SD 21

Evaluation of Potential for Aquatic Effects as a Result of Effluent Releases Related to Beaver Dam Mine

Atlantic Gold
A St Barbara Ltd Company

EVALUATION OF POTENTIAL FOR AQUATIC EFFECTS AS A RESULT OF EFFLUENT RELEASES RELATED TO BEAVER DAM MINE

Atlantic Mining NS Beaver Dam Mine Project

Technical Supporting Document

FINAL REPORT

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AQUATIC EFFECTS ASSESSMENT – BEAVER DAM MINE

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EVALUATION OF POTENTIAL FOR AQUATIC EFFECTS RELATED TO EFFLUENT EMISSIONS FROM BEAVER DAM MINE

1 INTRODUCTION

The Beaver Dam Mine Site will involve the construction, operation, and decommissioning of a surface gold mine at Marinette, Nova Scotia, if this project is approved. The proposed mine will be a surface mine and is proposed to include mine Haul Roads and associated mine infrastructure for crushing and haul-out (*e.g.* on-site power generation and local supply systems, fuel storage, temporary offices) (GHD, 2015). The proposed plan is to develop the mine, and crush the ore at the site, with subsequent trucking of the crushed ore to the approved Touquoy Mine Site for processing. The total development area of the Beaver Dam Mine Project is approximately 167 hectares (ha), which includes the ore extraction area (surface mine) (30 ha), materials storage (waste rock, overburden) (98 ha), ore stockpiles (10 ha), and the operational facilities (15 ha) (GHD, 2015).

The main elements of the Beaver Dam Mine Project are as follows (GHD, 2015):

- A surface mine from which 46.9 Mt of ore and waste rock will be excavated;
- A proposed ore extraction rate of 2 million t/y.

With respect to project stages, the following is the anticipated operations and closure timings:

- Site preparation and construction (year 1)
- Operation (years 2-5)
    - Pre-production (8 months)
    - Full production (3.3 years)
- Decommissioning and reclamation (years 6 to 8 and beyond)

An Environmental Assessment commenced in 2015, and an Environmental Impact Statement (EIS) for the Beaver Dam Mine Site was submitted for review to both the Canadian Environmental Assessment Agency (CEAA) and Nova Scotia Environment (NSE) in 2017. Several Information Requests (IRs) were provided on the submitted EIS. This aquatic effects assessment is being conducted as part of the re-submission of the EIS of the Beaver Dam Mine.

The Beaver Dam Mine project has two aquatic receiving environments. The first receiving environment is associated with the actual Beaver Dam Mine site and is known as the Killag River. Since the Beaver Dam site is a satellite surface mine operation to the Moose River Consolidated Projects (MRC), the ore from the Beaver Dam Mine project will be processed at the existing Touquoy Mine plant. With the transfer of ore to the Touquoy Mine site, there is need for an additional assessment of potential for aquatic effects associated with the added process emissions related to Beaver Dam ore at the Touquoy facility. Currently, the active Touquoy pit is dewatered and all water is pumped to the Tailings Management Facility (TMF). Effluent passes from the TMF, through a polishing pond and a series of geobags to a constructed wetland and is released into Scraggy Lake (Final Discharge Point; FDP). The Touquoy Mine pit will eventually be exhausted and will be allowed to fill naturally with water. Since processing of

Beaver Dam Mine ore at the Touquoy processing facility will commence after the Touquoy Mine pit is exhausted, tailings generated as a result of processing of Beaver Dam ore at Touquoy will be deposited in the exhausted Touquoy Mine pit. Once the Touquoy Pit fills naturally, and once water quality within the pit meets Metal and Diamond Mine Effluent Regulations (MDMER) discharge criteria, water surplus will be released at a new Effluent Final Discharge Point to the Moose River, via a spillway or channel (Stantec, 2018a). Therefore, this report includes an assessment of both the Killag River, as well as the Moose River, associated with the Beaver Dam Mine project.

As part of the mine planning process, GHD has developed a Mine Water Management Plan (MWMP) for the Beaver Dam Site. This plan serves to predict future water quality at End of Mine (EOM) and Post Closure (PC) in the mine pit on site, as well as in the receiving environment (Killag River). An assimilative capacity study was conducted for the Moose River receiving environment (Stantec, 2018a), to understand potential impacts associated with the processing of Beaver Dam ore and deposition of tailings in the Touquoy Mine pit.

Therefore, this aquatic effects assessment relies on the predicted receiving environment water quality in the Killag River (based on GHD, 2019a), and the Moose River (Stantec, 2018a).

The methods to conduct the aquatic effects assessment are presented in Section 2.0 of the report, whereas the assessment outcomes for the Killag River are presented in Section 3.0, and the assessment outcomes for the Moose River are in Section 4.0. Conclusions can be found in Section 5.0, with references in Section 6.0.

2 METHODS FOR CONDUCTING THE AQUATIC EFFECTS ASSESSMENT

2.1 Receiving Environment Characterization

To conduct the aquatic effects assessment, the receiving environment was characterized, based on available baseline data and descriptive text characterizing the receiving environments.

2.2 Exposure Assessment

To conduct the exposure assessment related to possible future concentrations of metals and other substances in the receiving environment, the predictive water quality modelling conducted by GHD (2019a) and Stantec (2018a) were used to characterize potential future receiving environment chemistry, as a result of mine-related emissions to either of the two environments, over various time frames.

2.3 Toxicity Assessment

Water quality guidelines used in the assessment are selected from the CCME water quality guidelines for the protection of aquatic life (CCME 2018) and the Nova Scotia Tier 1 surface water guidelines for use in freshwater (NSE 2014; many of which are based on CCME). For the selection of guidelines, the Nova Scotia Tier 1 surface water guidelines were given precedent over the CCME water quality guidelines, with the exception of the following cases:

- the Nova Scotia Tier 1 guidelines have not accounted for site-specific toxicity modifying factors (*i.e.*, pH, hardness); or,
- the CCME provides a more updated water quality guideline.

In these cases, the CCME guideline was selected over the Nova Scotia Tier 1 guideline. Table 2-1 presents the CCME and Nova Scotia Tier 1 water quality guidelines along with the selected guideline for each chemical. Where water quality varies between the Killag River and Moose River, the modified guidelines for each site are presented. The chemicals presented in Table 2-1 are based on the metals or substances considered in the predictive modelling for the Killag River (GHD, 2019a) or Moose River (Stantec, 2018a). Not all chemicals are assessed in both receiving environments. Only those chemicals considered in each of the modelling efforts are carried into the assessment of potential for aquatic effects. For example, cyanide treatment is only conducted at the Touquoy site, and hence, cyanide did not merit assessment in Killag River, but was assessed in Moose River. For the specific compounds assessed in the two receiving environments, see Section 3.0 (Killag River) and Section 4.0 (Moose River).

Table 2-1 Selected Water Quality Guidelines for Use in the Assessment

Chemical	***CCME (µg/L)***	***Nova Scotia Tier 1 (µg/L)***	***Selected Guideline***	***Regulation***
Silver	0.25	0.1	0.25	CCME
Aluminum	5/100[a]	5	5	Nova Scotia Tier 1
Antimony	NV	20	20	Nova Scotia Tier 1
Arsenic	5	5	5	Nova Scotia Tier 1
Cadmium	0.04/0.09[b]	0.01	0.04	CCME
Chromium	8.9[c]	1[d]	8.9	CCME
Cobalt	NV	10	10	Nova Scotia Tier 1
Copper	2/4[e]	2	2	Nova Scotia Tier 1
Iron	300	300	300	Nova Scotia Tier 1
Mercury	0.026	0.026	0.026	Nova Scotia Tier 1
Manganese	NV	820	820	Nova Scotia Tier 1
Molybdenum	73	73	73	Nova Scotia Tier 1
Nickel	25	25	25	Nova Scotia Tier 1
Lead	1/7[f]	1	1	Nova Scotia Tier 1
Selenium	1	1	1	Nova Scotia Tier 1
Sulphate	NG	NG	128,000[g]	BC MOE
Thallium	0.8	0.8	0.8	Nova Scotia Tier 1
Uranium	15	300	15	CCME
Zinc	7	30	7	CCME
WAD Cyanide	5	5	5	Nova Scotia Tier 1
Total Cyanide (based on Strong Acid Dissociated)	NG	NG	5[h]	CCME

Nitrite (as N)	NG	60	60	CCME
Total Ammonia - N	NG	Varies with pH and temperature	Varies with pH and temperature	CCME

Notes: NG = No guideline available from that agency

[a] The CCME water quality guideline for aluminum of 5 µg/L is for pH<6.5, and 100 µg/L is for pH ≥6.5. The background pH of the Killag River is 4.59 and 6; and mean pH of Moose River is 6.05; therefore, the guideline of 5 µg/L is appropriate for use at both sites.

[b] The CCME water quality guideline for cadmium of 0.04 µg/L is for water hardness >0 to <17 mg/L, and 0.09 µg/L is for water of 50 mg/L hardness. The background water hardness of the Killag River is between 1.6 and 5.5 mg/L $CaCO_3$; and the mean hardness of Moose River is 5.0 mg/L; therefore, the guideline of 0.04 µg/L is appropriate for use at both sites.

[c] Based on Cr^{3+}; this value was selected as $Cr^{6=}$ is unlikely to be present in the receiving environment

[d] Based on Cr^{6+}

[e] The CCME water quality guideline for copper of 2 µg/L is for water hardness of 0 to <82 mg/L or when the hardness is unknown. When the hardness is >82 to ≤180 mg/L, the following equation is used to calculate the guideline: CWQG (µg/L) = $0.2 * e^{\{0.8545[\ln(\text{hardness})]-1.465\}}$, and at a hardness >180 mg/L, the guideline is 4 µg/L. The background water hardness of the Killag River is between 1.6 and 5.5 mg/L $CaCO_3$ and the mean hardness of Moose River is 5.0 mg/L; therefore, the guideline of 2 µg/L is appropriate for use at both sites.

[f] The CCME water quality guideline for lead of 1 µg/L is for water hardness of 0 to ≤60 mg/L or when the hardness is unknown. When the hardness is >60 to ≤180 mg/L, the following equation is used to calculate the guideline: CWQG (µg/L) = $e^{\{1.273[\ln(\underline{\text{hardness}})]-4.705\}}$, and at a hardness >180 mg/L, the guideline is 7 µg/L. The background water hardness of the Killag River is between 1.6 and 5.5 mg/L $CaCO_3$ and the mean hardness in Moose River is 5.0 mg/L; therefore, the guideline of 1 µg/L is appropriate for use at both sites.

[g] No CCME or NS Tier 1 guideline is available; therefore a guideline from BC Moe was used (https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/wqg_summary_aquaticlife_wildlife_agri.pdf)

[h] This guideline is for free CN, and hence does not apply to Total CN. It is used to provide perspective only in the effects assessment.

Where substances were found to exceed the selected guideline, and the 75th percentile of baseline, consideration was given to developing a Site Specific Water Quality Objective (SSWQO), following CCME guidance (CCME, 2007). The typical starting points for assessment of surface water data Canadian Water Quality Guidelines for Protection of Freshwater Aquatic Life (WQGl - FWAL), established by the Canadian Council of Ministers of the Environment (CCME). These guidelines are generic, national recommendations which reflect the most current scientific data at the time they were developed. They are intended to provide protection to all forms of aquatic life and aquatic life cycles, including the most sensitive life stages, at all locations across Canada (CCME, 2007). Since they are generic and do not always account for site-specific factors that can alter toxicity, these national guidelines can be modified using widely accepted procedures, to derive site-adapted or SSWQOs for a given project or location (CCME, 2003). Modifications to the generic guidelines allow for protection of aquatic species accounting for specific conditions in the receiving environment, primarily due to the following reasons (CCME, 2003):

- There may be naturally-occurring levels of substances that are above the generic guidelines. This is commonplace for metals and metalloids near areas of natural enrichment, such as mines.

- There may be certain characteristics of the water at a specific location or site which modify the toxicity of the substance, such that the generic guideline is unnecessarily conservative (protective). These characteristics are known as exposure and toxicity modifying factors (ETMFs), and can include parameters such as pH, temperature, hardness, and organic matter, amongst others (CCME, 2007).

- There may be certain sensitive species considered in the development of the generic guideline which are not present in the area under assessment (e.g., warm water species which are absent from northern environments), and removal of these data allows for a more site-specific guideline to be developed, without compromising protection. In addition, information on toxicity of the substance in question to resident species in the area of interest may be lacking in the existing database, and therefore, there may be interest in expanding the database to include site-specific toxicity data. Or, the existing CCME guideline may be dated and hence, application of more advanced protocols and available data can result in a revised guideline, which is more representative of current scientific practice and available toxicity data.

Based on consideration of all the available information, a revised SSWQO was derived for arsenic, following CCME protocols (CCME, 2007). A SSWQO consistent with CCME (2007) guidance, using a species sensitivity distribution (SSD) approach was used to derive the SSWQO. The SSD approach was comprised of identifying chronic toxicity data for species, analyzing the data using a regression approach and selecting the final chronic effects benchmark. The HC5 (i.e., the concentration that is hazardous to no more than 5% of a species in the community) was selected as the final chronic effects benchmark as per CCME (2007) guidance. The resultant guideline using the protocol is 30 µg/L. The details related to the SSWQO for arsenic are provided in Appendix A.

2.4 Characterization of Potential for Adverse Effects

The resulting future conditions in the receiving environments were compared to either CCME (2018) freshwater aquatic life guidelines (FWAL) and/or Nova Scotia Tier 1 surface water guidelines (NSE, 2014), or SSWQO, as well as to an upper percentile of baseline (75th percentile concentrations of existing near-field baseline water quality stations), to characterize potential risks to aquatic life.

Each aspect of the assessment is provided in Chapter 3 (Killag River assessment), and Chapter 4 (Moose River assessment).

3 KILLAG RIVER ASSESSMENT

3.1 Description of Receiving Environment and Baseline Data

The Killag river is adjacent to the Beaver Dam mine property. The river is a tributary of the West River Sheet Harbour and flows across the eastern portion of the overall Beaver Dam Mine study area. It is approximately 27 km long and is organic-acid stained. The Killag River was damned some time ago, which created a reservoir along the eastern edge of the Study area, known as the Cameron Flowage (see Section 4.0, CRA, 2015, in GHD, 2017). Current land use in the area is sparse, with the exception of timber harvesting.

The Killag River has important fish spawning habitat, and The Nova Scotia Salmon Association has documented the presence of Atlantic salmon in the Killag River. As discussed in the EIS (GHD, 2017), Atlantic salmon are highly sensitive to fluctuations in habitat conditions, particularly pH and temperature. As such, many land use practices and impacts to the freshwater ecosystem can affect the abundance and distribution of salmon. Physical barriers (e.g., dams, improperly installed culverts, etc.) can limit the distribution of the species and fish harvesting can affect their abundance. The Killag River has been categorized as Type II fish habitat (taken from Beak, 1980), which is summarized as:

“Good salmonid rearing habitat with limited spawning, usually only in isolated gravel pockets, good feeding and holding areas for larger fish in deeper pools, pockets, or backwater eddies: flows: heavier riffles to light rapids; current: 0.3- 1.0 m/s; depth: variable from 0.3 - 1.5 m; substrate: larger cobble/rubble size rock to boulders and bedrock, some gravel pockets between larger rocks; general habitat types: run, riffle, pocket water, pool.”

The Killag River has low pH, which has been attributed to acid rain, and likely a low carbonate content in the surrounding geology. As such, the Nova Scotia Salmon Association has been operating an acid mitigation project on the West River for over 10 years. This program involves a lime dosing station which is used to increase the pH of the water to a suitable range for juvenile salmon (to approximately 5.5). The Nova Scotia Salmon Association has indicated that this project has resulted in significant increase in smolt populations and improved overall habitat quality within the West River Sheet Harbour. A second lime dosing station was installed in the Killag River, approximately 400 m downstream of the Beaver Dam Mine Site on November 1, 2017. The water quality characteristics collected at SW1 on the Killag in 2014 and 2015 clearly indicate low pH in the receiving environment (See Table 3-1), which are not conducive to supporting salmon, based on the available data. This may have improved since 2015. The Nova Scotia Salmon Association have indicated that maintenance of surface water quality and quantity is imperative to the continued success of ongoing salmon restoration efforts in the West River Sheet Harbour and its tributaries (GHD, 2017).

Table 3-1 outlines the available baseline data from the Killag River, as represented by Station SW1 (which is upstream of the new lime dosing unit). While an additional surface water station is available in the program (Station SW2A), it is north of the Cameron Flowage and distant to the proposed discharge site and hence was not used to characterize receiving environment conditions. Each sample was collected as a grab sample and analyzed for general chemistry and metals (RCAp-MS), mercury (Hg), with additional field measurements were recorded for dissolved oxygen (DO), temperature, total dissolved solids (TDS), conductivity, pH, and/or flow rate. Sampling at the Beaver Dam mine site began in October 2014 and was conducted monthly until August 2015.

Table 3-1 Baseline Surface Water Concentrations Collected from Killag River (Total Metals µg/L; N = 9)[a]

Parameter	*Min*	*Max*	*Mean*	*75th Percentile*	*90th Percentile*	*# of Non-Detects*	*CCME (µg/L)*	*Nova Scotia Tier 1 (µg/L)*
Silver	NDA	NDA	NDA	NDA	NDA	NDA	0.25	0.1
Aluminum	140	400	262	320	344	0/9	5	5
Arsenic	<1	3.7	1.84	2.60	2.9	2/9	5	5
Cadmium	<0.01	0.029	0.0199	0.0240	0.0282	1/9	0.04	0.01
Cobalt	<0.4	0.53	0.307	0.510	0.522	6/9	NV	10
Copper	<2	<2	1	1	1	9/9	2	2
Iron	240	1000	546	670	800	0/9	300	300
Mercury	<0.013	0.032	0.0103	0.0065	0.0184	7/9	0.026	0.026
Manganese	27	79	48.6	58.0	70.2	0/9	NV	820
Molybdenum	<2	1	1	1	1	9/9	73	73
Nickel	<2	2.6	1.18	1	1.32	8/9	25	25
Lead	<0.5	0.57	0.347	0.51	0.546	6/9	1	1
Antimony	<1	<1	0.5	0.5	0.5	9/9	NV	20
Selenium	<1	<1	0.5	0.5	0.5	9/9	1	1
Thallium	<0.1	<0.1	0.05	0.05	0.05	9/9	0.8	0.8
Uranium	<0.1	<0.1	0.05	0.05	0.05	9/9	15	300
Zinc	<5	7.8	4.13	5.10	7	5/9	7	30
pH	4.59	6	5.39	5.59	5.88	9/9	6 – 9.5	6-9.5

Notes:

NV indicates no value provided; NDA indicates no data available; reported pH is based on lab analysis, as field measurements were unusually low (range of 2.63 to 6.48)

[a] Summary statistics were calculated using the maximum value between duplicate samples and half the detection limit value when a chemical was not detected in a sample.

In general, the water quality stations in the study area were found to have elevated concentrations of aluminum and iron [above CCME Freshwater aquatic life guidelines (FWAL)] during most sampling events, which is a common feature of surface water in Nova Scotia. Mercury was identified above the CCME FWAL guidelines at all sampling locations during the last sampling event in August 2015, and arsenic concentrations were identified above the CCME FWAL guidelines at several stations in the study area (SW-4A, SW-5, SW-6A, and SW-10), but not at the station on Killag River (see Table 3-1). Arsenopyrite, an iron arsenic sulfide compound, is common in the surficial and bedrock geology of the area. Lead, cadmium, and copper fluctuate in surface water at most sampling locations and at times slightly exceeded the CCME FWAL across the study area. The relative soft waters in the area also present a challenge for mitigation of metals toxicity in the environment.

3.2 Description of Water Quality Modelling Conducted

The predictive water quality assessment was conducted by GHD (2019a) and involved calculations on a monthly basis for the average year climatic conditions. The approach taken involving monthly predictions enables consideration of water flow fluctuations in the receiving environment, which can affect mixing and dispersion within the river. Using this approach, the month with the greatest potential impact on the receiving environment can be identified, and treatment can be targeted for these types of worst-case conditions. Detailed description of the modelling approach is provided in GHD (2019a) and is summarized here. The modelling used historical rainfall data from the Environment Canada climate station Middle Musquodoboit (ID: 8203535) which has continuous historical daily precipitation data from 1968 to 2005. A water balance model (WBM) (GHD, 2019b) was created in GoldSim and was used to generate precipitation probabilities using a stochastic distribution of the precipitation data. Monthly precipitation totals were calculated from the Middle Musquodoboit Climate Station daily precipitation record for 41-years including 1968 – 2005, 2009, 2014 and 2016. Years that had a significant amount of missing data were excluded from the analysis.

As discussed in GHD (2019a), concentrations of each constituent leaving the site in water were determined by examining the geochemistry of each stockpile (till, waste rock, low grade ore) and the pit wall rock. This analysis was done by Lorax Environmental (Lorax Environmental, 2018). Two concentration ranges were predicted: Base Case conditions, which were representative of the most likely concentration scenario (median); and, Upper Case conditions, which were representative of the likely worst-case (90th percentile) concentration scenario. As discussed in GHD (2019a), for the EOM conditions, the source term model assumed the following:

- The waste rock stockpiles have reached their maximum height but remain uncovered and unrestored;
- The pit is constantly being dewatered and discharged into the north settling pond;
- Standard erosion and sediment control measures have been implemented on the soil and till piles.

For the PC conditions, the source term model assumed the following:

- Waste rock stockpiles have been covered with soil and seeded;
- The low grade ore stockpile has been removed from the Project Site and processed at the Touquoy site;
- The pit has been allowed to naturally fill with water to an elevation of 127 m;
- All site water will drain to the pit prior to discharge into the river;
- Other than what is mentioned above no other reclamation activities have been implement at the Project site.

GHD (2019a) provides further details of the water balance and modelling.

3.3 Discharge Points and Receiving Environment Prediction Points

The only contribution discharge points identified by GHD (2019a) with potential for discharge of impacted mine effluent into the Killag River system are the North Settling Pond (EOM scenario only) and the Pit (PC scenario only). The North Settling Pond is anticipated to be decommissioned for the PC scenario (see GHD, 2019a).

Water quality was predicted at 2 distances downstream of the discharge points; 100m (near field) and approximately 1 km (far field). Based on the water flow characteristics of the receiving environment, full mixing was assumed to occur at the near field prediction node.

Figure 3-1 provides an overview of the discharge and water quality prediction nodes.

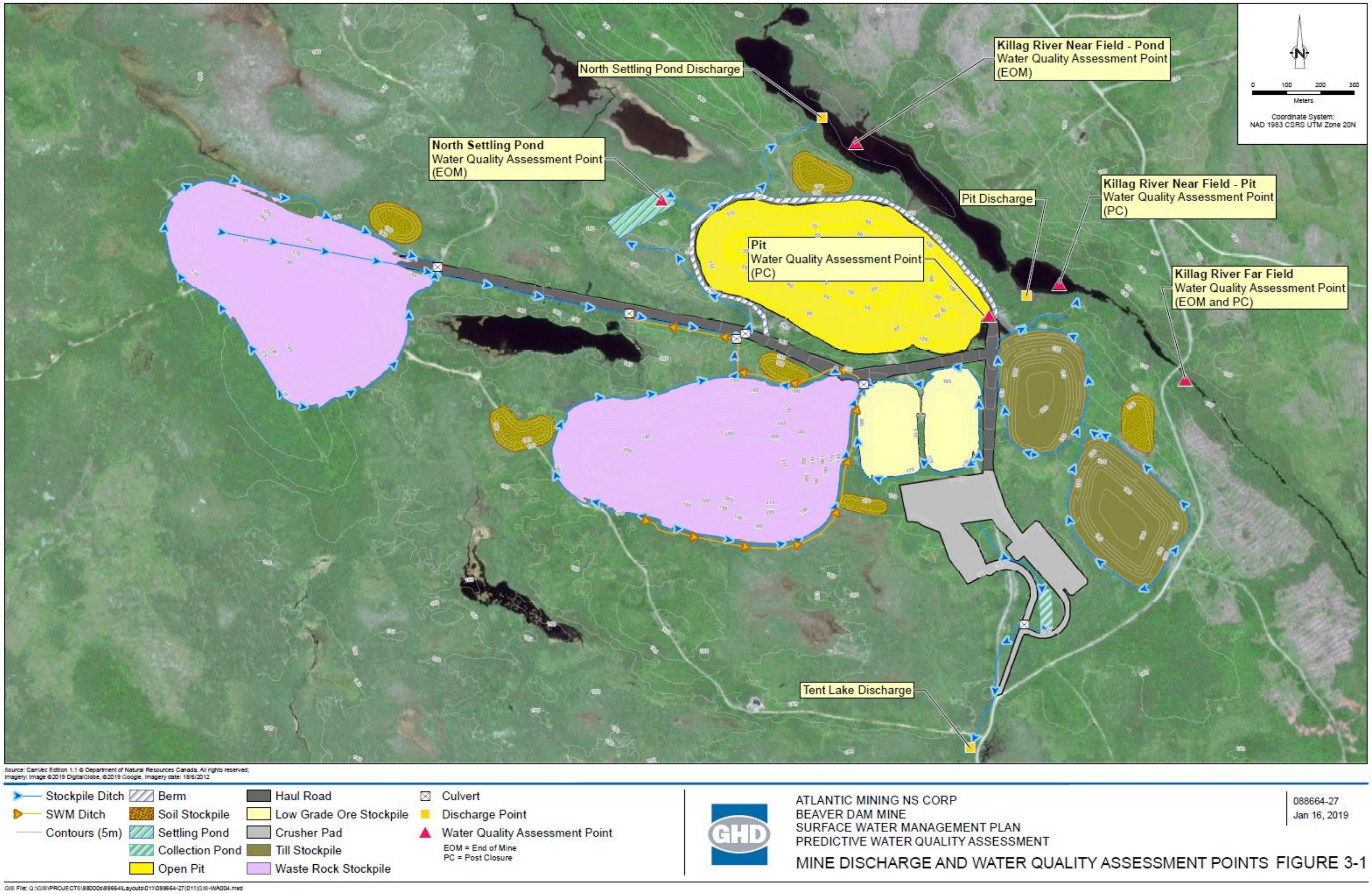

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Figure 3-1 Mine Discharge and Water Quality Assessment Points

3.4 Selected Benchmarks

Benchmark concentrations used for comparison against predicted water concentrations are presented in Table 3-2. Selection of these benchmark concentrations is described in Section 2.3. These benchmark concentrations were based on the greater of either the water quality guideline selected for use in the assessment (see Table 2-1), or the 75th percentile of the baseline surface water concentrations collected from the Killag River (Table 3-1), except for arsenic for which a site-specific water quality objective was calculated and adopted (see Section 2.3 and Appendix A).

Table 3-2 Selected Benchmark Concentrations for Use in the Assessment (µg/L)

Parameter	*Selected Guideline[a]*	*75th Percentile Baseline Concentration*	*Site-Specific Water Quality Objective*	*Selected Benchmark Concentration*
Silver	0.25[b]	NDA	-	0.25
Aluminum	5	320	-	320
Arsenic	5	2.60	30	30
Cadmium	0.04[b]	0.0240	-	0.04
Cobalt	10	0.510	-	10
Copper	2	1	-	2
Iron	300	670	-	670
Mercury	0.026	0.0065	-	0.026
Manganese	820	58.0	-	820
Molybdenum	73	1	-	73
Nickel	25	1	-	25
Lead	1	0.51	-	1
Antimony	20	0.5	-	20
Selenium	1	0.5	-	1
Thallium	0.8	0.05	-	0.8
Uranium	15[b]	0.05	-	15
Zinc	7[b]	5.10	-	7

Notes:
- not calculated; NDA: no data available

[a] Selected guidelines represent Nova Scotia Tier 1 guidelines unless specified otherwise.

[b] Selected guideline adopted from CCME.

3.5 Predicted Water Quality – No Water Treatment Scenario

GHD (2019a) assumed no water quality treatment for the predictions provided herein. Only receiving environment predictions are assessed herein, and discharge predictions relative to MDMER limits are provided in GHD (2019a). The predictions provided by GHD (2019a) include the Project increment + Mean Baseline. Mean baseline metrics are provided in GHD (2019a) and differ slightly from those in Table 2-1, as the mean used in GHD (2019a) included 9 samples + 1 duplicate sample (n = 10). With naturally occurring dilution within the Killag

River, some metals are predicted to be less than mean baseline at the near field prediction node (100 m downstream of point of discharge) and far field prediction node (approximately 1 km downstream from point of discharge).

3.5.1 Near-field Predictions

GHD (2019a) predicted chemical concentrations at the near field Northern Settling Pond discharge point under the EOM scenario and at the Pit lake discharge point under the PC scenario, each for a base case and an upper case. Table 3-3 and Table 3-4 present the chemical concentrations predicted for the near-field area (100 m down stream) of the Northern Settling Pond discharge point under the EOM scenario for the base case and the upper case, respectively. Table 3-5 and Table 3-6 present the chemical concentrations predicted at the near field area (100 m downstream) of the Pit lake discharge point under the PC scenario for the base case and the upper case, respectively. In each table, the predicted chemical concentrations are compared to the selected water quality benchmarks outlined in Section 3.4.

Table 3-3 Constituent Concentrations at Near Field Northern Settling Pond Discharge Point - EOM Conditions Base Case

Constituent	Selected Benchmark Concentration[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Silver	0.25[b]	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05
Aluminum	320[c]	233.35	235.32	244.08	247.41	232.21	226.68	206.9	195.43	210.8	235.91	241.69	238.28
Arsenic	30[d]	3.58	2.93	2.26	2.27	5.79	4.62	6.44	7.59	6.16	3.46	3.05	3.62
Cadmium	0.04[b]	0.018	0.018	0.018	0.019	0.018	0.018	0.017	0.016	0.017	0.018	0.018	0.018
Cobalt	10	0.31	0.31	0.3	0.31	0.34	0.33	0.36	0.37	0.35	0.32	0.31	0.32
Copper	2	0.96	0.96	0.98	0.98	0.97	0.96	0.93	0.92	0.94	0.97	0.98	0.97
Iron	670[c]	479.38	483.57	500.64	506.85	475.02	464.66	424.17	400.59	432.03	483.56	495.33	488.6
Mercury	0.026	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Manganese	820	49.67	48.77	48.44	48.75	53.19	50.79	52.03	52.91	51.91	49.69	49.52	50.17
Molybdenum	73	1.54	1.4	1.29	1.33	2.17	2.03	2.71	3.14	2.61	1.68	1.51	1.59
Nickel	25	1.02	1.01	1.01	1.02	1.09	1.06	1.11	1.14	1.1	1.04	1.03	1.03
Lead	1	0.33	0.32	0.33	0.33	0.34	0.33	0.32	0.31	0.32	0.33	0.33	0.33
Antimony	20	0.55	0.52	0.5	0.51	0.67	0.59	0.65	0.68	0.64	0.55	0.54	0.57
Selenium	1	0.52	0.5	0.5	0.5	0.58	0.54	0.56	0.57	0.56	0.52	0.52	0.53
Thallium	0.8	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05
Uranium	15[b]	0.73	0.53	0.36	0.39	1.51	1.25	2.02	2.5	1.9	0.82	0.63	0.77
Zinc	7[b]	3.76	3.78	3.85	3.88	3.77	3.71	3.54	3.44	3.57	3.78	3.83	3.81

Notes:

All values are presented as µg/L.

Shaded values indicate an exceedance of the selected benchmark concentration.

[a] Selected benchmarks represent Nova Scotia Tier 1 guidelines unless specified otherwise.

[b] Adopted from CCME.

[c] Based on baseline concentration in the Killag River (75th percentile)

[d] Site-specific water quality guideline

Table 3-4 Constituent Concentrations at Near Field Northern Settling Pond Discharge Point - EOM Conditions Upper Case

Constituent	*Selected Benchmark Concentration[a]*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Silver	0.25[b]	0.06	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.05
Aluminum	320[c]	238.8	240.44	246.63	248.82	236.75	233.36	218.61	210	221.46	240.31	244.57	242.06
Arsenic	30[d]	6.75	5.69	3.53	2.99	9.25	8.56	13.22	16.01	12.36	5.95	4.74	6
Cadmium	0.04[b]	0.025	0.025	0.022	0.02	0.023	0.026	0.031	0.034	0.03	0.023	0.022	0.023
Cobalt	10	0.36	0.35	0.33	0.32	0.39	0.4	0.47	0.52	0.46	0.36	0.34	0.35
Copper	2	1.07	1.06	1.03	1.02	1.08	1.1	1.17	1.22	1.16	1.06	1.04	1.05
Iron	670[c]	532.59	535.13	524.51	517.06	507.96	523.48	529.13	530.93	526.67	522.12	519.55	522.08
Mercury	0.026	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01
Manganese	820	63.48	61.68	54.44	51.64	64.15	66.81	80.24	87.94	77.5	60.08	56.25	59.48
Molybdenum	73	3.32	2.77	2.23	2.32	5.69	5.23	8.04	9.79	7.6	3.81	3.07	3.43
Nickel	25	1.14	1.12	1.07	1.05	1.22	1.22	1.39	1.48	1.36	1.14	1.1	1.13
Lead	1	0.34	0.33	0.33	0.34	0.37	0.35	0.36	0.36	0.36	0.34	0.34	0.35
Antimony	20	0.68	0.6	0.54	0.55	0.94	0.78	0.95	1.07	0.93	0.66	0.63	0.69
Selenium	1	0.57	0.53	0.51	0.52	0.71	0.62	0.7	0.75	0.69	0.57	0.56	0.59
Thallium	0.8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Uranium	15[b]	1.18	0.87	0.56	0.59	2.35	1.99	3.25	4.04	3.06	1.3	0.98	1.21
Zinc	7[b]	4.7	4.67	4.26	4.06	4.42	4.76	5.4	5.76	5.26	4.47	4.27	4.41

Notes:

All values are presented as µg/L.

Shaded values indicate an exceedance of the selected benchmark concentration.

[a] Selected benchmarks represent Nova Scotia Tier 1 guidelines unless specified otherwise.

[b] Adopted from CCME.

[c] Based on baseline concentration in the Killag River (75th percentile)

[d] Site-specific water quality guideline

Table 3-5 Constituent Concentrations at Near Field Pit Lake Discharge Point - PC Conditions Base Case

Constituent	Selected Benchmark Concentration[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Silver	0.25[b]	0.07	0.07	0.06	0.05	0.09	0.08	0.1	0.12	0.1	0.07	0.06	0.07
Aluminum	320[c]	235	235.82	244.1	247.76	237.89	228.51	208.38	196.67	212.46	236.93	242.96	240.53
Arsenic	30[d]	7.29	6.04	3.62	3.05	10.44	9.29	14.53	17.72	13.57	6.34	5.03	6.5
Cadmium	0.04[b]	0.025	0.023	0.021	0.02	0.029	0.027	0.032	0.035	0.031	0.024	0.022	0.024
Cobalt	10	0.32	0.31	0.3	0.3	0.35	0.33	0.36	0.37	0.35	0.32	0.31	0.32
Copper	2	2.08	1.82	1.36	1.25	2.74	2.47	3.48	4.1	3.3	1.89	1.64	1.94
Iron	670[c]	482.81	484.29	500.87	508.06	489.01	470	429.8	406.45	437.97	486.7	498.78	494.04
Mercury	0.026	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Manganese	820	50.36	49.56	48.58	48.46	52.57	50.7	51.99	52.82	51.77	49.58	49.38	50.25
Molybdenum	73	1.26	1.2	1.08	1.05	1.44	1.35	1.6	1.75	1.56	1.21	1.15	1.23
Nickel	25	1.05	1.03	1	1	1.11	1.07	1.11	1.14	1.1	1.03	1.02	1.05
Lead	1	0.33	0.33	0.33	0.33	0.34	0.33	0.32	0.32	0.32	0.33	0.33	0.33
Antimony	20	0.52	0.51	0.5	0.5	0.55	0.53	0.54	0.55	0.54	0.51	0.51	0.52
Selenium	1	0.51	0.5	0.5	0.5	0.54	0.52	0.53	0.54	0.53	0.51	0.51	0.51
Thallium	0.8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Uranium	15[b]	2.77	2.15	0.99	0.72	4.35	3.77	6.33	7.89	5.86	2.32	1.68	2.4
Zinc	7[b]	5.53	5.13	4.44	4.3	6.59	6.1	7.56	8.45	7.29	5.24	4.89	5.34

Notes:

All values are presented as µg/L.

Shaded values indicate an exceedance of the selected benchmark concentration.

[a] Selected benchmarks represent Nova Scotia Tier 1 guidelines unless specified otherwise.

[b] Adopted from CCME.

[c] Based on baseline concentration in the Killag River (75th percentile)

[d] Site-specific water quality guideline

Table 3-6 Constituent Concentrations at Near Field Pit Lake Discharge Point - PC Conditions Upper Case

Constituent	Selected Benchmark Concentration[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Silver	0.25[b]	0.1	0.08	0.06	0.06	0.13	0.11	0.16	0.18	0.15	0.09	0.08	0.09
Aluminum	320[c]	238.42	239.11	246.01	249.05	240.78	232.94	216.07	206.26	219.49	239.99	245.04	243.03
Arsenic	30[d]	12.34	10.36	5.58	4.16	16.28	15.6	25.47	31.38	23.58	10.29	7.72	10.33
Cadmium	0.04[b]	0.043	0.038	0.028	0.024	0.051	0.05	0.071	0.084	0.067	0.038	0.032	0.038
Cobalt	10	0.37	0.36	0.32	0.31	0.39	0.39	0.46	0.51	0.45	0.35	0.34	0.36
Copper	2	7.91	6.34	3.37	2.68	11.91	10.43	16.93	20.89	15.74	6.76	5.14	6.96
Iron	670[c]	502.93	503.98	515.03	518.43	511.17	503.77	489.16	481.21	492.69	510.7	515.07	510.74
Mercury	0.026	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01
Manganese	820	64.1	62.5	54.49	51.1	62.6	66.28	79.82	87.57	76.9	59.62	55.78	59.23
Molybdenum	73	2.26	2	1.44	1.29	2.87	2.68	3.85	4.56	3.63	2.02	1.73	2.05
Nickel	25	1.18	1.15	1.06	1.03	1.24	1.23	1.39	1.49	1.36	1.13	1.09	1.14
Lead	1	0.35	0.34	0.33	0.34	0.37	0.35	0.36	0.37	0.36	0.34	0.34	0.35
Antimony	20	0.61	0.58	0.53	0.52	0.69	0.65	0.76	0.82	0.74	0.59	0.56	0.6
Selenium	1	0.56	0.54	0.51	0.51	0.63	0.59	0.65	0.69	0.64	0.55	0.54	0.56
Thallium	0.8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Uranium	15[b]	4.26	3.32	1.51	1.08	6.64	5.79	9.75	12.16	9.02	3.56	2.57	3.67
Zinc	7[b]	6.65	6.16	4.91	4.52	7.52	7.4	9.86	11.33	9.38	6.07	5.43	6.1

Notes:

All values are presented as µg/L.

Shaded values indicate an exceedance of the selected benchmark concentration.

[a] Selected benchmarks represent Nova Scotia Tier 1 guidelines unless specified otherwise.

[b] Adopted from CCME.

[c] Based on baseline concentration in the Killag River.

[d] Site-specific water quality guideline

In the EOM scenario at the near field Northern Settling Pond discharge point, all predicted constituent concentrations were consistently below selected water quality benchmarks in the base case and upper case (Tables 3-3 and 3-4, respectively).

In the PC scenario at the near field Pit lake discharge point, copper and zinc concentrations predicted for several months of the year exceed selected water quality benchmarks in the base case (Table 3-5). In the upper case, zinc concentrations are still predicted to exceed benchmarks for several months while copper concentrations are predicted to exceed year-round. In addition, cadmium concentrations for several months and the arsenic concentration for a single month (August) are predicted to exceed selected water quality benchmarks in the upper case (Table 3-6).

Note that GHD (2019a) identified iron as being elevated, relative to mean baseline, in the EOM near field and far field, upper case, scenarios. Predicted concentrations are only marginally above mean baseline, and well within the baseline range, and hence, the iron concentrations were not considered to represent a risk to aquatic life.

3.5.2 Far-field Predictions

GHD (2019a) predicted chemical concentrations at the far field in Killag River under the EOM and PC scenarios for a base case and an upper case. Table 3-7 and Table 3-8 present the chemical concentrations predicted under the EOM scenario for the base case and the upper case, respectively. Table 3-9 and Table 3-10 present the chemical concentrations predicted under the PC scenario for the base case and the upper case, respectively. In each table, the predicted chemical concentrations are compared to the selected water quality benchmarks outlined in Section 3.4.

Table 3-7 Constituent Concentrations at Far Field in Killag River – EOM Condition Base Case

Constituent	Selected Benchmark Concentration[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Silver	0.25[b]	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05
Aluminum	320[c]	230.44	232.44	242.86	247.05	230.84	223.63	201.2	188.26	205.72	233.97	240.55	236.61
Arsenic	30[d]	3.48	2.85	2.22	2.25	5.62	4.48	6.22	7.33	5.95	3.37	2.98	3.53
Cadmium	0.04[b]	0.018	0.018	0.018	0.019	0.018	0.017	0.016	0.016	0.017	0.018	0.018	0.018
Cobalt	10	0.31	0.3	0.3	0.31	0.34	0.33	0.35	0.36	0.34	0.32	0.31	0.31
Copper	2	0.95	0.95	0.97	0.98	0.97	0.94	0.91	0.89	0.91	0.96	0.97	0.96
Iron	670[c]	473.37	477.64	498.13	506.13	472.25	458.41	412.5	385.89	421.63	479.59	493	485.18
Mercury	0.026	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Manganese	820	48.91	48.07	48.13	48.62	52.59	49.92	50.5	51	50.52	49.13	49.17	49.67
Molybdenum	73	1.51	1.37	1.27	1.31	2.12	1.98	2.62	3.03	2.52	1.64	1.48	1.56
Nickel	25	1	0.99	1	1.01	1.08	1.04	1.07	1.09	1.07	1.03	1.02	1.02
Lead	1	0.32	0.32	0.33	0.33	0.33	0.32	0.31	0.3	0.31	0.32	0.33	0.33
Antimony	20	0.54	0.52	0.5	0.51	0.66	0.58	0.63	0.66	0.62	0.54	0.54	0.56
Selenium	1	0.51	0.5	0.49	0.5	0.57	0.53	0.54	0.55	0.54	0.51	0.51	0.52
Thallium	0.8	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05
Uranium	15[b]	0.7	0.51	0.34	0.37	1.45	1.2	1.94	2.42	1.83	0.79	0.61	0.74
Zinc	7[b]	3.71	3.73	3.83	3.87	3.74	3.65	3.44	3.31	3.48	3.75	3.81	3.78

Notes:

All values are presented as µg/L.

Shaded values indicate an exceedance of the selected benchmark concentration.

[a] Selected benchmarks represent Nova Scotia Tier 1 guidelines unless specified otherwise.

[b] Adopted from CCME.

[c] Based on baseline concentration in the Killag River (75th percentile)

[d] Site-specific water quality guideline

Table 3-8 Constituent concentrations at Far Field in Killag River – EOM Condition Upper Case

Constituent	Selected Benchmark Concentration[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Silver	0.25[b]	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.05
Aluminum	320[c]	235.68	237.36	245.31	248.4	235.21	230.05	212.5	202.32	215.99	238.2	243.32	240.24
Arsenic	30[d]	6.53	5.51	3.45	2.93	8.95	8.27	12.76	15.45	11.93	5.77	4.61	5.81
Cadmium	0.04[b]	0.025	0.024	0.021	0.02	0.023	0.025	0.03	0.033	0.029	0.023	0.021	0.023
Cobalt	10	0.35	0.34	0.33	0.32	0.38	0.39	0.46	0.5	0.45	0.36	0.34	0.35
Copper	2	1.05	1.04	1.02	1.01	1.07	1.08	1.14	1.17	1.13	1.05	1.03	1.04
Iron	670[c]	524.5	527.16	521.04	515.92	503.94	514.99	513.67	511.68	512.82	516.63	516.26	517.33
Mercury	0.026	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01
Manganese	820	62.18	60.47	53.89	51.39	63.13	65.33	77.68	84.81	75.17	59.12	55.63	58.61
Molybdenum	73	3.22	2.68	2.18	2.27	5.5	5.06	7.75	9.45	7.34	3.69	2.98	3.32
Nickel	25	1.12	1.1	1.06	1.05	1.2	1.2	1.34	1.43	1.32	1.13	1.09	1.11
Lead	1	0.33	0.33	0.33	0.34	0.37	0.35	0.35	0.35	0.35	0.34	0.34	0.34
Antimony	20	0.66	0.59	0.53	0.54	0.92	0.76	0.92	1.03	0.9	0.65	0.62	0.68
Selenium	1	0.56	0.53	0.51	0.52	0.7	0.61	0.68	0.72	0.67	0.56	0.55	0.58
Thallium	0.8	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05
Uranium	15[b]	1.13	0.84	0.54	0.57	2.27	1.92	3.14	3.9	2.95	1.25	0.95	1.17
Zinc	7[b]	4.61	4.58	4.22	4.05	4.36	4.66	5.23	5.55	5.11	4.41	4.23	4.36

Notes:

All values are presented as µg/L.

Shaded values indicate an exceedance of the selected benchmark concentration.

[a] Selected benchmarks represent Nova Scotia Tier 1 guidelines unless specified otherwise.

[b] Adopted from CCME.

[c] Based on baseline concentration in the Killag River (75th percentile)

[d] Site-specific water quality guideline

Table 3-9 Constituent concentrations at Far Field in Killag River – PC Condition Base Case

Constituent	Selected Benchmark Concentration[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Silver	0.25[b]	0.07	0.07	0.06	0.05	0.09	0.08	0.1	0.11	0.1	0.07	0.06	0.07
Aluminum	320[c]	232.64	233.54	243.09	247.38	236.51	225.95	203.72	190.82	208.28	235.29	241.95	239.09
Arsenic	30[d]	7.23	5.99	3.6	3.03	10.33	9.21	14.39	17.56	13.44	6.28	4.99	6.44
Cadmium	0.04[b]	0.025	0.023	0.021	0.02	0.029	0.027	0.032	0.035	0.031	0.024	0.022	0.024
Cobalt	10	0.32	0.31	0.3	0.3	0.34	0.33	0.35	0.36	0.35	0.31	0.31	0.32
Copper	2	2.06	1.81	1.35	1.25	2.72	2.45	3.44	4.05	3.26	1.88	1.63	1.92
Iron	670[c]	477.93	479.58	498.79	507.28	486.16	464.72	420.18	394.37	429.34	483.32	496.7	491.07
Mercury	0.026	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Manganese	820	49.86	49.08	48.37	48.37	52.22	50.15	51	51.57	50.87	49.23	49.15	49.93
Molybdenum	73	1.25	1.19	1.07	1.05	1.43	1.34	1.57	1.72	1.53	1.2	1.14	1.22
Nickel	25	1.04	1.02	1	1	1.1	1.05	1.09	1.11	1.08	1.02	1.02	1.04
Lead	1	0.33	0.32	0.33	0.33	0.34	0.32	0.32	0.31	0.32	0.33	0.33	0.33
Antimony	20	0.51	0.5	0.5	0.5	0.55	0.52	0.53	0.54	0.53	0.51	0.51	0.52
Selenium	1	0.51	0.5	0.49	0.5	0.54	0.51	0.52	0.52	0.52	0.5	0.5	0.51
Thallium	0.8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Uranium	15[b]	2.75	2.14	0.98	0.71	4.3	3.73	6.27	7.83	5.81	2.3	1.67	2.38
Zinc	7[b]	5.48	5.09	4.42	4.29	6.54	6.04	7.45	8.32	7.2	5.2	4.86	5.3

Notes:

All values are presented as µg/L.

Shaded values indicate an exceedance of the selected benchmark concentration.

[a] Selected benchmarks represent Nova Scotia Tier 1 guidelines unless specified otherwise.

[b] Adopted from CCME.

[c] Based on baseline concentration in the Killag River (75th percentile)

[d] Site-specific water quality guideline

Table 3-10 Constituent concentrations at Far Field in Killag River – PC Condition Upper Case

Constituent	Selected Benchmark Concentration[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Silver	0.25[b]	0.09	0.08	0.06	0.06	0.13	0.11	0.15	0.18	0.15	0.09	0.08	0.09
Aluminum	320[c]	236.47	237.22	245.18	248.74	239.65	230.83	212.23	201.43	216.04	238.64	244.21	241.84
Arsenic	30[d]	12.23	10.27	5.54	4.13	16.1	15.45	25.23	31.09	23.35	10.2	7.65	10.23
Cadmium	0.04[b]	0.042	0.038	0.027	0.024	0.05	0.049	0.071	0.083	0.066	0.038	0.032	0.038
Cobalt	10	0.37	0.36	0.32	0.31	0.39	0.39	0.46	0.5	0.44	0.35	0.33	0.35
Copper	2	7.85	6.29	3.35	2.66	11.78	10.33	16.78	20.71	15.6	6.7	5.09	6.89
Iron	670[c]	497.81	499.03	512.76	517.52	508.04	498.07	478.83	468.28	483.4	507.01	512.78	507.55
Mercury	0.026	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01
Manganese	820	63.42	61.87	54.21	50.99	62.13	65.53	78.5	85.94	75.71	59.14	55.48	58.8
Molybdenum	73	2.24	1.98	1.43	1.28	2.84	2.65	3.81	4.51	3.59	2.01	1.71	2.04
Nickel	25	1.17	1.14	1.05	1.02	1.23	1.21	1.37	1.46	1.34	1.13	1.09	1.13
Lead	1	0.34	0.34	0.33	0.33	0.37	0.35	0.36	0.36	0.36	0.34	0.34	0.35
Antimony	20	0.61	0.58	0.53	0.52	0.69	0.65	0.75	0.81	0.73	0.59	0.56	0.6
Selenium	1	0.56	0.54	0.51	0.51	0.62	0.58	0.64	0.67	0.63	0.55	0.53	0.56
Thallium	0.8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Uranium	15[b]	4.23	3.3	1.5	1.07	6.56	5.73	9.67	12.06	8.94	3.53	2.54	3.63
Zinc	7[b]	6.59	6.11	4.89	4.51	7.46	7.32	9.73	11.17	9.26	6.02	5.39	6.05

Notes:

All values are presented as µg/L.

Shaded values indicate an exceedance of the selected benchmark concentration.

[a] Selected benchmarks represent Nova Scotia Tier 1 guidelines unless specified otherwise.

[b] Adopted from CCME.

[c] Based on baseline concentration in the Killag River (75th percentile)

[d] Site-specific water quality guideline

In the EOM scenario at the far field in the Killag River, all predicted constituent concentrations were consistently below selected water quality benchmarks in the base case and upper case (Table 3-7 and 3-8, respectively).

In the PC scenario at the far field in the Killag River, copper and zinc concentrations predicted for several months of the year exceed selected water quality benchmarks in the base case (Table 3-9). In the upper case, zinc concentrations are still predicted to exceed benchmarks for several months while copper concentrations are predicted to exceed year-round. In addition, cadmium concentrations for several months and the arsenic concentration for a single month (August) are predicted to exceed selected water quality benchmarks in the upper case (Table 3-10).

Each of these exceedances is discussed further, relative to the likelihood of toxicity, as follows:

- **Arsenic**: An arsenic SSWQO was developed for this project, using the CCME (2007) Species Sensitivity Distribution approach (SSD). All predictions in the EOM and PC scenarios were less than the SSWQO of 30 µg/L, with the exception of a single month, where a concentration of 31.1 µg/L was predicted for the month of August. This predicted value is still below the Lowest effect concentration of 48 µg/L (*Scenedesmus obliquus*; growth endpoint) in the SSD. Toxicity potential associated with this minor elevation, relative to the SSWQO, is considered to be low.
- **Cadmium**: Cadmium does not exceed the aquatic life guideline in any scenario, with the exception of the PC near field and far field scenarios, for the upper case. In these two situations, cadmium is predicted to range from 0.042 to 0.087 µg/L (see Table 3-6 and 3-10). Cadmium toxicity is modified by hardness, and hardness within the Killag River is soft (< 10 mg/L $CaCO_3$). Baseline data are limited (N = 9). Based on the available data, and consideration of toxicity data as cited in CCME (2014), the predicted concentrations would be unlikely to cause toxicity in fish, aquatic plants or in most invertebrate species. The predicted concentrations are within the range of concentrations that may be associated with some toxicity in Daphnia magna, depending on concentrations of modifying factors, such as hardness. While the available data suggest that some toxicity is possible due to the low hardness in the receiving environment, further refinement of source terms in the model, and additional baseline data, will assist in understanding toxicity potential.
- **Copper**: Predicted concentrations do not exceed the guideline in the EOM scenarios, but do exceed guidelines in the PC scenario, for both near field and far field, in the base case and upper case. Concentrations range from 2 to 4 µg/L in the base case, and 2.6 to 20 µg/L in the upper case, relative to a guideline of 2 µg/L. The potential for toxicity is highest in the upper case scenario, particularly in light of the soft waters in the Killag River. Therefore, risk mitigation may be necessary for copper, following refinement of modelling and expansion of baseline data understanding. The current baseline dataset has non-detectable copper concentrations, with a detection limit if 2 µg/L, which is the same as the guideline for copper. The predicted concentrations are added to ½ of the Method Detection Limit (1 µg/L), which may not accurately reflect copper concentrations within the Killag River. Based on the existing information, there is a potential for toxicity associated with copper, and hence, mitigation, such as treatment, may be necessary.

- **Zinc**: Predicted concentrations of zinc do not exceed the NS Tier 1 standard of 30 µg/L in any scenario. The predicted concentrations do not exceed the new CCME guideline for zinc in the EOM scenarios, but do exceed the guideline in the PC scenarios (Base case predictions are 7.3 to 8.5 µg/L in the near field, and 7.2 to 8.3 µg/L in the far field, and range from 7.3 to 11.3 µg/L in the PC upper case far field scenarios, relative to a guideline of 7 µg/L). The Lowest observed effect concentration (LOEC) listed in the CCME (2018) fact sheet is 9.89 µg/L (11 week study; development; Chironomid sp.; normalized to 50 mg/L $CaCO_3$ and Dissolved Organic Carbon (DOC) of 0.5 mg/L). Some of the predicted concentrations are within the range of background (< 5 to 7.8 µg/L; based on limited sample size N=9). While the waters of the Killag River are soft (< 10 mg/L $CaCO_3$), the DOC is currently not known, and could provide adequate protection, for several months indicating elevated levels. Since many of these exceedances are marginal, relative to the guideline, and since background levels based on limited sampling are elevated relative to the guideline, the likelihood of toxicity occurring in the Base case scenarios is considered to be low. Similarly, within the PC scenario, 2 of 5 months with predicted exceedances are within the range of baseline concentrations (suggesting changes in water quality that are similar to naturally occurring conditions), and other predictions are in close approximation to the LOEC of 9.89 µg/L, or slightly higher. The new CCME guideline is a dissolved zinc guideline, as opposed to total zinc. At this time, dissolved zinc levels are unknown, as only total metals baseline data are available. Consideration of dissolved zinc, as well as DOC, may reveal predictions are within guideline levels. Based on the marginal degree of exceedance, and the existing baseline data range, predicted zinc concentrations are considered to have a low potential for toxicity. Expansion of the baseline dataset, including dissolved zinc levels and DOC, as well as additional refinement of source terms in the water modelling, will assist in refinement of this conclusion.

3.6 Predicted Water Quality – With Treatment

Table 3-11 summarizes the scenarios evaluated above in Section 3.5 which had exceedances over the selected benchmarks, suggesting a need for water treatment.

Table 3-11 Summary of Metals Exceeding Selected Aquatic Life Benchmarks in Killag River and Comments Related to Water Treatment Needs

Scenario	Exceedances over Benchmarks		Comments Related to Water Treatment Needs
	Metal/Metalloid	Frequency (months)	
Near Field			
EOM Base Case	NE	NE	No apparent need for treatment
EOM Upper Case	NE	NE	No apparent need for treatment
PC Base Case	Cu; Zn	6; 3[a]	Copper merits further evaluation to determine need for water treatment. Zinc exceedances are marginal, and zinc is considered to have a low potential for risk to aquatic life. Copper and Zinc predictions were added to mean baseline, which is ½ of the detection limit (Copper MDL:

			2 µg/L; zinc MDL: 5 µg/L). Collection of more robust baseline data with improved detection limits may reveal Baseline + Project concentrations remain within benchmarks and treatment requirements are minimal
PC Upper Case	As; Cd; Cu; Zn	1;6;12;5[a]	See above for Copper and Zinc discussion; Arsenic involves a single month which is marginally in exceedance of the SSWQO; risk potential is considered low. Cadmium exceedance is predicted over 6 months. Increased water hardness, relative to cadmium or copper, would assist in mitigating toxicity potential. Copper and potentially cadmium merit further evaluation to determine need for water treatment.
Far Field			
EOM Base Case	NE	NE	No apparent need for treatment
EOM Upper Case	NE	NE	No apparent need for treatment
PC Base Case	Cu; Zn	6;3	See above discussion
PC Upper Case	As; Cd; Cu; Zn	1;6;12;5[a]	See above discussion

NE = No exceedance

[a] No exceedance over NS Tier 1 value; exceeds newer CCME guideline, but in some instances, predicted values are within baseline range

As discussed in GHD (2019a), based on the outcomes of the predictive modelling there is likely a need for some form of water quality treatment. The focus of water treatment based on existing modelling and data would be copper. Refinement of source terms and expansion of the baseline dataset will assist in confirming treatment needs for copper, and whether additional metals/metalloids, such as zinc and arsenic (which have a low risk potential, and hence are not currently meriting treatment) or cadmium, also require treatment. Atlantic Gold has indicated that a water treatment system will be designed to ensure that all site effluent water meets MDMER (at point of release) and CCME or Site Specific objectives (at an appropriate distance downstream, following some mixing). Water quality will be continuously measured in the North Settling Pond, during EOM conditions, and the pit lake, during PC conditions, so that a treatment system, if required, can be scaled as needed to meet effluent discharge guidelines. Sufficient freeboard will be provided in both the North Settling Pond and the pit lake to allow for adequate timing to adjust the treatment process as needed.

GHD (2019a) provides summaries of the anticipated constituent loading removals from the site effluent water required to meet regulatory guideline limits during EOM conditions at the Killag River (Near Field), as well as PC conditions at the Killag River (Near Field) and Far field. The proposed water quality treatment system will be designed to remove the necessary predicted constituent loadings, but will consider the loadings in concert with an expanded baseline database, and refinement of source terms used in the modelling effort. The predicted increments developed by GHD (2019a) are added to the mean of baseline concentrations, which currently only includes 9 samples. Therefore, a better understanding of baseline concentrations of metals will be important, including increased number of samples, total and dissolved metals data, improved detection limits for several metals (e.g., copper and zinc, which have elevated detection limits, and are largely non-detect), such that the predicted increments can be re-examined in light of improved baseline understanding. Some predicted exceedances may not present a risk, following refinement of detection limits and a more robust baseline dataset.

3.7 Summary – Killag River

Under the EOM scenarios, predicted near-field (northern settling pond discharge) and far-field chemical concentrations in the base case and upper case are consistently below selected water quality benchmarks without water treatment. Under the PC scenarios, there is little difference between predicted chemical concentrations at near-field (pit lake discharge) and far-field locations for each assessment each case. In base case PC scenarios, copper and zinc concentrations are predicted to exceed selected water quality benchmarks at both locations without water treatment. At both locations, copper is predicted to exceed in January and from May to September, while zinc is predicted to exceed from July to September. In the upper case PC scenarios, arsenic is predicted to exceed the selected water quality benchmark in August, cadmium is predicted to exceed in January and from May to September, copper is predicted to exceed year-round, and zinc is predicted to exceed from May to September, without water treatment. Zinc and arsenic exceedances are concluded to have a low potential for toxicity, based on the marginal degree of exceedance, relative to the guidelines for these substances. Cadmium may be associated with some potential for toxicity, but the highest exceedances are within two-fold of the guideline, and hence, may have limited toxic potential, depending on baseline water quality characteristics. Copper predictions are more noticeably elevated, relative to the guideline, and hence, have a higher potential for toxicity.

Atlantic Gold Corporation is committed to water treatment, if necessary, to meet appropriate guidelines or site specific water quality objectives in the receiving environment following an appropriate degree of mixing (based on either baseline metrics, such as aluminium or iron, or toxicity data, such as arsenic). As such, metals considered to pose a risk in the receiving environment will be dealt with through appropriate and targeted water treatment, which will be determined based on the following:

- Review and updating of source terms within the water quality modelling to ensure the most accurate data is used to predict potential for impacts;
- An expanded database of baseline data will be important in evaluating need for treatment for some elements, as some elements currently predicted to exceed benchmarks may be within benchmarks when more robust baseline data with improved detection limits are obtained.

4 MOOSE RIVER ASSESSMENT

4.1 Description of Receiving Environment and Baseline Data

As summarized by GHD (2017), Moose River is the largest watercourse at the Touquoy site, and it flows along the western border of the property. As discussed in Chapter 6.6 of the EIS (Surface Water Quality and Quantity), where Moose River is adjacent to the Mine Pit (at surface water monitoring station SW-2, which is the most relevant surface water monitoring station for the assessment of potential aquatic effects associated with discharge from the Touquoy Pit), it is a 3rd order watercourse with an approximately 12.5 m bankfull width as measured in the 2017 hydrometric program. The substrate was noted in the 2017 hydrometric monitoring report is characteristically muddy consisting predominantly of cobbles and small boulders, silt/sand with gravel. An unnamed tributary to Moose River flows south through the Touquoy property, between the open pit and tailings management area. A first order unnamed tributary to the latter, south of the proposed pit, flows southward. Fish River drains Square Lake, northeast of the property, to Scraggy Lake. Fish River then flows west and then south into Lake Charlotte, eventually emptying into Ship Harbour. The Fish River Watershed river system is significant for trout, gaspereau and Atlantic salmon populations. A study area and site map is presented in Figure 4-1.

As discussed in GHD (2017), the tributary to Moose River is very small north of the Mooseland Road and was dry for much of 2005 and 2006. Fish habitat is marginal, dependent on surface flow, and at flow levels observed in 2005 and 2006, expected to be limited to fish excursions during high flows. The culvert at the Mooseland Road was installed incorrectly and is hung, thus preventing fish passage during average and low flow conditions. From the wetland area, downstream there is limited potential for seasonal brook trout habitat. Two small juvenile brook trout were captured just downstream of the woods road (south of the wetland). Moose River may host a small salmon population. Some years, however, Moose River dries up into a series of pools.

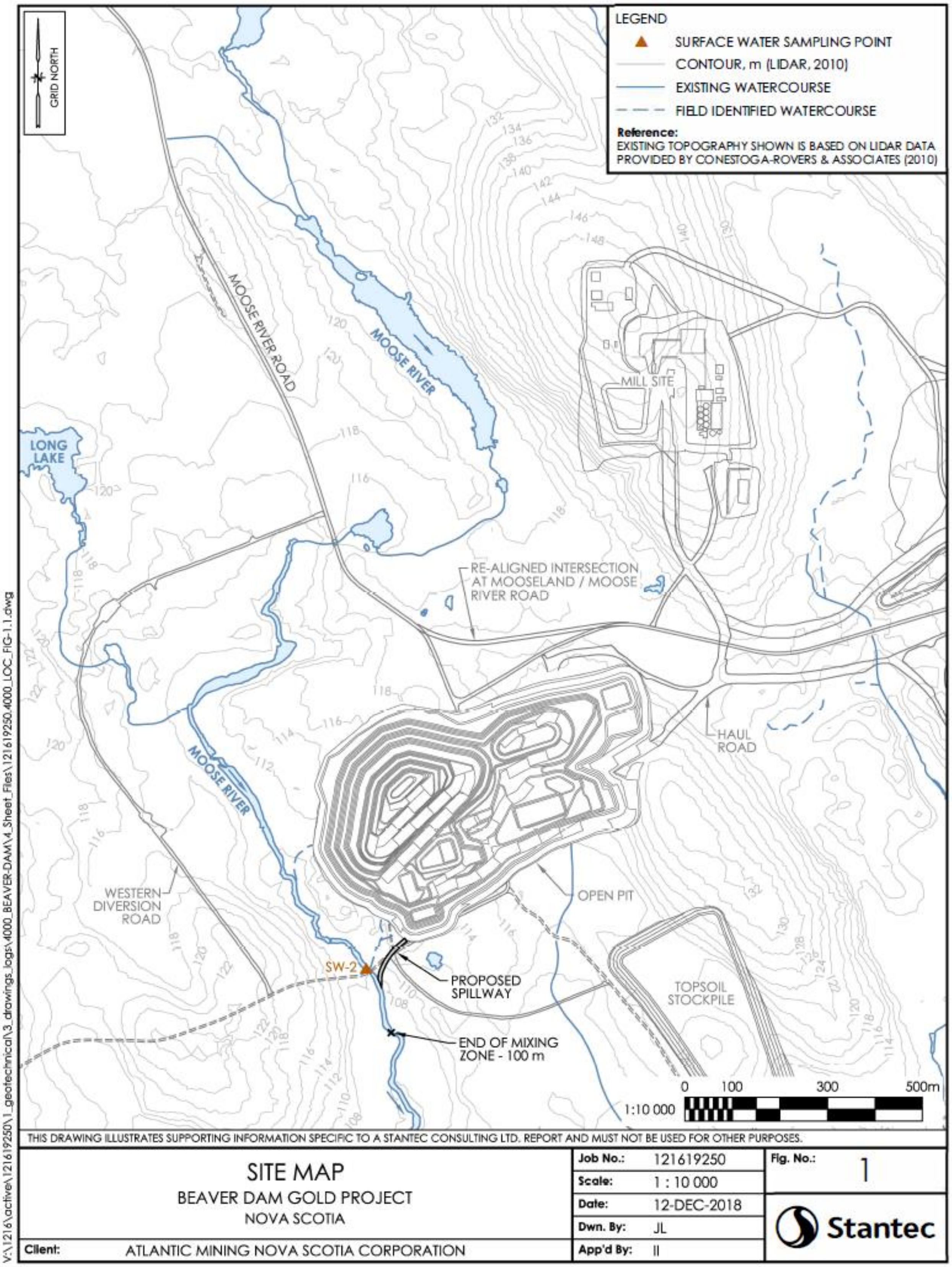

Figure 4-1 Site Map of Beaver Dam Gold Project

Baseline data for surface waters in the area is presented in Table 4-1. The data in Table 4-1 are for surface water monitoring station SW-2, which is where discharge from the Mine Pit at Touquoy will be released, once the pit fills. This station is the most representative of the receiving environment conditions for the assessment of aquatic effects. As discussed in Section 6.6 of the EIS (Surface Water), dissolved ions are low and the water is very soft, indicating little mineral content and influence from weathered rock. The watersheds in the area of Beaver Dam Mine have been logged extensively, yet turbidity is low, indicating a lack of silt in the soils and/or little erosion from logging practices. Alkalinity is low at all sampling locations throughout the Project Area (PA). This is anticipated due to the surficial geology being resistant to weathering and containing little carbonate. pH was generally low in all sampling locations and outside the range identified in the CCME. In addition, as discussed in Chapter 6.6 of the EIS (Surface Water; 6.6.3.2.2), arsenic was noted to consistently exceed the Tier 1 EQS at SW-2 downstream of the open pit in both 2016 and 2017. These elevated arsenic concentrations are not attributed to operation and may be from historical tailing piles and/or the Touquoy ore body itself. A remedial action plan is currently underway by AMNS that involves the delineation, removal, and management of these historical tailings piles around the open pit area. In general, water quality exceedances for aluminum, iron, arsenic, cadmium are commonplace in the environment, even at surface water quality monitoring stations upgradient of the mine ("background" stations) (Stantec, 2018b).

Table 4-1 Baseline Surface Water Concentrations Collected from Moose River (Total Metals mg/L)

Chemical	*Min*	*Max*	*Mean*	*75th Percentile*	*# of Non-Detects*	*CCME (mg/L)*	*Nova Scotia Tier 1 (mg/L)*
Aluminium	0.073	0.35	0.169	0.187	0/22	0.005	0.005
Arsenic	0.004	0.03	0.012	0.018	0/22	0.005	0.005
Calcium	0.84	1.7	1.2	1.3	0/22	NV	NV
Cadmium	<0.00001	0.00004	0.000014	0.000019	7/22	0.00004	0.00001
Cobalt	<0.0004	0.00071	<0.0004	<0.0004	21/22	NV	0.01
Chromium	<0.001	0.0017	<0.001	<0.001	20/22	8.9	NV
Copper	<0.002	<0.002	<0.002	<0.002	22/22	0.002	0.002
Iron	0.19	0.85	0.48	0.62	0/22	0.3	0.3
Lead	<0.0005	0.00086	<0.0005	<0.0005	20/22	0.001	0.001
Mercury	<0.000013	0.00002	<0.000013	<0.000013	20/22	0.000026	0.000026
Magnesium	0.35	0.75	0.488	0.52	0/22	NV	NV
Manganese	0.029	0.18	0.06	0.07	0/22	NV	0.82
Molybdenum	<0.002	<0.002	<0.002	<0.002	22/22	0.073	0.073
Nickel	<0.002	<0.002	<0.002	<0.002	22/22	0.025	0.025
Tin	<0.002	<0.002	<0.001	<0.001	22/22	NV	NV
Selenium	<0.001	<0.001	<0.001	<0.001	22/22	0.001	0.001
Silver	<0.0001	<0.0001	<0.0001	<0.0001	22/22	0.00025	0.0001
Dissolved Sulphate	<2	2.6	<2	<2	19/22	NV	NV
Thallium	<0.0001	<0.0001	<0.0001	<0.0001	22/22	0.0008	0.0008

Uranium	<0.0001	<0.0001	<0.0001	<0.0001	22/22	0.015	0.3
Zinc	<0.005	0.0061	<0.005	<0.005	19/22	0.007	0.03
WAD Cyanide	<0.003	0.004	<0.003	<0.003	21/22	NV	0.005
Total Cyanide (based on Strong Acid Dissociated)	<0.001	0.002	<0.005	<0.005	19/22	NV	0.005
Nitrate (as N)	<0.05	0.18	<0.05	0.054	15/22	13	NV
Nitrite (as N)	<0.01	<0.01	<0.01	<0.01	22/22	0.06	NV
Ammonia	<0.05	0.14	<0.05	0.062	13/21	23.7	NV
pH	4.9	6.89	6.05	6.24	22/22	6-9	NV
Hardness (mg/L $CaCO_3$)	3.5	7.3	5.0	5.25	22/22	NV	NV

Notes:
NV indicates no value provided

As discussed in Stantec (2018a,b), arsenic concentrations varied throughout the stations in the surface water monitoring program near the mine. Moose River experiences levels above the CCME guideline in the summer (lower water flow). This is likely due to arsenopyrite, an iron arsenic sulfide compound, which is common in the surficial and bedrock geology of the area. Other exceedances over freshwater aquatic life guidelines occurred with lead, cadmium, copper, selenium, and zinc, which fluctuated throughout the year at most sampling locations and sometimes slightly exceed the guidelines. Alkalinity is low at all sampling locations throughout the study area, again due to naturally occurring surficial geology being resistant to weathering and containing little carbonate. Similarly, pH was generally low in all sampling locations and outside the range identified in the CCME guidelines; however, this a common feature of surface water in Nova Scotia being influenced by acidic precipitation originating in the northeast United States. At the Touquoy site, pH measures were highly variable, in particular on Moose River, where on several sampling events at two sampling stations, the pH varies by two orders of magnitude. locations.

4.2 Description of Water Quality Modelling Conducted

Stantec (2018a) conducted an assimilative capacity modelling exercise, to predict future water quality in the receiving environment, Moose River. The methodology used followed CCME (2003), which is a framework established for assessing assimilative capacity of receiving environments. As outlined by Stantec (2018a), this approach involved identifying parameters of potential concern within the proposed discharge (such as those that may exceed applicable regulatory limits within the open pit effluent); establishing water quality objectives for the receiving environment (in this case, CCME and NS Tier 1 standards); establishing background parameter concentrations, in the instance that some compounds may be naturally elevated above regulatory objectives; determination of the initial mixing zone; and, development of end of pipe effluent discharge limits which will meet ambient water quality objectives at the edge of the mixing zone.

The specific details of the hydrology of the receiving environment are presented in Stantec (2018a). A water balance model was developed to predict the Open pit effluent overflow to

Moose River at mine closure. Effluent water quality was predicted using the water quality and quantity model and groundwater flow model (see Stantec 2018a). Water quality modelling considered pore water within the tailings, as well as groundwater inflow quality in the pit floor and walls, and dilution from surface runoff, as well as direct precipitation and process water surplus, etc (Stantec, 2018a). Both an average concentration within the open pit and a maximum concentration were predicted.

Based on the modelling conducted, only aluminium, arsenic, cobalt, copper and nitrate were predicted to be present in effluent discharge from the Open Pit at concentrations exceeding NS Tier 1 (2014) or CCME FWAL guidelines, and hence, only these compounds were carried forward for receiving environment predictions (see Stantec, 2018a; Table 5). The modelling effort also examined the potential seepage from the Open Pit via groundwater to the Moose River receiving environment, and none of the elements were predicted to be present in groundwater at concentrations approaching either NS Tier 1 (2013) or CCME FWAL guidelines (see Table 6; Stantec, 2018a).

Receiving environment concentrations of the selected compounds of potential concern (aluminium, arsenic, cobalt, copper and nitrate) were predicted using CORMIX, version 11, and all assumptions and model inputs are provided in Stantec (2018a).

4.3 Selected Benchmarks

Benchmark concentrations used for comparison against predicted water concentrations are presented in Table 4-2. Selection of these benchmark concentrations is described in Section 2.3. These benchmark concentrations were based on the greater of either the water quality guideline selected for use in the assessment (see Table 2-1), or the 75th percentile of the baseline surface water concentrations collected from the Moose River (Table 4-2), except for arsenic for which a site-specific water quality objective was calculated and adopted (see Section 2.3 and Appendix A). As discussed previously, only those chemicals determined to merit further evaluation in the receiving environment by Stantec (2018a) are listed in Table 4-2. Note that GHD (2019a) modelling was provided in µg/L, and the Stantec (2018a) modelling was provided in mg/L. The units used by the authors of these reports were retained in this assessment, to allow comparisons to the original reports, as needed, without confusion.

Table 4-2 Selected Benchmark Concentrations for Use in the Moose River Assessment (mg/L)

Parameter	*Selected Guideline[a]*	*75th Percentile Baseline Concentration*	*Site-Specific Water Quality Objective*	*Selected Benchmark Concentration*
Aluminum	0.005	0.187	-	0.187
Arsenic	0.005	0.018	0.030	0.030
Chromium	0.0089[b]	<0.001	-	0.0089
Cobalt	0.010	<0.0004	-	0.010
Copper	0.002	<0.002	-	0.002
Sulphate	128[c]	<2	-	128
WAD Cyanide	0.005[b,d]	<0.003	-	0.005[b,d]

Total Cyanide (based on Strong Acid Dissociated)	0.005[b,d]	<0.005	-	0.005[b,d]
Nitrite (as N)	0.06[b]	<0.01	-	0.06
Total Ammonia - N	Varies with pH and temperature	0.062	-	1.97[b,e]

Notes:

- not calculated; NDA: no data available

[a] Selected guidelines represent Nova Scotia Tier 1 guidelines unless specified otherwise; see Table 2-1

[b] Selected guideline adopted from CCME.

[c] Selected guideline from BC MOE (see Table 2-1)

[d] based on free cyanide; the application of this guideline for Total Cyanide is overly conservative, and is applied for discussion purposes

[e] Ammonia toxicity increases with increasing temperature and pH. Using the maximum pH from Table 4-1 (6.89), and maximum temperature provided in CCME, 2010 (30 degrees C), a Total ammonia - N guideline of 2.39 mg/L ammonia-N is selected.

4.4 Predicted Water Quality

Predicted future water quality in the effluent from the Open Pit, groundwater and receiving environment of Moose River is provided in Table 4-3. The parameters in the effluent identified by Stantec (2018a) as being in exceedance of regulatory limits included aluminium, arsenic, WAD and Total cyanide, cobalt, copper and nitrite. In addition, as indicated in Table 4-4 some compounds had no regulatory limits identified in either NS Tier 1 (2014), or CCME, and hence, these were included in the aquatic effects assessment, using guidelines from other jurisdictions, where available. These include sulphate and ammonia. The maximum predicted concentration in effluent, as well as the maximum predicted concentration in seepage were both assessed. Where predicted concentrations exceed regulatory guidelines, they are further discussed relative to background concentrations in the receiving environment, and available site specific water quality objectives (arsenic) or other toxicity data and information. Note that the predicted arsenic concentrations in effluent are currently greater than the MDMER limit of 0.3 mg/L (commencing on June 1, 2021), at 0.86 mg/L (Table 6; Stantec, 2018a), and hence, treatment will be required for arsenic to ensure the MDMER limit of 0.3 mg/L is met. For the purposes of predicting receiving environment concentrations at the end of the 100 m mixing zone, arsenic was assumed to meet the MDMER limit of 0.3 mg/L (Stantec, 2018a). The predicted water quality concentrations at the edge of a 100 m mixing zone in the receiver are presented in Table 4-4, relative to the selected benchmarks in Table 4-2.

Table 4-3 Water Quality Modelling Results for Effluent, Groundwater Seepage, and Predicted concentrations at end of 100 m Mixing Zone in Receiving Environment of Moose River, relative to Selected Benchmarks

WQ Parameter[a]	Effluent Max, mg/L[a]	Seepage, Average, mg/L[a]	Receiver, 75th percentile	Concentration at end of 100 m mixing zone	Selected Benchmarks
Aluminum	0.04	Below DL	0.187	0.184	0.187
Arsenic	0.3	0.002	0.018	0.023	0.030
Chromium[b]	0.00038[b]	Below DL[c]	<0.001	0.0005[h]	0.0089
Sulphate[b]	219.0[b]	0.62[c]	< 2.0	5.29[h]	128

WAD Cyanide	0.123	Below DL	<0.003	0.002	0.005
Total Cyanide	0.351[b]	Below DL[c]	<0.001[d]	0.007[h]	0.005
Cobalt	0.064	Below DL	<0.0004	0.0012	0.010
Copper	0.036	Below DL	<0.002	0.0007	0.002
Nitrite (as N)	1.74	Below DL	<0.01	0.034	0.06
Total Ammonia - N	0.88	0.023[c]	0.062	0.077[i]	1.97

Notes:

* Free form of cyanide;

[a] From table 8 of Stantec, 2018, unless indicated

[b] From Table 5 of Stantec, 2018;

[c] From Table 6 of Stantec, 2018;

[d] Total cyanide receiver concentrations are based on Strong Acid Dissociated concentrations

[e] For hexavalent chromium

[f] For Trivalent chromium

[g] No CCME guideline is available; therefore a guideline from BC Moe was used (https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/wqgs-wqos/approved-wqgs/wqg_summary_aquaticlife_wildlife_agri.pdf)

[h] Calculated using a dilution ratio of 51, as per Table 7 of Stantec, 2018, and receiving environment concentration (assumed at ½ the detection limit);

[i] Value provided via email from Stantec, 2019

Based on the predicted future concentrations, relative to available water quality guidelines, total cyanide merits further evaluation. A discussion is also provided for arsenic, as the CCME guideline of 5 µg/L is superseded in this project by a SSQWO of 30 µg/L, to provide additional context.

Arsenic:

While predicted receiving environment concentrations of arsenic at the end of the 100 m mixing zone within Moose River (0.023 mg/L) exceed the CCME FWAL guideline of 0.005 mg/L, this guideline was derived some time ago using a safety factor applied to the Lowest Observed Effect Level [the 14-day EC50 (growth) of 50 µg/L for the algae *Scenedesmus obliquus* (Vocke et al., 1980), with a safety factor of 0.1 (CCME, 1991)]. The Vocke et al. (1980) study was the most sensitive freshwater organism to arsenic identified by the CCME, following consideration of data from 21 different species of fish, 14 species of invertebrates and 14 species of plants. Other regulatory guidelines are also available from other jurisdictions, such as the National recommended water quality criterion known as the Criterion Continuous Concentration (CCC) from the US EPA (US EPA, 2018; arsenic criteria developed in 1995). The CCC is “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 CCC for arsenic are based on the amount of dissolved metal in the water column and is 150 µg/L (0.150 mg/L) and was derived on 1995.

Using the CCME protocol for development of water quality guidelines (CCME, 2007), a Species Sensitivity Distribution approach was used to develop a site specific water quality objective (SSWQO), as discussed in Section 2.3. Details are presented in Appendix A. The value developed is 0.030 mg/L (30 µg/L) and concentrations predicted in receiving environment of

Moose River are below this value. The predicted receiving environment concentration of 0.023 mg/L is below any of the no observed effect concentration (NOEC) or low observed effect concentration (LOEC) data for arsenic provided in Table A-2 for chronic studies. Hence, risks to aquatic life are anticipated to be low.

Total Cyanide:

The chemistry of cyanide is complex, and the toxicity of various cyanide complexes varies widely. So, the form of cyanide in the environment greatly affects the toxicity of the compound. The most toxic form of cyanide is free cyanide, which includes the cyanide ion ($^-$ CN) and HCN (ICMC, 2018). Cyanide is highly reactive, and readily forms simple salts with earth cations and ionic complexes. The strength of the bonds of these associations vary depending upon the salt, and the pH of the environment. Weak or moderately stable complexes are known as WAD (weak acid dissociable), and typically involve cations such as cadmium, copper and zinc. WAD cyanide is less toxic than free cyanide, but when they dissociate they release free cyanide and the metal cation. Typically, WAD complexes dissociate and release HCN under mildly acidic conditions such as those ranging from pH 3 – 6 (OI, 2009). Cyanide can also form very stable complexes with gold, mercury, cobalt and iron. The stability of these complexes in the environment depends on pH in the environment, but strong metals-cyanide complexes (SAD) typically require strongly acidic conditions (pH<2) to dissociate and release HCN (OI, 2009). The term “total cyanide” typically refers to the sum of all cyanide species that are converted to HCN following digestion in a strong acid solution (Total cyanide = free cyanide + WAD + SAD). Other cyanide compounds, such as thiocyanate and cyanate, are markedly less toxic than free cyanide (ICMC, 2018).

With this in mind, a measured or estimated Total Cyanide concentration can range from including 100% SAD forms of cyanide, to 100% free cyanide, depending upon the chemistry of the effluent, and the receiving environment. Some SAD forms of cyanide (iron cyanide complexes) can dissociate in sunlight and release free CN (ICMC, 2018). Other environmental fate processes, such as volatilization, wherein the amount of cyanide lost increases with decreasing pH, and biodegradation, where aerobic conditions result in microbial degradation of cyanide to ammonia, and subsequently, nitrate (ICMC, 2018). Therefore, environmental fate of cyanides in the receiving environment is modified by a number of factors.

It is important to note that the NS Tier 1 guideline of 5 µg/L (which is based on the CCME guideline), is for free cyanide. This guideline is not a relevant guideline to compare Total cyanide, SAD or even WAD forms of cyanide to, as it is based on the free ion, as opposed to bound forms of cyanide, which have far lower toxic potential. Based on the receiving environment predictions in Table 4-3, WAD cyanide is less than half of the Total Cyanide predicted concentration (0.002 mg/L WAD, compared to 0.007 mg/L Total). This implies that the majority of the Total Cyanide prediction would be SAD, and hence, unlikely to dissociate in the receiving environment (mean pH in receiving environment is 6.05; see Table 4-1). Predicted WAD concentrations in the receiving environment are below the NS Tier 1 guideline, indicating acceptable levels of risk to aquatic life. The predicted Total Cyanide concentration in the receiving environment only marginally exceeds the free cyanide guideline, and since the majority of the predicted cyanide is anticipated to be SAD, risk to aquatic life are predicted to be low.

4.5 Summary – Moose River

Based on the predictive modelling conducted, only Total cyanide was predicted to exceed the NS Tier 1 guideline, which is based on free cyanide, and hence not a relevant benchmark for comparison purposes. Based on the available toxicity data and predictions, Total Cyanide is unlikely to be present in concentrations of concern to aquatic life. Arsenic predictions exceed the CCME guideline of 5 µg/L, but not the SSWQO of 30 µg/L, and hence, risks to aquatic life related to arsenic are anticipated to be low

5 UNCERTAINITIES AND LIMITATIONS

As inherent in any risk assessment study, there are limitations, uncertainties and conservative assumptions applicable to this screening level risk assessment, as follows:

- Modelling was conducted to predict surface water concentrations in Killag River and Moose River. Uncertainties associated with the modelling studies are provided in GHD (2019) and Stantec (2018). Conservative assumptions were applied in both modelling exercises, and hence, predicted concentrations should be conservative. For example, to calculate the receiving environment for Moose River, the most conservative dilution ratio (51), was used, using the maximum Open Pit concentrations (Stantec, 2018).
- Baseline data to characterize existing metals concentrations in Killag river are limited (N = 9 samples). In addition, some detection limits are elevated, relative to aquatic life guidelines. Since mean baseline concentrations were added to the predicted increment from the Project, in situations where the mean baseline metric is based on non-detect data and half of the detection limit was used to represent baseline, this characterization is uncertain. Gathering additional baseline data, with improved detection limits will reduce uncertainties in these predictions and assist in identifying water treatment needs.
- The water quality in both Moose River and Killag River is soft. Some mine effluents have increased hardness which can assist in ameliorating receiving environment conditions. In addition, the Killag River has naturally low pH, and the Nova Scotia Salmon Association has been operating an acid mitigation project on the West River for over 10 years. This program involves a lime dosing station which is used to increase the pH of the water to a suitable range for juvenile salmon (to approximately 5.5). The Nova Scotia Salmon Association has indicated that this project has resulted in significant increase in smolt populations and improved overall habitat quality within the West River Sheet Harbour. A second lime dosing station was installed 400 m downstream from the Beaver Dam site, which could substantially improve downstream water quality (pH) and fish survivorship, as current, naturally occurring pH levels are below the CCME required range. Additional baseline data collection will assist in understanding current water quality conditions in the Killag River.
- Toxicity data were assessed to derive the arsenic SSWQO, as per standard methods provided by CCME (2007). Speciation of arsenic in the receiving environments could vary, depending upon various water quality parameters. In all cases, where toxicity data

for both arsenic V and arsenic III were available, the data with the greatest toxicity were selected irrespective of receiving environment conditions. In addition, chronic test time frames were selected over those of shorter durations.

- Toxicity data for certain receptor groups are limited, including amphibians and reptiles. Specific targeted literature searches were conducted to identify any available data for these receptor groups. The standard CCME (2007) protocol was used to derive the SSWQO, and where amphibian and reptile data were available, they were included.

6 CONCLUSIONS

For Killag River, predicted near-field (northern settling pond discharge) and far-field chemical concentrations in the base case and upper case of the EOM scenarios were consistently below selected water quality benchmarks without any included water treatment. Hence, this scenario does not present a risk to the receiving environment. Under the PC scenarios, base case predictions suggest that copper and, to a lesser degree, zinc concentrations will exceed selected water quality benchmarks if no water treatment is included. In the upper case PC scenarios, arsenic is predicted to exceed the site specific water quality benchmark in August, cadmium and zinc are predicted to exceed guidelines in several months, and copper is predicted to exceed guidelines year-round, in the absence of water treatment. Zinc and arsenic exceedances are concluded to have a low potential for toxicity, based on the marginal degree of exceedance, relative to the guidelines for these substances. Cadmium may be associated with some potential for toxicity, but the highest exceedances are within two-fold of the guideline, and hence, may have limited toxic potential, depending on baseline water quality characteristics. Copper predictions are more noticeably elevated, relative to the guideline, and hence, have a higher potential for toxicity.

Atlantic Gold Corporation is committed to water treatment, if necessary, to meet appropriate guidelines or site specific water quality objectives (based on either baseline metrics, such as aluminium or iron, or toxicity data, such as arsenic) in the receiving environment following an appropriate degree of mixing. As such, metals considered to pose a risk in the receiving environment will be dealt with through appropriate and targeted water treatment, which will be determined based on the following:

- Review and updating of source terms within the water quality modelling to ensure the most accurate data is used to predict potential for impacts;
- An expanded database of baseline data will be important in evaluating need for treatment for some elements, as some elements currently predicted to exceed benchmarks may be within benchmarks when more robust baseline data with improved detection limits are obtained.

For Moose River, Total cyanide is predicted to be above a free cyanide guideline in the receiving environment. The free cyanide guideline is not an appropriate benchmark for Total cyanide, and examination of the possible concentrations of WAD and SAD cyanide within the predictions indicate that Total cyanide in the receiving environment is unlikely to pose a risk to aquatic life.

7 REFERENCES

CCME (Canadian Council of Ministers of the Environment). 2003. Canadian water quality guidelines for the protection of aquatic life: Guidance on the site-specific application of water quality guidelines in Canada: Procedures for deriving numerical water quality objectives. In: Canadian environmental quality guidelines, 1999. Winnipeg, MB.

CCME (Canadian Council of Ministers of the Environment). 2007. Canadian water quality guidelines for the protection of aquatic life: Summary table. Updated December 2007. In: Canadian environmental quality guidelines, 1999. Winnipeg, MB.

CCME 2010. Ammonia. http://ceqg-rcqe.ccme.ca/download/en/141

CCME (Canadian Council of Ministers of the Environment). 2018. Canadian Environmental Quality Guidelines. https://www.ccme.ca/en/resources/canadian_environmental_quality_guidelines/

CRA, 2015. Beaver Dam Mine Environmental Impact Statement. Marinette Nova Scotia, Appendix O. https://novascotia.ca/nse/ea/beaver-dam-mine-project/Appendix_O_Beaver_Dam_Mine_EIS.pdf

GHD, 2015. Beaver Dam Mine Project Description; Beaver Dam Mines Road, Marinette, Nova Scotia. Atlantic Gold Corporation. October5, 2015.

GHD, 2017. Beaver Dam Mine Project Environmental Impact Statement Marinette, Nova Scotia https://www.ceaa.gc.ca/050/documents/p80111/119307E.pdf

GHD, 2019a. Predictive Water Quality Assessment, Beaver Dam Mine. Atlantic Gold Corporation. GHD

GHD, 2019b. Beaver Dam Mine Site - Water Balance Analysis. Beaver Dam Mine Project, Marinette, Nova Scotia.

Lorax Environmental, 2018. Beaver Dam Project Geochemical Source Term Predictions for Waste Rock, Low-Grade Ore, Tailings and Overburden. Technical Report prepared for Atlantic Gold Corp. in November 2018.

NSE (Nova Scotia Environment). 2014. Environmental Quality Standards for Contaminated Sites – Rationale and Guidance Document. April 2014.

Stantec, 2018a. Beaver Dam Gold Project Assimilative Capacity Study of Moose River – Touquoy Open Pit Discharge December 21, 2018 File: 121619250. Prepared for:Atlantic Mining Nova Scotia Corporation

Stantec, 2018b. 2017 Annual Report – Surface Water and Groundwater Monitoring Touquoy Gold Project Stantec Project No. 121619250 April 30, 2018

U.S. EPA. 2018. National Recommended Water Quality Criteria. http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm

APPENDIX A
ARSENIC SITE-SPECIFIC WATER QUALITY OBJECTIVE

1.0 INTRODUCTION

The typical starting point for assessment of surface water data in an aquatic effects assessment are the Canadian Water Quality Guidelines for Protection of Freshwater Aquatic Life (WQGl - FWAL), established by the Canadian Council of Ministers of the Environment (CCME). These guidelines are generic, national recommendations which reflect the most current scientific data at the time they were developed. They are intended to provide protection to all forms of aquatic life and aquatic life cycles, including the most sensitive life stages, at all locations across Canada (CCME, 2007). Since they are generic and do not account for site-specific factors that can alter toxicity, these national guidelines can be modified using widely accepted procedures, to derive site-adapted or site-specific water quality objectives (SSWQOs) for a given project or location (CCME, 2003). Modifications to the generic guidelines allow for protection of aquatic species accounting for specific conditions in the receiving environment, primarily due to the following reasons (CCME, 2003):

- There may be naturally-occurring levels of substances that are above the generic guidelines. This is commonplace for metals and metalloids near areas of natural enrichment, such as mines.

- There may be certain characteristics of the water at a specific location or site which modify the toxicity of the substance, such that the generic guideline is unnecessarily conservative (protective). These characteristics are known as exposure and toxicity modifying factors (ETMFs), and can include parameters such as pH, temperature, hardness, and organic matter, amongst others (CCME, 2007).

- There may be certain sensitive species considered in the development of the generic guideline which are not present in the area under assessment (e.g., warm water species which are absent from Canadian environments), and removal of these data allows for a more site-specific guideline to be developed, without compromising protection. In addition, information on toxicity of the substance in question to resident species in the area of interest may be lacking in the existing database, and therefore, there may be interest in expanding the database to include site-specific toxicity data. Or, the existing CCME guideline may be dated and hence, application of more advanced protocols and more recently published data can result in a revised guideline, which is more representative of current scientific practice and available toxicity data.

The purpose of this report is to develop SSWQO for arsenic, based on the assessment of toxicity data and the application of more advanced water quality objective protocols for the Beaver Dam Mine Project. The SSWQO developed in this report will be used to assess surface water arsenic concentrations in the aquatic effects assessment.

2.0 METHODOLOGY

As discussed in CCME (2003), there are typically four possible approaches that can be taken to derive a SSWQO, as follows:

The Background Concentration Approach: This approach can be taken in instances where natural background concentrations exceed the WQGl-FWAL, typically due to natural enrichment (in the case of metals/metalloids). A statistical approach is used to determine the upper limit of natural background, based on available data, which may differ depending upon the number of samples and non-detectable results for a given parameter.

The Recalculation Procedure: This approach could involve the recalculation of the generic FWAL guideline, through removal of data on species that are not relevant to the Beaver Dam Mine area (such as warm water species, etc.), and more recently published data which has become available since the existing guideline was developed. In addition, this procedure would use more recently developed techniques recommended by the CCME in their 2007 protocol. Minimum data requirements outlined in the protocol (CCME, 2007) must be met, and therefore, literature-based data can be supplemented with additional toxicity testing on resident species, if data are limited.

This approach is particularly of interest where existing guidelines are old, and hence may not include scientific literature published in recent years. The CCME (2007) protocol prefers that a Species Sensitivity Distribution (SSD) approach be used to calculate the revised guideline, where there are sufficient data.

Water Effect Ratio (WER) Procedure: This approach allows for site-specific toxicity tests using indicator species and/or resident species which are conducted in side-by-side tests with site water and laboratory water. Using this approach, ETMFs inherent in the site water are accounted for in the toxicity tests. By conducting concurrent toxicity tests using two water types, a ratio of effects between laboratory water and site water can be developed, based on the concept that the laboratory water is representative of that typically utilized in studies captured within the WQGl-FWAL. This ratio is subsequently applied to the WQGl-FWAL to derive a SSWQO.

The Resident Species Approach: This approach involves generating a complete set of toxicity data, using resident species and site water. This approach is typically selected when there are limited toxicity data, or where the ETMF associated with a site may have a significant influence on the guideline.

For the purposes of this assessment, the recalculation procedure was used to derive a SSWQO for arsenic using the SSD approach as per guidance from the CCME (2007) protocol.

2.1 Review of Environmental Fate and Exposure Toxicity Modifying Factors (EMTFs)

2.1.1 Environmental Fate

Arsenic is a ubiquitous metalloid which occurs naturally in the earth's crust (Sharma and Sohn, 2009; HC and EC, 1993). Arsenic exists in four oxidation states: +V (arsenate), +III (arsenite), 0 (arsenic), and –III (arsine). Arsenic compounds can be grouped from a biological and toxicological perspective as inorganic arsenic compounds, organic arsenic compounds and arsine gas (IARC, 2012). In nature, arsenic is most often found in its sulfide form (either alone or with various metals such as silver, lead, copper, nickel, antimony, cobalt and iron), but occasionally occurs as a solid in the elemental state (HC and EC, 1993; IARC, 2012).

Arsenic is mobilized through natural processes such as weathering and erosion of soil and rocks, biological activity and volcanic emissions, and through anthropogenic activities such as smelting of metal ores, coal fired power generation, and use in pesticides and in wood preservers (Smedley and Kinniburgh, 2002; ATSDR, 2007; HC and EC, 1993).

In freshwater, the most prevalent dissolved forms of arsenic are inorganic As V (arsenate) and As III (arsenite). Under aerobic conditions, As V is more stable than As III (WHO, 2001). In lake and river waters, As V is generally the dominant species (e.g., Pettine et al., 1992); however relative portions of As III and As V vary depending upon input sources, redox conditions and biological activity (Smedley and Kinniburgh, 2002). Organic species produced by microbial activity may also be found in freshwater, but to a lesser degree than the inorganic forms. When present in freshwater systems, monomethylarsonic acid (MMA or monomethyl arsenate) and dimethylarsinic acid (DMA or dimethylarsenate), both in the As V state, are the most common forms of dissolved organic arsenic (Braman and Foreback, 1973; Cullen and Reimer, 1989; Markley, 2004; Vukasinovic-Pesic et al., 2005; Smedley and Kinniburgh, 2002). In summer, levels of MMA and DMA have been reported to increase due to increased microbial activity (e.g., Hasegawa, 1997).

The form and concentration of arsenic in water is dependent upon several factors including:

- water oxygen levels (e.g., arsenate predominates under oxidizing / high dissolved O_2 conditions, arsenite predominates under reducing / low dissolved O_2 conditions);
- the degree of biological activity (which is associated with the conversion of inorganic to organic arsenic);
- the type of water source (e.g., freshwater, seawater or groundwater); and,
- how close the water source is to areas naturally enriched in arsenic and / or anthropogenic arsenic sources (Seyler and Martin, 1989; WHO, 2000, 2001).

For the purposes of the assessment, both As V and As III were considered in the development of the arsenic SSWQO as it is possible that both forms exist in the aquatic environment in the area of the Beaver Dam Mine Project.

Natural concentrations of arsenic can be significantly elevated in areas of arsenic-enriched bedrock (HC and EC, 1993). In surface waters, typical arsenic concentrations are <10 µg/L, and are frequently <1 µg/L. Near anthropogenic sources, concentrations have been reported to be as high as 5 mg/L (IARC, 2012; Smedley and Kinniburgh, 2002). In Canada, arsenic concentrations in uncontaminated surface waters are typically <2 µg/L (CCME, 2001).

Arsenic water concentrations tend to be higher in summer than in winter which is likely due to the release of arsenic by surface sediments that have become anoxic causing a release into the water column of arsenic adsorbed on iron and manganese oxides (Singh et al., 1988; Crecelius et al., 1994).

While arsenic can bioaccumulate in aquatic organisms such as algae, crustaceans and fish, it does not appear to biomagnify in freshwater food chains (Eisler, 1988).

2.1.2 Exposure Toxicity Modifying Factors

The toxicity of arsenic is highly dependent on its chemical speciation which influences its mobility in water. The main processes controlling arsenic mobility in water are adsorption (e.g., attachment of arsenic to iron oxide / iron oxyhydroxide surfaces) and desorption reactions and solid-phase precipitation and dissolution reactions (Vukasinovic-Pesic et al., 2005; Senn and Hemond, 2002). Dissolved arsenic can be removed from solution, thereby decreasing bioavailability, through a variety of processes including: biotic uptake, absorption onto iron and manganese hydroxides or clay particles, fixation by organic matter, or to a lesser degree, by precipitation or co-precipitation (Frost and Griffin, 1977; Pierce and Moore, 1982; Thanabalasingam and Pickering, 1986; Korte and Fernando, 1991; Markley, 2004). These processes are, in turn, influenced by pH, redox potential (Eh), organic matter, key inorganic substances such as sulfide and phosphate, and adsorbents (Sharma and Sohn, 2009). The most important factors controlling arsenic speciation have been reported to be Eh and pH (Smedley and Kinniburgh, 2002).

Differing major and minor species of As III, As V, MMA and DMA will be present depending upon pH (Sharma and Sohn, 2009). In natural waters, as the pH increases, arsenate (As V) tends to become less strongly sorbed. When pH increases above 8.5, the concentration of arsenic in solution increases as a result of either i) the adsorbed arsenic desorbing from the surfaces of mineral oxides (especially iron oxides) or ii) the increased pH prevents these anions from being adsorbed (Vukasinovic-Pesic et al., 2005; Smedley and Kinniburgh, 2002). At near neutral pH levels, arsenic can stay in solution at relatively high concentrations (Smedley and Kinniburgh, 2002). Under strongly reducing conditions and at near neutral pH, As desorbs from mineral oxides (Smedley and Kinniburghm 2002). At low to near-neutral pH and under oxidizing conditions, arsenic is strongly adsorbed by oxide minerals as the arsenate ion (As V). Arsenic behaves differently from most metals, which occur in solution as cations, where an increase in pH decreases solubility (Smedley and Kinniburgh, 2002; Vukasinovic-Pesic et al., 2005).

Arsenic, similar to other heavy metalloids (e.g., selenium, antimony, molybdenum, vanadium, chromium) is an oxyanion-forming element (i.e., compound with generic chemical formula $A_xO_y^{z-}$ where A represents an element and O represents oxygen) (Smedley and Kinnburgh, 2002). Arsenic is however, relatively mobile under a wide range of redox conditions (both oxidizing and reducing). This differs from other heavy metalloids (e.g., Se, Cr) which become immobilized under reducing environments (Smedley and Kinnburgh, 2002).

The distribution of arsenic species as a function of pH and Eh were illustrated in Smedley and Kinnburgh (2002) and copied below (Figure A-1). At low pH (<6.9) and under oxidizing conditions (high Eh values) inorganic arsenic occurs mainly as $H_2AsO_4^-$ and as pH increases, $HAsO_4^{-2}$ becomes dominant. Under reducing conditions (low Eh) and at pH <9.2, $H_3AsO_3^0$ predominates (Smedley and Kinnburgh, 2002).

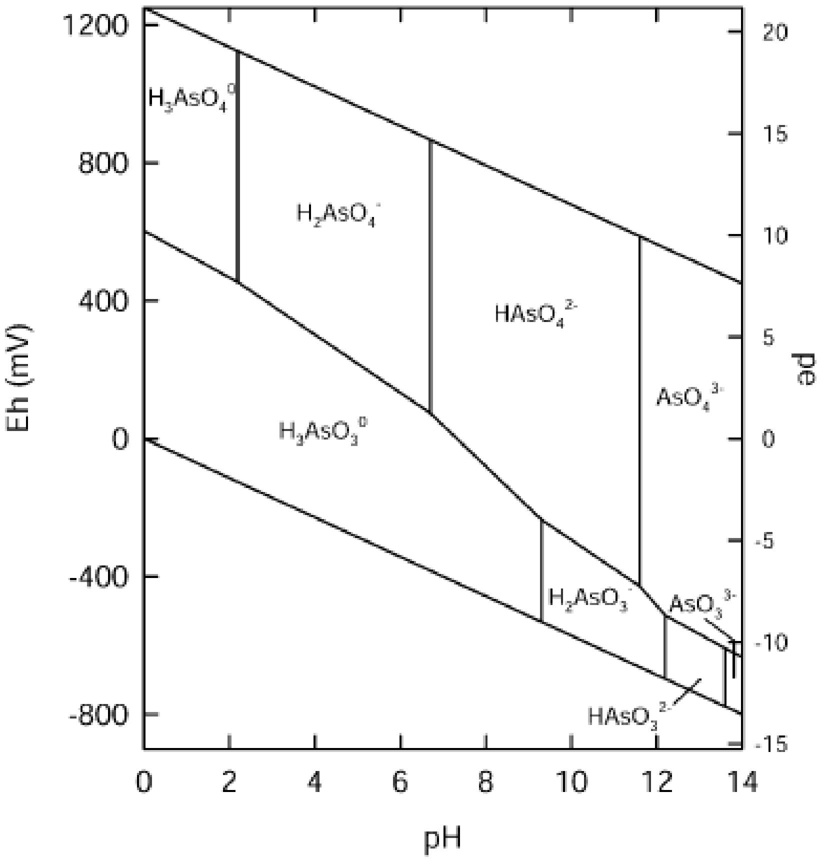

Figure A-1 Eh-pH Diagram for Aqueous Species in the System As-O_2-H_2O at 25ºC and 1 Bar Total Pressure (as presented in Smedley and Kinnburgh, 2002)

Anions such as phosphate, carbonate, bicarbonate, silicate and possibly dissolved organic matter (DOM) can outcompete arsenic for sorption sites which can inhibit arsenic adsorption or increase arsenic leaching from mineral surfaces (Sharma and Sohn, 2009; Campos, 2002; Vukasinovic-Pesic et al., 2005, Smedley and Kinnburgh, 2002). This will result in higher concentrations of dissolved arsenic in surface waters.

In summary, arsenic toxicity in surface water is influenced primarily by pH, Eh, and the presence of other anions.

2.2 Data Considered in the Derivation of the Existing CCME Arsenic Guideline

The CCME WQGl was developed following a review of toxicity data from 21 different species of fish, 14 species of invertebrates and 14 species of plants (CCME, 2001). Toxicity endpoints upon which the chronic CCME (2001) WQGl-FW was developed are provided in Table A-1, where available. Note that chronic data for *Anabus testudineus* (climbing perch) and *Clarius batrachus* (walking catfish) are not included in Table A-1, as these species are not relevant to Canadian waters. The final guideline derived by the CCME was based on the 14-day EC50 (growth) for the algae *Scenedesmus obliquus* (Vocke et al., 1980), which was the most sensitive freshwater organism to arsenic identified. The 50 µg/L EC50 was multiplied by a safety factor of 0.1, to obtain the current guideline value of 5 µg/L (CCME, 1991).

Table A-1 Chronic Toxicity Data for Species Used by CCME for Arsenic WQGl-FW Derivation [1]

Species Used in Toxicity Study	Toxicity Endpoint	Metric	Value (µg/L)	Chemical Form	Reference
Bosmina longirostris	Immobility	96-hour EC50	850	Sodium arsenate	Passino and Novak, 1984
Oncorhynchus mykiss	Lethality	28 day LC50	550	NA	Birge et al., 1978
Cyclops vernalis	Reduced growth (20%)	14 day EC20	320	NA	Borgmann et al., 1980
Daphnia magna	Reproduction (16% ↓ in reproduction)	21 day EC16	520	Sodium arsenate	Biesinger and Christensen, 1972
Gammarus pseudolimnaeus	Lethality	7 day LC80	960	NA	Spehar et al., 1980
Ceriodaphnia dubia	Immobilization	7 day LOEC	1000	NA	Spehar and Fiant, 1986
Scenedesmus obliquus	Growth	14 day EC50	50	Inorganic AsV	Vocke et al., 1980
Melosira granulata	Growth	14 day EC50	75	NA	Planas and Healey, 1978
Ochromonas vallesiaca	Growth	14 day EC50	75	NA	Planas and Healey, 1978

Notes:
NA = not available
1. Data obtained from CCME (2001).

2.3 Review of Available Arsenic Toxicity Data

Toxicity data for use in the derivation of the arsenic SSWQO were compiled from a number of sources, including the following:

- CCME, 2001 Water quality guideline document for arsenic
- US EPA ECOTOX database (www.epa.gov/ecotox/); all forms of arsenic were searched
- Literature searches for arsenic toxicity review papers

A summary of the identified toxicity data for arsenic is provided in Table A-2. Toxicity data for tropical species were excluded as they do not inhabit waterbodies in the region of the Beaver Dam Mine Project. It should also be noted that this is not a comprehensive arsenic review, however, this review is considered to capture most relevant toxicity studies. It was assumed that the CCME conducted a thorough literature search in the derivation of the guideline, and hence the starting point for the literature search was literature commencing following that point. In addition, not all studies were reviewed in detail. The focus of this research was to identify chronic studies, using standardized accepted protocols, on relevant species to Canadian waters.

Chronic test durations are discussed in CCME (2007) and include tests for non-lethal endpoints with durations greater than or equal to 21 days for fish (juveniles or adults), or greater than or equal to 7 days for egg and larval studies. For aquatic invertebrates, chronic test durations are considered to be greater than or equal to 96-h for non-lethal endpoints for shorter-lived invertebrates (e.g., *D. magna*), for nonlethal endpoints of ≥ 7 days duration for longer-lived invertebrates (e.g., crayfish), and lethal endpoints from tests of ≥ 21 days duration for longer-lived invertebrates. Lethal endpoints from shorter-lived invertebrates from tests with <21-day exposure periods are considered on a case-by-case basis. For algal species, all toxicity tests with algae with exposure durations of longer than 24 hours are considered long-term exposure tests because of the length of the algal life cycle compared to the duration of the exposure.

Only those studies of acceptable quality were included in Table A-2. See Attachment 1 for summaries of acceptability rankings.

2.4.1 Identifying Relevant Chronic Toxicity Data

To calculate a chronic SSD, the CCME (2007) has set out the following minimum data requirements which must be met for a Type A guideline:

- Fish: Three studies on freshwater fish species, including one salmonid and one non-salmonid.
- Invertebrates: Three studies on freshwater aquatic / semi-aquatic invertebrate species, at least one of which is a planktonic crustacean species. For semi-aquatic species, life stage tested must be aquatic.
- Plants / Algae: At least one study on freshwater vascular plant or freshwater algal species. Where plants or algae are identified as being among the most sensitive species, the chemical of interest is classified as phytotoxic and three studies on freshwater plant or algal species are then required to derive a long term SSD.

Freshwater toxicity data for arsenic was summarized in Table A-2. Each of these toxicity studies were evaluated for quality and categorized as Primary, Secondary or Unacceptable (see

Attachment 1). Toxicity data from Primary and Secondary studies are considered acceptable for use in the derivation of a SSWQO, however unacceptable data are not. Note that studies by Birge were considered suspect based on a review of the U.S. EPA’s water quality criteria for aluminum and arsenic, which revealed that the corresponding data from these studies were listed as ‘other data’ but were not included in the datasets used for criteria derivation; no reason was given for this exclusion. The Birge (1978) and Birge et al. (1978) data have been found to yield anomalously low toxic concentrations for numerous microelements and were excluded from the SSD. Therefore, the results from these experiments were considered questionable and were not included.

Briefly, for Primary studies, toxicity test must have used currently acceptable standard methods and measured concentrations must be reported. Studies must have sensitive test endpoints with preferred test endpoints for Primary studies including effects on embryonic development, hatching, or germination success; survival of juvenile stages, growth, reproduction; and survival of adults. Other effects such as behavioural or endocrine-disrupting effects can be used if it can be demonstrated these effects are a result of the exposure, they result in an adverse ecological effect and the studies are scientifically sound. For secondary studies, the requirements for standard test methods and measured concentrations are less stringent. The same preferred test endpoints exist for Secondary studies in addition to pathological and behavioural effects (if ecological relevance can be shown, but the requirement for this is not a stringent as it is for primary data) and physiological effects. Toxicity data that do not meet the criteria for either Primary or Secondary studies are considered to be Unacceptable. Additional clarification of Primary, Secondary and Unacceptable studies is provided in CCME (2007).

From the compiled freshwater arsenic toxicity data (Table A-2), those studies designated as Primary or Secondary were considered for use in deriving the SSD.

Table A-2 Arsenic Chronic Toxicity Data

Species	**Chemical**	**Water Quality Parameters**			**Test Duration / Life Stage**	**Chronic Value (µg/L)**	**Reference**
		pH	**T** (ºC)	**Alkalinity / Hardness (mg/L; $CaCO_3$)**			
Aquatic Invertebrate							
Daphnia magna (Water flea)	Sodium arsenite (As III)	7.2 – 8.1	20.8	37 – 45/46 - 49	28 day survival; reproduction NOEC	633	Lima et al., 1984
Daphnia magna	Sodium arsenite (As III)	7.2 – 8.1	20.8	37 – 45/46 - 49	28 day survival; reproduction LOEC	1320	Lima et al., 1984
Daphnia magna	Arsenite (As III)	7.4	21.5 +/-3	45.5/47.2	28 day (growth and reproduction) NOEC	630	Call et al, 1983
Daphnia magna	Arsenite (As III)	7.4	21.5 +/-3	45.5/47.2	28 day (growth and reproduction) LOEC	1320	Call et al, 1983
Daphnia magna	Sodium arsenate (Na_2HAsO_4)	7.4 – 8.2	NR	42.3 / 45.3	21 day EC16 (16% ↓ in reproduction)	520	Biesinger and Christensen, 1972
Daphnia magna	Arsenic III	6.9 – 7.3	14 - 16	40 – 44/42 - 45	14 day Survival and Reproduction; NOEC	955	Spehar et al, 1980
Daphnia magna	Arsenic V	6.9 – 7.3	14 - 16	40 – 44/42 - 45	14 day Survival and Reproduction; NOEC	932	Spehar et al, 1980
Daphnia magna	Arsenic trioxide (As_2O_3)	Measured but NR	21+1	NR	21 day IC10 (reproduction)	1300	Tisler and Zagorc-Koncan, 2002
Cyclops vernalis; C. bicuspidatusthomasi (Copepod)	Sodium arsenite (As III)	7.6 - 8.8	15	88 / 139	14 day EC20	320	Borgmann et al., 1980
Hyallela azteca (Amphipod)	Sodium arsenate (Na_2HAsO_4)	7.23 – 8.83	25	84 / 124	7 day LC50	483	Borgmann et al., 2005
Ceriodaphnia dubia (Water flea)	Sodium Arsenate (As V)	7.9	25.8	50.5/119.4	8 day survival (IC 12.5)	1020	Naddy et al, 1995
Ceriodaphnia dubia	Specific form NR; data for low UV radiation	7.29 – 9.27	25	NR	24 day to 3rd generation NOEC brood size	1000	Hansen et al, 2002
Ceriodaphnia dubia	Specific form NR; data for low UV radiation	7.29 – 9.27	25	NR	24 day to 3rd generation survival NOEC	1500	Hansen et al, 2002

Ceriodaphnia dubia	Sodium arsenite (As III)	8.1 – 8.2	25 +/- 2	97 – 112/100 – 165	7 day MATC (immobilization)	1140	Spehar and Fiandt, 1986
Pteronarcys dorstata (Stonefly)	Arsenic III	6.9 – 7.3	14 - 16	40 – 44/42 - 45	28 day Survival; NOEC	961	Spehar et al, 1980
Pteronarcys dorstata	Arsenic V	6.9 – 7.3	14 - 16	40 – 44/42 - 45	28 day Survival; NOEC	973	Spehar et al, 1980
G. fossarum (Amphipod)	As^{3+} (sodium arsenite)	8	12 +/- 2	NR	10-day LC50	200	Canivet et al, 2001
G. pseudolimnaeus (amphipod)	As^{3+}	6.9 – 7.3	14 - 16	40 – 44/42 - 45	7 day LC80 14 day LC15	960 88	Spehar et al, 1980
G. pseudolimnaeus (amphipod)	As V	6.9 – 7.3	14 - 16	40 – 44/42 - 45	14 day LC20	973	Spehar et al, 1980
H. campanulate (snail)	As^{3+}	6.9 – 7.3	14 - 16	40 – 44/42 - 45	28 day LC5 (LOEC)	960	Spehar et al, 1980
H. campanulate (snail)	As V	6.9 – 7.3	14 - 16	40 – 44/42 - 45	28 day LC10 (LOEC)	973	Spehar et al, 1980
S. emarginata (snail)	As^{3+}	6.9 – 7.3	14 - 16	40 – 44/42 - 45	28 day LC0 (NOEC)	960	Spehar et al, 1980
S. emarginata (snail)	As V	6.9 – 7.3	14 - 16	40 – 44/42 - 45	28 day LC10 (LOEC)	973	Spehar et al, 1980
H. sulfurea (Ephemeroptera)	As^{3+}	8	12 +/- 2	NR	10-day LC50	1650	Canivet et al, 2001[a]
A. aquaticus (Isopod)	As^{3+}	8	12 +/- 2	NR	10-day LC50	2300	Canivet et al, 2001
N. rhenorhodanensis (Amphipod)	As^{3+}	8	12 +/- 2	NR	10-day LC50	3900	Canivet et al, 2001
H. pellucidula (Trichoptera)	As^{3+}	8	12 +/- 2	NR	10-day LC50	2400	Canivet et al, 2001
Physa fontinalis (Snail)	As^{3+}	8	12 +/- 2	NR	10-day LC50	2200	Canivet et al, 2001
G. pulex (amphipod)	Arsenic acid (H_3AsO_4)	NR	10.0	NR	10 day Survival; LC10	376.5	Vellinger et al. 2013[a]
Aquatic Plant / Algae							
Melosira granulata (Diatom)	Na_3AsO_4 (arsenate)	NR	20	NR	IC20/ LOEC (growth) (8 – 24 days)	75	Planas and Healey, 1978
Ochromonas vallesiaca (Algae)	Na_3AsO_4 (arsenate)	NR	20	NR	IC35/ LOEC (growth) (8 – 24 days)	75	Planas and Healey, 1978
Ankistrodesmus falcatus (Algae)	Disodium arsenate	7	24 +/- 2	-/-	14 day EC50 (growth)	256	Vocke et al, 1980
Scenedesmus obliquus (Green algae)	Disodium arsenate	7	24 +/- 2	-/-	14 day EC50 (growth)	48	Vocke et al, 1980

Scenedesmus subspicatus (Green algae)	Arsenic trioxide (As_2O_3)	NR	21+1	NR	72 hour EC10 (growth – biomass)	9400	Tisler and Zagorc-Koncan, 2002
Chlorella sp. (Algae)	As (III)	7.6	27	NR	72 IC50 growth	25,200	Levy et al, 2005
Chlorella sp. (Algae)	As (V)	7.6	27	NR	LOEC/72 h IC50 growth	1930/ 25400	Levy et al, 2005
Monoraphidium arcuatum (Algae)	As (III)	7.6	27	NR	LOEC/ 72 h IC50 growth	3750/ 14600	Levy et al, 2005
Monoraphidium arcuatum (Algae)	As(V)	7.6	27	NR	LOEC/ 72 h IC50 growth	81/254	Levy et al, 2005
Freshwater Fish and Amphibians							
Pimephales promelas (Fathead minnow)	Sodium arsenite (As III)	7.2 – 8.1	23 - 25	37 – 45/46 - 49	29 day post-fertilization (weight, length) NOEC	2130	Lima et al., 1984
Pimephales promelas	Sodium arsenite (As III)	7.2 – 8.1	23 - 25	37 – 45/46 - 49	29 day post-fertilization (weight, length) LOEC	4300	Lima et al., 1984
Pimephales promelas	Sodium arsenite (As III)	7.4	25 +/- 3	42.4/43.9	32 day (growth) MATC	3330	Spehar and Fiandt, 1986
Pimephales promelas	Arsenite (As III)	7.2	23 +/- 2.7	38/49.2	30 day post fertilization (growth) NOEC	2130	Call et al, 1983
Pimephales promelas	Arsenite (As III)	7.2	23 +/- 2.7	38/49.2	30 day post fertilization (growth) LOEC	4300	Call et al, 1983
Pimephales promelas	Sodium arsenate (As V)	6.7 - 7.8	25	- /45 - 48	30 day early life stage test ; growth; NOEC	530	DeFoe, 1982
Pimephales promelas	Sodium arsenate (As V)	6.7 - 7.8	25	- /45 - 48	30 day early life stage test ; growth; LOEC	1500	DeFoe, 1982
Rana pipiens (Northern leopard frog)	Arsenic V	7.9	22 - 23	170	113-day survival, growth, and metamorphosis NOEC	1000	Chen et al. 2009
Micropterus salmoides (Largemouth bass)	$NaAsO_2$	NR	NR	NR	28-day LC1	4601	Birge et al, 1978
Oncorhynchus kisutch (Coho salmon)	As_2O_3	8.2	3.8 – 13.8	88/ 69	6 month LOEC (juvenile migration)	300	Nichols et al, 1984
Oncorhynchus kisutch	As_2O_3	8.2	3.8 – 13.8	88/ 69	6 month NOEC (juvenile survival, growth)	300	Nichols et al, 1984
Oncorhynchus mykiss (Rainbow trout)	$NaAsO_2$	NR	NR	NR	28-day LC1	40	Birge et al, 1978
Oncorhynchus mykiss	Arsenic III	6.9 – 7.3	14 - 16	40 – 44/42 - 45	28 day Survival; NOEC	961	Spehar et al, 1980

Oncorhynchus mykiss	Arsenic V	6.9 – 7.3	14 - 16	40 – 44/42 - 45	28 day Survival; NOEC	973	Spehar et al, 1980
Oncorhynchus mykiss	$NaAsO_2$	7.4	13 +/- 0.5	-/104	28 day LC1	39.7	Birge, 1978
Oncorhynchus mykiss	$NaAsO_2$	7.4	13 +/- 0.5	-/104	28 day LC50	540	Birge, 1978
Oncorhynchus mykiss	Arsenic III (As_2O_3)	7.8	13.4	282/380	181-d growth LOEC 181-d growth NOEC 181-d threshold of chronic toxicity	9640 2480 4900	Rankin and Dixon, 1994

Notes:

T = temperature; NR = not reported

A Data generated by Canivet et al, 2001 and Vellinger et al, 2013 are included in Table A-2 for completeness, but are not considered for the SSD as a 10-day LC50 is not considered long enough to be classified as a chronic study

2.4 Arsenic SSD

Consistent with CCME (2007) guidance, a species sensitivity distribution (SSD) approach was used to derive a Type A guideline. The SSD approach was comprised of identifying chronic toxicity data for species relevant to the Beaver Dam Mine area, analyzing the data using a regression approach and selecting the final chronic effects benchmark. The HC5 (*i.e.*, the concentration that is hazardous to no more than 5% of a species in the community) was selected as the final chronic effects benchmark as per CCME (2007) guidance.

Further details of the approach are provided in the following sections.

2.4.2 SSD Modelling

Data for the aquatic community including freshwater fish, invertebrates, and aquatic vascular and non-vascular plants were used to develop a species sensitivity distribution for arsenic. SSD Master v3 (CCME, 2007) was used to fit four sigmoid-shaped (cumulative distribution function – CDF) models to the chronic toxicity values for freshwater species. SSD Master v3 was designed to facilitate the derivation and selection of appropriate SSD models for use in benchmark setting and risk assessment. The CCME currently uses this application in the development of Type A water quality guidelines for the protection of aquatic life. SSD Master v3 evaluates the data using four models including the Normal, Logistic, Extreme Value (Gompertz) and Gumbel (Fisher-Tippett) models (CCME, 2007). In arithmetic space the Weibull model is also available. The application is fully automated and Excel-based. SSD Master v3 uses the standard Excel Solver add-in to fit the CDF models. Solver proceeds through different combinations of model parameter values until the sum of square error term cannot be further minimized. The application automatically generates residual plots and goodness-of-fit, probability-probability (p-p) and quantile-quantile (q-q) plots, as well as plots of the SSDs and associated approximate confidence intervals.

As is evident in Table A-2, there were a number of test durations, endpoints, and effects reported in the arsenic freshwater toxicity studies. Based on guidance for a CCME WQGl - FWAL (CCME, 2007), the most sensitive endpoint (i.e., growth, reproduction, and mortality) based on appropriate standard test durations are preferred. For the development of a long-term WQGl - FWAL, growth and reproduction endpoints (non-lethal) are preferred. Ideally, the data used to generate the SSD would be regression based (ECx/LCx) for no to low toxic effects (e.g., EC<25). The preferred order of endpoints is: ECx/ICx representing a no-effects threshold >EC10/IC10 > EC11-25/IC11-25 > MATC > NOEC > LOEC> nonlethal EC26-49/IC26-49 > nonlethal EC50/IC50 (CCME, 2007).

In the case of arsenic, there is a varied dataset available with many endpoints and durations for numerous species (Table A-2). The most common endpoint available for most taxa is the no observed effect concentration (NOEC). This is not the preferred endpoint for WQGl - FWAL development as it typically has a significant amount of uncertainty associated with it. NOECs and LOECs are generally poor predictors of low toxic effects (Moore and Caux, 1997). However, there are sufficient NOECs to derive an SSD for the aquatic community using the

CCME WQGl Type A approach, based on the data available. The one exception is for aquatic plants. There are few aquatic plant studies available that are relevant and of acceptable quality. The available data report only LOECs, EC50 and EC10 data for growth (Table A-2), but all of these studies are of an acceptable duration to represent chronic exposures. While only LOECs, EC50 and EC10 data were available for use in the SSD modeling, the effects reported occurred at much lower concentration than were associated with no-effects in other studies, with the exception of the EC10 (growth – biomass) for *Scenedesmus subspicatus* of 9400µg/L (Tisler and Zagorc-Koncan, 2002). As such, all of these data with alternative endpoints (non – NOEC studies) were considered appropriate for use in the SSD modeling.

When deriving an SSD for an aquatic community, it is important to ensure that no one species over-weights the SSD due to its relative sensitivity/tolerance. In many datasets, standard test organisms (e.g., fathead minnow, *Daphna magna*) can bias the results due to the abundance of data for those species. Therefore, when multiple data were available for the same species, the geometric mean of these values was used to represent that species in the SSD. This calculation was required for *Daphnia magna*, *Pimphales promelas*, and *Ceriodaphnia dubia*.

Also, when arsenic III and V data were present for a single species, only the most sensitive dataset was entered into the SSD.

Table A-3 presents the dataset used in the generation of the SSD.

Certain studies had to be excluded, despite being of adequate quality, due to their duration, relative to chronic exposures. These include Canivet et al (2001) and Vellinger et al (2013), which only involved 10 day study durations. Due to the survival endpoint in these studies, and the species tested, a duration of > 21 days would be required for these data to be included in a chronic SSD (as per CCME protocols). Similarly, some of Spehar et al (1980) data for amphipods was of shorter duration (7 day to 14 day) and therefore had to be excluded.

Table A-3 Data Selected and Geometric Means for the same Species for the Species Sensitivity Distribution for Arsenic

Species	Chemical	Water Quality Parameters			Test Duration / Life Stage	Chronic Value (µg/L)	Geometric Mean Value (µg/L)	End Point	Reference	Rating
		pH	T (ºC)	Alkalinity / Hardness (mg/L; $CaCO_3$)						
Aquatic Invertebrates										
Daphnia magna	Sodium arsenite (As III)	7.2 – 8.1	20.8	37 – 45/46 - 49	28 day survival; reproduction NOEC	633	631.5	NOEC	Lima et al., 1984	P
Daphnia magna	Arsenite (As III)	7.4	21.5 +/- 3	45.5/47.2	28 day (growth and reproduction) NOEC	630		NOEC	Call et al, 1983	P
Ceriodaphnia dubia	Specific form not stated; low UV radiation only reported	7.29 – 9.27	25	NR	24 day to 3rd generation NOEC brood size	1000	1224.7	NOEC	Hansen et al, 2002	S
Ceriodaphnia dubia	Specific form not stated; low UV radiation only reported	7.29 – 9.27	25	NR	24 day to 3rd generation survival NOEC	1500		NOEC	Hansen et al, 2002	S
Cyclops vernalis; C. bicuspidatus thomasi (Copepod)	Sodium arsenite (As III)	7.6 - 8.8	15	88 / 139	14 day EC20	320		EC20	Borgmann et al., 1980	S
H. campanulate (snail)	As^{3+}	6.9 – 7.3	14 - 16	40 – 44/42 - 45	28 day LC5 (LOEC)	960		LOEC	Spehar et al, 1980	P
S. emarginata (snail)	As^{3+}	6.9 – 7.3	14 - 16	40 – 44/42 - 45	28 day LC0 (NOEC)	960		LOEC	Spehar et al, 1980	P
Pteronarcys dorstata	Arsenic III	6.9 – 7.3	14 - 16	40 – 44/42 - 45	28 day Survival; NOEC	961		NOEC	Spehar et al, 1980	P
Aquatic Plants										
Ankistrodesmus falcatus (Algae)	Disodium arsenate	7	24 +/- 2	-/-	14 day EC50 (growth)	256		EC50	Vocke et al, 1980	P

Species	Chemical	Water Quality Parameters			Test Duration / Life Stage	Chronic Value (µg/L)	Geometric Mean Value (µg/L)	End Point	Reference	Rating
		pH	T (ºC)	Alkalinity / Hardness (mg/L; $CaCO_3$)						
Chlorella sp. (Algae)	As (V)	7.6	27	NR	LOEC/72 h IC50 growth	1930		LOEC	Levy et al, 2005	S
Monoraphidium Arcuatum (Algae)	As(V)	7.6	27	NR	LOEC/ 72 h IC50 growth	81		LOEC	Levy et al, 2005	S
Scenedesmus obliquus (Green algae)	Disodium arsenate	7	24 +/- 2	-/-	14 day EC50 (growth)	48		EC50	Vocke et al, 1980	P
Scenedesmus subspicatus (Green algae)	Arsenic trioxide (As_2O_3)	NR	21+1	NR	72 hour EC10 (growth – biomass)	9400	9400	EC10	Tisler and Zagorc-Koncan, 2002	P
Melosira granulata	Na_3AsO_4 (arsenate)	NR	20	NR	LOEC (growth) (8 – 24 days)	75	75	LOEC	Planas and Healey, 1978	S
Ochromonas vallesiaca	Na_3AsO_4 (arsenate)	NR	20	NR	LOEC (growth) (8 – 24 days)	75	75	LOEC	Planas and Healey, 1978	S
Freshwater Fish and Amphibians										
Pimephales promelas	Sodium arsenite	7.2 – 8.1	23 - 25	37 – 45/46 - 49	29 day post-fertilization (weight and length) NOEC	2130	1339.7	NOEC	Lima et al., 1984	P
Pimephales promelas	Arsenite	7.2	23 +/- 2.7	38/49.2	30 day post fertilization (growth) NOEC	2130		NOEC	Call et al, 1983	P
Pimephales promelas	Sodium arsenate	6.7 - 7.8	25	- /45 - 48	30 day early life stage test ; growth; NOEC	530		NOEC	DeFoe, 1982	S
Oncorhynchus kisutch	As_2O_3	8.2	3.8 – 13.8	88/ 69	6 month survival and growth (juvenile): NOEC	300		NOEC	Nichols et al, 1984	P
Oncorhynchus mykiss	Arsenic III	7.8	13.4	282/380	181-d growth NOEC	2480		NOEC	Rankin and Dixon, 1994	P

Species	Chemical	Water Quality Parameters			Test Duration / Life Stage	Chronic Value (µg/L)	Geometric Mean Value (µg/L)	End Point	Reference	Rating
		pH	T (ºC)	Alkalinity / Hardness (mg/L; $CaCO_3$)						
Rana pipiens (Northern leopard frog)	Arsenic V	7.9	22 - 23	170	113-day survival, growth, and metamorphosis NOEC	1000		NOEC	Chen et al. 2009	S

2.4.3 SSD Results

Table A-4 presents the data selected to model the SSD and the associated plotting positions in the graph.

Table A-4 Data Selected for the Species Sensitivity Distribution and Associated Plotting Positions

Taxon Grouping	Species	Concentration (µg/L)	Log Concentration	Plotting Position	Species Number
Plant	*Scenedesmus obliquus*	48	1.681241237	0.03	1
Plant	*Melosira granulata*	75	1.875061263	0.08	2
Plant	*Ochromonas vallesiaca*	75	1.875061263	0.14	3
Plant	*M.arcuatum*	81	1.908485019	0.19	4
Plant	*Ankistrodesmus falcatus*	256	2.408239965	0.25	5
Fish	*Oncorhynchus kisutch*	300	2.477121255	0.31	6
Invertebrate	*Cyclops vernalis; C. bicuspidatusthomasi*	320	2.505149978	0.36	7
Invertebrate	*Gammarus pulex*	376.5	2.575764981	0.42	8
Invertebrate	*Daphnia magna*	631.5	2.800373355	0.47	9
Invertebrate	*H. campanulate*	960	2.982271233	0.53	10
Invertebrate	*S. emarginata*	960	2.982271233	0.58	11
Invertebrate	*Pteronarcys dorstata*	961	2.982723388	0.64	12
Amphibian_Reptile	*rana pipens*	1000	3	0.69	13
Invertebrate	*Ceriodaphnia dubia*	1224.7	3.088029718	0.75	14
Fish	*Pimephales promelas*	1339.7	3.127007557	0.81	15
Plant	*Chlorella*	1930	3.285557309	0.86	16
Fish	*Oncorhynchus mykiss*	2480	3.394451681	0.92	17
Plant	*Scenedesmus subspicatus*	9400	3.973127854	0.97	18

Overall, the extreme value distribution provided the best overall fit for the generation of an SSD for the aquatic community according to the Anderson-Darling (AD) goodness-of-fit test statistic (AD statistic = 0.440, $p > 0.05$) and the Mean Square Error in the Lower Tail (MSE lower tail: 0.0286). However, for the purposes of the SSWQO, the fit of the distribution around the HC5 value in the lower tail is of greater importance. Visual inspection of the curve (Figure A-1) indicates that the extreme value model does not represent the data in the lower tail as well as the normal model, which comes much closer to the lowest value in the dataset (48 µg/L for *Scenedesmus obliquus*) (Figure A-2). Comparison of the confidence limits around the HC5 values for the extreme value and normal distributions indicates that the confidence limits around the HC5 of the extreme value distribution (lower confidence limit = 17.56 µg/L; upper confidence limit = 48.87 µg/L; HC5 = 29.29 µg/L) is also wider than that for the normal distribution (lower confidence limit = 41.94 µg/L; upper confidence limit = 68.38 µg/L; HC5 = 53.55 µg/L). A summary of the model results is presented in Table A-5 for comparison purposes. Therefore, based on overall fit, the extreme value distribution provides a better fitting model; however, based on the fit at the lower tail of the distribution, the normal distribution provides a better fitting model and as such, likely provides a more realistic prediction of the HC5. To be conservative however, the HC5 from the extreme value model was selected for use as it provides a lower HC5 (selected extreme value model HC5 is 29.29 µg/L; rounded to 30 µg/L).

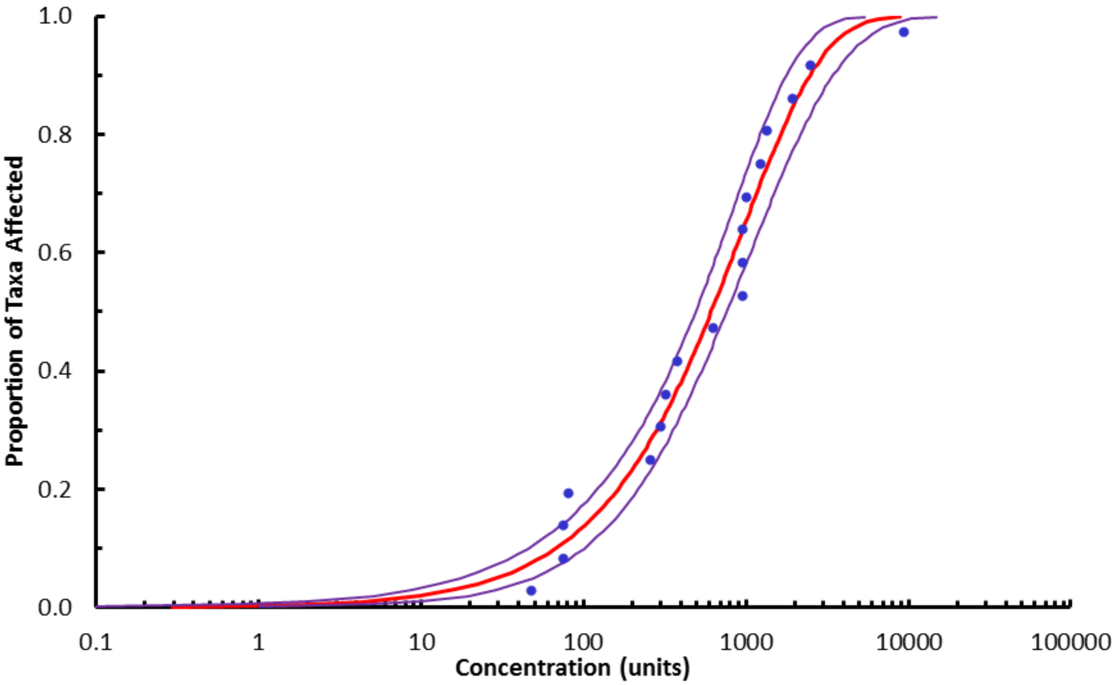

Figure A-1 SSD Based on the Sensitivity of the Freshwater Aquatic Community to Arsenic using the Extreme Value Model

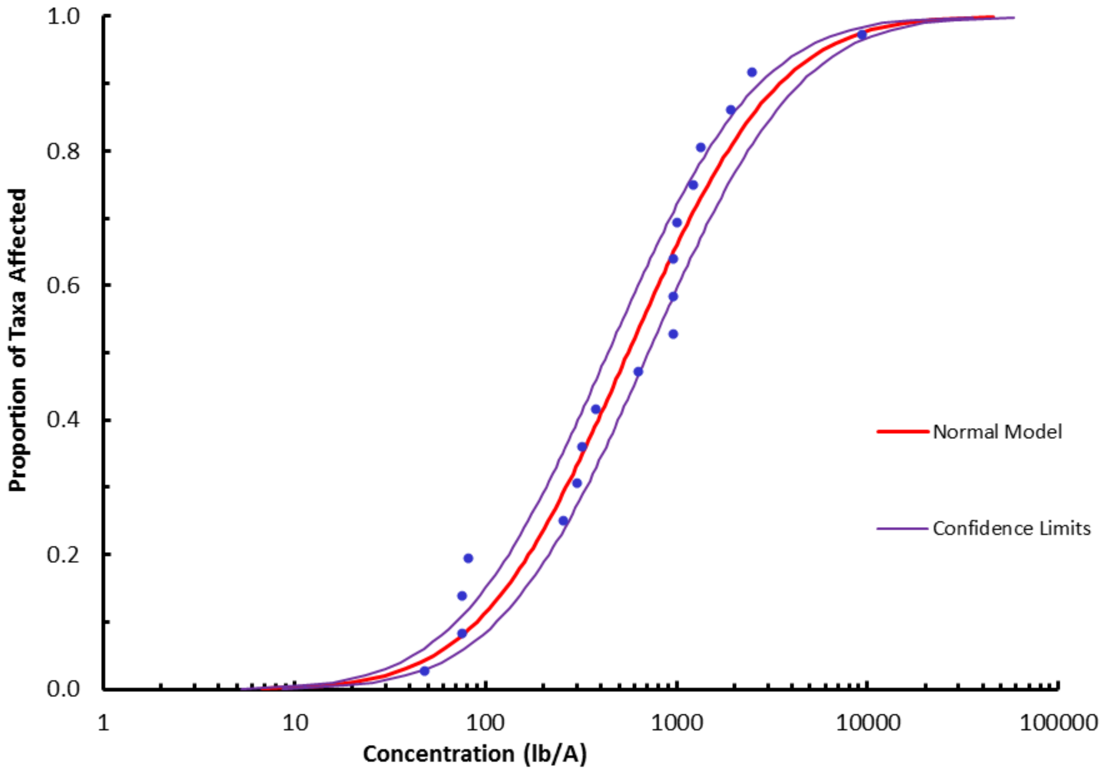

Figure A-2 SSD Based on the Sensitivity of the Freshwater Aquatic Community to Arsenic using the Normal Model

Table A-5 **Comparison of Goodness of Fit Statistics and Model Results (HC5 in µg/L) based on the results from SSD Master v3**

Result	Normal	Logistic	Extreme Value	Gumbel
MSE	0.0035	0.0034	0.0025	0.0057
MSE Lower Tail	0.0368	0.0353	0.0286	0.0554
Data from specified distribution? Anderson-Darling (n>5)	Yes	Yes	Yes	Yes
Anderson-Darling Statistic (A^2)	0.417	0.404	0.440	0.789
HC50 (µg/L)	558.376	565.929	610.058	514.600
HC5 (µg/L)	53.55	45.93	29.29	76.32
Lower confidence limit on the mean (expected HC5)	41.94	31.86	17.56	46.50
Upper confidence limit on the mean (expected HC5)	68.38	66.22	48.87	125.27

The equation for the extreme value model is:

$$f(x) = 1 - e^{-e^{(X-\mu)/S}}$$

Where, *f(x)* = proportion of taxa affected;

x = concentration metameter;

μ = location parameter; and

s = scale parameter (always positive).

The fitted model parameters were: μ = 2.97 and s = 0.506 for the toxicity dataset used in µg/L. The HC5 (concentration that will affect 5% of species in the SSD) was 29.29 µg/L with an approximate lower confidence limit (LCL) of 17.56 µg/L and upper confidence limit (UCL) of 48.87 µg/L.

2.4.4 Proposed SSWQO for Arsenic

The HC5 value of **30 µg/L** (29.29 µg/L rounded upwards) is proposed as the SSWQO for arsenic at the Beaver Dam Mine Area.

While this HC5 value is above the CCME WQGl-FWAL of 5 µg/L (2001), it is more conservative than the toxicity endpoint upon which the CCME WQGl-FWAL is based (i.e., 14-day EC50 (growth) of 48 µg/L for the algae *Scenedesmus obliquus* (Vocke et al., 1980), which was the most sensitive freshwater organism to arsenic identified).

This proposed SSWQO for arsenic is less than the U.S. EPA (1995) CCC for arsenic of 150 µg/L based on dissolved concentrations.

References:

ATSDR (Agency for Toxic Substances and Disease Registry). 2007. Arsenic. CAS# 7440-38-2. ToxFAQs. Agency for Toxic Substances and Disease Registry. http://www.atsdr.cdc.gov/tfacts2.pdf

Biesinger K. E., and Christensen G.M. 1972. Effects of various metals on survival, growth, reproduction and metabolism of Daphnia magna. Journal of the Fish Research Board of Canada, 29, 1691–1700.

Birge, W. J. 1978. Aquatic toxicology of trace elements of coal and fly ash. In Department of Energy (DOE) Symposium Series Energy and Environmental Stress in Aquatic Systems (Augusta, GA, 1977), edited by J. H. Thorp and J.W. Gibbons, 48, 219–240. Springfield, VA: DOE.

Birge, W. J., Hudson J. E., Black J.A., and Westerman, A.G. 1978. Embryo-larval bioassays on inorganic coal elements and in situ biomonitoring of coal-waste effluents. In Proceedings of US

Fish and Wildlife Service Symposium on Surface Mining and Fish/Wildlife Needs in Eastern United States, edited by D.E. Samuel, J.R. Stauffer, C.H. Hocutt and W.T. Mason, 97–104. Washington, DC: US Fish and Wildlife Service.

Borgmann, U., Couillard, Y., Doyle, P., and Dixon, D.G. 2005. Toxicity of Sixty-Three Metals and Metalloids to *Hyalella Azteca* at Two Levels of Water Hardness. Environmental Toxicology and Chemistry, 24 (3), 641–652.

Borgmann, U., Covea, R., and Loveridge, C. 1980. Effect of metals on the biomass production kinetics of freshwater copepods. Canadian Journal of Fisheries and Aquatic Science, 37, 567-575.

Braman, R.A. and Foreback, C.C. 1973. Methylated forms of arsenic in the environment. Science, 182: 1247–1249. Cited In: WHO, 2001.

Call D.J., Brooke L.T., Ahmad, N., and Richter, J.E., 1983. Toxicity and metabolism studies with EPA priority pollutants and related chemicals in freshwater organisms. EPA 600/3-83-095. Duluth, MN: US EPA.

Campos, V. 2002. Arsenic in groundwater affected by phosphate fertilizers at Sao Paulo, Brazil. Environmental Geology 42:83-87. Cited In: Markley, 2004.

Canivet, V., Chambon, P., and Gibert, J. 2001. Toxicity and bioaccumulation of arsenic and chromium in epigean and hypogean freshwater macroinvertebrates. Archives of Environmental Contamination and Toxicology, 40, 345–354.

CCME (Canadian Council of Ministers of the Environment). 1991. Appendix IX—A protocol for the derivation of water quality guidelines for the protection of aquatic life (April 1991). In: Canadian water quality guidelines, Canadian Council of Resource and Environment Ministers. 1987. Prepared by the Task Force on Water Quality Guidelines. [Updated and reprinted with minor revisions and editorial changes in Canadian environmental quality guidelines, Chapter 4, Canadian Council of Ministers of the Environment, 1999, Winnipeg.]

CCME (Canadian Council of Ministers of the Environment). 2001. Canadian water quality guidelines for the protection of aquatic life: Arsenic. Updated. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg. http://ceqg-rcqe.ccme.ca/

CCME (Canadian Council of Ministers of the Environment). 2003. Canadian water quality guidelines for the protection of aquatic life: Guidance on the site-specific application of water quality guidelines in Canada: Procedures for deriving numerical water quality objectives. In: Canadian environmental quality guidelines, 1999. Winnipeg, MB.

CCME (Canadian Council of Ministers of the Environment). 2007. Canadian water quality guidelines for the protection of aquatic life: Summary table. Updated December 2007. In: Canadian environmental quality guidelines, 1999. Winnipeg, MB.

Chen, T.H., Gross, J.A., and Karasov, W.H. 2009. Chronic exposure to pentavalent arsenic of larval leopard frogs (*Rana pipiens*): bioaccumulation and reduced swimming performance. Ecotoxicology. 18, 587-593.

Crecelius, E.A., Apts, C.A., Bingler, L.S. and Cotter, O.A. 1994. The cycling of arsenic species in coal-fired power plant cooling reservoirs. In: Nriagu JO ed. Arsenic in the environment: Part I: Cycling and characterization. New York, John Wiley & Sons, pp 83–97. Cited In: WHO, 2001.

Cullen, W.R. and Reimer, K.J. 1989. Arsenic speciation in the environment. Chem Rev 89:713-764. Cited In: HC and EC, 1993.

De Foe, D. L., 1982. Arsenic (V) test results US EPA, Duluth, MN. Memo to R.L. Spehar, US EPA, Duluth, MN, as cited in ECOTOX database.

Eisler, R. 1988. Arsenic hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 85(1.12). http://www.pwrc.usgs.gov/infobase/eisler/CHR_12_Arsenic.pdf

Frost, R.R., and R.A. Griffin. 1977. Effect of pH on adsorption of arsenic and selenium from landfill leachate by clay minerals. Soil Sci. Soc. Am. J. 41: 53-57. Cited In: HC and EC, 1993.

Hansen, L. J., Whitehead, J. A., and Anderson, S. L. 2002. Solar UV radiation enhances the toxicity of arsenic in *Ceriodaphnia dubia*. Ecotoxicology, 11, 279–287.

Hasegawa, H. 1997. The behavior of trivalent and pentavalent methylarsenicals in Lake Biwa. Appl.Organolnet. Chem., 11, 305-311.

HC & EC (Health Canada and Environment Canada). 1993. Arsenic and its compounds. Canadian Environmental Protection Act. Priority Substances List Assessment Report. Health Canada and Environment Canada. Available on-line at: http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/psl1-lsp1/arsenic_comp/arsenic_comp_2-eng.php

IARC (International Agency for Research of Cancer). 2012 A review of human carcinogens. Part C: Arsenic, metals, fibres, and dusts/ IARC Working Group on the Evaluation of Carcinogenic Risks to Humans (2009: Lyon, France). http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C.pdf

Korte, N.E., and Q. Fernando. 1991. A review of arsenic(III) in groundwater. Critical Reviews in Environmental Control 21(1): 1-39. Cited In: HC and EC, 1993.

Levy, J.L., Stauber, J.L. Adams, M.S., Maher, W.A., Kirby, J.K., and Jolley, D.F. 2005. Toxicity, biotransformation, and mode of action of arsenic in two freshwater microalgae (*Chlorella* sp. and *Monoraphidium arcuatum*). Environmental Toxicology and Chemistry, 24, 2630-2639.

Lima, A. R., Curtis, C., Hammermeister, D. E., Markee, T. P., Northcott, C. E., and Brooke, L. T. 1984. Acute and chronic toxicities of arsenic (III) to fathead minnows, flagfish, daphnids and an amphipod. Archives of Environmental Contamination and Toxicology, 13, 595–601.

Markley, C.T. 2004. Arsenate uptake, sequestration and reduction by a freshwater cyanobacterium: A potential biological control of arsenic in South Texas. A Thesis by Christopher Thomas Markley. Submitted to the Office of Graduate Studies of Texas A and M University in partial fulfillment of the requirements for the degree of Masters of Science. http://geoweb.tamu.edu/Faculty/Herbert/docs/04CTMThesis.pdf

Moore, D.R., and Caux, P. 1997. Estimating low toxic effects. Environmental Toxicology and Chemistry, 16, 794–801.

Naddy, R. B., La Point, T. W., and Klaine, S. J. 1995. Toxicity of Arsenic, Molybdenum and Selenium Combinations to *Ceriodaphnia Duma*. Environmental Toxicology and Chemistry, 14, (2), 329-336.

Nichols, J. W., Wedemeyer, G. A., Mayer, F. L., Dickhoff, W. W., Gregory, S. V., and Yasutake, W. T. 1984. Effects of freshwater exposure to arsenic trioxide on the Parr–Smolt transformation of Coho salmon (*Oncorhynchus kisutch*). Environmental Toxicology and Chemistry, 3, 143–149.

Passino, D.R.M. and Novak, A.J. 1984. Toxicity of arsenate and DDT to the Cladoceran *Bosmina longirostris*. Bulletin of Environmental Contamination and Toxicology, 33, 325–329.

Pettine, M., Camusso, M. and Martinotti, W. 1992. Dissolved and particulate transport of arsenic and chromium in the Po River, Italy. Sc. Tot. Environ. 119, 253–280. Cited In: Smedley and Kinnburgh, 2002.

Pierce, M.L., and C.B. Moore. 1982. Adsorption of arsenite and arsenate on amorphous iron hydroxide. Water Res. 16: 1247-1253. Cited In: HC and EC, 1993.

Planas, D. and F.P. Healey. 1978. Effects of arsenate on growth and phosphorus metabolism of phytoplankton. Jour. Phycol. 14: 337. Cited In: U.S.EPA, 1984.

Rankin, M.G., and Dixon, D.G. 1994. Acute and chronic toxicity of waterborne arsenite to rainbow trout (*Oncorhynchus mykiss*). Canadian Journal of Fisheries and Aquatic Sciences, 51, 372-380.

Senn, D. B. and H. F. Hemond, 2002. Nitrate controls on iron and arsenic in an urban lake. Science, 296: 2373-2375.

Seyler, P. and Martin, J.M. 1989. Biogeochemical processes affecting arsenic species distribution in a permanently stratified lake. Environ Sci Technol, 23(10): 1258–1263. Cited In: WHO, 2001.

Sharma V.K. and Sohn M. 2009. Aquatic Arsenic: Toxicity, speciation, transformations, and remediation, Environment International, 35: 743–759.

Singh, D.B., Prasad, G., Rupainwar, D.C. and Singh, V.N. 1988. As(III) removal from aqueous solution by adsorption. Water Air Soil Pollut, 42(3/4): 373–386. Cited In: WHO, 2001.

Smedley, P.L. and Kiniburgh, D.G. 2002. A review of the source, behavior and distribution of arsenic in natural waters. Applied Geochemistry 17:517-568.

Spehar, R. L., and Fiandt, J. T. 1986. Acute and chronic effects of water quality criteriabased metal mixtures on three aquatic species. Environmental Toxicology and Chemistry, 5, 917–931.

Spehar, R. L., Fiandt, J. T., Anderson, R. L., and De Foe, D. E. 1980. Comparative toxicity of arsenic compounds and their accumulation in invertebrates and fish. Archives of Environmental Contamination and Toxicology, 9, 53–63.

Thanabalasingam, P., and W.F. Pickering. 1986. Effect of pH on interaction between As(III) or As(V) and manganese(IV) oxide. Water Air Soil Pollut. 29: 205-216. Cited In: HC and EC, 1993.

Tišler, T., and Zagorc-Končan, J. 2002. Acute and Chronic Toxicity of Arsenic to Some Aquatic Organisms. Bulletin of Environmental Contamination and Toxicology: 69 (3), 421-429.

U.S. EPA. 1995. 1995 Updates: Water Quality Criteria Documents for the Protection of Aquatic Life in Ambient Water. Office of Research and Development, Mid-Continent Ecology Division, Duluth, MN.

Vellinger, C., Gismondi, E., Felten, V., Rouselle, P., Mehennaoui, K., Parant, M., and Usseglio-Polatera. 2013. Single and combined effects of cadmium and arsenate in *Gammarus pulex* (Crustacea, Amphipoda): Understanding the links between physiological and behavioural responses. Aquatic Toxicology, 140-141, 106-116.

Vocke, R.W., K.L. Sears, J.J. O'Toole, and R.B. Wildman. 1980. Growth responses of selected freshwater algae to trace elements and scrubber ash slurry generated by coal-fired power plants. Water Res. 14: 141.

Vukašinović-Pešić, V.L., Đikanović, M., Blagojević, N. Z., and Rajaković, Lj. V. 2005. The source, characteristic and distribution of arsenic in the environment. *Chem. Ind.Chem. Eng. Q.* 11: 44.

WHO (World Health Organization). 2000. *Air Quality Guidelines for Europe*, 2nd ed. Copenhagen: WHO Regional Publications, European Series, No. 91, 288 pp.

WHO (World Health Organization). 2001. *Arsenic and Arsenic Compounds (Environmental Health Criteria 224)*, 2nd ed. Geneva: World Health Organization, International Programme on Chemical Safety. http://www.who.int/ipcs/publications/ehc/ehc_224/en/