Dear Mr. Mackenzie:

Subject: DDMI Submission – AEMP Calcium Effects Response Plan

Please find attached Diavik Diamond Mines (2012) Inc.’s Aquatic Effects Monitoring Program (AEMP) Calcium Response Plan. This Response Plan proposes a site-specific AEMP Effects Benchmark of 60 mg/L for dissolved calcium that is considered adequately protective of aquatic life.

Please do not hesitate to contact the undersigned if you have any questions related to this submission.

Yours sincerely,

Sean Sinclair
Superintendent, Environment

cc: Anneli Jokela, WLWB
AEMP RESPONSE PLAN FOR DIAVIK DIAMOND MINE – PROPOSED CALCIUM EFFECTS BENCHMARK

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by Diavik Diamond Mines (2012) Inc. (DDMI) to prepare an Aquatic Effect Monitoring Program (AEMP) Response Plan, to meet requirements set out in Part J Item 6(b) of the Water Licence W2015L2-0001 for submission to the Wek’èezhìı Land and Water Board (WLWB).

The results of the Action Level evaluation completed for the 2018 AEMP identified 19 water quality variables that triggered Action Levels (Golder 2019). Nineteen triggered Action Level 1 and ten subsequently also triggered Action Level 2. None of the water quality variables triggered Action Level 3 in 2018. An additional four variables were included in the Action Level assessment because they triggered an effect equivalent to Action Level 1 at one or more mid-field stations located within the estimated zone of influence from dust deposition (but not in the near-field area). Under the AEMP Response Framework (as described in the approved AEMP Design Plan Version 4.1), when a water quality variable triggers Action Level 2, the required management action is to establish an AEMP Effects Benchmark for that variable if one does not already exist. One of the variables that triggered Action Level 2 (i.e., dissolved calcium) does not have an existing Effects Benchmark, therefore the objective of this memorandum is to propose a site-specific Effects Benchmark for dissolved calcium that is protective against chronic toxicity under site-specific conditions.

No further action is required based on the results of the Action Level evaluation for water quality in 2018.

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1 Action Level 1 is triggered if there is a two-fold difference between NF median concentrations and reference dataset median concentrations (calculated using the procedure outlined in the AEMP Reference Conditions Report Version 1.1 [Golder 2015]).

2 Action Level 2 is triggered if the 5th percentile concentration in the Near-field area is greater than two-times the median concentration in reference datasets, and greater than the normal range in Lac De Gras (Golder 2019).

3 Action Level 3 would occur if the 75th percentile concentration of mixing zone values are greater than the normal range and also greater than 25% of the distance between the top of the normal range and the Effects Benchmark.
2.0 CALCIUM EFFECTS BENCHMARK DEVELOPMENT

As calcium is a relatively toxicologically inert relative to other major ions (Mount et al. 1997), the Effects Benchmark was developed based on total dissolved solids (TDS) concentrations. This exercise involved the following tasks:

- Review of major ion toxicity with a focus on calcium relative to other major ions
- Discussion of site-specific TDS composition
- Derivation of an Effects Benchmark for calcium as a proportion of the site-specific TDS Effects Benchmark

2.1 Major Ion Toxicity

Ions are naturally present in aquatic environments with major ions consisting of calcium (Ca\(^{2+}\)), chloride (Cl\(^{-}\)), sodium (Na\(^{+}\)), potassium (K\(^{+}\)), magnesium (Mg\(^{2+}\)), sulphate (SO\(_{4}\)\(^{2-}\)), bicarbonate (HCO\(_{3}\)\(^{-}\)) and nitrate (NO\(_{3}\)\(^{-}\)). Some ions are essential for supporting aquatic life (e.g., Na\(^{+}\), Ca\(^{2+}\), and Cl\(^{-}\)). The relative composition of individual ions in the aquatic environment is determined by natural features, such as geology, atmospheric precipitation, and the water balance (i.e., evaporation-precipitation) (Weber-Scannell and Duffy 2007). Although these ions are naturally present, anthropogenic activities can increase ion concentrations to levels that may be toxic to aquatic life.

The toxicity of major ions is variable. Mount et al. (1997) exposed the water fleas Ceriodaphnia dubia and Daphnia magna as well as Fathead Minnow (Pimephales promelas) to over 2,900 ion solutions for 24, 48 or 96-hours and assessed organism survival against ionic composition (via statistical regression) to determine relative ion toxicity. In general, ion toxicity from highest to lowest was K\(^{+}\) > HCO\(_{3}\)\(^{-}\) = Mg\(^{2+}\) > Cl\(^{-}\) > SO\(_{4}\)\(^{2-}\). Sodium and calcium were not identified as significant variables in the regression and therefore, Mount et al. (1997) attributed the toxicity of sodium and calcium salts primarily to their anion (e.g., chloride, sulphate, bicarbonate).

Recent experiments have evaluated the effect of calcium as a toxicity modifying factor in exposures of TDS to sensitive freshwater taxa. Scheibener et al. (2017) demonstrated that for the mayfly (Neocleon triangulifer), waters with high calcium to magnesium (Ca:Mg) ratios exhibited reduced toxicity. This is an important finding given that mayflies (Order Ephemeroptera) have been identified as a sensitive test organism to elevated major ion concentrations in mine-influenced waters (Soucek et al. 2018). Hardness-dependence of major ion toxicity to cladocerans, amphipods, and fish is well known. To this end, calcium has recently been identified as the key component of hardness that ameliorates toxicity (Davies and Hall 2007; Mount et al. 2016).

Calcium is relatively inert; its toxicity has been evaluated in aquatic test species as summarized below:

- Patrick et al. (1968) exposed the diatom Nitzschi linearis to four salts and reported 120-h effects concentration\(^4\) (i.e., EC\(_{50}\)) as follows: calcium sulphate (3,200 mg/L), calcium chloride (3,130 mg/L), sodium chloride (2,430 mg/L) and potassium chloride (1,337 mg/L). Based on these results, the diatom was more sensitive to sodium and potassium anions relative to calcium.

- Biesinger and Christensen (1972) exposed D. magna to calcium and reported 48-hr lethal concentration\(^5\) (i.e., LC\(_{50}\)) values of 52 and 464 mg/L Ca\(^{2+}\) with tests conducted without and with food, respectively.

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\(^4\) Effects concentration, as EC\(_{x}\), is the concentration of sample estimated to cause a specified effect to \(x\%\) of the test organisms.

\(^5\) Lethal concentration, as LC\(_{x}\), is the concentration of sample estimated to be lethal to \(x\%\) of the test organisms.
Typically, acute toxicity testing with *D. magna* is conducted without food because the presence of food may affect toxicant bioavailability. In this study, the presence of food increased the LC50 value by approximately nine-fold. Biesinger and Christensen (1972) also conducted a 21-day chronic toxicity test (with feeding, due to test duration) and reported 21-d LC50 of 330 mg/L Ca2+ and 21-day inhibitory concentration6 (i.e., IC50 and IC16 values) for reduced reproduction of 220 and 116 mg/L Ca2+, respectively. As reviewed in Golder (2011), the 52 mg/L value is likely an outlier, as it was lower than all other reported values in this study.

- Goodfellow et al. (2000) and Ketola et al. (1988) reported effects on fish exposed to calcium of 266 mg/L Ca2+ (96-hr LC50) and 520 mg/L Ca2+ (66% mortality). In the former study (Goodfellow et al. 2000), effects on survival of Fathead Minnow were observed and attributed to the Ca2+ to Na+ ratio in the water; when a higher proportion of calcium relative to sodium was present in the effluent, organism survival was reduced. In the latter study (Ketola et al. 1998), effects of water chemistry (e.g., Ca2+) during the water hardening stage on egg survival were observed in Rainbow Trout, Atlantic Salmon (*Salmo salar*), and Brook Trout (*Salvelinus fontinalis*). Several other studies evaluating the acute toxicity of calcium chloride to various fish species have reported acute LC50 values ranging from 4,000 to >10,000 mg/L (Dowden and Bennett 1965; Patrick et al. 1968; Grizzle and Mauldin 1995; Stoss et al. 1977; Waller et al. 1996).

- A few studies (Alstad et al. 1999; Hessen et al. 2000) have reported adverse effects in *D. magna* due to calcium limitation, which can affect the distribution of zooplankton species (Alstad et al. 1999; Waevagen et al. 2002). Hessen et al. (2000) reported reduced age-specific egg production in *D. magna* due to reduced growth rates in the presence of calcium concentrations less than 10 mg/L.

Calcium and magnesium are the predominant dissolved cations in most freshwaters (SETAC 2004). Collectively, these cations contribute to water hardness. Although potentially toxic, water hardness (as calcium and magnesium) is commonly incorporated into water quality guidelines as a toxicity modifying factor because water hardness can influence the toxicity of major ions and metals (CCME 2007); generally, as water hardness increases, toxicity decreases.

The toxicity of major ions as part of a complex mixture known as TDS is also commonly assessed, as discussed below.

### 2.2 Total Dissolved Solids

Total dissolved solids is often measured in water as an indication of the concentration of major ions in aquatic environments. TDS is defined as the sum of the concentration of all common dissolved ions (e.g., sodium, calcium, magnesium, potassium, chloride, sulphate, bicarbonate, nitrate) in freshwaters (APHA 2005) and is calculated as:

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\text{TDS}_{\text{calculated}} \ (\text{mg/L}) = \sum [\text{Na}^+, \ \text{K}^+, \ \text{Ca}^{2+}, \ \text{Mg}^{2+}, \ \text{Cl}^-, \ \text{F}^-, \ \text{SO}_4^{2-}, \ 4.42\times\text{NO}_3^- \ (\text{as N}), \ 0.6\times\text{total alkalinity} \ (\text{as CaCO}_3)]
\]

In 2018, TDS concentrations for Lac De Gras in the near-field, mid-field, and far-field areas ranged from 11 to 36 mg/L. The percent contribution of individual constituent ions to overall TDS concentration on average in the near-field, mid-field and far-field areas in 2018 was approximately 24% sulphate, 20% carbonate alkalinity (as CO32-).

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6 Inhibitory concentration, as ICx, is the concentration of sample estimated to cause a x% reduction in an endpoint (e.g., growth, reproduction) of the test organisms.
19% chloride, 13% sodium, 12% calcium, 6% magnesium, 6% potassium, with minor contributions from fluoride and nitrate (1.2% of TDS combined). The proportion of calcium in TDS in 2018 was consistent with previous years; from 2015 to 2017 the average percentage (in the near-field, mid-field and far-field areas) ranged between 11% and 12%. The calcium proportion was also spatially consistent in 2018 with an average contribution to TDS of 12% in all sampling areas.

Under the AEMP, there is an Effects Benchmark for TDS of 500 mg/L. This Effects Benchmark was adopted from the Alaska Department of Environmental Conservation (ADEC 2012) and as dictated by the WLWB (2013). Chapman et al. (2000) reported that studies conducted for Coeur Alaska’s Kensington Mine site resulted in the first site-specific TDS permit in Alaska. In Alaska, TDS may not exceed 1,000 mg/L (ADEC 2012) or 500 mg/L during spawning periods (Brix et al. 2010). However, concentrations of TDS up to 1,500 mg/L are permitted during periods when salmonids are not spawning, and if the TDS mixture comprises greater than 50% calcium by weight of the total cations (ADEC 2012; Brix et al. 2010).

DDMI proposed a TDS Effects Benchmark of 1,000 mg/L based on the ADEC (2012) water quality standard but following review by the WLWB (2013), an Effects Benchmark of 500 mg/L was selected and is reflective of the lower-bound ADEC (2012) guideline.

2.3 Derivation Procedure and Results

Toxicity data specific to calcium are limited, partly due to the challenges in discerning the toxicity attributable to calcium from that associated with the counter-ions used in testing (Mount et al. 1997). As discussed in Section 1.0, calcium is relatively inert compared to the other major ions within TDS. The toxicity of ions can be assessed individually or as part of a complex mixture (i.e., TDS); where testing of TDS mixtures has been evaluated, higher proportions of calcium exhibit lower toxicity than those with less calcium. Calcium may modify toxicity of other major ions and metals, through water hardness, with lower toxicity observed at elevated hardness. Given the challenges with decoupling calcium toxicity from overall TDS toxicity, a conservative approach is to adjust the Effects Benchmark for TDS of 500 mg/L to account for the proportion of calcium observed in site-specific mixtures. Because calcium is less toxic than most components of TDS, this results in an Effects Benchmark that will likely be lower than the true threshold for toxicity.

Calcium contributed an average of 12% of TDS in 2018 in Lac De Gras in the near-field, mid-field and far-field areas. Therefore, an Effects Benchmark of 60 mg/L calcium was derived (i.e., 12% of 500 mg/L TDS). A bounding analysis was conducted to calculate the lower- and upper-bound of the calcium Effects Benchmark based on the 2018 whole-lake 5th and 95th percentiles of percent calcium in TDS. The lower- and upper-bound Effects Benchmarks based on a percent calcium in TDS of 10% (in the mid-field area) and 13% (in the far-field area) are 50 and 65 mg/L, respectively. The historical dataset was also reviewed to determine if the average proportion of calcium within TDS has increased in the past several years. A review of data collected between 2015 to 2017 indicated that the average whole-lake percent calcium within TDS has remained steady, between 11% and 12%. Therefore, an Effects Benchmark of 60 mg/L is representative of current and recent historical conditions in Lac de Gras.

An Effects Benchmark of 60 mg/L is protective when compared to the available toxicity data for exposure to the calcium ion. Again, this approach is conservative because aquatic toxicity tends to be lower when there is a mixture of cations present (as occurs in field conditions), rather than one or two ions in a synthetic laboratory.
mixture (Mount et al. 1997). The benchmark of 60 mg/L is four-times lower than the lowest effects concentration reported for fish (i.e., 96-hr LC$_{50}$ of 266 mg/L; Goodfellow et al. 2000), and two-times lower than the lowest acceptable effects concentration reported for aquatic invertebrates (21-d IC$_{16}$ of 116 mg/L; Biesinger and Christensen 1972). Therefore, the Effects Benchmark of 60 mg/L calcium is considered adequately protective of aquatic life.

3.0 CLOSURE

We trust that the information provided in this technical memorandum is sufficient for your needs at this time. Should you have any questions or concerns, please do not hesitate to contact the undersigned at 780-483-3499.

GOLDER ASSOCIATES LTD.

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REFERENCES

ADEC (Alaska Department of Environmental Conservation). 2012. Water Quality Standards. 18 AAC 70. Alaska Department of Environmental Conservation, Juneau, AK, USA.


