# APPENDIX F

## Closure Water Treatment Plan – Conceptual Design

17 October 2016

REPORT ON

# Mount Polley Mine Closure Water Treatment - Conceptual Design

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REPORT

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**Distribution:**

1 Electronic Copy - Mount Polley Mining Corporation
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# Glossary of Terms

| Abbreviation | Definition |
|---|---|
| BC | British Columbia |
| BCR | biochemical reactor |
| BLM | biotic ligand model |
| BOD | biochemical oxygen demand |
| BOE | basis of estimate |
| CAD | Canadian dollars |
| DO | dissolved oxygen |
| FWS | free water surface |
| HRT | hydraulic retention time |
| MPMC | Mount Polley Mining Corporation |
| PETBP | Perimeter Embankment Till Borrow Pond |
| SED | sedimentation pond |
| SPC | sulphide polishing cell |
| SSF | subsurface |
| TDS | total dissolved solids |
| TSF | Tailings Storage Facility |
| TSS | total suspended solids |
| WQG | water quality guideline |
| % | percent |
| °C | degrees Celsius |
| ha | hectare |
| kg/yr | kilograms per year |
| L/s | litres per second |
| m | metre |

| Abbreviation | Definition |
| --- | --- |
| $m^2$ | square metre |
| $m^3$ | cubic metre |
| $m^3/d$ | cubic metres per day |
| $m^3/s$ | cubic metres per second |
| masl | metres above sea level |
| mg/L | milligrams per litre |
| mg/L (as N) | milligrams per litre as nitrogen |
| mol/d | moles per day |
| $mol/m^3$-day | moles per cubic metre per day |
| w/w | wet weight |

# Executive Summary

Mount Polley Mining Corporation (MPMC) is evaluating technology options for treating Mine contact water in the Closure and Post-closure phases. An option that reflects the stated preference of MPMC and some stakeholders is the use of a passive water treatment system and return of water to pre-development watersheds.

As a first step toward a passive, distributed system, a conceptual design of a centralized passive treatment system was developed. For this design basis, it is assumed that all Mine contact water would be conveyed to a common treatment facility located on the Tailings Storage Facility and on the Polley Flats area, with treated water discharged to Hazeltine Creek.

The conceptual passive treatment system would have a total footprint of 96 ha, and a design treatment capacity of 13,000 $m^3$/d, subject to confirmation in future phases of design, as well as potential optimizations to the Closure drainage system such as diverting higher quality water from some areas of the reclaimed mine directly to nearby watersheds, and refining the input water quality data. The system is designed to reduce concentrations of key constituents of potential concern, most notably copper, selenium and sulphate, to levels within acceptable discharge targets. The system, however, is unlikely to meet phosphorous concentration targets. The conceptual passive treatment system consists of the following main process units: sedimentation pond, biochemical reactors, sulphide polishing cells, and constructed wetlands.

To support the development of the Post-closure treatment concept, a conceptual design for a passive treatment pilot plant was also developed. The pilot plant would have a total footprint of 1.5 ha, and a design treatment capacity of 55 $m^3$/d. The pilot plant would be constructed and run during Operations, providing the opportunity to not only demonstrate the feasibility of the passive treatment system components listed above, but also to test, refine and size alternative treatment components and design approaches, as required. Further optimization may be gained during this period as the models used to generate inputs to the conceptual design are validated, which would provide a higher level of confidence, and consequently, require a lower level of conservatism in the inputs. Apart from the described passive process units, the following alternative process units are included with the conceptual pilot plant: biochemical reactor with inert material, sulphide reactor, aeration cascade, and aerated and settling ponds.

In this report, it is noted that the sizing of the system is primarily driven by the load removal of constituents of potential concern, and as such could conceptually also be apportioned to the distributed sources at design sizes relative to their respective load contributions.

A trade-off study should be conducted to compare the passive and semi-passive treatment concepts with active treatment concepts. Once the most suitable treatment option is selected, bench or pilot testing should be performed before implementation of the full-scale treatment system.

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# 1.0 INTRODUCTION

## 1.1 Background

To support the Mount Polley Mining Corporation (MPMC) water management strategy, Golder Associates Ltd. (Golder) has developed this conceptual plan for treating contact water from the Mount Polley Mine (the Mine). MPMC is evaluating technology options for treating Mine contact water in the Closure and Post-closure phases. An option that reflects the stated preference of MPMC and some stakeholders is the use of a passive water treatment system and return of water to pre-development watersheds.

As a first step toward a passive, distributed system, a conceptual design of a centralized passive treatment system was developed. For this design basis, it is assumed that all Mine contact water would be conveyed to a common treatment facility located on the Tailings Storage Facility and on the Polley Flats area, with treated water discharged to Hazeltine Creek. It is noted that the sizing of the system is primarily driven by the load removal of constituents of potential concern, and as such could conceptually also be apportioned to the distributed sources at design sizes relative to their respective load contributions.

Other optimizations may lead to reduced sizing of the system presented herein, such as diverting higher quality water from some areas of the reclaimed Mine directly to nearby watersheds, and reducing conservatism in inputs to the design as the models used to generate inputs are validated with operational data.

The purpose of this plan is to demonstrate, at a conceptual level, how passive or semi-passive water treatment technology could be used to meet the Mine's long-term (Post-closure) requirements with respect to water discharges to the receiving environment. Ideally, a transition towards such passive or semi-passive water treatment will phase out the currently operational active treatment (Veolia) water treatment plant (WTP) utilized at the Mine.

## 1.2 Previous Work

In June 2016, Golder completed a preliminary review of active, passive, and semi-passive water treatment systems for contact water at the Mine (Golder 2016a), summarized in Section 3 below.

This report is intended to provide additional detail for passive and semi-passive technologies identified in the screening report in the context of more detailed water quality information that has since been developed.

# 2.0 SCOPE OF WORK

## 2.1 Summary and Limitations

The scope of this document is limited to considering passive (including semi-passive) treatment systems to show how these could be integrated into the Mine's Closure and Post-closure plans. There is potential to construct one such passive treatment system in the Polley Flats area near Polley Lake (see Figure 01), with piloting in the near term and full-scale implementation in the long term.

With respect to the Polley Flats area, if considering Post-closure flows generated from the entire Mine site (i.e., centralized flow), it is unlikely to be large enough to accommodate a completely passive full-scale treatment system. Therefore, other areas are shown as candidates as well. In this regard, one of the objectives of piloting is to define the area required for passive treatment, as it is the stated goal of MPMC to return water, to the maximum extent practicable, back to natural (i.e., pre-mining) watersheds, which may require multiple passive treatment systems across the Mine site.

It may be appropriate, however, to also consider piloting and evaluating one or more active technologies for comparison. This work could be done concurrently with the proposed work on the passive plant, but is not discussed further herein.

As noted in Golder 2016a, two main advantages of passive systems are the infrequent maintenance and low power required compared to active systems; however, the flow rates (and therefore surface area) projected to be required for a passive system to treat the entirety of Mine contact water for the Closure and Post-closure scenarios are higher than is usually practical for passive plants. Reduction of this flow rate would likely be possible through incorporation of specific water management considerations into reclamation and closure planning. However, it is not guaranteed that a passive or semi-passive system would prove to be the preferred option, once the results of the pilot testing are in hand.

## 2.2 Water Treatment Phases

The conceptual plan to treat Mine contact water over the Mine's Operations phase through to Post-closure is considered in this section. The scopes of work for the various life stage phases are presented in Table 1 and followed by more detailed descriptions.

**Table 1: Water Treatment Phases**

| Phases | Operations | Closure | Post-closure |
|---|---|---|---|
| Timeframe | July 2016 – July 2020 | July 2020 – July 2022 | July 2022 – 2100 |
| Mine activities | Active mining | Reclamation and rehabilitation | None |
| Water treatment approach | Active treatment<br>Bench testing and piloting of passive/semi-passive treatment technologies | Transitional phase from active treatment to passive/semi-passive treatment | Passive/semi-passive treatment |

### 2.2.1 Operations

The Operations phase ranges from the time that full operations resume (projected to be in July 2016 for the purpose of this report), continues for the duration of active mining, and ends in July 2020 when active mining will cease under the currently authorized Mine plan. The Mine's existing WTP consists of an Actiflo (Veolia) solids settling and metals removal system that discharges via Hazeltine Creek and a diffuser system into Quesnel Lake. To meet the water treatment requirements for the remainder of the Operations phase of the Mine, Golder developed a separate water treatment plan (Golder 2016b, TAR Appendix E) that describes the projected modifications and additions required to the Actiflo system. Attachment A, Figure 2 shows the site plan for treatment during Operations.

### 2.2.2 Closure and Post-closure

The period following active mining is defined as Closure and ranges from July 2020 to July 2022, by which time mining operations would have ceased and reclamation work would have commenced. Closure is followed by a period defined as Post-closure, defined nominally for the purposes of this work from July 2022 to 2100. It is envisioned that water treatment will transition from relying on the Actiflo system to a more passive treatment system in Post-closure, or sooner if feasible. Apart from applying source control measures, MPMC intends to mitigate Mine contact water at source by means of distributed passive treatment systems, and to restore water flow into the natural watersheds. This reflects an aspirational goal rather than an environmental imperative, as the active WTP and diffuser system could continue to be used to manage the Mine's contact water during Closure and Post-closure.

There is considerable chemical and flow variability associated with the impacted site water sources, and also significant differences in the potential receiving environments. These factors indicate that a distributed treatment system may be appropriate; however, a centralized passive treatment system was developed, which assumes that all the water sources would be combined before treatment, and then discharged to a single receiving environment (i.e., Hazeltine Creek). In this report, it is noted that the sizing of the system is primarily driven by the load removal of constituents of concern, and as such could conceptually also be apportioned to the distributed sources at design sizes relative to their respective load contributions. Reduction of the flow rate requiring treatment would also be possible through incorporation of specific water management considerations into reclamation and closure planning.

Attachment A, Figure 1, shows the conceptual site plan for treatment during the Post-closure phase.

### 2.2.3 Pilot Testing

To support the development of the Post-closure treatment concept, a conceptual design for a passive treatment pilot plant is presented in this document. In concept, the pilot plant would be constructed and run during Operations, providing the opportunity to not only demonstrate the feasibility of all the passive treatment system components proposed for the Post-closure phase, but also to test, refine and size alternative treatment components and design approaches, as required. Due to the unprecedented scale (considering total flow required to be treated, even if potentially across multiple treatment systems) for which Post-closure treatment may be required at the Mine, the pilot plant is designed with added features to test and demonstrate how active components (e.g., chemical dosing equipment, and instrumentation and control features) could potentially improve the efficiency of the passive treatment technologies proposed for Post-closure. Although designed to demonstrate Post-closure technologies, it is envisioned that the pilot plant would treat Operations quality water, with the ability to either discharge to the receiving environment or return the treated water to the WTP.

Attachment A, Figure 2, shows the site plan for the pilot treatment facility.

# 3.0 TREATMENT TECHNOLOGY SCREENING

## 3.1 Introduction

The preliminary technology screening (Golder 2016a) was based on conservative assumptions to identify a large number of potential constituents of concern, and consequently a broad range of constituent-specific treatment technologies that could be applied.

The screening exercise documented the advantages and disadvantages associated with active and passive treatment technologies. Active treatment systems can be capital intensive and require control systems, regular reagent and labour inputs, and typically rely on electrical and mechanical processes for routine operation. In contrast, although passive treatment systems may also be capital intensive to construct, they do not require reagent inputs or electrical/mechanical processes, but harness naturally available means such as microbial activity and topography, and may require regular, but less frequent, maintenance to operate.

Consideration was also given to semi-passive treatment systems in which active and passive components may be used in conjunction with each other to improve treatment efficiency and minimize footprint and costs, while providing flexibility to treat a variety of flows and loads.

## 3.2 Selected Technologies

The screening of active, passive, and semi-passive treatment technologies that were developed during the preliminary screening were used to inform the development of treatment options for the conceptual treatment plan described in this document.

At the request of MPMC, Golder considered a passive system to treat the site runoff during the Post-closure phase. Due to the potential practical and economical limitations of a passive system in terms of the maximum flow rate that can be successfully treated and the large footprint requirement, it is proposed that a semi-passive system as well as the passive system components be piloted during Operations. Refer to Section 7.0 for a detailed description and conceptual design of the proposed pilot plant.

The passive treatment process selected for Post-closure consists of the following technology components:

- sedimentation pond (SED) for total suspended solids (TSS) and particulate metal removal as an alternative to the sedimentation achieved in the Springer Pit, the SED will function as a pre-treatment step for the passive treatment system
- biochemical reactor (BCR) for the removal of sulphate, nitrate, most dissolved metals, and selenium
- sulphide polishing cell (SPC) for removal of reduced sulphur
- subsurface (SSF) constructed wetland for the removal of biochemical oxygen demand (BOD) generated by the BCR
- free water surface (FWS) constructed wetland for further BOD polishing and manganese removal

# 4.0 CONCEPTUAL INFLOW DESIGN CRITERIA

The following section describes the conceptual inflow design criteria for the Post-closure water treatment phase.

For developing the Post-closure treatment concept, it was assumed that most site runoff will converge in the Perimeter Embankment Till Borrow Pond (PETBP), from which water will be pumped (via additional site water management systems) to the Springer Pit for flow equalization and storage, while the Mine water associated with the Temporary Northwest (NW) Potentially Acid Generating (PAG) Stockpile system (9K Sump, NW PAG Sump) will be directly pumped to the Springer Pit. This is particularly proposed during periods of high flows (i.e., freshet). The system was designed with flexibility so that direct treatment of surface water runoff from catchment areas nearby the proposed water treatment system is possible, as TSS removal can be provided by SED. From the Springer Pit, water will then be pumped to a centralized passive water treatment system. Although it is not envisioned to rely on pumping in Post Closure, pumping was included as a starting point for the development of the Post Closure treatment concept. Directing all water to the Springer Pit, and then metering out over nine months of the year, is not a preferred option, especially during Closure, and would represent a large pumping cost in Post-closure.

Following the same rationale used during preliminary screening (Golder 2016a), the combination of a 50$^{th}$ percentile (median) flow rate with a 95$^{th}$ percentile concentration was selected for the Post-closure design criteria. With the Springer Pit providing flow equalization for the proposed treatment system, median flows could be used for the design.

Golder prepared a stochastic site water balance model to predict Post-closure flows for the period of July 2020 to 2100. Fiftieth percentile (median) monthly flows for each month of the year were modelled, from which the maximum median predicted monthly flows were extracted. Winter month flows (December to February) are forecast to be significantly smaller than the flows for other months. Because of cold climate conditions, some of the biological water treatment components may not operate well during winter months due to lower biological activity, so maximum monthly flow rates from January to December were added and averaged for a period of nine months, and the predicted median flow rate of 13,000 $m^3$/d was selected for conceptual water treatment design for Post-closure (this assumes that all the yearly site runoff could be treated during a nine month period).

As part of the proposed conceptual design, TSS will be removed during a pre-treatment step using a SED (which was sized to treat water that has not passed through Springer Pit) and the associated particulate metals concentrations will be reduced accordingly. Thus, water quality was predicted using a stochastic probabilistic model for the PETBP and the 95$^{th}$ percentile concentration of constituents of concern, assuming a TSS concentration of 15 mg/L to the main water treatment system, was selected as a design criterion. Water quality target values for discharge to Hazeltine Creek (without considering an initial dilution zone) based on post-closure and existing hardness were used to screen the predicted water quality for the PETBP, and the results are shown in Table 2.

**Table 2: Post-closure Inflow Design Criteria**

| Parameter | Units | Hazeltine Creek Post Closure Treatment Water Quality Targets | | Closure |
|---|---|---|---|---|
| | | Post Closure no Dilution | Notes | 13,000 $m^3/d$ |
| **Major Ions** | | | | |
| Sulphate | mg/L | 309 | D | 841 |
| **Nutrients** | | | | |
| Ammonia | mg/L (as N) | 0.100 | D | 0.19 |
| Nitrate | mg/L (as N) | 3.0 | D | 19 |
| Nitrite | mg/L (as N) | 0.020 | D | 0.52 |
| Total phosphorus | mg/L | 0.030 | B | 0.048 |
| **Total Metals** | | | | |
| Antimony | mg/L | 0.009 | E | 0.0011 |
| Beryllium | mg/L | 0.00013 | E | 0.00038 |
| Chromium | mg/L | 0.001 | E | 0.0019 |
| Cobalt | mg/L | 0.004 | D | 0.005 |
| Copper | mg/L | 0.019 | A | 0.054 |
| Iron | mg/L | 1.0 | D | 1.1 |
| Manganese | mg/L | 1.4 | D | 2.1 |
| Mercury | mg/L | 0.00002 | D | 0.000024 |
| Selenium | mg/L | 0.010 | C | 0.11 |
| **Dissolved Metals** | | | | |
| Aluminum[(a)] | mg/L | 0.050 | D | 0.094 |
| Antimony | mg/L | 0.0009 | E | 0.0011 |
| Beryllium | mg/L | 0.00013 | E | 0.00037 |
| Cobalt | mg/L | 0.004 | D | 0.0044 |
| Copper | mg/L | 0.019 | A | 0.044 |
| Manganese | mg/L | 1.4 | D | 2.1 |
| Selenium | mg/L | 0.010 | C | 0.11 |

Notes:

X = Indicates concentration exceeding the HAC preliminary treatment WQ targets for post closure no dilution.

*a) = Treatment Target specifically for Dissolved Metals.

A = Derivation of copper target is provided in Attachment B.

B = pre-breach mean 0.033; pre-discharge mean 0.03.

C = Derivation of selenium target is provided in Attachment C.

D = approved 30- d WQG

E = working 30- d WQG

# 5.0 POST-CLOSURE PROCESS DESCRIPTION

Surface water from the different site sources will be pumped to the Springer Pit for storage, sedimentation and equalization. From the Springer Pit, water will be pumped to the centralized water treatment system, which will consist of the following passive treatment components:

- one SED (parallel to the Springer Pit)
- four BCRs
- 16 SPCs
- 16 SSF wetlands
- four FWS wetlands

The treatment system will be split into four identical trains to allow modular construction, distributed layout, and sequential maintenance. Apart from the Springer Pit and the SED (which is provided as an alternative sedimentation feature), which are common units preceding all four trains, each train will consist of the following treatment components:

- one BCR
- four SPCs, operating in parallel
- four SSF wetlands, operating in parallel
- one FWS wetland

It is expected that the Springer Pit and the SED will reduce the feed water TSS concentration. From there, the water should be discharged to four BCR trains. The BCRs are expected to remove nitrate, aluminum, antimony, cobalt, copper, and selenium, and to partially remove sulphate from the water. Due to the organic nature of the BCR substrate media, it is expected that the water discharged from the BCR will have high BOD along with phosphorus and ammonia content. The effluent from each BCR cell should discharge into the SPCs, from which sulphide is expected to be removed through iron precipitation. The effluent from each SPC should be discharged by gravity into an SSF wetland cell, where the bulk of the BOD is expected to be removed. For each train, water from the SSF wetland cells will flow by gravity into a common FWS wetland, which is expected to remove manganese, and to polish BOD prior to discharge into Hazeltine Creek.

The relative change in constituents that have design implications are qualitatively demonstrated in Table 3 for each of the process units listed above and described in the sections that follow. The information provided here is for conceptual design purposes only and subject to confirmation with bench and pilot testing work.

**Table 3: Qualitative Process Unit Matrix of Design Constituents**

| Parameter | Feed | Springer Pit / SED | BCRs | SPCs | SSFs | FWS |
|---|---|---|---|---|---|---|
| TDS | ● | ● | ● | ● | ● | * |
| TSS | ● | ○ | ○ | ○ | - | - |
| Sulphate | ● | ● | ○ | - | - | - |
| Nitrate/nitrite | ● | ● | ○ | ○ | ○ | - |
| Total phosphorous | ○ | ○ | ● | * | * | * |
| Selenium | ● | ● | - | - | - | - |
| Manganese | ● | ● | ● | ● | ● | - |
| Aluminum | ● | ● | - | - | - | - |
| Antimony | ● | ● | - | - | - | - |
| Cadmium | ● | ● | - | - | - | - |
| Cobalt | ● | ● | - | - | - | - |
| Copper | ● | ● | - | - | - | - |
| Zinc | ● | ● | - | - | - | - |
| Other metals | ● | ● | ○ | ○ | ○ | * |
| BOD | - | - | ● | ● | ○ | * |

● Indicates presence of constituent.

○ Indicates relative presence compared to what is indicated by ●.

- Indicates removal to below expected target values.

* Indicates uncertainty as to either removal efficiency or target values.

SED = sedimentation pond; BCR = biochemical reactor; SPC = sulphide polishing cell; SSF = subsurface; FWS = fresh water surface; TDS = total dissolved solids; TSS = total suspended solids; BOD = biochemical oxygen demand.

The process flow diagram for Closure is provided in Attachment A, Figure 3.

The following sections will discuss each component of the passive water treatment system in more detail.

## 5.1 Water Treatment Location

Because of the passive nature of the water treatment system, the SED and treatment cells need to be arranged so that water will flow by gravity within the treatment system. The topography of the terrain needs to be assessed in more detail during the detailed design of the passive treatment system so that appropriate static pressure is provided for successful water flow through the system. Earthworks and pressure requirements for operation of each water treatment component were not assessed during the conceptual design of the water treatment system.

Several potential locations were considered, but not evaluated in detail:

- Polley Flats area
- on top of the Tailings Storage Facility (TSF)
- at the Old Till Borrow Pit (near Gavin Lake Bridge), and adjacent to (south of) the TSF

For the purposes of the central passive treatment concept design, the Polley Flats area of approximately 30 ha, adjacent to Polley Lake and Hazeltine Creek, was selected for placement of part of the conceptual water treatment system. Because the total footprint of the passive treatment system proposed exceeds 30 ha, a portion of the treatment system was located at the Polley Flats area (for easy effluent discharge into Hazeltine Creek) and the rest located in other areas.

During Post-closure, the TSF will accumulate local runoff in a pond to be located in the north-west corner. The maximum operating level of the pond will be at 966.6 metres above sea level (masl). A sloped beach area will be built and an area of approximately 150 ha located above the 966.6 masl line may be available for placement of the water treatment system.

Alternatively, the Old Till Borrow Pit location, near the Gavin Lake Bridge, could be used. The area is currently undeveloped. Based on the results of piloting and future design refinement, additional locations may be feasible, preferably in locations well-suited to the preferred Post-closure distributed discharge strategy, and taking into consideration other factors, such as topography, potential future TSF expansion and rehabilitation plans.

For this conceptual design, the water treatment system is located in the Polley Flats and the TSF, as described.

## 5.2 Sedimentation Pond

The SED is included as an alternative sedimentation feature to the Springer Pit and discharges to four individual BCRs (downstream). For the main configuration, Mine contact water will initially be conveyed to the Springer Pit to provide flow equalization and sedimentation, from where it will be pumped to BCRs. Alternatively, Mine contact water can also be conveyed through the SED at a maximum design flow rate of 22,000 $m^3$/d (0.26 $m^3$/s). This represents the sum of the maximum monthly flows for a 1-in-10 year event (90$^{th}$ percentile), divided by nine months. Although the other treatment components were sized to treat the median flow rate of 13,000 $m^3$/d, the SED was designed to accommodate a higher hydraulic flow rate to allow for additional hydraulic equalization during freshet. At the initial stages of Post-closure, higher concentrations of constituents are more likely to occur, and provision is made for the rest of the treatment system to be bypassed and the outflow from the Springer Pit or SED to be discharged to Quesnel Lake through the Operations phase's diffuser system.

The primary design objective of the SED is to lower the TSS of Mine contact water, which will reduce the particulate component of metal constituents prior to discharge to the BCRs. The current permit for the existing short-term effluent discharge (*Environmental Management Act* Permit 11678) allows a maximum TSS level of 15 mg/L to be discharged to Quesnel Lake, via Hazeltine Creek and a diffuser. Considering this, the purpose of the SED is to reduce the incoming Mine contact water TSS level at the pond discharge point.

The SED dimensions are based on the design criteria set out by the BC Ministry of Environment (MOE 2015) which primarily uses the Stokes settling theory to calculate the required effective pond surface area. The Stokes equation is used to calculate the settling velocity for a range of particle diameters from a sediment sample taken from site runoff. The range in settling velocities is compared to the pond critical settling velocity, in the direction of the pond depth, based on the incoming flow rate divided by the effective surface area of pond. This comparison is used to calculate the sediment mass fraction removed from the inflow at the pond discharge point. The pond dimensions are adjusted to achieve an effective pond surface area that results in the targeted TSS being met. The SED is sized to remove particle sizes above 15 microns. The TSS removal rate will depend on the particle size distribution properties of the site run off water, and would need to be confirmed as part of the detailed design. The SED conceptual design includes an internal pond length of 110 m, width of 25 m and a depth of 4 m. The internal batter slopes are 3H:1V, and the berm crest width is 5 m to allow access for maintenance vehicles. The SED also includes inactive storage for deposited sediments to a maximum depth of 2 m, an active storage level of 1 m depth and freeboard of 1 m. The inlet and outlet pipes have design invert elevations to allow the pond level to achieve the effective pond surface area prior to discharging to the biochemical reactor cells. The SED design is summarized in Table 4.

**Table 4: Sedimentation Pond Design**

| Design Attribute | Unit | Value |
|---|---|---|
| Internal pond length | m | 110 |
| Internal width | m | 25 |
| Depth | m | 4 |
| Internal batter slopes | ZH:1V | 3 |
| Berm crest width | m | 5 |
| Inactive storage for deposited sediment | m | 2 |
| Active storage depth | m | 1 |
| Freeboard | m | 1 |

For this conceptual design, the particle settling velocity calculation is based on a single sample and more sampling will be required to confirm this calculation in the next design phase.

## 5.3 Biochemical Reactor

The design of the BCR is based on design guidelines by the Interstate Technology and Regulatory Council (ITRC 2013) and has been informed by previous bench and pilot testing as well as full scale designs by Golder. The pilot plant work at the Mine site on passive remediation by means of a bioreactor (Baldwin et al. 2015) was also reviewed.

The BCR consists of a lined pond filled with carbon source substrate and submerged water column, where oxygen is consumed by microorganisms, and anaerobic conditions prevail. The anaerobic conditions are ideal for development of microorganisms that use organic substrate as a nutrient source, such as sulphate and selenium reducing bacteria.

Sulphate reducing bacteria oxidize organic matter, produce bicarbonate, raise the pH and alkalinity content of the water, and are able to convert sulphates present in the feed water to sulphides, which should bind with soluble metals and form insoluble metal sulphides. Because plants are not required in anaerobic BCRs, and to maintain anaerobic conditions, this system can be constructed underground or buried. In cold climates, BCRs need to be covered to maintain biological activity and to optimize the performance of the system during cold months.

Due to the organic nature of the BCR substrate media, as biodegradable material is broken down under anaerobic conditions, contaminants contained in the substrate media may be released. It is expected that the water discharged from the BCR will have high BOD along with phosphorus and ammonia content, and metals associated with specific substrate media. One of the objectives during bench testing is to optimize the substrate composition to minimize phosphate, BOD, and metal leaching from the substrate media components.

### 5.3.1 Design Description

The flow from the Springer Pit or SED should be equally split and distributed to four BCRs operating in parallel. The BCR design requirements for removal of selenium, nitrate and sulphate were compared. As the minimum hydraulic retention time (HRT) required for sulphate removal is greater than that required for selenium or nitrate removal, sulphate removal HRT is the limiting factor, and hence was selected as the main design criterion.

The BCR relies on sulphate reduction and metal sulphide precipitation to reduce metal concentrations. If there is excess sulphide present, the sulphate removal depends on the sum of the metal loads to the BCR. The resulting total metal load along with sulphate load were estimated and compared, and the results are presented in Table 5. Because the sulphate load is greater than the total metal load, the system would remove the metals of concern and only a portion of the sulphate. The remaining sulphate (now in the reduced sulphide form) is removed in the SPC, located downstream of the BCR.

The BCR system was designed to remove aluminum, antimony, cobalt, copper, selenium, nitrate, and a portion of sulphate from the water. The design parameters for the BCR are summarized in Table 5.

**Table 5: Biochemical Reactor Design Parameters**

| Parameter | Units | Value |
|---|---|---|
| Total flow to BCR system | $m^3/d$ | 13,000 |
| Flow per BCR | $m^3/d$ | 3,300 |
| pH | pH units | 8.0 |
| Total metal load | mol/d | 160 |
| Sulphate load | mol/d | 110,000 |
| Hydraulic retention time for sulphate removal | days | 11 |

BCR = biochemical reactor; mol/d = moles per day.

The minimum required footprint for each BCR cell based on sulphate removal was found to be 42,000 $m^2$.

The BCR has a total depth of 3.0 m, which consists of the following:

- 2 m substrate
- 0.3 m bottom gravel discharge
- 0.3 m free water with wood chips
- 0.4 m freeboard

The substrate layer volume consists of the following:

- 60% wood chips
- 19% hay
- 1% manure
- 20% limestone

The side slope was assumed to be 3H:1V. Details of the proposed BCR geometry (typical cross-section) are shown on the Closure Sections provided in Attachment A, Figure 5.

The static water head required for BCR operation needs to be determined during future work. Additionally, during detailed design, the substrate hydraulic conductivity must be taken into consideration for the head loss calculation. The hydraulic conductivity of the substrate can be established during bench- and pilot-scale testing.

The system was conceptually designed such that it may be operated in both upflow and downflow modes, facilitated by a suitable valve arrangement. Upon start-up, the BCR could leach high concentrations of BOD, which would need to be recirculated through the system until a steady state BOD concentration of 60 mg/L is achieved. A bypass line for water to be recirculated through the BCR during commissioning and start-up needs to be considered during the next phase. Recirculation may be carried out by installing a pump at the BCR outlet and by opening and closing appropriate valves. The pump must be capable of providing a minimum water head (to be determined) to feed the BCR at 0.15 $m^3/s$.

### 5.3.2 List of Assumptions

The assumptions used for the conceptual design of the BCR system include the following:

- A flow meter will be provided upstream of each BCR.
- Suitable substrate for the BCR will be available.
- The substrate media will have a porosity close to 50%.
- Pilot or bench testing on Mine contact water will be performed to confirm the design and sizing criteria (e.g., substrate composition and porosity, and hydraulic retention time).

- The main mode of operation will be in the upflow configuration.
- The BCR material will be replaced every 10 to 15 years, or as required. Material replacement frequency should be reviewed during detailed design.

For a list of general design assumptions, refer to Section 6.0.

## 5.4 Sulphide Polishing Cell

The SPC is a lined pond filled with wood chips mixed with sacrificial iron material, submerged in water. The sacrificial iron can be obtained from various sources. Since the Mine site has magnetite available, it is proposed to consider using magnetite as a potential source of sacrificial iron.

The SPC is designed with a bottom-fed vertical flow configuration which should preserve the anaerobic state of the BCR effluent as it comes into contact with the iron and wood chips mixture. An anaerobic state is required to remove the remaining sulphide from the BCR by precipitating it as iron sulphide. Failure to remove sulphides would result in the sulphide being oxidized back to sulphate.

The introduction of a SPC will have the added benefit that it could potentially remove phosphate through iron co-precipitation. This is something that will be confirmed through the proposed bench and pilot testing.

The media containing the iron source and wood chips mixture (referred to as the “iron sponge”) will be consumed over time and, if exhausted, may require replacement with fresh media. The design can be optimized to allow media replacement when required.

### 5.4.1 Design Description

The flow from each BCR will be equally split and distributed into to four SPCs operating in parallel. Design parameters for the SPCs is are provided in Table 6.

**Table 6: Sulphide Polishing Cell Design Parameters**

| Parameter | Units | Value |
|---|---|---|
| Total flow to SPC system | $m^3/d$ | 13,000 |
| Flow per SPC | $m^3/d$ | 810 |
| Sulphate to be bound | mol/d | 84,000 |
| Iron required for sulphate removal | mol/d | 84,000 |
| Sacrificial iron required | kg/yr | 1,700,000 |
| Controlling iron sponge req. per cell | $m^3$ | 7600 |
| Minimum SPC HRT | days | 0.5 |
| Calculated HRT for SPC system | days | 8.0 |

SPC = sulphide polishing cell; HRT = hydraulic retention time; mol/d = moles per day.

The footprint of the system is proportional to HRT. The minimum required footprint for each SPC cell based on sulphate removal was found to be 6,200 $m^2$.

Each SPC has a total depth of 4.0 m, which consists of the following:

- 3 m of polishing media (iron sponge)
- 0.3 m bottom gravel discharge
- 0.3 m free water with wood chips
- 0.4 m freeboard

The iron sponge volume consists of the following:

- 35% wood chips
- 65% sacrificial iron (e.g., magnetite)

Side slopes are assumed to be 2H:1V.

Details of the proposed SPC geometry (typical cross-section) are shown on the Closure Sections provided in Attachment A, Figure 5.

The static water head required for the SPC operation needs to be determined during future work. Additionally, during detailed design, the substrate hydraulic conductivity must be taken into consideration for head loss calculations. The hydraulic conductivity of the polishing media, as well as its composition, needs to be verified during bench-scale and pilot testing. The magnetite available on site needs to be sampled to determine the iron concentration in it and suitability for use as sacrificial iron.

### 5.4.2 List of Assumptions

The assumptions made in the conceptual design of the SPC system include the following:

- Sufficient hydraulic pressure will be available to operate the SPC in the upflow mode of operation.
- A flow meter will be provided upstream of each SPC.
- Magnetite and wood chips will be available as substrate for the SPC.
- The amount of iron in the magnetite will be sufficient to be used as sacrificial iron material.
- The iron concentration in the media will be at a minimum 40%.
- The polishing media will have a porosity close to 50%.

- Pilot or bench testing with Mine contact water will be performed to confirm the design and sizing criteria (e.g., iron sponge material and porosity, and hydraulic retention time).
- The SPC material will be replaced every 10 years, or when required. Material replacement frequency should be reviewed during detailed design. If more metal constituents of concern co-precipitate with iron, then more frequent replacement of the polishing media might be required.

For a list of general design assumptions, refer to Section 6.0.

## 5.5 Constructed Wetlands

Constructed wetlands are manmade structures designed to mimic processes occurring in natural wetlands in removing pollutants from the water. In wetlands, there are high degrees of interaction between soil chemistry, nutrient cycles, and habitat, amongst others. A constructed wetland consists of a shallow lined basin filled with substrate, with either submerged water in the case of SSF wetlands, or open water in the case of FWS wetlands, and often with aquatic plants. Anaerobic and aerobic bacteria can exist in both SSF and FWS wetlands, although aerobic conditions tend to prevail in a FWS wetland because of the open water surface. A constructed wetland is typically provided as a polishing step following biological treatment of wastewater.

### 5.5.1 Description

Although the Mine contact water is not expected to have high levels of BOD, there is a possibility of appreciable levels of BOD being released from the BCR. In addition, a BCR typically is not effective for manganese removal, which is one of the parameters of concern in the Mine contact water. Hence, the constructed wetland system is designed mainly for BOD and manganese removal. The design calculations are based on guidelines provided by Ziemkiewicz et al. (2002) and the US Environmental Protection Agency (US EPA 1988, 1993).

For this conceptual design, a passive system composed of sixteen SSF horizontal flow wetland cells and four FWS wetland cells is proposed. The passive system incorporates the benefits of both SSF and FWS wetlands. The SSF cells are designed to remove the majority of the BOD load while being less exposed to the effects of cold climates, whereas the FWS cells are designed to polish the BOD level down to 5 mg/L in Hazeltine Creek, assuming no assimilative capacity in the creek. The FWS cells are also designed to provide aerobic treatment for manganese removal.

Design temperatures, and influent and effluent BOD levels, are important considerations for wetland sizing. Golder considered water temperatures from site monitoring data (2006 to 2016) for the sizing of the wetlands, excluding the coldest months of the year when ice conditions prevail. Since biological activity decreases with temperature, the wetland design size increases to compensate for the lower biological activity.

The expected influent water quality and quantity following the SPC for the wetland design considerations is summarized in Table 7.

**Table 7: Influent Water Quality/Quantity for Wetland Design Considerations**

| Parameter | Units | Value |
|---|---|---|
| Flow | $m^3/d$ | 13,000 |
| Temperature | °C | 0.5 |
| pH | pH units | 6.8 to 8.5 |
| Design BOD | mg/L | 70 |
| Dissolved manganese concentration | mg/L | 1.6 |

BOD = biochemical oxygen demand.

During start-up, elevated BOD levels are expected and will need to be managed with interim measures such as returning the wetland discharge to the wetland inflow.

The minimum required footprint for each SSF wetland cell based on BOD removal was found to be 21,000 $m^2$.

Each of the SSF wetland cells is expected to have a total depth of 1.4 m consisting of the following:

- 1 m substrate
- 0.72 m water (the water level is below the substrate)
- 0.4 m freeboard

The substrate layer would consist of the following:

- 0.95 m medium sand
- 0.05 m fine sand

The SSF wetland cells are expected to be placed in areas with a natural slope of 1.5% for drainage. Flow would be equally distributed to each of the SSF cells.

The minimum required footprint for each FWS wetland cell based on BOD and manganese removal was found to be 81,000 $m^2$ to 82,000 $m^2$. The areas of some FWS cells are slightly different due to site constraints.

Each of the FWS wetland cells is expected to have a total depth of 1.6 m, consisting of the following:

- 0.35 m substrate
- 0.6 m water (the water level is above the substrate)
- 1 m freeboard (to account for additional head loss due to the SSF cells and to provide flexibility in the water level and capacity)

The substrate layer would consist of the following:

- 0.3 m medium sand
- 0.05 m fine sand

The FWS wetland cells are expected to be designed with a slight slope for drainage. As with the flow distribution to the SSF cells, the FWS cells would be designed with equal distribution of flow. Details of the proposed SSF and FWS cells geometry (typical cross-sections) are shown on conceptual provided in Attachment A, Figure 6.

### 5.5.2 List of Assumptions

The assumptions used to design the constructed wetland system include the following:

- The final topography of the Mine site at Closure would be suitable for the construction of the wetland cells.
- The substrate media would have a porosity close to 40%.
- Pilot testing with Mine contact water would be performed to confirm the design and sizing criteria (e.g., hydraulic conductivity, temperature dependent rate constant, porosity, evapo-transpiration rate, vegetation viability, and root penetration).

For a list of general design assumptions, refer to Section 6.0.

Preliminary conceptual plans and sections are provided in Attachment A, Figures 1 and 6.

## 5.6 Treatment System Footprint

The passive system is estimated to have a total footprint of approximately 96 ha. Table 8 shows the breakdown areas for the different components of the passive system.

**Table 8: Closure System Footprint**

| Unit Process Name | Unit | Area per Unit ($m^2$) | Total ($m^2$) |
|---|---|---|---|
| SED | 1 | 6,800 | 6,800 |
| BCR | 4 | 42,000 | 170,000 |
| SPC | 16 | 6,200 | 99,000 |
| SSF wetland | 16 | 21,000 | 336,000 |
| FWS wetland | 4 | 82,000 | 330,000 |
| Estimated total footprint area (accounting for berms and offsets) | - | - | 960,000 |

SED = sedimentation pond; BCR = biochemical reactor; SPC = sulphide polishing cell; SSF = subsurface; FWS = free water surface.

## 5.7 Process Limitations

The passive water treatment system was conceptually designed so that its effluent should be able to meet the target water quality limits for all constituents of concern as identified in Table 2. The predicted influent chemistry does not fully account for seasonal variations. This means the $95^{th}$ percentile predicted concentrations of some constituents may typically only be associated with seasonal low flow scenarios. These seasonal variations were not considered in the design.

There are some constituents that could either not be removed effectively or that could be introduced at concentrations that might not meet target water quality limits. The issues around these constituents will be addressed through additional model refinement, pilot testing, design optimization, and receiving environment assessment work.

It is expected that phosphorus may be introduced by the substrate used in the BCR, and a concentration of 1 to 3 mg/L in the effluent from the BCR could be expected. Although this impact could potentially be reduced through iron co-precipitation in the SPC and the wetlands, the phosphorus concentration in the effluent water prior to discharge may not meet the target water quality limit as provided in Table 2.

Although the treatment system is designed to reduce the sulphate concentration in the feed water and with sulphate being a major component in total dissolved solids (TDS), the TDS will be reduced concurrently. However, this TDS removal benefit is off-set by the alkalinity introduced by the BCR during treatment, with the net effect resulting in the TDS concentration being unchanged.

The BCR is also expected to leach out high concentrations of BOD in the range of 100 to 600 mg/L during start-up (which will require flow recirculation), and around 60 mg/L when steady state is achieved. Although the constructed wetlands are designed to remove the BOD load, the BOD concentration will need to be monitored downstream of the treatment system. A discharge BOD concentration of between 5 to 10 mg/L to Hazeltine Creek is expected. This BOD effluent concentration range could exceed discharge limits, and the latter needs to be confirmed.

Depending on the composition of the substrate being used, it is possible that metals and other constituents may also leach from the BCR. These constituents should be monitored during bench and pilot testing.

# 6.0 GENERAL DESIGN ASSUMPTIONS

The following is a list of general assumptions that are applicable to the conceptual designs presented in this report:

- The final topography of the Mine site at Closure will be suitable for the construction of each of the system components.
- Input parameters will be as specified in the design criteria.
- The required water head will be confirmed during detailed design stage.
- Earthworks were not considered for conceptual design.
- The substrate media will be available, where appropriate.
- The minimum required footprint where presented for individual process units, do not make provision for berms.

# 7.0 PILOT TESTING

The following section describes a pilot plant that could be installed to test and refine the passive water treatment system described conceptually above. The fundamental processes in the pilot plant are the same as those in the full-scale plant, so to reduce repetition, the technology descriptions refer to sections above. The sizing and other design specifications listed in Section 7 refer to the pilot plant. Certain aspects of the pilot plant that are applicable to semi-passive optimizations are provided in Section 7 but are not listed for the full-scale system as these have not been applied to the full-scale conceptual design.

## 7.1 Introduction

For passive treatment systems, the concept design is typically followed by bench tests using laboratory scale equipment to confirm some of the design assumptions and parameters. Based on the information obtained from the bench tests, a pilot-scale plant could then be constructed. The pilot scale is followed by a demonstration-scale plant where all the design components are often run in such a way as to represent a first module of the full-scale plant. For some commercially available active treatment systems, suppliers shorten this process to only conduct pilot testing before full-scale implementation.

The primary purpose of the pilot system is to demonstrate the Post-closure passive treatment concept; however, it is designed with added features to also test and demonstrate semi-passive treatment concepts. This is an approach where the efficiency and footprint associated with passive treatment technologies can potentially be improved upon, through the introduction of active components (e.g., chemical dosing equipment, and instrumentation and control features).

The typical range for pilot plant flow rates are 1 to 10 gpm (or 5 to 55 $m^3$/day). It becomes difficult to control flow rates below 5 $m^3$/day, while a flow rate of 55 $m^3$/day is usually sufficient to inform full-scale design of a fully proven technology concept. Demonstration-scale plants are typically run with flow rates of between 5 and 20 gpm (27 and 109 $m^3$/day), and are sized to as the first module of a multi-modular full-scale application.

## 7.2 Conceptual Inflow Design Criteria

Golder selected a flow rate of 55 $m^3$/d for this passive treatment pilot plant, a flow rate that is in a range where it overlaps with the demonstration-scale plant. At this flow rate, the passive and semi-passive treatment principles could be piloted and/or demonstrated on a scale that could either be applied to the design of a full-scale facility or used as a template for a modular approach.

Since the intention of the pilot plant is to demonstrate Post-closure treatment technologies, the Post-closure inflow water quality design criteria are used for the pilot plant (see Section 4.0), but at the smaller flow rate of 55 $m^3$/day. However, since the pilot testing will be conducted during Operations, the feed water will be sourced either from the Springer Pit or the PETBP (prior to Actiflo treatment), or from the Actiflo outflow (in case TSS removal upstream of the pilot system is required). The pilot plant outflow will ideally discharge to Hazeltine Creek, with the option to return the outflow to the Actiflo plant if it is not suitable for direct discharge to Hazeltine Creek.

## 7.3 Facility Location

It is proposed that the pilot system be located in the Polley Flats area, in a location independent of the location for which a Closure treatment system is being proposed. For the pilot system overall site plan drawing, refer to Attachment A, Figure 2.

## 7.4 Process Description

Golder has proposed to evaluate the treatment efficacy for the Post-closure passive water treatment system downstream of the SED through pilot testing, during which the performance of a passive and variation of semi-passive systems would be evaluated over a minimum period of one full year, but ideally for a period of two years.

The components of the passive Post-closure system are as follows:

- BCR (filled with substrate)
- SPC
- SSF wetland
- FWS wetland
- aeration cascade

The semi-passive system proposed for pilot testing uses some active components with the purpose of enhancing the performance of the passive system. The semi-passive components that will be tested are:

- BCR (inert material filled) with active addition of molasses and nutrients
- sulphide reactor, to which ferric or ferrous chloride will be actively added
- mechanically aerated pond, followed by a settling pond

The conceptual pilot system was designed with sufficient operational flexibility to allow for alternative process configurations to be selected, as illustrated in the pilot system process flow diagram (see Attachment A, Figure 4). The following process components are common to all treatment configurations that will be tested:

- metal/sulphate removal
- sulphide removal
- BOD removal
- manganese removal

The components of the pilot system will be described in more detail in the following sections.

## 7.5 Biochemical Reactors

For the technology description, refer to Section 5.3

### 7.5.1 Design Description

Two types of BCRs are being considered for the pilot system: one filled with substrate (conventional), and another filled with inert material. The substrate filled BCR will be able to operate without molasses and nutrient addition; however, it is proposed to also conduct pilot tests when active molasses and nutrient addition takes place, to determine if the performance of the BCR or its footprint can be reduced through active chemical addition. The BCR filled with inert material will require constant chemical addition. Aside from the difference in fill material, both BCRs were designed identically.

The BCRs will be able to take in water either from the Springer Pit or the PETBP (prior to Actiflo treatment), or from the Actiflo outflow (in case TSS removal upstream of the pilot system is required). Both BCRs are designed to operate either independently or with equally split flows. The BCR system was designed to remove aluminum, antimony, copper, selenium, nitrate, and a portion of sulphate from the water.

Similar to the Post-closure BCR described in Section 5.3, the minimum HRT required for sulphate removal was found to be the limiting factor for this design. Table 9 summarizes the design parameters for the BCR.

**Table 9: Pilot Biochemical Reactor Design Parameters**

| Parameter | Units | Value |
|---|---|---|
| Total flow to BCR | $m^3/d$ | 55 |
| pH | pH units | 8.0 |
| Total metal load | mol/d | 0.7 |
| Sulphate load | mol/d | 482 |
| Sulphate removal load | $mol/m^3$-day | 0.3 |
| Hydraulic retention time for sulphate removal | days | 11 |

BCR = biochemical reactor; mol/d = moles per day; $mol/m^3$-day = moles per cubic metre per day.

The footprint of the system increases with an increase in HRT. The minimum required footprint for the BCR based on sulphate removal was found to be 1,800 $m^2$.

The BCR has a total depth of 3.0 m, which consists of the following:

- 2 m substrate
- 0.3 m bottom gravel discharge
- 0.3 m free water with wood chips
- 0.4 m freeboard

For the BCR which filled with substrate, the substrate volume consists of the following:

- 60% wood chips
- 19% hay
- 1% manure
- 20% limestone

For the BCR filled with inert material, the bed volume will consist of crushed gravel.

Side slopes are assumed to be 3H:1V.

Details of the proposed BCR geometry (typical cross-section) are shown on the pilot sections provided in Attachment A, Figure 7.

The portable pump must be capable of providing a minimum water head (to be determined) to feed the BCR at 0.150 $m^3$/s.

For details of the design description that is similar to what was previously presented, refer to Section 5.3.1.

### 7.5.2 List of Assumptions

The assumptions used to design the BCR systems were presented in Section 5.3.2. Pilot plant specific assumptions include the following:

- The pilot system will be run for at least two full years to properly assess start-up and long-term removal rates of the constituents of concern.
- Bench testing with Mine contact water will be performed to confirm the design and sizing criteria (e.g., substrate composition and porosity, hydraulic retention time).
- Power will be available for molasses and nutrient dosing.
- Feed water from the PETBP or Springer Pit will be available for pilot testing.
- Although a design flow of 55 $m^3$/d was assumed for the BCRs, the system was designed with flexibility so that higher flows rates can be tested to evaluate the limitation of the system.
- Molasses and nutrient addition quantities and flows will be established during detailed design.

For a list of general design assumptions, refer to Section 6.0.

## 7.6 Sulphide Reactor

As part of the semi-passive system, it is proposed that sulphide removal be achieved through iron co-precipitation with dosing of ferric and ferrous chloride. A sulphide reactor consists of a plastic, vertical, closed-top tank in which the iron sulphide reaction will take place.

### 7.6.1 Design Description

The flow from the BCR system will be sent to the SPC system, which will consist of a sulphide reactor and a SPC. Either sulphide reactor or SPC were designed to be able to operate independently and to treat the full pilot testing flow. For sulphide removal, an adequate amount of ferric or ferrous chloride needs to be added to the water. The sulphide reactor design parameters are defined in Table 10.

**Table 10: Sulphide Reactor Design Parameters**

| Parameter | Units | Value |
|---|---|---|
| Total flow to SPC | $m^3/d$ | 55 |
| Sulphate to be bound | mol/d | 360 |
| Influent sulphide | mg/L | 620 |
| Iron required for sulphate removal | mol/d | 360 |
| Ferric chloride procured strength | % w/w | 39 |
| Ferrous chloride procured strength | % w/w | 36 |
| Iron dose as percentage of sulphide produced | % | 10 |
| Specific gravity of procured ferric chloride solution | - | 1.4 |
| Specific gravity of procured ferrous chloride solution | - | 1.2 |
| Usage period of ferric or ferrous chloride solution | months | 1 |
| Maximum flow rate of continuous dosing pump | L/s | 7.4 |
| Estimated ferric chloride dosing | L/month | 323 |
| Estimated ferrous chloride dosing | L/month | 319 |

SPC = sulphide polishing cell; mol/d = moles per day.

Since the estimated ferric chloride dosing rate is higher than ferrous chloride, the sulphide reactor was sized based on the estimated required ferric chloride dosing. It is proposed that a 0.35 $m^3$ (90 US gallons, 0.9 m [34 inches] in diameter by 0.9 m [36 inches]) high) vertical, closed-top tank with graduation marks be provided.

### 7.6.2 List of Assumptions

The assumptions used to design the sulphide reactor include the following:

- Either ferric or ferrous chloride will be added to precipitate sulphide.
- A flow meter will be provided upstream of the sulphide reactor.

- Bench-scale testing with Mine contact water will be performed to confirm the design, ferric/ferrous chloride dosing, and sizing criteria.
- Power will be available for molasses and nutrient dosing.
- Feed water from the PETBP or Springer Pit will be available for pilot testing.
- Although design flow for the sulphide reactor was assumed to be 55 $m^3$/d, the system was designed with flexibility so that higher flows rates can be tested to evaluate the limitation of the system.
- The introduction of chloride into the treatment system's effluent resulting from the ferrous or ferric chloride dosing will be evaluated during pilot testing.
- Required contact time for iron sulphide precipitation will be determined during pilot testing.
- A storage tank for the ferric/ferrous chloride solution will be provided and a metering pump will be available for ferric/ferrous chloride addition.
- Cleaning frequency of the sulphide reactor will be determined during pilot testing.

For a list of general design assumptions, refer to Section 6.0.

## 7.7 Sulphide Polishing Cell

For technology description, refer to Section 5.4.

### 7.7.1 Design Description

The flow from the BCR system will be sent to the SPC system. For design of the SPC it was considered to receive the full flow from the BCR and that it would operate independently of chemical addition. Similarly to the Closure SPC, sulphide removal will depend on the availability of sacrificial iron. The design parameters for the SPC are shown in Table 11.

**Table 11: Sulphide Polishing Cell Design Parameters**

| Parameter | Units | Value |
|---|---|---|
| Total flow to SPC | $m^3$/d | 55 |
| Sulphate to be bound | mol/d | 357 |
| Iron required for sulphate removal | mol/d | 357 |
| Sacrificial iron required | kg/yr | 7,268 |
| Controlling iron sponge required | $m^3$ | 103 |
| Minimum SPC HRT | days | 0.5 |
| Calculated HRT for sulphide removal | days | 2.9 |

SPC = sulphide polishing cell; HRT = hydraulic retention time; mol/d = moles per day.

The footprint of the system increases with an increase in HRT. The minimum required footprint for the SPC was estimated based on sulphate removal, and it was found to be 1,200 $m^2$.

The SPC has a total depth of 3.0 m, which consists of the following:

- 2 m of polishing media (iron sponge)
- 0.3 m bottom gravel discharge
- 0.3 m free water with wood chips
- 0.4 m freeboard

The iron sponge volume consists of the following:

- 35% wood chips
- 65% sacrificial iron (magnetite)

The SPC slope was considered to be 3H:1V.

Details of the proposed SPC geometry (typical cross-section) are shown on the Pilot Sections provided in Attachment A, Figure 7.

For details of the design description similar to what was previously presented for the Post-closure process, refer to Section 5.4.1.

### 7.7.2 List of Assumptions

The assumptions used to design the SPC system were presented in Section 5.4.2. Assumptions specific to the pilot plant include the following:

- A flow meter will be provided upstream of the SPC.
- Bench-scale testing on Mine contact water will be performed to confirm the design and sizing criteria (e.g., iron sponge composition and porosity, hydraulic retention time).
- The SPC material will be replaced after two years, if needed.
- Feed water from PETBP or Springer Pit will be available for pilot testing.
- Although design flow for the SPC was assumed to be 55 $m^3/d$, the system was designed with sufficient flexibility to allow testing of higher flows in order to evaluate the load limitations of the system.

For a list of general design assumptions, refer to Section 6.0.

## 7.8 Constructed Wetlands

For a technology description, refer to Section 5.5.

### 7.8.1 Design Description

The pilot passive system consists of subsurface and free water surface wetlands, and an aeration cascade structure, all of which are placed downstream of the sulphide polishing cell. Although the Mine water from the Springer Pit or PETBP is not expected to have high levels of BOD, there is a possibility of appreciable levels of BOD being released from the BCR.

The pilot system was designed with flexibility, so that the semi-passive system may also incorporate the benefits of both SSF and FWS wetlands. The SSF cell is designed to remove the majority of the BOD load while minimizing water loss due to evaporation and being less exposed to the effects of cold climates, whereas the FWS cell is designed to polish the BOD level down to the proposed target for BOD in Hazeltine Creek, assuming no assimilative capacity in the creek. The FWS cell is also designed to provide aerobic treatment for manganese removal.

Similar to what was discussed in Section 5.5.1, design temperatures, and influent and effluent BOD are important considerations for wetland sizing.

Table 12 summarizes the expected influent water quality and quantity post BCR for the wetland design considerations.

**Table 12: Influent Water Quality/Quantity for Wetland Design Considerations**

| Parameter | Units | Value |
|---|---|---|
| Flow | $m^3/d$ | 55 |
| Temperature | °C | 0.5 |
| pH | pH units | 6.8 to 8.5 |
| Design BOD | mg/L | 70 |
| Dissolved manganese concentration | mg/L | 1.6 |

BOD = biochemical oxygen demand.

During start-up, elevated BOD levels are expected and will need to be managed with interim measures such as returning the wetland discharge to the wetland inflow.

The minimum required footprint for each SSF wetland cell based on BOD removal was found to be 1,800 $m^2$.

The SSF wetland cell is expected to have a total depth of 1.4 m, consisting of the following:

- 1 m substrate
- 0.72 m water (where the water level is below the substrate)
- 0.4 m freeboard

The substrate layer would consist of the following:

- 0.95 m medium sand
- 0.05 m fine sand

The SSF wetland cell is to be placed in areas with natural slope of 1% for drainage. The minimum required footprint for the FWS wetland cell based on BOD and manganese removal was found to be 2,200 $m^2$.

The FWS cell is expected to have a total depth of 1.6 m, consisting of the following:

- 0.35 m substrate
- 0.6 m water (the water level is above the substrate)
- 1 m freeboard (to account for additional head loss due to the SSF cell and to provide flexibility in the water level and capacity)

The substrate layer consists of the following:

- 0.3 m medium sand
- 0.05 m fine sand

The FWS wetland cell is designed with a slight slope for drainage. Details of the proposed SSF and FWS cells geometry (typical cross-section) are shown on conceptual drawings provided in Attachment A, Figure 7.

### 7.8.2 List of Assumptions

The assumptions used to design the constructed wetland system include the following:

- The final topography of the site at Closure will be suitable for the construction of the BCR and wetland cells.
- An FWS can take several years to reach maturity.
- The substrate media will have a porosity close to 40%.

For a list of general design assumptions, refer to Section 6.0.

Preliminary conceptual plans and sections are provided in Attachment A, Figures 2 and 7.

## 7.9 Aeration Cascade

Aeration cascade is a low cost and low energy method to raise dissolved oxygen (DO) levels, especially if the site conditions permit the design of gravity flow. Aeration cascade utilizes the available discharge head to create turbulence as the water falls in a thin film over a series of steps.

### 7.9.1 Design Description

Golder has proposed to investigate the impact of the addition of aeration cascade in between the SSF wetland cell and FWS wetland cell as a measure to supplement the removal of BOD and manganese through addition of oxygen to the water. Oxygen is required for both biological activity for BOD removal downstream of the FWS wetland cell, as well as for the oxidation of soluble manganese.

For this conceptual design, the steps are expected to be lined with limestone to produce a net alkaline water which would facilitate in the removal of manganese. The performance of cascade aeration depends on the length and height of the cascade, initial oxygen level, required discharge DO, and Mine water temperature.

Design temperature, as well as influent and effluent DO, are important considerations for the sizing of the cascade aeration. Golder has considered the minimum and maximum temperatures from representative monitoring data set (2006 to 2016) for the sizing of the cascade aeration.

Table 13 summarizes the design criteria for cascade aeration.

**Table 13: Design Criteria for the Cascade Aeration**

| Parameter | Units | Value |
|---|---|---|
| Flow | $m^3/d$ | 55 |
| Temperature | °C | 0.1 to 20 |
| Influent DO (assumed) | mg/L | 0.1 |
| Effluent DO | mg/L | 6 |

DO = dissolved oxygen.

Golder has adopted the more conservative scenario for the design of the cascade aeration (summer condition) due to the lower saturation of DO at higher temperature.

The minimum required footprint for the aeration cascade based on oxygen addition was found to be 0.4 $m^2$, influent distribution.

The cascade is expected to have a total height of 4 m, consisting of the following:

- 20 steps lined with limestone
- step height of 0.2 m
- step length of 0.45 m
- step width of 0.04 m

### 7.9.2 List of Assumptions

The assumptions used to design the aeration cascade system include the following:

- The final topography of the site would be suitable for the construction of the cascade structure.
- Limestone material would be available for the lining of the steps.
- Input parameters would be as specified in the design criteria section.

Preliminary conceptual plans and sections are provided in Attachment A, Figures 2 and 7.

## 7.10 Aerated and Settling Ponds

In an aeration pond, sufficient retention time and active aeration are provided for the biological removal of contaminants to take place. Following the aeration pond, water is allowed to settle in the settling pond whereby the suspended solids generated from the aeration process are removed through a settling process.

### 7.10.1 Design Description

In the active technology train, Golder has proposed an aerated pond and a settling pond following the sulphide reactor to remove the BOD from the BCR and sulphide reactor process as well as to remove the soluble manganese not removed by the BCR and sulphide reactor process.

In the aeration pond, active aeration would be provided via a set of blowers and diffuser system to provide sufficient mixing and oxygen for BOD removal through biological activity to take place. The biological and oxidation process would generate sludge that would be removed from the water by means of a settling pond. Periodically, the sludge would have to be removed from the settling pond. Following the settling pond, the flow would be directed to the FWS wetland for manganese removal. An option is allowed to directly discharge the effluent from the settling pond provided the manganese level is acceptable.

Design temperature, influent water quality, oxygen concentration to be maintained in the pond and effluent water quality are important considerations for the sizing of the aeration pond. Golder has considered representative site water temperatures from the monitoring data (2006 to 2016) for the sizing of the aeration pond.

Table 14 summarizes the design criteria for the aeration pond.

**Table 14: Design Criteria for the Aeration Pond**

| Parameter | Units | Value |
|---|---|---|
| Flow | $m^3/d$ | 55 |
| Temperature | °C | 0.1 |
| Influent DO (assumed) | mg/L | 0.1 |
| Influent total Kjeldahl nitrogen (assumed) | mg/L | 6 |
| Influent total sulphur (assumed) | mg/L | 208 |
| Oxygen concentration to be maintained in water | mg/L | 6 |
| Effluent BOD | mg/L | <5 |

DO = dissolved oxygen; BOD = biochemical oxygen demand.

The minimum required footprint for the aerated pond and settling pond based on the design criteria above was found to be 720 $m^2$ and 390 $m^2$ respectively.

The aeration pond would have a total depth of 2.4 m with a freeboard of 0.3 m, whereas the settling pond would have a total depth of 2.7 m with a freeboard of 0.6 m.

### 7.10.2 List of Assumptions

The assumptions used to design the aeration pond include the following:

- Aeration will be supplied with a diffuser system.
- Power will be available for aeration system.

For a list of general design assumptions, refer to Section 6.0.

Preliminary conceptual plans and sections are provided in Attachment A, Figures 2 and 7.

## 7.11 Treatment System Footprint

The pilot plant system is estimated to have a total footprint of approximately 1.5 ha. Table 15 shows the breakdown of areas for the different components of this system.

**Table 15: Operations and Pilot System Footprint**

| Unit Process Name | Unit | Area per Unit ($m^2$) | Total Area ($m^2$) |
|---|---|---|---|
| BCR | 2 | 1,800 | 3,600 |
| SPC | 1 | 1,200 | 1,200 |
| SSF wetland | 1 | 1,800 | 1,800 |
| Sulphide reactor | 1 | 0.6 | 0.6 |
| FWS wetland | 1 | 2,200 | 2,200 |
| Aeration pond | 1 | 720 | 720 |
| Settling pond | 1 | 390 | 390 |
| Estimated total footprint area (accounting for berms and offsets) | - | - | 15,000 |

BCR = biochemical reactor; SPC = sulphide polishing cell; SSF = subsurface; FWS = fresh water surface.

## 7.12 Process Limitations

The pilot passive system shares similar limitations to those of the Closure passive system in the sense that the system may introduce additional phosphorus, alkalinity and BOD to the discharge water, while TDS is not likely to be reduced. Additionally, it is expected that the effluent from the pilot system might not meet the discharge limits for phosphorus. These parameters would specifically be included in the performance monitoring program of the pilot plant. Depending on the performance of the plant, effluent can either be discharged (if within established compliance limits), or returned for reprocessing using the existing WTP. For design criteria of these constituents, refer to Section 7.2. A discharge BOD concentration of between 5 and 10 mg/L is expected from the pilot system. This BOD and TDS effluent concentrations could exceed discharge limits, and would need to be confirmed.

The pilot system was designed with flexibility to allow for operation of some active components, transforming the system into a semi-passive treatment. When the active components are in operation, it is expected that the BOD and phosphorus concentrations in the effluent would decline. Conversely, should ferrous/ferric chloride be selected as iron source for the sulphide reactor, it is expected that the chloride concentration in the effluent water would increase. Through piloting, design assumptions and parameters could be confirmed. The piloting phase is also used to modify and optimize the design approaches, and it also presents an opportunity to study and monitor potential constituents of concern.

# 8.0 DISCUSSION AND NEXT STEPS

Although the footprint of the full-scale passive treatment system represented in this report is large, the size may be reduced through refinement and optimization of the inflow design criteria, specifically in terms of seasonal variations in water quality, source water isolation and treatment, and reduction of the total flow requiring treatment through strategies such as incorporation specific water management considerations into reclamation and closure planning and design. It is possible that the size associated with this conceptual passive treatment system may be further reduced through bench- and pilot-scale testing and incorporation of the aforementioned potential mitigation strategies, which may include the adoption of a semi-passive system.

A trade-off study could be undertaken to compare the life-cycle costs and risks associated with active treatment systems to those of the conceptual passive and semi-passive treatment components described in this document. Following the trade-off study, bench testing or piloting work could be conducted to confirm the passive and semi-passive treatment components' design parameters, and to compare these with commercially available active treatment systems.

Golder recommends that MPMC take the following next steps to advance the proposed concept:

- Confirm the conceptual influent basis of design for Post-closure water treatment, once the output from the site water quality and site water balance models as well as the water quality targets are finalized. Conservatism in design inputs may be reduced after these models have been validated and uncertainty in future predictions has been reduced.
- Identify optimization potential strategies (i.e., flow reduction and water quality improvement measures) that can be implemented and incorporated into modelling, Mine operations and Mine planning for reclamation and closure.
- Complete sensitivity analyses for the design basis to understand the impact of potential optimization strategies and incorporate resulting scenarios into bench- and pilot-scale development.
- Conduct a high-level trade-off study and a risk assessment between the passive and semi-passive treatment concepts developed in this report and alternative commercially available active treatment technologies.
- Pending the results of the trade-off study, further refinement of bench and/or pilot testing scenarios would be recommended to confirm and compare treatment processes.

If the high-level trade-off study could be conducted before the end of 2016, the bench and/or pilot testing could be well-established by 2018, which would leave sufficient time for the full-scale treatment system to be designed and constructed to be operational before 2022.

## 9.0 CLOSURE

This conceptual design was done out of Golder's Vancouver Office, with senior review by Tom Rutkowski (PE, MSc, Associate, Senior Engineer), from Golder's Denver Office, who is a leading water treatment specialist. Mr. Rutkowski's entire career has been spent in the field of water treatment with a focus on mine water treatment. He has worked extensively on treatment of selenium and passive treatment of metals. Mr. Rutkowski's project experience includes evaluation and development of process solutions, including bench and pilot plant studies, multi-disciplinary design of treatment facilities, and direct construction of treatment facilities.

We trust the above meets your present requirements. If you have questions or additional requirements, please contact the undersigned.

**GOLDER ASSOCIATES LTD.**

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Environmental/Process Engineer

Henlo du Preez, BEng
Senior Water Treatment Specialist

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Associate, Senior Water Resources Engineer

TdSS/HDP/APB/TR/bb/it/kp



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## STUDY LIMITATIONS

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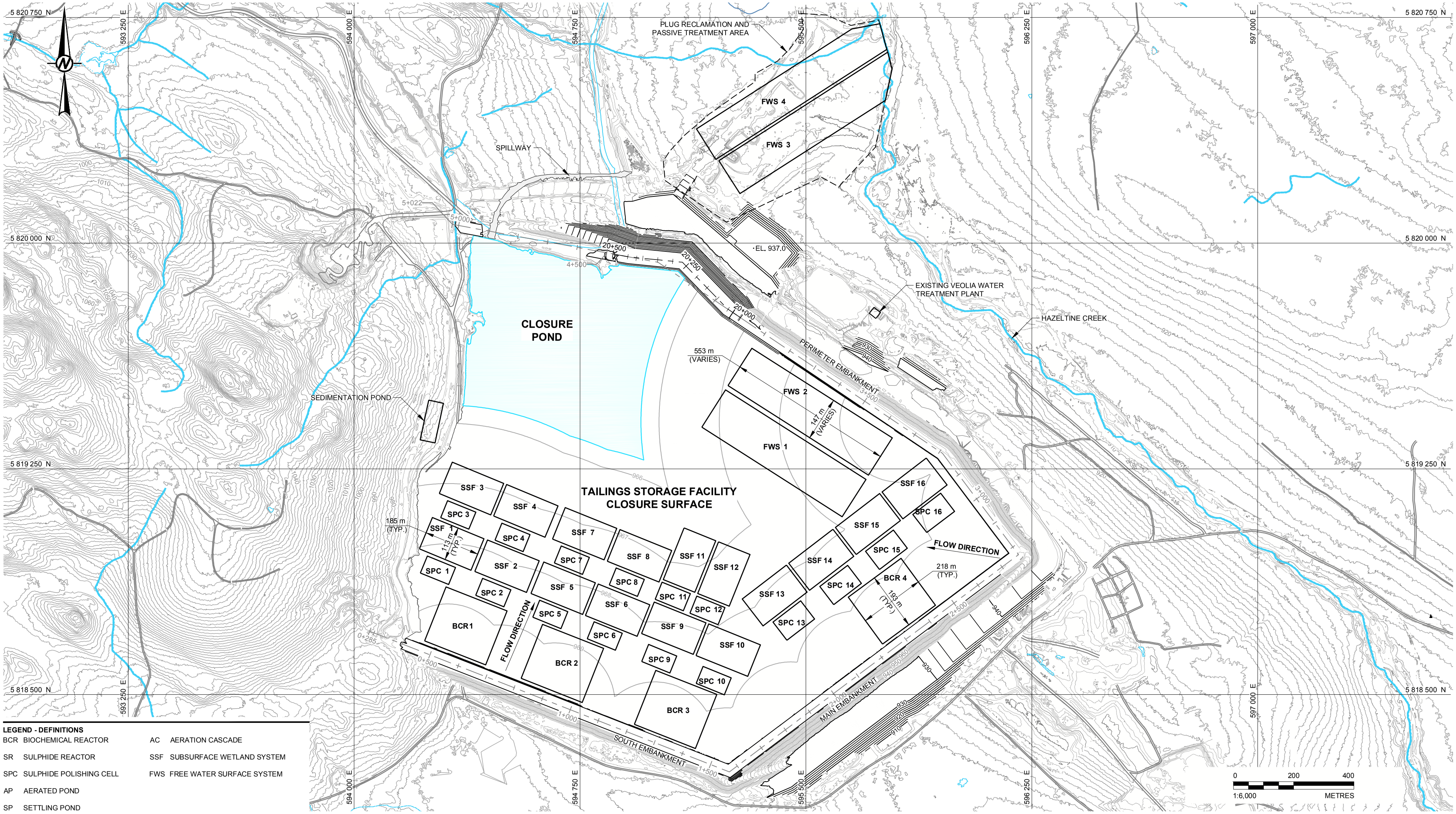
# ATTACHMENT A

## Figures




**LEGEND - DEFINITIONS**

| | | | |
|---|---|---|---|
| BCR | BIOCHEMICAL REACTOR | AC | AERATION CASCADE |
| SR | SULPHIDE REACTOR | SSF | SUBSURFACE WETLAND SYSTEM |
| SPC | SULPHIDE POLISHING CELL | FWS | FREE WATER SURFACE SYSTEM |
| AP | AERATED POND | | |
| SP | SETTLING POND | | |

**LEGEND**

4+400 SETOUT LINE - S.O.L. - ORIGINAL ALIGNMENT (SEE REFERENCE 3)

**NOTES**

1. ALL UNITS IN METRES UNLESS OTHERWISE NOTED. ELEVATIONS ARE IN METRES RELATIVE TO TAILINGS GRID DATUM.
2. COORDINATES ARE SHOWN IN TAILINGS GRID.
3. CONTOUR INTERVAL 2 m MINOR AND 10 m MAJOR. CONTOURS OF THE MOUNT POLLEY MINE SITE (SEE REFERENCE 1) WERE COMBINED WITH THE UPDATED TAILINGS STORAGE FACILITY SURVEY (SEE REFERENCE 2).
4. FOR CLOSURE CELL SPECIFICATIONS AND DETAILS, REFER TO FIGURES 6 AND 7.

**REFERENCES**

1. BASE TOPOGRAPHY PROVIDED BY MPMC, FILE NAME: "MtPolley_20140805_1m_LiDAR_Contour.dwg", RECEIVED: SEPTEMBER 3, 2014.
2. TOPOGRAPHY PROVIDED BY MPMC, FILE NAMES: "10cm contours full tailings.dxf" AND FILE: "10cm Hazeltine 3 Reprocessed.dxf", SURVEYED: MAY 27, 2015, RECEIVED: JUNE 11, 2015 AND FILE: "151015 ASBUILT SURFACE.msr", RECEIVED: OCTOBER 15, 2015.
3. S.O.L - ORIGINAL ALIGNMENT PROVIDED BY BGC ENGINEERING INC., DRAWING NO. 01, DRAWING TITLE, "SI PLANNING PLAN MAP", PROJECT NO. P14178, FILE NAME: "ACAD-01.DWG", DATED: SEPTEMBER 2014.

CLIENT
MOUNT POLLEY MINING CORPORATION

CONSULTANT
Golder Associates

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| YYYY-MM-DD | 2016-09-30 |
| DESIGNED | TdSS |
| PREPARED | MSH |
| REVIEWED | TdSS/HC/LA |
| APPROVED | AB |

PROJECT
MOUNT POLLEY CLOSURE WATER TREATMENT SYSTEM

TITLE
**MOUNT POLLEY WATER TREATMENT SYSTEM CLOSURE - OVERALL SITE PLAN**

| PROJECT NO. | PHASE/TASK/DOC. | REV. | FIGURE |
|---|---|---|---|
| 1411734 | 16000/3004/150 | 0 | 1 |

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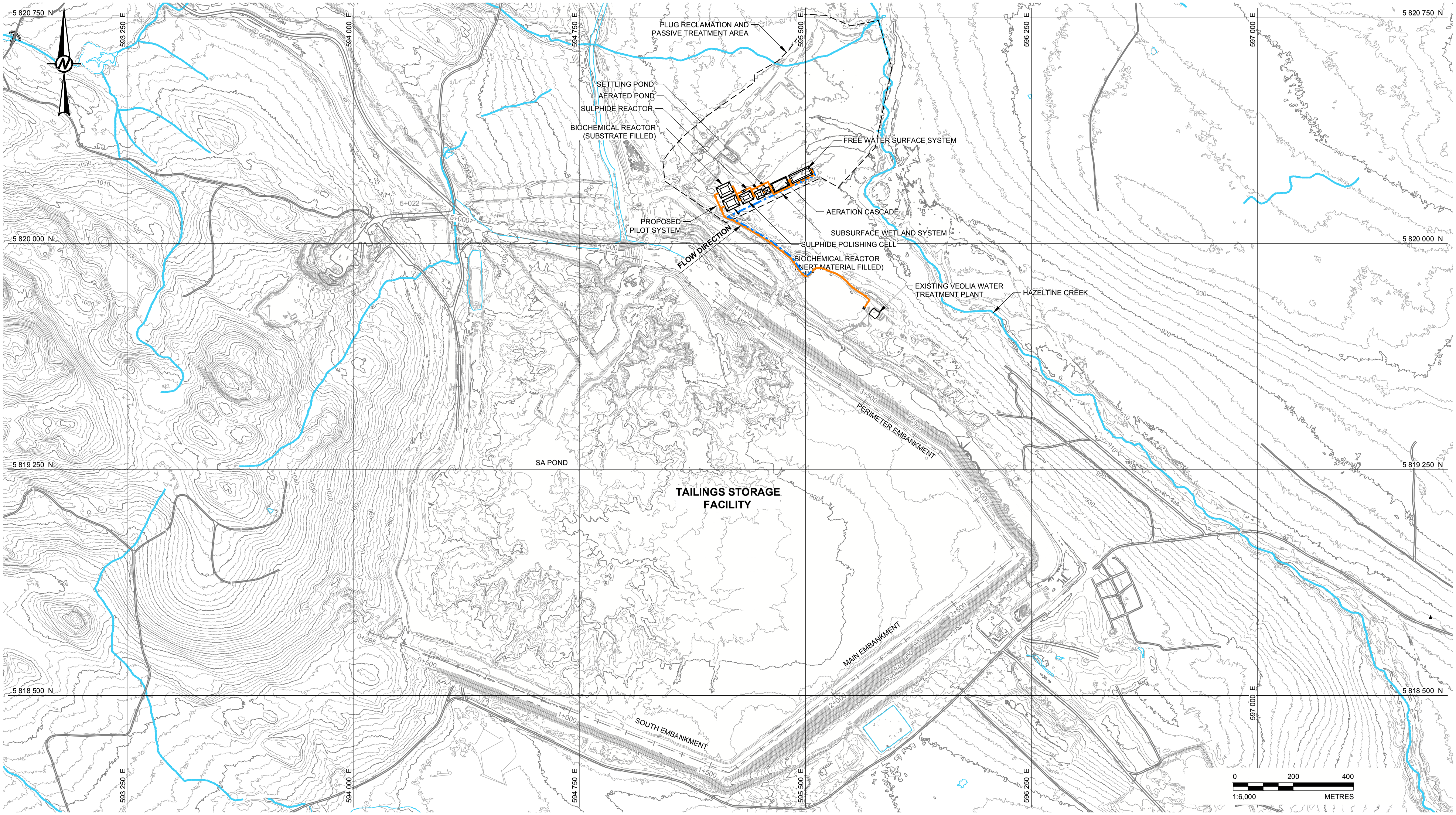
0 25 mm




**LEGEND**

4+400 — SETOUT LINE - S.O.L. - ORIGINAL ALIGNMENT (SEE REFERENCE 3)

**NOTES**

1. ALL UNITS IN METRES UNLESS OTHERWISE NOTED. ELEVATIONS ARE IN METRES RELATIVE TO TAILINGS GRID DATUM.
2. COORDINATES ARE SHOWN IN TAILINGS GRID.
3. CONTOUR INTERVAL 2 m MINOR AND 10 m MAJOR. CONTOURS OF THE MOUNT POLLEY MINE SITE (SEE REFERENCE 1) WERE COMBINED WITH THE UPDATED TAILINGS STORAGE FACILITY SURVEY (SEE REFERENCE 2).
4. FOR CLOSURE CELL SPECIFICATIONS AND DETAILS, REFER TO FIGURE 8.

**REFERENCES**


1. BASE TOPOGRAPHY PROVIDED BY MPMC, FILE NAME: "MtPolley_20140805_1m_LiDAR_Contour.dwg", RECEIVED: SEPTEMBER 3, 2014.
2. TOPOGRAPHY PROVIDED BY MPMC, FILE NAMES: "10cm contours full tailings.dxf" AND FILE: "10cm Hazeltine 3 Reprocessed.dxf", SURVEYED: MAY 27, 2015, RECEIVED: JUNE 11, 2015 AND FILE: "151015 ASBUILT SURFACE.msr", RECEIVED: OCTOBER 15, 2015.
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| YYYY-MM-DD | 2016-09-30 |
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| PREPARED | TAK |
| REVIEWED | TdSS/HC/LA |
| APPROVED | AB |

PROJECT
MOUNT POLLEY CLOSURE WATER TREATMENT SYSTEM

TITLE
**MOUNT POLLEY WATER TREATMENT SYSTEM**
**OPERATIONS & PILOT SYSTEM - OVERALL SITE PLAN**

| PROJECT NO. | PHASE/TASK/DOC. | REV. | FIGURE |
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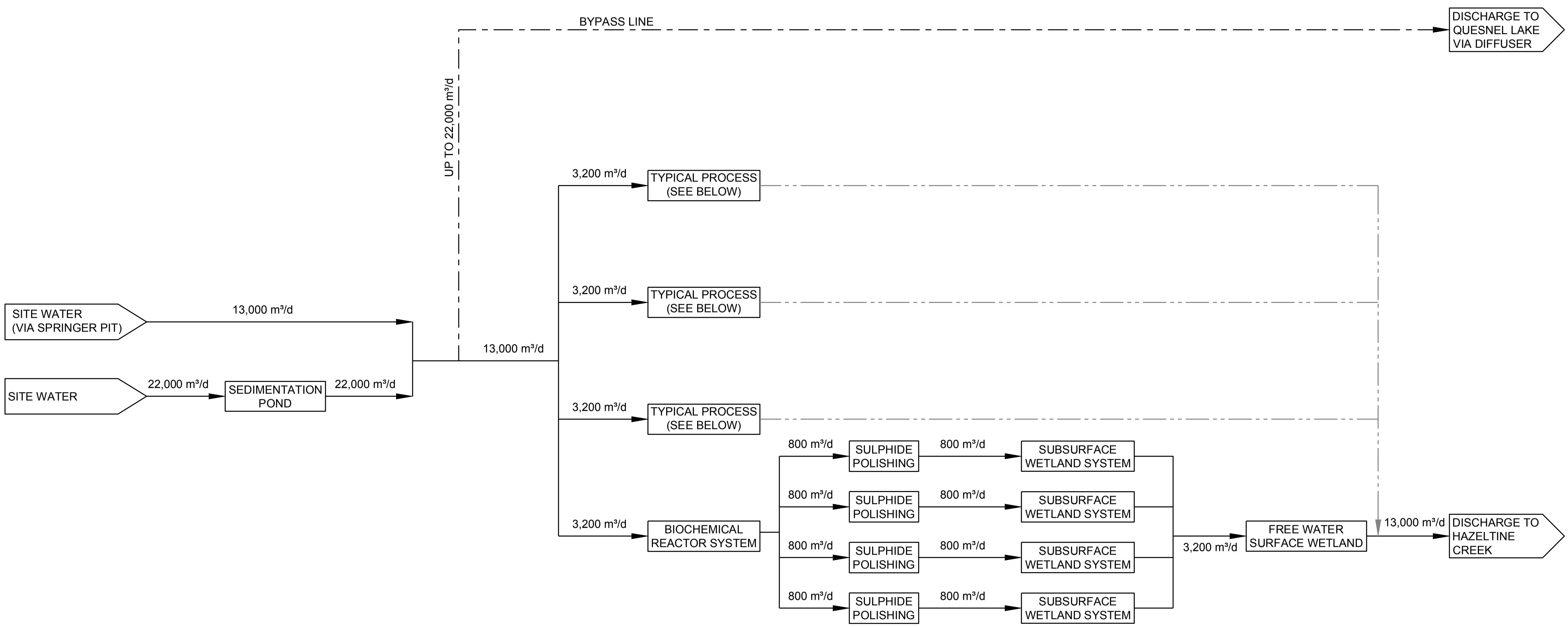
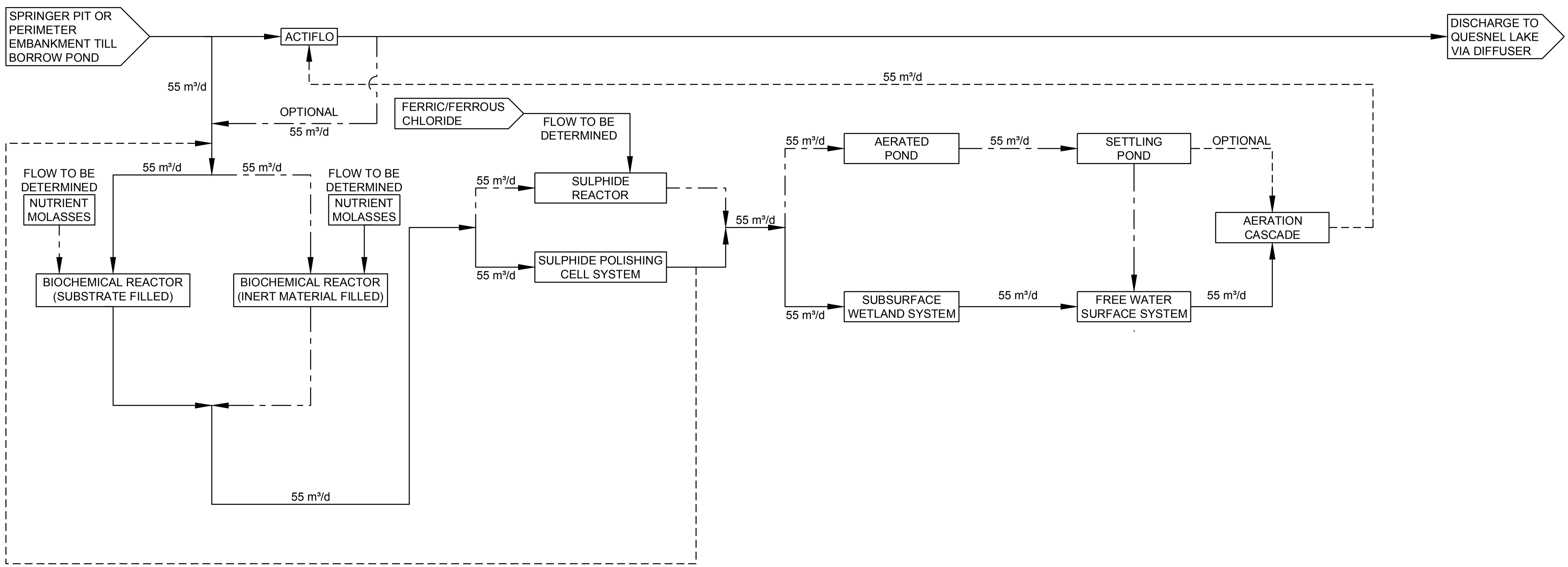



**LEGEND**

NORMAL FLOW PATH

OPTIONAL FLOW PATH

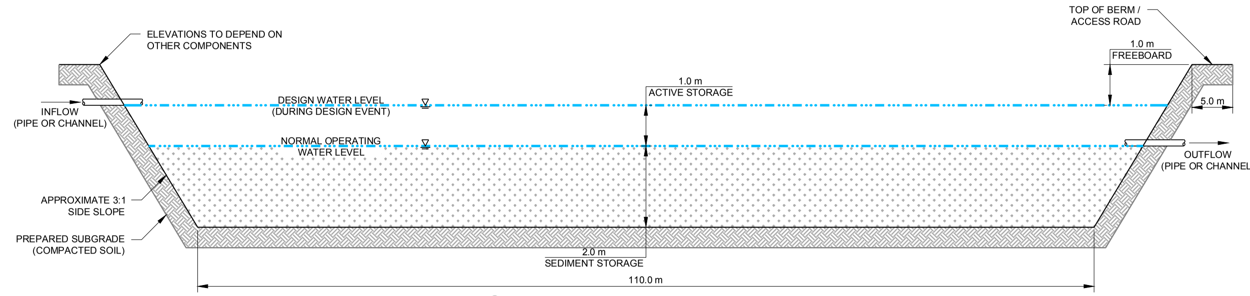
| | | | |
|---|---|---|---|
| CLIENT | MOUNT POLLEY MINING CORPORATION | PROJECT | MOUNT POLLEY CLOSURE WATER TREATMENT SYSTEM |
| CONSULTANT | Golder Associates | TITLE | **MOUNT POLLEY WATER TREATMENT SYSTEM CLOSURE - BLOCK FLOW DIAGRAM / CONCEPTUAL PASSIVE SYSTEM** |
| YYYY-MM-DD | 2016-09-30 | PROJECT NO. | 1411734 |
| DESIGNED | TdSS | PHASE/TASK/DOC. | 16000/3004/150 |
| PREPARED | MSH | REV. | 0 |
| REVIEWED | TdSS/HC/LA | FIGURE | 3 |
| APPROVED | AB | | |




**LEGEND**

- NORMAL FLOW PATH
- OPTIONAL FLOW PATH
- OPTIONAL RECIRCULATION LINE

| | | | |
|---|---|---|---|
| CLIENT | MOUNT POLLEY MINING CORPORATION | PROJECT | MOUNT POLLEY CLOSURE WATER TREATMENT SYSTEM |
| CONSULTANT | Golder Associates | TITLE | **MOUNT POLLEY WATER TREATMENT SYSTEM PILOT - BLOCK FLOW DIAGRAM** |
| YYYY-MM-DD | 2016-09-30 | | |
| DESIGNED | TdSS | | |
| PREPARED | MSH | | |
| REVIEWED | TdSS/HC/LA | PROJECT NO. 1411734 | PHASE/TASK/DOC. 16000/3004/150 |
| APPROVED | AB | REV. 0 | FIGURE 4 |

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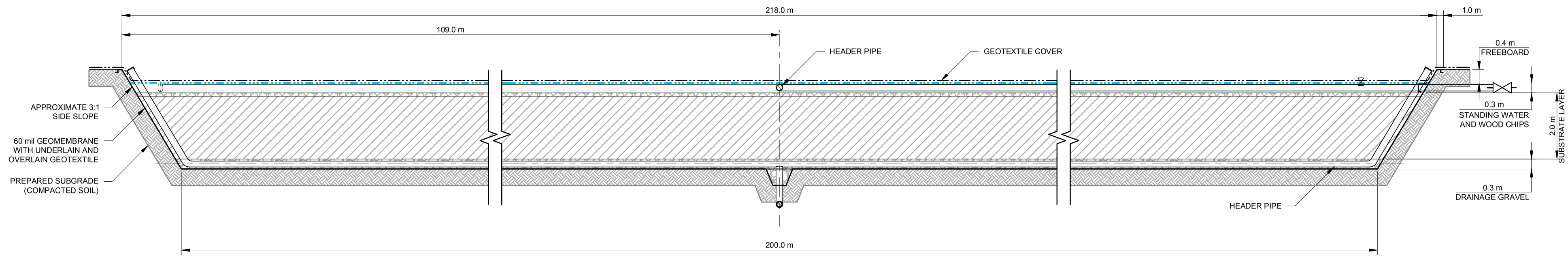


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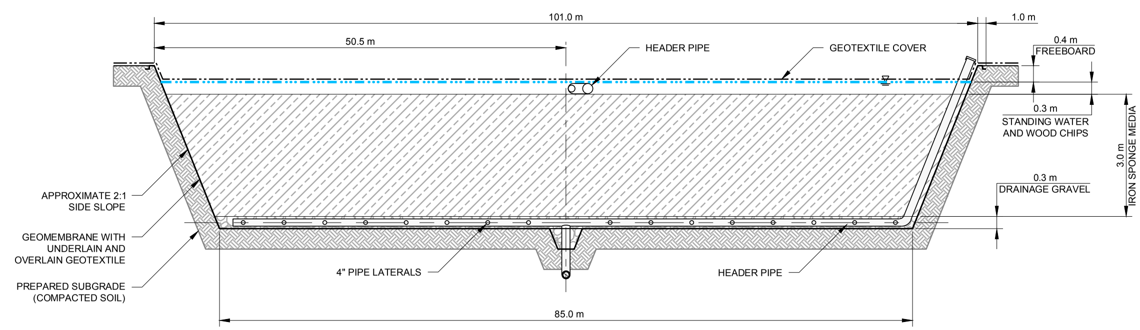


NOT TO SCALE (C) TYPICAL SECTION THROUGH SULPHIDE POLISHING CELL

**LEGEND**

- WATER LEVEL
- SUBSTRATE
- IRON SPONGE MEDIA
- SEDIMENT
- DRAINAGE GRAVEL
- PREPARED SUBGRADE

**NOTES**

1. ALL UNITS ARE IN METRES UNLESS OTHERWISE NOTED.
2. PIPES SHOWN FOR CLARITY ONLY, AND ARE NOT TO SCALE.
3. ALL SECTIONS CUT THROUGH LONGEST PORTION OF EACH CELL.

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|---|---|
| CLIENT | MOUNT POLLEY MINING CORPORATION |
| CONSULTANT | Golder Associates |
| YYYY-MM-DD | 2016-09-30 |
| DESIGNED | TdSS |
| PREPARED | TAK |
| REVIEWED | TdSS/HC/LA |
| APPROVED | AB |

PROJECT
MOUNT POLLEY CLOSURE WATER TREATMENT SYSTEM

TITLE
**MOUNT POLLEY WATER TREATMENT SYSTEM CLOSURE SECTIONS (1 OF 2)**

| PROJECT NO. | PHASE/TASK/DOC. | REV. | FIGURE |
|---|---|---|---|
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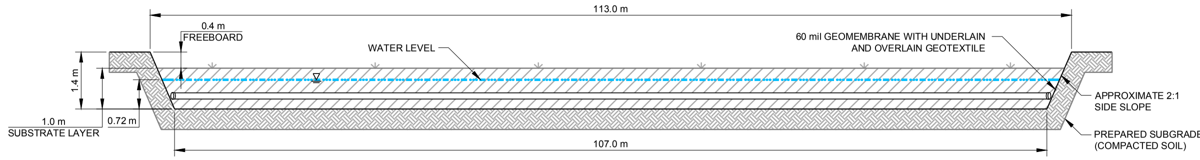


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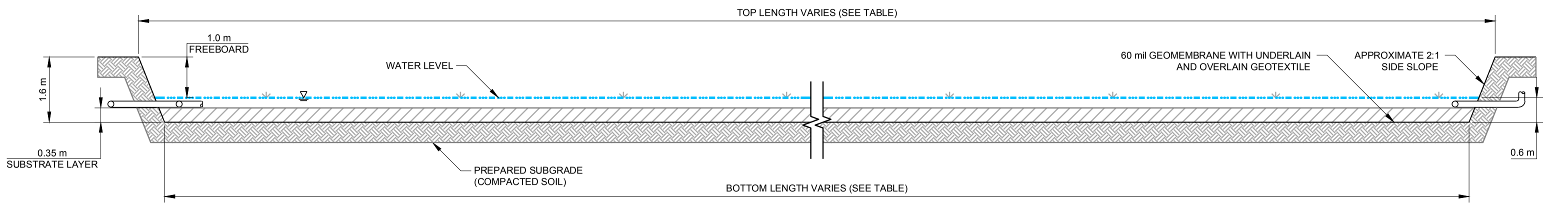


NOT TO SCALE E TYPICAL FREE WATER SURFACE CONSTRUCTED WETLAND SECTION

| CELL | TOP LENGTH (m) | BOTTOM LENGTH (m) |
|---|---|---|
| FWS 1 | 553 | 546 |
| FWS 2 | 553 | 546 |
| FWS 3 | 631 (AVG.) | 619 |
| FWS 4 | 679 (AVG.) | 673 |

**LEGEND**

WATER LEVEL

SUBSTRATE

PREPARED SUBGRADE

**NOTES**

1. ALL UNITS ARE IN METRES UNLESS OTHERWISE NOTED.
2. PIPES SHOWN FOR CLARITY ONLY, AND ARE NOT TO SCALE.
3. ALL SECTIONS CUT THROUGH LONGEST PORTION OF EACH CELL.

| | |
|---|---|
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| CONSULTANT | Golder Associates |
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| DESIGNED | TdSS |
| PREPARED | TAK |
| REVIEWED | TdSS/HC/LA |
| APPROVED | AB |
| PROJECT | MOUNT POLLEY CLOSURE WATER TREATMENT SYSTEM |
| TITLE | **MOUNT POLLEY WATER TREATMENT SYSTEM CLOSURE SECTIONS (2 OF 2)** |
| PROJECT NO. | 1411734 |
| PHASE/TASK/DOC. | 16000/3004/150 |
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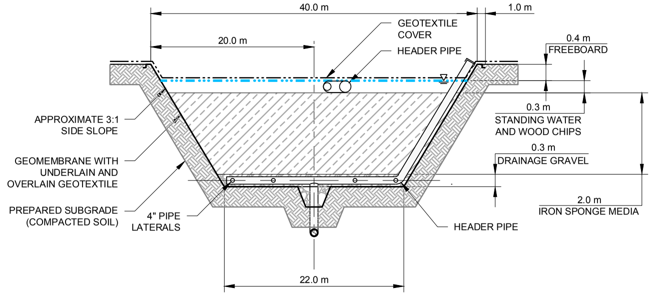
| FIGURE | 6 |

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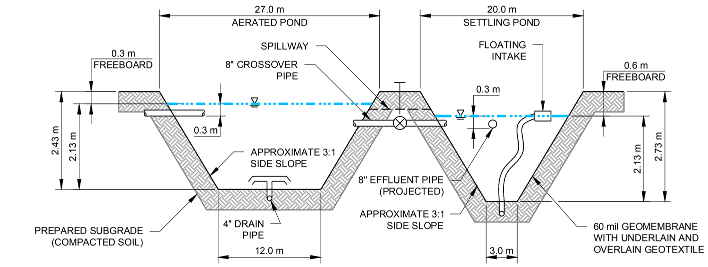
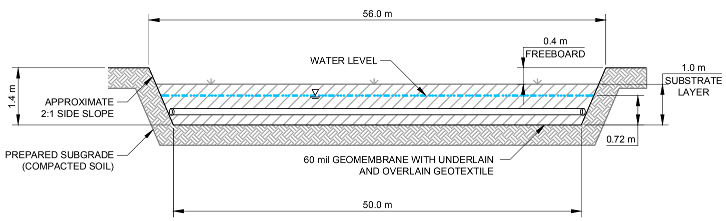



NOT TO SCALE G TYPICAL AERATED AND SETTLING POND SECTION

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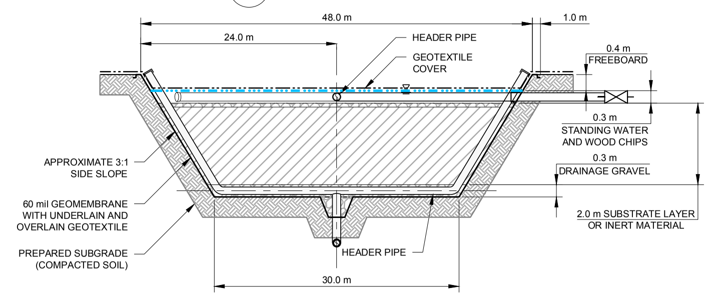


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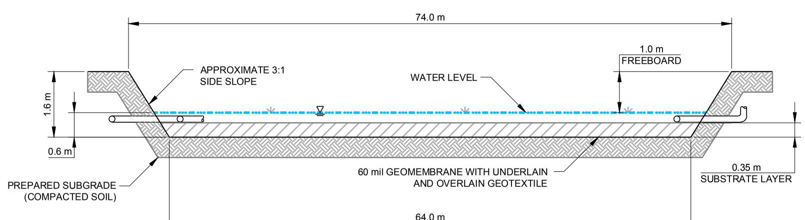
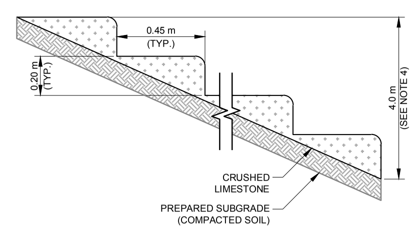



NOT TO SCALE J TYPICAL FREE WATER SURFACE CONSTRUCTED WETLAND SECTION




NOT TO SCALE K TYPICAL AERATION CASCADE SECTION

**LEGEND**

- WATER LEVEL
- SUBSTRATE
- IRON SPONGE MEDIA
- CRUSHED LIMESTONE
- DRAINAGE GRAVEL
- PREPARED SUBGRADE

**NOTES**

1. ALL UNITS ARE IN METRES UNLESS OTHERWISE NOTED.
2. PIPES SHOWN FOR CLARITY ONLY, AND ARE NOT TO SCALE.
3. ALL SECTIONS CUT THROUGH LONGEST PORTION OF EACH CELL.
4. AERATION CASCADE CONSISTS OF 20 STEPS.

| | |
|---|---|
| CLIENT | MOUNT POLLEY MINING CORPORATION |
| PROJECT | MOUNT POLLEY CLOSURE WATER TREATMENT SYSTEM |
| CONSULTANT | Golder Associates |
| YYYY-MM-DD | 2016-09-30 |
| DESIGNED | TdSS |
| PREPARED | TAK |
| REVIEWED | TdSS/HC/LA |
| APPROVED | AB |
| TITLE | **MOUNT POLLEY WATER TREATMENT SYSTEM PILOT SECTIONS** |
| PROJECT NO. | 1411734 |
| PHASE/TASK/DOC. | 16000/3004/150 |
| REV. | 0 |
| FIGURE | 7 |

# ATTACHMENT B

## Copper Target Derivation

# TECHNICAL MEMORANDUM

**DATE** 17 October 2016

**REFERENCE No.** 1411734-175-TM-Rev0-16000

**TO** Dale Reimer, General Manager
Mount Polley Mining Corporation

**CC** Elaine Irving and Jerry Vandenberg

**FROM** Kerrie Serben and Adrian de Bruyn

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**MOUNT POLLEY MINE – DEVELOPMENT OF A TREATMENT TARGET FOR COPPER IN HAZELTINE CREEK USING THE BIOTIC LIGAND MODEL**

Golder Associates Ltd. (Golder) is pleased to provide Mount Polley Mining Corporation (MPMC) with the following technical memorandum describing the approach adopted to develop a treatment target for copper in Hazeltine Creek in the vicinity of the Mount Polley Mine (the Mine). The following analysis is intended to support closure planning for the Mine. It is understood that development and approval of a permit limit for copper will require further consultation with British Columbia Ministry of Environment (MOE) prior to Closure. The purpose of the treatment target is to provide a receiving environment target for use in the conceptual design of a passive treatment system for Closure that may be piloted during the four-year Operations period. The treatment target is intended to be applicable to Closure and Post-closure conditions in which mine contact waters are returned to pre-development watersheds. These periods are nominally defined as beginning in July of 2020 and 2022, respectively, based on the current mine plan.

## 1.0 INTRODUCTION

Copper (Cu) can be toxic to aquatic life, but at low concentrations it is an essential nutrient for both aquatic plants and animals (US EPA 1985). In natural waters, copper occurs primarily as the divalent cupric ion ($Cu^{2+}$) in free and complexed forms. The cupric ion is the most readily available form of copper (Suedel et al. 1996) and is highly reactive, forming complexes and precipitates with organic and inorganic constituents and suspended solids in the water column (US EPA 1985). As a result, water quality characteristics can substantially affect the toxicity and bioavailability of copper to aquatic life. Generally, a decrease in copper toxicity is observed as water hardness increases because water hardness in natural waters is controlled by the presence of calcium and magnesium that compete with metal cations for binding sites on the gills of aquatic organisms (ICME 1995). For this reason, the 30-day BC Water Quality Guideline (BC WQG) for copper is hardness dependent (MOE 1987).

## 1.1 Approach to Develop Treatment Target

Setting the treatment target for copper by adopting the hardness-dependent BC WQG was not appropriate for Hazeltine Creek because copper concentrations in the creek were above this guideline prior to mine construction. At the pre-mine mean hardness level of 54 mg/L, the BC WQG for Hazeltine Creek is 2.16 µg/L total copper, whereas pre-mine mean copper concentrations reported by Minnow Environmental Inc. (Minnow 2014) were 2.5 µg/L dissolved copper and 3 µg/L total copper. In addition, the BC WQG does not consider exposure and toxicity modifying factors such as pH and dissolved organic carbon (DOC) that, in addition to hardness, have been shown to influence the binding, speciation, and biological availability of copper (US EPA 2007). A more comprehensive approach to evaluating copper bioavailability is the biotic ligand model (BLM), which currently serves as the basis for recommended site-specific freshwater criteria for copper in the United States. The BLM is considered by the US Environmental Protection Agency (US EPA) to utilize the best available science (US EPA 2007). Therefore, the BLM was used to set a treatment target for copper in Hazeltine Creek.

## 1.2 Biotic Ligand Model Overview

The BLM predicts copper toxicity by simulating copper accumulation at the "biotic ligand" that represents the site of toxic action in biota (HydroQual 2007a). BLM copper toxicity predictions have been shown to be consistent with measured values in published studies (US EPA 2007). The BLM uses receiving water characteristics to develop site-specific water quality criteria. A comparison of US EPA criteria in Figure 1 using the BLM and the hardness-based equation illustrates how both models characterize a similar effect of hardness at low DOC concentrations, but the BLM additionally accurately characterizes a decrease in the toxicity of copper when DOC is increased to 10 mg/L.

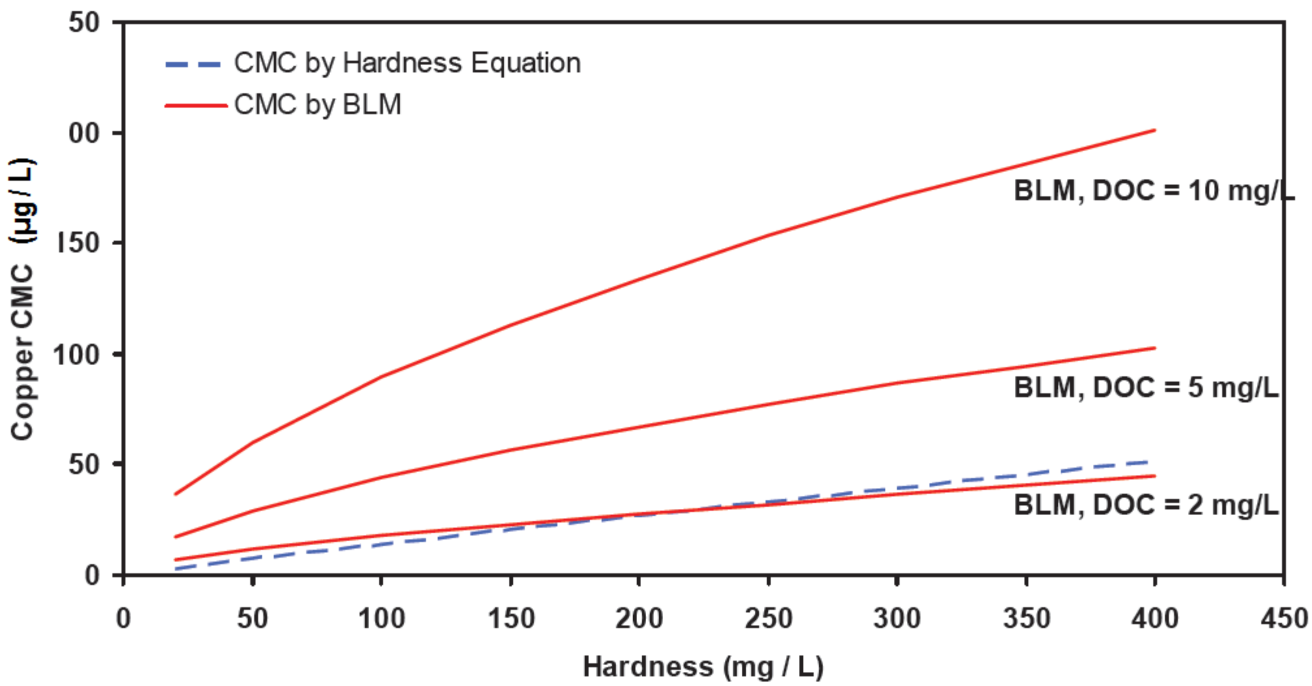


*Figure 1: US Environmental Protection Agency Criterion Maximum Concentration Calculated Using Hardness Equation and Biotic Ligand Model*

Source: US EPA 2007.

CMC = criterion maximum concentration; BLM = biotic ligand model; DOC = dissolved organic carbon.

Detailed information regarding the development of the BLM is provided in US EPA (2007); the following provides a brief summary. The toxicity database for the BLM was derived using acute medial lethal concentration ($LC_{50}$) data from approximately 350 tests that included 15 species of invertebrates, 22 species of fish, and 1 species of amphibian, and represented 27 different genera (US EPA 2007). These $LC_{50}$ values were generated using various exposure conditions and thus were normalized to a reference exposure condition, specifically moderately hard reconstituted water[1]. Species mean acute values were calculated, then grouped by genus to calculate genus mean acute values. The 5$^{th}$ percentile of genus mean acute values was used as the final acute value. This final acute value was divided by a factor of two to derive the dissolved copper criterion maximum concentration (CMC), which is defined by US EPA as "*an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect*" (US EPA 2016).

To derive a chronic criterion, the final acute value is divided by a final acute to chronic ratio (ACR) to derive the final chronic value, which is then used as the chronic criterion concentration (CCC). The final ACR for copper is 3.22, calculated as the geometric mean of the ACRs for sensitive freshwater species, daphnids (i.e., *Ceriodaphnia dubia*, *Daphnia magna*, *D. pulex)*, chinook salmon (*Oncorhynchus tshawytscha)*, and rainbow trout (*O. mykiss),* along with the one saltwater species ACR for sheepshead minnow (*Cyprinodon variegatus)* (US EPA 2007). The CCC is defined by US EPA as "*an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.*"

The BLM derives a CCC for dissolved copper and to convert to total copper a conversion factor of 1.04 is used per US EPA guidance (US EPA 2016).

# 2.0 METHODS

## 2.1 Biotic Ligand Model Input Requirements

The BLM Windows user interface, Version 2.2.3 (HydroQual 2007b) was used to derive the treatment target for copper. The water quality parameters necessary to run the BLM are:

- physical parameters (water temperature and pH)
- DOC and proportion of humic acid
- major cations (calcium, magnesium, sodium, and potassium)
- major anions (sulphate and chloride)
- alkalinity
- sulphide

[1] Moderately hard reconstituted water was defined as water temperature = 20°C, pH 7.5, DOC = 0.5 mg/L, calcium = 14 mg/L, magnesium = 12 mg/L, sodium = 26.3 mg/L, potassium = 2.1 mg/L, sulphate = 81.4 mg/L, chloride = 1.90 mg/L, alkalinity = 65.0 mg/L, and sulphide = 0.0003 mg/L.

Hardness is calculated in the model from calcium and magnesium concentrations. In general, the proportion of humic acid is not measured in water quality assessments; this is recognized by US EPA (2007) and is not considered a deterrent to running the BLM. As recommended by the BLM user guide (HydroQual 2007a), the humic acid proportion of DOC was assumed to be 10%. Sulphide is listed as an optional input parameter, but currently does not affect the BLM as research is needed to better characterize metal-sulphide interactions. Metal-sulphide interactions can occur, and will likely be incorporated into the BLM's equilibrium in the future (Grosell 2012; HydroQual 2007a). The sulphide concentration was assumed to be $1\times10^{-10}$, based on the BLM user guide's recommendation (HydroQual 2007a).

The copper BLM was developed and calibrated under a range of water quality parameters, which reflect conditions in the toxicity tests selected to support BLM development. However, US EPA (2015) does note that the BLM can be used when input parameter concentrations fall outside of the calibration ranges. For the treatment target development study presented here, some input parameters and temperature, in particular, had measured values that fell outside of the calibration ranges. In these cases, the BLM was run with the original measured value as well as with the upper or lower bound of the calibration range for that parameter.

## 2.2 Receiving Environment Chemistry Inputs

For the purposes of this treatment target development study, it was assumed that existing water chemistry would provide an appropriate representation of water quality in Hazeltine Creek during Closure; this is considered conservative, as copper concentrations in Hazeltine Creek water are anticipated to decrease as a result of ongoing rehabilitation works. Ongoing monitoring during the next four years of mine operations will verify this. For comparison purposes, the BLM was also run using pre-mine water quality data for Hazeltine Creek.

Summaries of datasets used in the model runs are provided below.

### 2.2.1 Hazeltine Creek Pre-mine Conditions

Hazeltine Creek pre-mine baseline conditions were characterized by water quality data collected prior to the initiation of mining operations (i.e., from 1990 to 1996). Mean values for relevant input parameters were obtained from the aquatic environment description report issued by Minnow (2014) and used for the BLM (Attachment 1, Table 1).

### 2.2.2 Hazeltine Creek Existing Conditions

Existing conditions in Hazeltine Creek were characterized using water samples collected after channel reconstruction and the stabilization of water quality conditions following the August 2014 tailings dam failure (June and November 2015—all monitoring stations in upper and lower Hazeltine Creek) as well as samples collected between December 2015 and April 2016 upstream of the treated effluent discharge. A total of 56 water chemistry samples were collected during this time period, of which 54 samples had measured values for all BLM-required input parameters. Water chemistry results of individual samples were included in the model run (Attachment 1, Table 2).

## 3.0 RESULTS

Measured values for water temperature were often lower than the lower bound of the calibration range, particularly during the late fall or early spring sampling events. However, adjusting water temperature to the lower bound of the calibration range either did not change or slightly increased the resulting CCC. Therefore, using CCCs derived with measured temperatures resulted in a lower (more conservative) treatment target.

In a few cases in the Hazeltine Creek existing conditions dataset, measured calcium and sulphate concentrations were slightly higher than the upper bound of their calibration ranges. Adjusting these input parameters to the upper bound of the calibration range had little or no effect on the resulting CCC.

Detailed summaries of the BLM outputs for each dataset are provided below.

### 3.1 Hazeltine Creek Pre-mine Conditions

Using mean measured concentrations of input parameters, the total copper CCC generated by the BLM under pre-mine conditions was 32 µg/L (Table 1).

**Table 1: Predictions of the Copper Biotic Ligand Model for Hazeltine Creek Pre-mine Conditions**

| Dataset | Final Acute Value (µg/L) | Criterion Maximum Concentration for Dissolved Copper (µg/L) | Criterion Continuous Concentration for Dissolved Copper (µg/L) | Criterion Continuous Concentration for Total Copper (µg/L) |
|---|---|---|---|---|
| Mean – 1990 to 1996 | 99 | 50 | 31 | 32 |

The dataset for pre-mine conditions summarized by Minnow (2014) is limited, which consequently constrained the usefulness of the BLM approach using this dataset. Minnow (2014) provided mean, median, and 95$^{th}$ percentile values for most of the required input parameters (with the exception of water temperature and chloride); however, there were only 19 samples for pH, alkalinity, and sulphate; 12 samples for calcium, magnesium, potassium, and sodium; and six samples for DOC.

- Pre-mine mean water temperature was not provided in Minnow 2014 and was assumed to be 7.1°C, which was the mean temperature measured in Hazeltine Creek pre-breach (2011 to 2014).
- Pre-mine chloride concentrations were not included in the summarized dataset (Minnow 2014), and were assumed to be non-detect (at a detection limit of 0.5 mg/L) for the BLM run. This assumption is conservative because lower chloride concentrations would yield a lower CCC.

Because of the limited dataset for pre-mine conditions, the copper treatment target for Hazeltine Creek was selected based on existing conditions (Section 3.2).

## 3.2 Hazeltine Creek Existing Conditions

Total copper CCCs calculated for the 54 individual samples with sufficient water quality data ranged from 14 to 73 µg/L, with an overall mean of 31 µg/L (Table 2). The highest CCCs were associated with samples collected in June–July 2015 and March–April 2016 (Figure 2), in samples having the highest DOC within the dataset (greater than or equal to 11 mg/L; March–April 2016) or samples having high pH (greater than or equal to 8.4) co-occurring with DOC greater than or equal to 6.5 mg/L (June–July 2016) (Attachment 1, Table 2). However, lower DOC and lower pH were observed in other samples collected around the same time, and these concentrations were not considered to be indicative of a seasonal trend. The majority of CCCs were between 20 and 30 µg/L (Figure 2), with the 5$^{th}$ and 10$^{th}$ percentile equal to 19 µg/L and 20 µg/L, respectively (Table 2).

**Table 2: Predictions of the Copper Biotic Ligand Model for Hazeltine Creek Existing Conditions**

| Dataset | Final Acute Value (µg/L) | Criterion Maximum Concentration for Dissolved Copper (µg/L) | Criterion Continuous Concentration for Dissolved Copper (µg/L) | Criterion Continuous Concentration for Total Copper (µg/L) |
|---|---|---|---|---|
| Range of results | 42–226 | 21–113 | 13–70 | 14–73 |
| Mean of results | 97 | 49 | 30 | 31 |
| 5$^{th}$ percentile of results | 58 | 29 | 18 | 19 |
| 10$^{th}$ percentile of results | 61 | 31 | 19 | 20 |

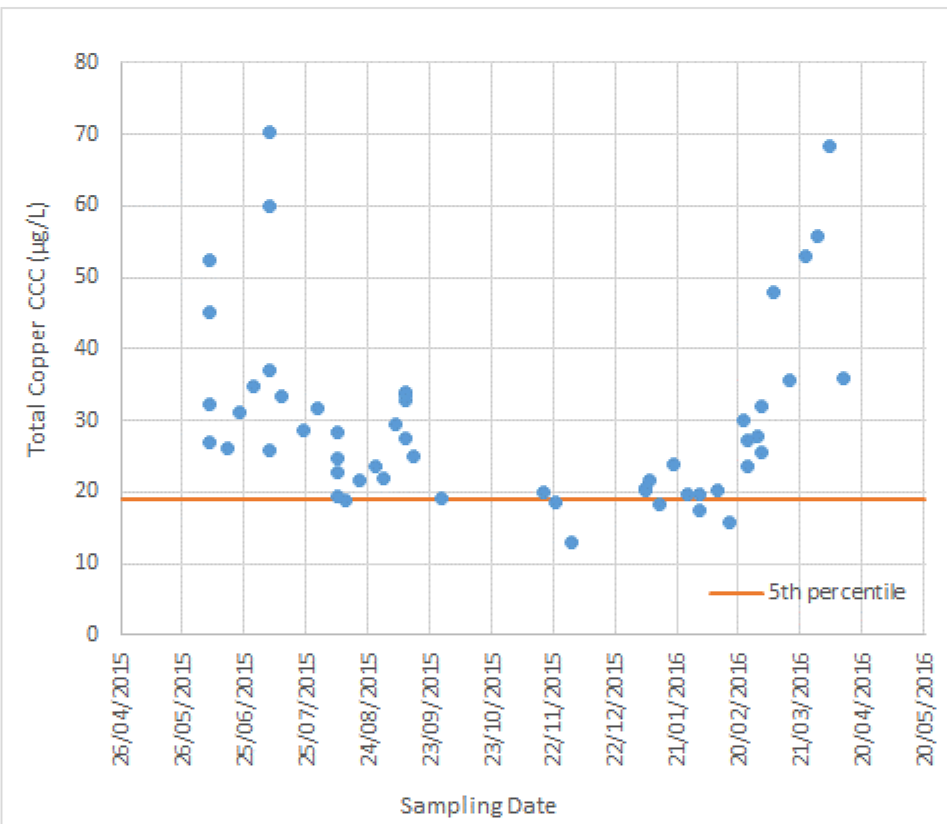


*Figure 2: Temporal Distribution of Total Copper Criterion Continuous Concentrations for Individual Samples from Hazeltine Creek under Existing Conditions*

CCC = criterion continuous concentration.

The 5th percentile of 19 µg/L total copper was selected as the treatment target for Hazeltine Creek, which is consistent with the guidance given by US EPA (2015) for selecting a single numeric site-specific criterion from multiple BLM-derived instantaneous criteria. The use of the 5th percentile suggests that 5% of the time the water quality conditions in Hazeltine Creek may yield a scenario whereby copper is more bioavailable, and the instantaneous CCC may be lower than the treatment target. However, this scenario is expected to occur infrequently (less than or equal to 5% of the time). In addition, the proposed treatment target is lower than the lowest CMC derived using the existing conditions dataset (i.e., 21 µg/L; Table 2). The CMC represents a concentration that aquatic life in Hazeltine Creek could be exposed to briefly without resulting in an unacceptable effect. Therefore, the proposed treatment target is expected to be protective under short-term and long-term exposure conditions.

The proposed treatment target is further supported by an analysis previous reported in MPMC (2009). A site-specific water quality objective (SSWQO) for copper in Hazeltine Creek was developed using the water effects ratio (WER) approach. Toxicity tests in Hazeltine Creek water and laboratory water indicated WERs ranging from 2.5 to 28.8 for the site, which resulted in a calculated SSWQO value of 14 µg/L for low-DOC conditions. Under conditions of higher hardness, calculated SSWQO values ranged from 18 to 33 µg/L. Thus, similar estimates of protective copper concentrations were derived using the experimental approach described in MPMC (2009) and the BLM calculation used herein.

### 3.3 Summary

The use of the BLM approach for Hazeltine Creek pre-mine conditions was limited due to the available water quality data. However, the total copper CCC based on mean values for pre-mine conditions (32 µg/L) was similar to the mean CCC for existing conditions (31 µg/L), which suggests that general water quality conditions in Hazeltine Creek pre-mine and existing conditions may have been relatively similar, and setting the treatment target for Hazeltine Creek using existing conditions is defensible. In addition, the proposed treatment target was selected as a lower bound estimate of the available CCC generated using individual samples from the existing conditions dataset, which yields a more conservative target than if the mean pre-mine conditions were used.

Both CCCs are higher than the hardness-dependent BC WQG because the BLM considered the influence of other exposure and toxicity modifying factors, including pH and DOC, on copper bioavailability. The similarity between the two CCCs is due to the relative influence of pH and DOC. For pre-mine conditions, mean pH was slightly alkaline (i.e., pH 7.5) and mean DOC concentration was relatively high (i.e., 14 mg/L; Attachment 1, Table 1). Existing conditions in Hazeltine Creek are characterized by a more alkaline pH (i.e., mean = pH 8.0), but lower DOC concentrations (i.e., mean = 6.5 mg/L; Attachment 1, Table 2). The relative importance of DOC and pH in the BLM is further illustrated in the sensitivity analysis (Section 4.0).

## 4.0 MODEL SENSITIVITY

Trials using the BLM were run to determine sensitivity of the model to changes of the individual inputs. Mean concentrations in the Hazeltine Creek existing conditions dataset were assumed (Attachment 1, Table 2), then each individual parameter was increased 25%, while holding the remaining parameters constant. As pH is based on a log scale, it was tested at pH 7.4 and 8.7 (i.e., minimum and maximum measured values) to simulate realistic variations in pH. The resulting CCCs were reported as a percentage of the original (Table 3).

With the exception of pH and DOC, a 25% change in any parameter did not change the CCC by more than 6% (Table 3). An increase in pH from 8.0 to 8.7 resulted in CCC for copper that was 63% higher, whereas decreasing pH to 7.4 reduced the CCC by 47%. Increasing DOC by 25% caused the CCC to increase by 25% (Table 3). Based on these results, the BLM used to derive the treatment target is most sensitive to changes in pH and DOC.

**Table 3: Sensitivity of the Biotic Ligand Model to 25% Increases in Individual Parameters with Other Parameters Unchanged**

| Parameter | Original Concentration[a] | Increased 25% | Original CCC (µg/L)[a] | CCC After 25% Increase in Parameters (µg/L) | % Change |
|---|---|---|---|---|---|
| Water temperature (°C) | 7.7 | 9.625 | 27.1 | 27.5 | 1.8% |
| pH[b] | 8.0 | 7.4 | 27.1 | 14.5 | -46.5% |
| pH[b] | 8.0 | 8.7 | 27.1 | 44.1 | 62.9% |
| Humic acid (%) | 10 | 12.5 | 27.1 | 28.7 | 5.9% |
| Dissolved organic carbon (mg/L) | 6.5 | 8.125 | 27.1 | 33.8 | 25.0% |
| Calcium (mg/L) | 55 | 68.75 | 27.1 | 28.0 | 3.4% |
| Magnesium (mg/L) | 9.0 | 11.25 | 27.1 | 27.4 | 1.4% |
| Potassium (mg/L) | 1.6 | 2.0 | 27.1 | 27.1 | 0.2% |
| Sodium (mg/L) | 12 | 15 | 27.1 | 27.1 | 0.0% |
| Sulphate (mg/L) | 67 | 83.75 | 27.1 | 26.8 | -0.8% |
| Chloride (mg/L) | 1.6 | 2.0 | 27.1 | 27.1 | 0.0% |
| Alkalinity (mg/L) | 123 | 153.75 | 27.1 | 27.0 | -0.2% |
| Sulphide (mg/L) | - | - | - | - | - |

a) The original parameter concentrations and CCC presented are for mean concentrations in Hazeltine Creek under existing conditions.

b) pH was tested at pH 7.4 and 8.7, which corresponds to minimum and maximum measured values.

BLM = biotic ligand model; CCC = criterion continuous concentration; – = sensitivity analysis was not conducted for sulphide because this parameter is not currently considered in the model.

## 5.0 UNCERTAINTY

As with all models, the BLM has limitations based on its assumptions and data inputs. Model limitations were mainly related to uncertainty associated with measured water quality used as inputs and that not all potential BLM parameters were measured or predicted (e.g., humic acid and sulphide were not incorporated). Specific uncertainties associated with the use of the BLM to derive a treatment target for Hazeltine Creek at Closure are assessed in Table 4. The assessment concluded that the identified uncertainties had low influence on the interpretation or use of the BLM results for the purpose of deriving a treatment target. The predictive ability of the BLM and conservative assumptions incorporated are expected to offset the uncertainties in parameterization, such that the BLM model as implemented is expected to be more accurate than through the use of hardness alone.

**Table 4: Uncertainties Associated with the Copper Biotic Ligand Model Approach to Derive a Treatment Target for Hazeltine Creek at Closure**

| Uncertainty Source / Assumption | Influence on the Interpretation or Use of the BLM Results |
|---|---|
| Some measured values of input parameters were outside the calibration range | **Low**—US EPA (2015) states that "*The BLM can be used when the parameters, particularly temperature, fall outside these ranges, as these ranges reflect data available at time of model calibration.*" The analysis described in Section 3.0 indicated that when this occurred, conservatism in the treatment target selection increased. |
| Use of existing conditions to define future conditions | **Low**—Using existing condition model inputs could lead to lower or higher copper BLM-derived treatment targets if future concentrations vary substantially from this condition.<br>■ Increased DOC concentrations would mitigate copper toxicity (Grosell 2012) and result in a higher BLM-derived treatment targets for copper.<br>■ Increased pH would also mitigate copper toxicity, but a decrease in pH would exacerbate copper toxicity.<br>■ Geochemical testing at the Mine indicates that long-term changes in pH in mine waters is not likely.<br><br>The reasonableness of the input parameters used in this assessment will be assessed over time through ongoing water quality monitoring in Hazeltine Creek during operations. The BLM can be used to update the proposed BLM-derived treatment target as required; however, the selection of treatment targets based on lower bound estimate of the distribution of CCCs derived using individual samples is a conservative approach that accounts for this uncertainty. |

BLM = biotic ligand model; CCC = criterion continuous concentration; DOC = dissolved organic carbon.

## 6.0 CONCLUSION

Based on the BLM approach and using existing conditions, the proposed treatment target for total copper in Hazeltine Creek is 19 µg/L (Table 5). As defined by the US EPA, the CCC represents a concentration that aquatic life in Hazeltine Creek could be exposed to indefinitely without resulting in an unacceptable effect. Therefore, setting the treatment target as the 5$^{th}$ percentile of the distribution of CCC provides an appropriate level of protection for aquatic life in Hazeltine Creek.

**Table 5: Summary of Treatment Targets for Hazeltine Creek**

| Receiving Environment | Input Data Description | Dissolved Copper (µg/L) | Total Copper (µg/L) | Notes |
|---|---|---|---|---|
| Hazeltine Creek | Individual samples (Jun–Nov 2015, upstream of discharge Dec–April 2016), 54 samples | 18 | 19 | Based on 5th percentile of the distribution of CCC for total copper |

CCC = criterion continuous concentration.

## 7.0 CLOSURE

The reader is referred to the Study Limitations, which follows the text and forms an integral part of this memorandum.

We trust that the information provided in this technical memorandum is sufficient for your present needs. If you have any questions, please do not hesitate to contact the undersigned at (306) 667-1531.

**GOLDER ASSOCIATES LTD.**

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KCS/EC/EI/ADB/cf/pn/kp

Attachments: Study Limitations
Attachment 1: Water Quality Input Concentrations

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## STUDY LIMITATIONS

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# ATTACHMENT 1
## Water Quality Input Concentrations

**Table 1: Water Quality Input Concentrations for Hazeltine Creek Pre-Mine Conditions**

| Station | Sampling Date | Water Temperature (°C) | pH | DOC (mg/L) | Humic Acid (%) [a] | Calcium (mg/L) | Magnesium (mg/L) | Potassium (mg/L) | Sodium (mg/L) | Sulphate (mg/L) | Chloride (mg/L) | Alkalinity (mg/L) | Sulphide (mg/L) [a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean (Minnow 2014) | 1990 to 1996 | 7.1 [b] | 7.5 | 14 | 10 | 17 | 3 | 0.44 | 3.2 | 3 | 0.5 [c] | 63 | $1 \times 10^{-10}$ |

Notes: Red values = values outside of the BLM calibration range. The BLM was run with the original measured value as well as the upper or lower bound of the calibration range, as appropriate.

a) Humic acid and sulphide concentrations were assumed per the BLM user guide (HydroQual 2007a).

b) Temperature not reported; assumed 7.1°C, which was the mean temperature measured in Hazeltine Creek pre-breach (2011 to 2014). Because 7.1°C is less than the lower bound of the calibration range, the BLM was also run with at the lower bound calibration range for temperature (i.e., 10°C).

c) Chloride not reported; assumed non-detected at a detection limit of 0.5 mg/L.

DOC = dissolved organic carbon; BLM = biotic ligand model.

**Table 2: Water Quality Input Concentrations for Hazeltine Creek Existing Conditions**

| Station | Sampling Date | Water Temperature (°C) [a] | pH | DOC (mg/L) | Humic Acid (%) [b] | Calcium (mg/L) [c] | Magnesium (mg/L) | Potassium (mg/L) | Sodium (mg/L) | Sulphate (mg/L) [d] | Chloride (mg/L) | Alkalinity (mg/L) | Sulphide (mg/L) [b] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean of all available samples | Jun to Nov 2015 and upstream of discharge Dec 2015 to Apr 2016 | 7.7 | 8.0 | 6.5 | 10 | 55 | 9.0 | 1.6 | 12 | 67 | 1.6 | 123 | $1 \times 10^{-10}$ |
| HAC-01b | 06/09/2015 | 18.0 | 8.064 | 6.18 | 10 | 48.3 | 8.3 | 1.41 | 11.2 | 49.2 | 1.39 | 128 | $1 \times 10^{-10}$ |
| HAC-01b | 16/06/2015 | 18.1 | 8.091 | 5.22 | 10 | 51.8 | 9.76 | 1.68 | 11.4 | 49.4 | 1.4 | 141 | $1 \times 10^{-10}$ |
| HAC-01b | 22/06/2015 | 18.8 | 8.093 | 6.11 | 10 | 55.8 | 9.85 | 1.55 | 11.2 | 54.4 | 1.47 | 132 | $1 \times 10^{-10}$ |
| HAC-01b | 29/06/2015 | 22.1 | 8.137 | 6.07 | 10 | 56.6 | 10.6 | 1.83 | 12.1 | 53.6 | 1.47 | 148 | $1 \times 10^{-10}$ |
| HAC-01b | 07/07/2015 | 18.7 | 7.998 | 5.74 | 10 | 47.6 | 8.53 | 1.76 | 11.3 | 49.3 | 1.37 | 130 | $1 \times 10^{-10}$ |
| HAC-05 | 07/07/2015 | 23.4 | 8.633 | 6.66 | 10 | 42.9 | 6.39 | 1.53 | 9.94 | 47 | 1.32 | 104 | $1 \times 10^{-10}$ |
| HAC-08 | 07/07/2015 | 21.6 | 8.262 | 6.03 | 10 | 45.2 | 7.38 | 1.67 | 10.6 | 49.3 | 1.35 | 114 | $1 \times 10^{-10}$ |
| HAC-10 | 07/07/2015 | 23.1 | 8.698 | 7.51 | 10 | 42.3 | 5.95 | 1.42 | 9.35 | 46.9 | 1.29 | 101 | $1 \times 10^{-10}$ |
| HAC-01b | 13/07/2015 | 19.6 | 8.164 | 6.23 | 10 | 46.2 | 7.9 | 1.52 | 10.4 | 50 | 1.37 | 118 | $1 \times 10^{-10}$ |
| HAC-01b | 23/07/2015 | 17.1 | 8.14 | 5.68 | 10 | 47.9 | 8.11 | 1.45 | 11 | 47 | 1.35 | 118 | $1 \times 10^{-10}$ |
| HAC-01c | 30/07/2015 | 18.4 | 8.114 | 6.28 | 10 | 49.8 | 8.35 | 1.5 | 10.6 | 48.8 | 1.41 | 124 | $1 \times 10^{-10}$ |
| HAC-01c | 08/06/2015 | 17.4 | 8.124 | 5.39 | 10 | 47.4 | 8.16 | 1.7 | 11.3 | 47.6 | 1.34 | 129 | $1 \times 10^{-10}$ |
| HAC-05 | 08/06/2015 | 18.9 | 8.655 | 6.46 | 10 | 44.6 | 6.17 | 1.49 | 10.1 | 45.7 | 1.33 | 110 | $1 \times 10^{-10}$ |
| HAC-08 | 08/06/2015 | 17.2 | 8.284 | 5.6 | 10 | 47.3 | 7.6 | 1.68 | 11.3 | 49.6 | 1.34 | 122 | $1 \times 10^{-10}$ |
| HAC-10 | 08/06/2015 | 20.1 | 8.437 | 6.58 | 10 | 41.3 | 5.61 | 1.5 | 9.79 | 47.1 | 1.27 | 98 | $1 \times 10^{-10}$ |
| HAC-01c | 13/08/2015 | 19.2 | 7.87 | 4.73 | 10 | 49.3 | 9.18 | 1.65 | 11.4 | 48 | 1.48 | 135 | $1 \times 10^{-10}$ |
| HAC-01c | 20/08/2015 | 15.4 | 8.117 | 4.35 | 10 | 53 | 10.3 | 1.59 | 11.9 | 47.7 | 1.44 | 156 | $1 \times 10^{-10}$ |
| HAC-01c | 27/08/2015 | 18.8 | 8.161 | 4.16 | 10 | 59.3 | 12 | 1.68 | 12.9 | 49.4 | 1.6 | 160 | $1 \times 10^{-10}$ |
| HAC-01c | 31/08/2015 | 17.5 | 8.082 | 4.27 | 10 | 59 | 12.9 | 1.75 | 13.9 | 49.9 | 1.51 | 167 | $1 \times 10^{-10}$ |
| HAC-01c | 09/08/2015 | 12.7 | 8.17 | 4.45 | 10 | 57.7 | 12.6 | 1.62 | 13.4 | 50.3 | 1.47 | 170 | $1 \times 10^{-10}$ |
| HAC-05 | 09/08/2015 | 11.5 | 8.15 | 5.81 | 10 | 57.2 | 10.7 | 1.48 | 12.1 | 42.6 | 1.75 | 157 | $1 \times 10^{-10}$ |
| HAC-08a | 09/08/2015 | 11.7 | 8.31 | 4.37 | 10 | 59.7 | 13.2 | 1.65 | 15.9 | 58.8 | 1.45 | 164 | $1 \times 10^{-10}$ |
| HAC-10 | 09/08/2015 | 13.8 | 7.62 | 7.09 | 10 | 44.8 | 6.09 | 1.41 | 9.97 | 48.3 | 1.36 | 99.1 | $1 \times 10^{-10}$ |
| HAC-01c | 15/09/2015 | 10.6 | 8.367 | 4.3 | 10 | 60.1 | 13 | 1.7 | 14.3 | 55.6 | 1.59 | 175 | $1 \times 10^{-10}$ |
| HAC-01c | 28/09/2015 | 8.6 | 8.06 | 4.31 | 10 | 62.8 | 13.6 | 1.62 | 14.8 | 62.4 | 1.6 | 170 | $1 \times 10^{-10}$ |

| Station | Sampling Date | Water Temperature (°C) [(a)] | pH | DOC (mg/L) | Humic Acid (%) [(b)] | Calcium (mg/L) [(c)] | Magnesium (mg/L) | Potassium (mg/L) | Sodium (mg/L) | Sulphate (mg/L) [(d)] | Chloride (mg/L) | Alkalinity (mg/L) | Sulphide (mg/L) [(b)] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HAC-05a | 11/09/2015 | 4.8 | 8.346 | 6.82 | 10 | 53.5 | 8.17 | 1.58 | 10.9 | 62.2 | 1.68 | 124 | $1 \times 10^{-10}$ |
| HAC-08 | 11/09/2015 | 3.1 | 8.439 | 6.43 | 10 | 59.1 | 10.6 | 1.61 | 12.5 | 72.4 | 1.73 | 132 | $1 \times 10^{-10}$ |
| HAC-10 | 11/09/2015 | 5.8 | 8.204 | 6.14 | 10 | 44.5 | 5.91 | 1.43 | 9.37 | 48.2 | 1.37 | 99.4 | $1 \times 10^{-10}$ |
| HAC-12 | 11/09/2015 | 2.5 | 8.314 | 6.69 | 10 | 64 | 12.1 | 1.65 | 13 | 81.4 | 1.81 | 145 | $1 \times 10^{-10}$ |
| HAC-12 | 17/11/2015 | 0.8 | 7.99 | 5.24 | 10 | 55.1 | 9.73 | 1.31 | 11.2 | 55.1 | 1.46 | 135 | $1 \times 10^{-10}$ |
| HAC-12 | 23/11/2015 | 0.3 | 7.99 | 4.88 | 10 | 54.1 | 9.6 | 1.31 | 10.8 | 54.2 | 1.45 | 135 | $1 \times 10^{-10}$ |
| HAC-12 | 30/11/2015 | 0.1 [(e)] | 7.62 | 4.73 | 10 | 58.1 | 10.6 | 1.27 | 11.3 | 54.4 | 1.46 | 143 | $1 \times 10^{-10}$ |
| HAC-10 | 05/01/2016 | 0.1 [(e)] | 8.02 | 5.44 | 10 | 43.1 | 5.72 | 1.45 | 9.44 | 48.1 | 1.34 | 100 | $1 \times 10^{-10}$ |
| HAC-10 | 01/02/2016 | 0.7 | 7.86 | 5.93 | 10 | 46.8 | 6.14 | 1.47 | 10.5 | 49.9 | 1.41 | 99.5 | $1 \times 10^{-10}$ |
| HAC-10 | 24/02/2016 | 2.4 | 8.1 | 6.77 | 10 | 43.5 | 5.94 | 1.41 | 9.81 | 47.8 | 1.34 | 95.5 | $1 \times 10^{-10}$ |
| HAC-10 | 02/03/2016 | 1.7 | 8.06 | 6.58 | 10 | 44.8 | 5.83 | 1.36 | 9.55 | 48 | 1.37 | 94.8 | $1 \times 10^{-10}$ |
| HAC-13 | 05/01/2016 | 0.1 [(e)] | 7.98 | 5.6 | 10 | 50.4 | 6.93 | 1.46 | 11.3 | 57.5 | 1.59 | 113 | $1 \times 10^{-10}$ |
| HAC-13 | 07/01/2016 | 0.1 [(e)] | 7.96 | 6.04 | 10 | 48 | 6.46 | 1.34 | 9.5 | 52.8 | 1.43 | 99.9 | $1 \times 10^{-10}$ |
| HAC-13 | 12/01/2016 | 0.3 | 7.81 | 5.81 | 10 | 48.1 | 6.52 | 1.44 | 9.87 | 55.1 | 1.54 | 107 | $1 \times 10^{-10}$ |
| HAC-13 | 19/01/2016 | 0.8 | 8.06 | 6.08 | 10 | 49.7 | 6.58 | 1.48 | 10.4 | 55.6 | 1.51 | 100 | $1 \times 10^{-10}$ |
| HAC-13 | 26/01/2016 | 0.2 | 7.78 | 6.35 | 10 | 53.8 | 7.3 | 1.58 | 11.5 | 65.9 | 1.67 | 107 | $1 \times 10^{-10}$ |
| HAC-13 | 01/02/2016 | 0.7 | 7.66 | 6.32 | 10 | 54.5 | 7.47 | 1.57 | 11.8 | 67.1 | 1.68 | 111 | $1 \times 10^{-10}$ |
| HAC-13 | 09/02/2016 | 0.6 | 7.73 | 6.85 | 10 | 52.6 | 7.22 | 1.47 | 11.2 | 62.1 | 1.58 | 107 | $1 \times 10^{-10}$ |
| HAC-13 | 15/02/2016 | 0.1 [(e)] | 7.44 | 7.29 | 10 | 52.3 | 7.76 | 1.54 | 11.4 | 70.1 | 1.73 | 108 | $1 \times 10^{-10}$ |
| HAC-13 | 22/02/2016 | 2.1 | 8.06 | 7.53 | 10 | 53.5 | 7.29 | 1.55 | 10.6 | 64.9 | 1.61 | 105 | $1 \times 10^{-10}$ |
| HAC-13 | 24/02/2016 | 2.3 | 7.8 | 7.48 | 10 | 49.7 | 7.19 | 1.56 | 11.4 | 63.2 | 1.59 | 105 | $1 \times 10^{-10}$ |
| HAC-13 | 29/02/2016 | 2.1 | 8.06 | 7 | 10 | 51.4 | 7.11 | 1.55 | 10.9 | 63.2 | 1.6 | 106 | $1 \times 10^{-10}$ |
| HAC-13 | 02/03/2016 | 2.7 | 8.3 | 6.86 | 10 | 49.2 | 7 | 1.52 | 10.6 | 61.1 | 1.58 | 105 | $1 \times 10^{-10}$ |
| HAC-13 | 08/03/2016 | 3.6 | 8.08 | 11 | 10 | 86.3 | 13.2 | 2.07 | 16.9 | 149 | 2.7 | 130 | $1 \times 10^{-10}$ |
| HAC-13 | 15/03/2016 | 2.4 | 7.96 | 9.65 | 10 | 54.7 | 7.79 | 1.51 | 11.3 | 75.6 | 1.7 | 106 | $1 \times 10^{-10}$ |
| HAC-13 | 23/03/2016 | 2.7 | 7.999 | 12.5 | 10 | 121 | 19.5 | 3.14 | 24.6 | 268 | 4 | 145 | $1 \times 10^{-10}$ |
| HAC-13 | 29/03/2016 | 7.4 | 8.009 | 12.3 | 10 | 134 | 20.4 | 3.07 | 28 | 288 | 4.1 | 147 | $1 \times 10^{-10}$ |
| HAC-13 | 04/04/2016 | 5.7 | 7.903 | 17.7 | 10 | 93.1 | 14.8 | 3.01 | 20.3 | 184 | 2.67 | 127 | $1 \times 10^{-10}$ |
| HAC-13 | 11/04/2016 | 5.4 | 8.259 | 7.9 | 10 | 39.8 | 5.48 | 1.17 | 7.88 | 47.8 | 1.15 | 84.3 | $1 \times 10^{-10}$ |

Notes: Red values = values outside of the BLM calibration range. The BLM was run with the original measured value as well as the upper or lower bound of the calibration range, as appropriate.
a) The lower bound of the calibration range for temperature is 10°C; therefore, the BLM was also run with the lower bound (10°C) replacing the measured value if the measured value was less than 10°C.
b) Humic acid and sulphide concentrations was assumed as per the BLM user guide (HydroQual 2007a).
c) The upper bound of the calibration range for calcium is 120.24 mg/L; therefore, the BLM was also run with the upper bound (120.24 mg/L) replacing the measured value if the measured value was greater than 120.24 mg/L.
d) The upper bound of the calibration range for sulphate is 278.4 mg/L; therefore, the BLM was also run with the upper bound (278.4 mg/L) replacing the measured value if the measured value was greater than 278.4 mg/L.
e) Zero values replaced with 0.1.
DOC = dissolved organic carbon; BLM = biotic ligand model.

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# ATTACHMENT C

## Selenium Target Derivation

# TECHNICAL MEMORANDUM

**DATE** 17 October 2016 **REFERENCE No.** 1411734-169-TM-Rev0-16000

**TO** Dale Reimer
Mount Polley Mining Corporation

**CC** Elaine Irving and Jerry Vandenberg

**FROM** Jordana Van Geest and Adrian de Bruyn **EMAIL** Jordana_vanGeest@golder.com; Adrian_deBruyn@golder.com

**ANALYSIS OF SELENIUM BIOACCUMULATION AND POTENTIAL TOXICITY TO FISH IN HAZELTINE CREEK AT THE MOUNT POLLEY MINE**

## 1.0 INTRODUCTION

Golder Associates Ltd. (Golder) is pleased to provide Mount Polley Mining Corporation (MPMC) with the following analysis of selenium bioaccumulation and toxicity information related to establishing a treatment target for selenium in Hazeltine Creek at the Mount Polley Mine (the Mine) during Closure. This analysis was undertaken to evaluate whether a total selenium concentration in water of 10 µg/L, shown to provide an appropriate level of protection to aquatic life in receiving waters at other mine sites in British Columbia (BC), could be applied to support the management of selenium at the Mount Polley Mine. The following analysis was intended to support Closure planning for the Mine. It is understood that development and approval of a permit limit for selenium will require further consultation with BC Ministry of Environment (MOE), First Nations, and stakeholders prior to Closure.

During Closure, drainage of site contact water may be permitted to return to the natural hydrology of waterbodies and water courses around the Mine site. Contact water may be diverted through treatment systems before being released to natural catchments. Even if Best Available Technologies for passive treatment systems proposed for Closure are applied, selenium concentrations in treated source water may exceed the BC Water Quality Guideline (WQG) of 2 µg/L for the protection of aquatic life. The performance of a closure passive water treatment system is subject to evaluation through piloting. For releases to Hazeltine Creek during Closure, it has been conservatively assumed that there will be no dilution of treated contact water since the dilution capacity of the creek is limited by seasonal flow (Hazeltine Creek is snowmelt driven with the majority of annual runoff occurring during freshet, typically in April and May [KP 2014]). Therefore, selenium concentrations in Hazeltine Creek during Closure may also exceed the BC WQG.

BC WQGs are intended to be conservative environmental quality benchmarks with built-in safety factors, representing concentrations at which there is confidence that designated uses will not be adversely affected. For selenium in particular, the BC WQG was derived to be protective of aquatic life in the most sensitive lentic environments. Site-specific studies at other mines in BC have supported the derivation of protective water quality targets higher than the BC WQG where lentic environments are limited or absent.

The following sections of this technical memorandum provide an overview of a technical approach to developing a treatment target for selenium (Section 2.0), an analysis of relevant published and site-specific data to compare receiving environment characteristics at the Mount Polley Mine to other mines in BC (Section 3.0), and a conclusion regarding a potential treatment target for discharge to Hazeltine Creek (Section 4.0).

## 2.0 DERIVATION OF PROTECTIVE SELENIUM TARGETS

Site-specific studies have been used to support protective selenium targets of 10 µg/L or higher at a number of coal and metal mines in BC, recognizing the importance of site-specific conditions to selenium management.

The approach taken to derive target values for the other sites was a back-calculation from tissue-based effects benchmarks for reproductive effects on sensitive resident fish species, using bioaccumulation relationships reflecting selenium uptake into fish eggs. Supporting analyses confirmed that fish reproduction was the most sensitive endpoint and that the derived targets would also be protective of other potentially sensitive taxa and endpoints, including: growth, reproduction, and survival of aquatic invertebrates; growth and survival of juvenile fish; growth and survival of juvenile birds; and reproduction of aquatic-feeding birds and amphibians. This approach was consistent with that taken by the US Environmental Protection Agency (US EPA 2015[1]) and MOE (2014), which determined that reproductive effects through maternal transfer provide the most reliable basis for the establishment of protective ecological benchmarks.

## 3.0 COMPARISON OF MOUNT POLLEY DATA TO OTHER DATA

The following subsections summarize selenium bioaccumulation and toxicity information relevant to the Mount Polley Mine. The objective of this summary is to compare conditions in Hazeltine Creek to those in receiving waters at other mines, where protective selenium concentrations have been proposed or approved. This comparison will inform the potential application of a protective selenium concentration as a treatment target for Closure planning for the Mine.

### 3.1 Bioaccumulation Data

Selenium bioaccumulation is a stepwise process, with an initial uptake step from water into algae and other micro-organisms, followed by a series of trophic transfer steps from algae to invertebrates, invertebrates to fish, and so on. The initial uptake step is the largest and most variable part of this stepwise process, in which selenium concentrations increase on the order of 100× to 10,000× from parts per billion (µg/L) in water to parts per million (mg/kg dry weight [dw]) in algae. The magnitude of increase in the initial uptake step depends on aqueous selenium concentration and other site-specific factors such as sulphate concentration and biogeochemical conditions (Williams et al. 1994; Stewart et al. 2010; Lo et al. 2015). The subsequent trophic transfer steps are much smaller and less variable than the initial uptake step: selenium concentration ratios between adjacent trophic levels (sometimes called "trophic transfer factors") tend to be on the order of 2 to 3 for invertebrates, approximately 1 for fish muscle or whole body concentrations, and typically between 1 and 3 for fish egg concentrations (Presser and Luoma 2010). Thus, selenium concentrations at all levels in the food web are correlated and proportional to site-specific uptake at the base of the food web.

[1] US EPA released a draft document entitled "*Draft Aquatic Life Ambient Water Quality Criterion for Selenium – Freshwater 2015*". The draft US EPA document is not currently intended for distribution, quotation, or citation.

Given the above, it is possible to determine whether selenium bioaccumulation is similar among sites by comparing patterns of bioaccumulation in lower trophic level organisms. If the pattern of bioaccumulation from water to algae or invertebrates is similar among locations, then bioaccumulation in fish is also expected to be similar.

Previous monitoring of tissue selenium concentrations at the Mine was undertaken because of selenium inputs to the receiving environment from the North Dump Creek and the NEZ Dump. These inputs were mitigated in late 2009 by construction of a seepage collection system. Monitoring was conducted in 2009, 2010, and 2012 to characterize conditions, document temporal trends, and evaluate the potential for effects on aquatic life due to the bioaccumulation of selenium through the food web (Minnow 2013). Previous monitoring included periphyton, benthic invertebrate, and fish tissue sampling in various waterbodies on or adjacent to the Mine site.

The breach of the Tailings Storage Facility dam at the Mount Polley Mine in August 2014 and subsequent debris flow resulted in damage to aquatic habitat along Hazeltine Creek. The channel invert is now considerably lower and, while the alignment of the creek is approximately similar, the creek is now different (e.g., riparian vegetation coverage). Therefore, the degree to which pre-breach data reflect current conditions in the creek is unknown. Reconstruction of the creek channel was completed in May 2015 as part of the rehabilitation of Hazeltine Creek. There has been some recolonization of the benthic invertebrate community within the creek, and monitoring of selenium in benthic invertebrates tissue was undertaken in August 2015 to evaluate post-breach conditions in the creek. In addition, the benthic invertebrates that have recolonized the system will be disturbed again when the fish habitat features are installed in the reconstructed creek channel.

Pre-breach invertebrate selenium data from locations in upper and lower Hazeltine Creek represent a total of 28 samples collected in 2009 ($n = 5$), 2010 ($n = 10$), and 2012 ($n = 13$) (Minnow 2013). Post-breach data collected in 2015 ($n = 10$; MPMC unpublished data) were from similar areas of upper and lower Hazeltine Creek; however, the same pre-breach locations could not be sampled because of the physical changes that occurred to the creek channel. Geometric mean benthic invertebrate selenium concentrations from Hazeltine Creek were paired with aqueous selenium concentrations (annual geometric mean concentration for pre-breach monitoring; monthly sampling concentration for post-breach monitoring) and plotted in Figure 1.

For comparison, invertebrate selenium data from other systems are also plotted in Figure 1. These data represent a total of 58 samples collected in 2012 ($n = 13$), 2013 ($n = 21$), and 2014 ($n = 24$), predominantly from Quarry Creek, Quarry Creek wetlands, and Trail Creek. The general range of values observed in these systems is shaded for visual comparison.

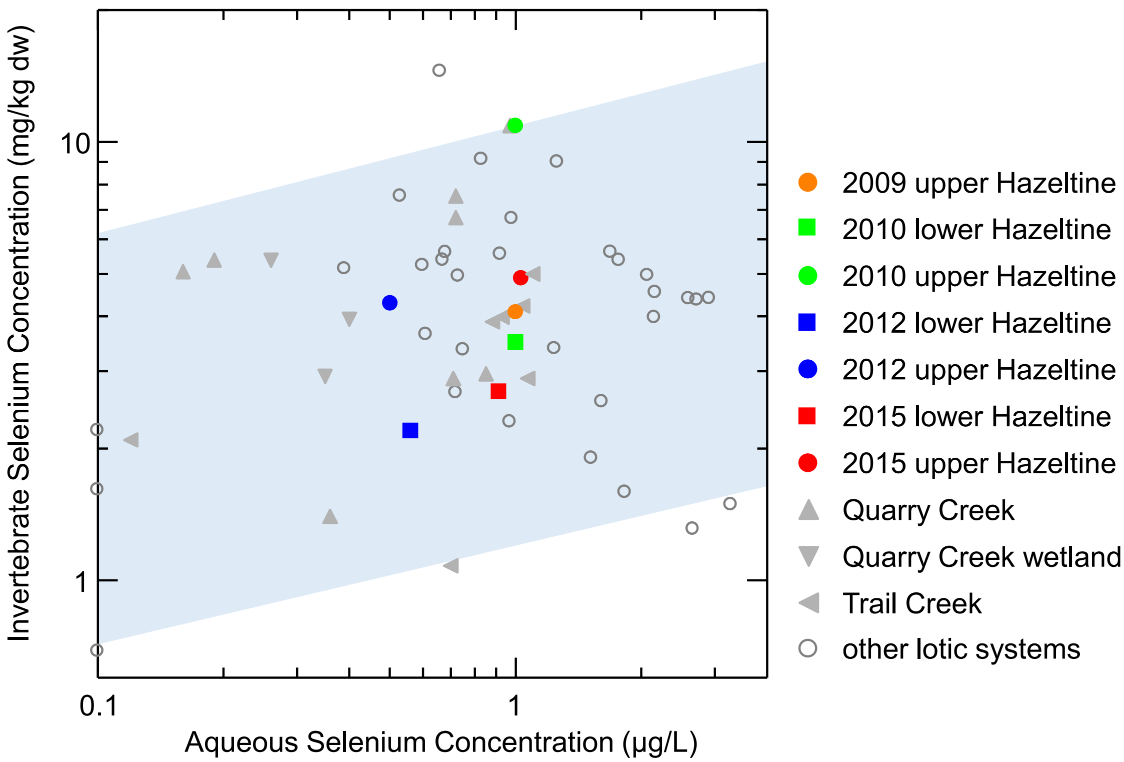


*Figure 1: Patterns of Selenium Bioaccumulation in Invertebrates from Upper and Lower Hazeltine Creek (coloured symbols) Compared to Data from Other Systems*

Note: Samples collected in August 2015 represent post-breach conditions in Hazeltine Creek.

dw = dry weight.

Invertebrate selenium data from Hazeltine Creek were not sufficient to describe a site-specific bioaccumulation relationship due to the narrow range of aqueous selenium concentrations. However, Hazeltine Creek data were generally near the middle of the pattern observed at other systems. One pre-breach sampling event (2010 upper Hazeltine) was higher than other observations, but still within the range observed at other systems. All post-breach data from Hazeltine Creek were consistent with the pattern observed at other systems. This consistency indicates that Hazeltine Creek exhibits invertebrate selenium concentrations typical of other lotic environments.

## 3.2 Toxicity Data

Prior to the breach, rainbow trout appeared to be the only species inhabiting upper Hazeltine Creek (Minnow 2014). Other fish species found in lower Hazeltine Creek near its mouth in Quesnel Lake included sockeye salmon (*Oncorhynchus nerka*), chinook salmon (*O. kisutch*), coho salmon (*O. tshawytscha*), kokanee (*O. nerka*), rainbow trout (*O. mykiss*), mountain whitefish (*Prosopium williamsoni*), burbot (*Lota lota*), largescale sucker (*Catostomus macrocheilus*), longnose sucker (*C. catostomus*), longnose dace (*Rhinichthys cataractae*), peamouth chub (*Mylocheilus caurinus*), and redside shiner (*Richardsonius balteatus*), with rainbow trout and burbot being the most abundant (SNC-Lavalin 2015).

The published threshold for reproductive effects of selenium on rainbow trout, expressed as a 10% effects concentration ($EC_{10}$), is approximately 22 mg/kg dw in eggs (data from Holm et al. 2005; $EC_{10}$ estimated by DeForest et al. 2012 and US EPA 2014). This value is slightly higher (less sensitive) than effects benchmarks used to derive protective selenium concentrations at other sites in BC, which ranged from a published threshold of 18 mg/kg dw for brown trout (*Salmo trutta*; Formation Environmental LLC 2009) applied in southeast BC to 20 mg/kg dw for sensitive coldwater fish species from a species sensitivity distribution analysis (DeForest et al. 2012), applied in northeast BC. Brown trout is the most sensitive species that was tested in the aforementioned studies that are relevant to receiving waters at the Mine. Thus, a selenium target derived to be protective of sensitive species at other sites would be expected to be protective of rainbow trout and other fish species potentially present in Hazeltine Creek.

## 4.0 CONCLUSION AND RECOMMENDATIONS

The information presented above supports the application of an aqueous selenium concentration of 10 µg/L as a treatment target for planning for Closure for Hazeltine Creek. Receiving waters at the Mount Polley Mine do not exhibit distinct patterns of selenium bioaccumulation compared to receiving waters at other mines (Section 3.1) and rainbow trout as the most abundant fish species in Hazeltine Creek are not expected to be more sensitive to selenium compared to benchmarks adopted elsewhere in BC (Section 3.2). Therefore, a total selenium concentration of 10 µg/L, if met in Hazeltine Creek, would not be expected to cause adverse effects to resident aquatic life.

Residual uncertainty in the protectiveness of 10 µg/L as a treatment target for Hazeltine Creek relates to the relatively limited data available on selenium bioaccumulation under post-breach conditions. It is recommended that further studies be undertaken to characterize selenium bioaccumulation in biota both upstream and downstream of the current treated effluent discharge in Hazeltine Creek to address this residual uncertainty, in particular temporal uncertainty associated with recovery of the system over time. Monitoring in Hazeltine Creek while it receives effluent (i.e., before November 2017; planned as part of MPMC's Comprehensive Environmental Monitoring Program) would provide an opportunity to assess bioaccumulation at selenium concentrations above the BC WQG for aquatic life and would improve confidence in long-term selenium targets derived for the Mine. It is expected that this information will form part of a program developed in consultation with MOE to develop a long-term protective target for selenium in Hazeltine Creek.

Fish are presently excluded from Hazeltine Creek by physical barriers in place during the creek rehabilitation and the approved short-term discharge of treated effluent; therefore, monitoring of fish is not possible at this time. Under future conditions of water management at the Mine, when fish habitat and access in Hazeltine Creek are restored, it would be prudent to undertake limited (i.e., being cognizant of the impacts of sacrificing fish) sampling of fish, both to monitor fish exposure to selenium and to support bioaccumulation modelling.

## 5.0 CLOSURE

We trust that the information provided in this technical memorandum is sufficient for your present needs. If you have any questions, please do not hesitate to contact the undersigned at (604) 296-4200.

**GOLDER ASSOCIATES LTD.**

Jordana Van Geest, PhD, RPBio
Environmental Scientist

Adrian de Bruyn, PhD, RPBio
Associate, Senior Environmental Scientist

JVG/AMD/pn/bb/it/kp

Attachment: Study Limitations

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