgreywackes, and felsic volcanics. All bedrock units have undergone extensive hydrothermal alteration and mineralization. The altered rocks are naturally enriched in sulfides. Mineralization and alteration extends upgradient within the HGMC drainage a considerable distance beyond the mined areas. The Tertiary Coastal Plain Sand (CPS) unit overlies bedrock on the higher areas of the HGMC watershed but has been eroded away along the stream valleys. This unit is predominantly comprised of bedded sand and silty sand.

The site-wide groundwater movement generally reflects topography, with gradients and flow directions towards the HGMC and tributary drainages. The CPS groundwater moves downslope relatively quickly, with a fairly short residence time. It enters into the lower-lying areas and contributes to surface water flow in the creek. Groundwater movement in the bedrock is much more limited because of the overall low permeability of the rock units, and also because of geologic structures which form barriers to groundwater flow. Thus, the bedrock groundwater is a very minor component of stream flow in the HGMC.

Gold was first discovered in stream placer deposits in 1827. Subsequently, lode deposits were developed into hillsides and eventually into glory hole and underground mining. The early mine facilities were destroyed during the Civil War but mining resumed at the site after the war and significant production occurred from 1888 to 1908. Mining was discontinued after this time until 1936, and then shut down again during World War II. Several mine shafts to depths greater than 35 m were constructed and the historic Blauvelt and Bequelin pits were used for tailing disposal during the 1930's and 1940's.

Modern mining operations at the site started in 1985 and produced gold through 1991. Operations consisted of mining ore from four small open pits and processing it using cyanide heap leaching technology. The modern mine features include the Champion, Snake, Red Hill, and Haile open pits, waste dumps, heap leach pads, and other associated mine facilities. In 2001, the Champion Pit was successfully closed and reclaimed as a pit lake and in 2003 the Snake Pit was closed as a shallow pit lake that incorporated an organic layer comprised of a 50/50 mix of inert soil and organic matter (woodchips, manure) with small amounts of crushed limestone (Rowe and Turner 2005). Both closures have performed very well to date. The Red Hill and Haile pits were closed as evaporative wetlands and the Blauvelt/Bequelin pits containing historic tailings were closed as a passive treatment wetland system in about 2005.

## Red Hill Pit

The Red Hi1ll Pit was mined to a depth of about 40 m, which exposed sulfides in the pit walls. The closure approach selected for the Red Hill Pit included partial backfilling of the pit and creation of an evaporative sink/wetland on the surface of the backfill. Groundwater is man-

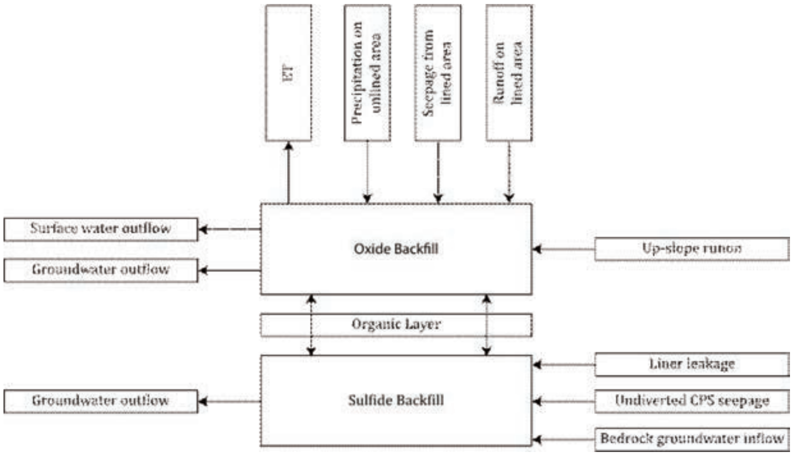


***Fig. 1*** *Red Hill Pit Closure Water Balance Components*

aged such that the groundwater table is maintained at or near the land surface.

Prior to designing a closure system, the hydrogeological, hydrological and climatic conditions for the pit were incorporated into a water balance model illustrated in Fig. 1. The model incorporated the key components of the closure system, including a sulfide backfill layer, an organic layer, and an inert oxide backfill layer.

Fig. 2 is a schematic section illustrating the cover system that was constructed in the central portion of the pit where the evaporative sink/wetland was formed. It consists of the following elements:

- Limestone-amended backfill consisting of sulfide waste rock. The alkalinity added to the backfill was sufficient to offset the existing acidity of the sulfide backfill material. Potential future ARD generation from the sulfide backfill is minimized by permanently submerging the material.
- An organic soil layer consisting of inert soil material mixed with organic media and limestone placed above the backfilled sulfides. This layer promotes reducing conditions that help stabilize the pore water chemistry and strip oxygen from waters that may from migrate from surface into the sulfide backfill.
- A top layer consisting of inert borrow material mixed with crushed limestone to provide a vegetative soil cover. The groundwater level in the pit was stabilized within the upper soil cover to provide permanent submergence of the sulfide backfill.
- A central swale across the cover surface to collect and control runoff of non-contact

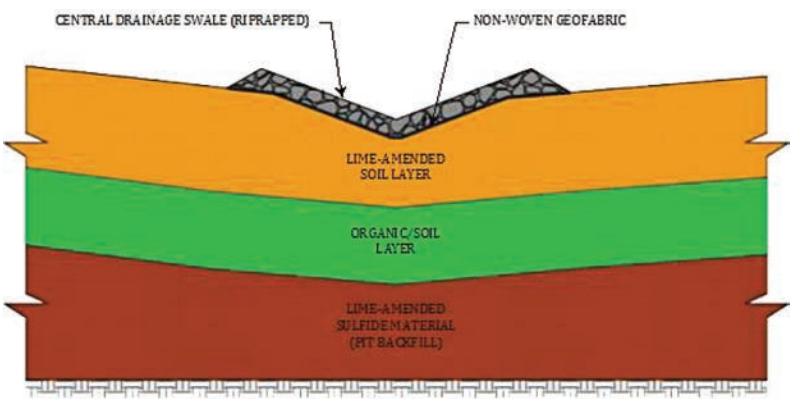


***Fig. 2*** *Organic System for Central Area of Red Hill Pit*

stormwater falling on the pit area. This channel keeps water from ponding on the cover.

Other elements of the closure system included:

- Engineered fill slopes on the pit walls with some areas covered by an impermeable synthetic liner and vegetative soil layer to isolate potentially reactive wall rocks from infiltrating precipitation and to minimize exposure of the wall rock to air. Precipitation falling on the cover will be shed as non-contact stormwater.
- Crushed limestone amendment along portions of the base of the pit wall to neutralize acidity that has built up over time in the pit walls. This zone may be saturated with groundwater or subject to periodic perched groundwater flows after closure.
- A collection drain at the top of the liner along some sections of the pit wall to intercept seepage from perched groundwater flowing in the CPS unit overlying bedrock to direct it out of the pit area before it can contact sulfide rocks.
- An interceptor ditch at the top of the liner along sections of the pit wall to intercept surface runoff from upslope areas and direct it out of the pit area. This ditch was designed with rip rap to prevent erosion and is intended to require minimal maintenance.

Fig. 3 is a photograph of the Red Hill pit shortly after the closure systems were implemented. It shows the diversion channel located near the bedrock/CPS contact on the pit slope, the lined and covered pit slopes below the channel, and the central portion of the pit. Stormwater originating below the diversion channel was retained by a temporary embankment at the outlet to the pit and sent to the treatment facility until it was demonstrated that the closure system was functioning as designed. It is now released as non-contact stormwater.

### Blauvelt/Bequelin Pits

The Blauvelt and Bequelin pits were historic mine features dating back to about 1935. They were filled with tailing material from a nearby historic mill. The Blauvelt Pit was about 40 m deep and the Bequelin Pit was about 30 m deep. Historic mine maps indicated that underground workings also intersected the pits. The tailings area was very wet, being fed by both upstream surface water and groundwater sources. Fig. 4 shows a photograph of the tailings located in the Blauvelt Pit prior to closure. Water from the tailings area was collected and treated.

***Fig. 3*** *Red Hill Pit after Closure*

***Fig. 4*** *Blauvelt Pit Tailings Area*

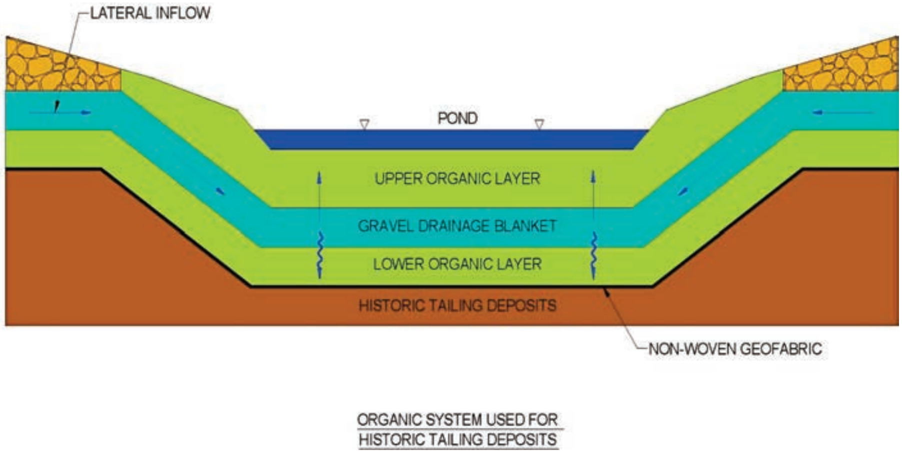


***Fig. 5*** *Conceptual Design of Wetland Area over Historic Tailings*

The closure and reclamation plan for the Blauvelt/Bequelin focused on capping and managing the historic tailing deposits contained in the area. The closure concepts used were similar to those being used elsewhere at the Haile Mine. They consisted of several key components that incorporated passive measures and a number of contingency measures to improve overall long-term performance.

Scattered tailing deposits in the Blauvelt/Bequelin area were consolidated into the pit areas and covered to prevent contact with stormwater. Sulfide materials that may exist in the historic tailings were submerged, stabilized, and permanently isolated to minimize the generation of acid drainage. The historic tailing deposits in the old pits were either covered with soil or a wetland area to minimize contact with stormwater. The cover system over the tailing deposits consisted of an organic layer to help stabilize the tailings and a gravel-drainage layer. Clean soil was placed over the top of the cover to reach final contours and then revegetated.

An upper wetland was established in the historic pit area to provide a source of water to keep the tailing material permanently submerged. The upper wetland included a gravel drainage layer sandwiched between organic layers. The gravel layer provides a subsurface pathway for shallow seepage to reach the wetland area, where most of it passes through the upper organic layer into a shallow pond. A schematic of the cover system is shown in Fig. 5. The upper wetland was designed to meet Best Management Practices for stormwater and shallow seepage occurring in the Blauvelt/Bequelin area.

All upgradient surface water flow was intercepted, diverted out of the Blauvelt/Bequelin area and released to the North Fork of Haile Gold Mine Creek. A significant portion of the subsurface flow in the upgradient CPS deposits was also intercepted and diverted out of the Blauvelt/Bequelin area by this feature. This significantly reduced the subsurface seepage to the Blauvelt/Bequelin area. A photograph of the construction of the central wetland is shown in Fig. 6 and the wetland area shortly after construction is shown in Fig. 7.

The North Fork of Haile Gold Mine Creek was diverted away from the existing channel that ran adjacent to the historic pits and a lower wetland was established in the old channel area to provide a contingency collection area for potential subsurface seepage from the historic pits. The lower wetland included a gravel drainage layer overlain by an organic layer and was designed to meet Best Management Practices for any shallow seepage flow from the historic Blauvelt/Bequelin area that may occur along the North Fork.

The Blauvelt/Bequelin closure system has functioned well since it construction in about 2005. Water from the wetland area meets applicable standards and is released to HGMC.

***Fig. 6*** *Wetland Closure System for Tailing Area*

***Fig. 7*** *Wetland Area After Construction*

## Conclusions

The prevention and management of ARD is a key element for the successful closure of many mines. Often, the need for long-term active treatment of mine waters can be minimized or eliminated by effective closure designs that utilize passive systems for managing ARD. Permanent submergence of sulfide material limits its exposure to oxygen and has been used successfully to manage ARD at many sites. Similarly, the use of organic materials to promote reducing conditions that result in the removal of metals and improvement of water quality is becoming increasingly common. The successful implementation of passive systems requires a good understanding of the overall site water balance to take advantage of the favorable site-specific hydrologic conditions. The Haile Mine implemented a number of closure systems that incorporated passive measures. These systems were constructed in the early to mid 2000s. Although detailed monitoring data are not publically available, the systems have functioned well to date.

## References

Ford KL (2003) Passive Treatment Systems for Acid Mine Drainage. Technical Note 409, BLM/ST/ST-02/001+3596, Bureau of Land Management Web based report available online at www.blm.gov/nstc/library/techno2.htm

Rowe J, Turner T (2005) Innovative Systems for ARD. Mining Environmental Management, March 2005

Tremblay G, Hogan C (Eds) (2001) MEND Manual Report 5.4.2. Natural Resources Canada