Application of Predictive Geochemical Modeling to Optimize Closure Design for the Williams Mine

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Abstract
The Williams Mine is located approximately 40 kilometers east of Marathon Ontario. This underground and open pit gold mine has operated since the 1980's and is the only one of three mines at the Hemlo camp still in operation, with operations planned to cease in 2015. Potentially acid generating and potentially metal leaching waste rock types are stored in two main areas adjacent to the pit. The challenge for the mine was to design a closure plan that minimized the need for post closure water management and treatment. Kinetic geochemical data was integrated with site hydrology and water quality data to develop a predictive water quality model. The model was used to assess potential water quality impacts, and to identify the option with the greatest potential to mitigate any potential impacts. The resulting closure plan that was selected utilizes the geochemical characteristics of the waste rock and the water management opportunities for the site to produce a closure configuration that does not require mine influenced waters to undergo treatment prior to discharge to the environment. Ongoing geochemical studies and water quality monitoring will be used to continuously review and update the water quality predictions to validate the closure design.

Keywords: mine closure, predictions, Hemlo

Introduction
The Williams Mine is located in the Hemlo Gold Camp near the north shore of Lake Superior, approximately 40 kilometres (km) east of Marathon, ON and 350 km east of Thunder Bay, ON. Two other former gold mines (Golden Giant and David Bell) are located contiguous to the Williams Mine. Underground workings between these mines are interconnected. All three mines are now owned by Barrick Gold Corporation.

The mine produces gold ore from open pit and underground operations at a rate of approximately 10,000 tonnes per day. Ore is processed on site to produce gold bullion. Waste rock is placed in several rock piles adjacent to the open pit whereas tailings are discharged into the Williams-David Bell tailings impoundment located approximately 3 kilometres southeast of the mine.

The mine began operation in 1985 and has operated continuously since that time. Currently the mine is scheduled to cease operations in 2015. Closure planning studies were initiated in 2008 to address the anticipated 2015 closure of the mine. These studies resulted in the preparation and issuance of a revised closure plan to address final closure of the site (AMEC 2010).

The Williams Mine site is bounded on the south by Highway 17 and the east by Cedar Creek. To the north of the property lies the Golden Giant mine tailings facility and the Botham Lake watershed to the west. These boundaries limit the available footprint for the mine operations. Topography in the area consists of weathered rocky ranges, forested uplands (partially logged), and several wetlands, creeks and lakes. Elevation ranges from approximately 310 to 385 metres above sea level (masl).

Mine Site Description

The Williams Mine consists of the following major mine components:

- C-Zone Open Pit
- Underground Workings
- East Mine Rock Pile
- West Mine Rock Pile
- Plant Site
- Tailings Facility

Most of the mine site is clustered around the C-Zone Pit (Figure 1). Descriptions of these site components are as follows.

Figure 1. Williams Mine site layout at Closure with projected elevation contours.

C-Zone open pit

The C-Zone open pit it is the main open pit at Williams Mine and is projected to be active until the end of 2015 with a design depth of 268 m. Removal of the crown pillar at the end of mining will directly connect the C-Zone Pit with the underground workings.

Two smaller open pits (Horizon and Sceptre) are now located adjacent to or within the C-Zone pit boundary. These pits are no longer active and are partially filled with waste rock. The A-Zone Pit, located east of the C-Zone Pit, was mined previously and is now partially backfilled. The bottom of the A-Zone Pit connects directly with the underground workings. With the planned removal of the C-Zone Pit crown pillar, the underground workings, and the A-Zone and C-Zone pits will be hydraulically connected.

Underground workings

Three underground mines were developed in the Hemlo Camp. The Williams, Golden Giant and David

Bell mines are spread out west to east over the ore body. All three mines are connected underground through a series of horizontal drifts, shafts and raises. Currently, underground mining operations are ongoing in both the David Bell and the Williams Mines, and are expected to continue until 2014 and 2015, respectively. Stopes at the David Bell Mine have been paste backfilled since 2005. Prior to this date, the stopes were backfilled with cemented sand fill. Williams Mine has been using paste fill since 2003, previous to this cemented rock backfill was used.

Monitoring and hydrogeology studies of the underground workings indicate that the mines are very dry, with minimal volumes of seepage (<10 L/s) entering the workings.

Mine rock piles
Two main waste rock piles are located at the Williams Mine. The East Mine Rock Pile (East Pile) is located north-east of the C-Zone Pit and has a footprint of approximately 22 ha. At closure it is estimated that the East Pile will contain approximately 16 million cubic metres (Mm^3) of waste rock, attaining a maximum elevation of about 430 masl.

The West Mine Rock Pile (West Pile) is located to the west of the C-Zone Pit and has an approximate footprint of 40 ha. Placement of waste in the West Pile began in 2005. It is estimated that the West Pile will contain about 20 Mm^3 of waste rock at closure and attain a maximum elevation of approximately 420 masl.

Beginning in 2005, potentially acid generating (PAG) and non-acid generating (NAG) lithologies were segregated during mining and placed in separate areas of the East and West piles. Prior to this time, waste rock was undifferentiated.

Plant site
The plant site area is located north of Highway 17 and Moose Lake, and east of the C-Zone Pit and has an approximate footprint of 36 ha. Milling at the Williams Mine is by a conventional carbon-in-pulp (CIP) circuit that is currently operated at a throughput of 10,000 tonnes per day.

Tailings facility
The Williams - David Bell tailings impoundment is located 3 km southeast of the mine site. Closure of this facility was considered independently from the rest of the site.

Geology and ML/ARD

Five major mine rock units are present at the Williams Mine, consisting of Metasediment (MS), Intermediate Volcanic (IV) Quartz Eye Porphyry (QEP), Quartz Eye Muscovite Schist (QEMS) and Diabase dykes (DIA).

Previous geochemical assessment studies had identified three lithologies (QEP, QEMS and DIA) as potentially acid generating (PAG). These lithologies comprise approximately 40% of the projected mine rock volume and pit wall surfaces.

The remaining two lithologies (MS and IV) were classified as non-acid generating (locally referred to as NAG), but were identified as potential sources of neutral metal leaching, with molybdenum as the primary metal of concern.

Closure Requirements

Key requirements for closure of the Williams Mine included the following:

1. Closure must be carried out in accordance with all applicable regulations to the site.

2. All existing permitting requirements have to be met during the site closure phase.
3. Primary considerations for closure are:
    - Protection of human health and the environment
    - Chance of success
    - Environmental benefits to the local environment
4. Management of the site waters for closure are simple and robust

Development of the closure plan and design considered Barrick's corporate standards for Mine Closure, First Nations and Provincial/Federal regulatory requirements for acceptance of the Closure Plan, and the cost requirements to successfully close the site.

A desired outcome was a closure design that required minimal long-term maintenance and operational support; returning the site to the Crown was the preferred ultimate outcome of closure.

Challenges for Closure

The primary long term closure concern with respect to the site is ML/ARD. Previous studies had shown that net acidity will be generated from some of the waste rock material. Several specific challenges, both physical and geochemical, were identified to be addressed for successful closure of the Williams Mine:

- Based on previous geochemical assessments approximately 40% of the projected waste rock volume and pit wall surfaces were classified as potentially acid generating (PAG) and assumed to produce acidic drainage in the future.
- Neutral metal leaching may potentially occur from the remaining 60% of the waste rock and pit wall surfaces. The remaining two lithologies (MS and IV) were classified as non-acid generating (locally referred to as NAG), but were identified as potential sources of neutral metal leaching, with molybdenum as the primary metal of concern.
- Direct hydraulic connection of the C-Zone Pit to the A-Zone Pit via the underground workings would result in discharge of mine water to the environment from the A-Zone Pit once the C-Zone Pit flooded to 312 masl.
- Property boundaries and other physical restrictions limit the mine footprint to its current extent.

With these recognized challenges and the projected mine closure in 2015, geochemical studies were undertaken to predict the potential long term water quality impacts after closure, and to optimize the closure design of the site to minimize any ML/ARD and water management requirements.

Geochemistry and Water Quality Predictions

Based on review of previous reports and data, studies were undertaken to collect and analyse additional data on mine rock geochemistry and drainage quality in the mine area. Site hydrology in the vicinity of the mine site was also assessed to understand mine water management requirements of the mine rock piles, open pit and underground workings. These results were integrated with earlier data to provide a better understanding of geochemical conditions of the Williams Mine site.

Previous geochemical assessments had identified two mine waste classifications; potentially acid generating (PAG) rock (QEMS, QEP and DIA rock types) and non-acid generating, but potentially metal leaching (NAG) rock (MS and IV rock types). These classifications were used to segregate rock into separate management areas of the rock piles beginning in 2005.

Additional studies for closure focussed on identifying these key attributes:
- Time for onset of acid conditions in PAG rock;
- Source terms for PAG and NAG rock under non-acidic conditions; and,

- Source terms for PAG rock under acidic conditions.
- Hydrologic conditions of the mine area, including the time to flood the underground workings and C-Zone Pit.

Acidic conditions from the surface mine rock materials have not been observed. Therefore, estimates of onset times for PAG rock were based on neutralization potential (NP) depletion times calculated from humidity cells and on-site long term field test cells. These estimates indicated that PAG rock will likely be depleted of its neutralizing potential in the range of 40 to 260 years from the time the rock is placed on surface. NAG mine rock types are not expected to generate acidic conditions.

Water quality monitoring of the mine rock piles and pit area was conducted to estimate the expected seepage quality from the NAG and PAG rock types. As a result the mine rock segregation initiated in 2005, drainage from distinct NAG and PAG piles were available to be sampled. Sampling was also conducted of drainage sumps within the C-Zone Pit and the natural drainage catchments surrounding the mine area. Multiparameter analysis of these samples included both filtered and dissolved metals, pH, and major anions. Based on a review of these data, concentrations representing the average and maximum (‘worst-case’) water qualities observed were selected as the NAG and non-acid PAG drainage source terms.

As mentioned previously, acidic drainage has not been observed from the mine rock piles or C-Zone Pit. However, localized occurrences of acidic drainage are found within the underground mine workings associated with highly sulphidic mineralized zones exposed on ramp and drift faces. Drainage from these areas had observed pH values of approximately 3 with elevated concentrations of sulphate and metals. Use of this data as a source term was considered to be very conservative and likely to significantly overestimate the drainage quality from the PAG mine rock which contains approximately 0.6% sulphide on average.

A significant outcome of the hydrologic studies of the mine area was the recognition that the drainage from the mine rock piles could be readily directed by direct (gravity) flow and ditching into the C-Zone Pit. The estimated average annual inflow from the waste dumps and open pit footprint to the pit was estimated to be approximately 1.0 Mm^3. The volume of the underground workings (including the interconnected Golden Giant and David Bell mines) and the C-Zone Pit to an elevation of 312 masl was calculated to be approximately 36.8 Mm^3. Flooding of the pit to 312 masl was estimated to take approximately 33 years after closure.

Based on the identification that the mine site drainage could be redirected to the C-Zone Pit, water quality modeling was focussed upon optimization of the closure design to take advantage of this feature. A mass balance model was developed to assess the water quality of the C-Zone Pit after flooding, in order to assess potential requirements for water management and treatment. The model was intentionally designed to simulate conservative (worst-case) conditions under the following assumptions:

1. Pit water quality was based on average and maximum total metal concentrations from surface water monitoring data in the catchments draining into the pit. Where total metal data was not available, dissolved metal concentrations were substituted. To eliminate outliers from the data set, the 90^{th} percentile value was calculated for each parameter and used as the maximum concentration.
2. PAG materials on the exposed pit walls were assumed to generate ML/ARD. For the purposes of the model it was assumed that the surface area of PAG materials on the pit walls were proportional to the mass of PAG rock in the waste rock. This PAG rock surface on the exposed pit walls was assumed to begin generating acid (and leaching metals) instantaneously following flooding of the pit to its maximum level (312 masl). Total metal concentrations for

the simulated PAG wall rock drainage were based on monitoring data from low pH seepage water derived from the underground workings. Average water quality monitoring data were used to represent drainage from the surrounding waste rock catchments. Water quality and volume inputs from this scenario were mixed using a simple mass balance model to produce estimated concentrations in the pit water. Results were not geochemically equilibrated.

3. Expected pit water quality was estimated assuming all PAG rock in the pit walls and all PAG rock from the surrounding waste dumps (both the PAG and unsegregated rock piles) were producing ML/ARD. The onset of acidic conditions was assumed to begin instantaneously in all PAG materials when the pit lake reached its maximum flooding level. Water quality and volume inputs from this scenario were mixed using a simple mass balance model to produce estimated concentrations in the pit water. Results were not geochemically equilibrated.

The model was developed assuming that runoff from watersheds surrounding the pit will drain into the open pit and contribute metal loads. Mixing of the hydraulically connected flooded underground with the pit lake was assumed not to occur due to the downwards hydraulic gradient, and assumed stratification within the underground workings. The model did not account for attenuation of metals due to mixing or mineral precipitation within the pit lake water column.

Initial results indicated that once the pit water reached the decant elevation (312 masl) the water quality was acidic and not suitable for discharge without water treatment. Drainage from the segregated PAG rock piles in the East and West mine rock piles were identified as the primary loading sources for acidity and metals to the C-Zone Pit. Subsequent assessment and modeling determined that the pit water concentrations would be reduced significantly if these PAG load sources could be isolated and prevented from entering the pit. Additional benefit would be provided by the 'clean' runoff from the PAG rock piles surfaces flowing into the pit. Resulting modeling of this configuration indicated that the pit water would be suitable for direct discharge to the receiving environment mixing zone (Table 1). Iron concentrations in the mass balance model were predicted to exceed permitted discharge values; however, the actual iron concentrations were deemed to be significantly less due to mineral precipitation constraints.

Further, given estimated lag times until the onset of acidic conditions within the PAG rock, and the time required to fill the C-Zone Pit, it was recognized that the engineering and construction activities required to isolate the PAG rock piles could be delayed for almost three decades prior to the onset of acid drainage and the pit lake reaching its decant elevation.

Engineering studies were commenced to develop designs to eliminate or limit drainage from the PAG rock stored in the East and West rock piles. The resulting design selected for closure utilizes geosynthetic covers on the PAG rock dump to isolate this material from direct precipitation and significantly reduce the volume of impacted seepage flowing into the C-Zone Pit. In addition, the volume of watershed from the geosynthetic cover would be directed to the pit to aid in dilution of the pit water, further improving the C-Zone Pit water quality.

The proposed closure configuration consisted of the following:

- After the cessation of mining operations, the northern slope of the West Pile will be regraded to 3H:1V or flatter. The northern toe of the West Pile is at the property boundary and, therefore, some PAG waste rock will be relocated to the top of the West Pile to achieve the 3H:1V slope;
- The northwestern portion of the East Pile will be regraded to 3H:1V or flatter. The northern toe of the East Pile is at the property boundary and, therefore, some PAG waste rock will be relocated to achieve the 3H:1V slope;

- Perimeter ditches, designed to convey the 1:100 year storm event, will be constructed around the West and East Piles to direct all runoff from the rock piles to the open pit;
- Islands of local vegetation (shrubs and trees) will be established on NAG rock piles to improve the aesthetics and promote natural revegetation; and,
- Prior to the onset of net acid generating conditions in the PAG rock, the PAG rock piles will be covered with a geosynthetic liner system.

Parameter	Permitted Discharge Value	Predicted Concentration
Sb	1	0.008
As	0.5	0.005
Cu	0.3	0.003
Fe	1	**1.59**
Pb	0.2	0.0006
Mo	1	0.047
Ni	0.5	0.007
Zn	0.5	0.017
All values in mg/L		

Table 1. Predicted concentrations of C-Zone Pit discharge for selected parameters.

Conclusions

The closure plan for the Williams Mine utilizes the geochemical characteristics of the mine rock and the site hydrology, coupled with engineered covers, to produce a closure configuration that does not require mine water treatment. Ongoing geochemical studies and water quality monitoring will be used to continuously review and update the water quality predictions in order to validate the closure design.

References

AMEC (2010) Williams Mine Closure Plan Amendment. Prepared for Barrick-Hemlo Williams Operating Corporation. December 2010.