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REPORT ON

SITE-SPECIFIC WATER QUALITY OBJECTIVE FOR COPPER FOR THE PROPOSED DORIS NORTH PROJECT

Submitted to:

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EXECUTIVE SUMMARY

Golder Associates Limited (Golder) was retained by Miramar Hope Bay Ltd. (MHBL) to derive a site-specific water quality objective for the proposed Doris North mining project. Naturally elevated background concentrations of copper in the receiving environment increase the probability that discharging water from the proposed tailings impoundment will result in exceedances of the Canadian Council of Ministers on the Environment (CCME) interim water quality guideline for copper in the receiving environment.

According to CCME:

> *Environmental quality guidelines should not be regarded as blanket values for national environmental quality. Variations in environmental conditions across Canada will affect environmental quality in different ways. Therefore, the users of EQG may need to consider local conditions and other supporting information (e.g., site-specific background concentrations of naturally occurring substances) during the implementation of EQGs.* ***Science-based site-specific criteria, guidelines, objectives, or standards may therefore differ from the Canadian EQGs recommended in this document*** (at Introduction, Canadian Environmental Quality Guidelines, p. 2; emphasis added).
>
> *In order to apply this scientific information, for example to recommend site-specific water quality objectives, many factors such as the local water quality, resident biotic species, local water demands, and other elements have to be considered* (at Introduction, Chapter 4, Canadian Water Quality Guidelines for the Protection of Aquatic life, p.2).

The CCME interim guideline for copper dates back to 1987. The "interim" classification reflects the fact that copper toxicity data that existed in 1987 did not meet the criteria for quality and/or quantity to derive a full water quality guideline (WQG). Since 1987 there have been a number of advances in the understanding of metal toxicity and factors that determine toxicity in surface waters. This improved understanding has shown that site-specific water quality parameters have an effect on the toxicity of dissolved metals. Two processes can affect predicted metal toxicity: complexation and competition. First, **complexation** of metals in the water column can occur when metals bind with organic and inorganic ligands, and can result in a decreased bioavailability of dissolved metals. Common examples are the strong binding of copper with dissolved organic carbon and carbonates. Second, **competition** for binding sites can occur at the surface of fish gills (or the respiratory surfaces of less evolved aquatic organisms). It is well known that acute toxicity of metals is related to the binding of metals to sodium channel sites on the gill surface (also referred to as the "biotic ligand"). However, in addition to metals, other anions that are commonly present in surface waters (such as calcium, hydrogen, sodium, magnesium and potassium) can also bind at the biotic ligand. These anions can compete with metals for binding sites at the biotic ligand, and an increase in anion concentration will result in a decrease in metal binding and therefore lower predicted toxicity due to metals.

Complexation and competition processes are described in biotic ligand models (BLMs). BLMs have been recognized by regulatory agencies in the US, the European Union (EU) and Canada as a tool for developing site-specific water quality objectives. The USEPA has recently drafted a water quality criteria derivation protocol for copper that incorporates a BLM (USEPA 2003a). The USEPA BLM was used in this report to develop a site-specific water quality objective for the proposed Doris North project based on a distribution of BLM-calculated water quality values (WQVs). The report includes a sensitivity analysis, an estimation of a site-specific water quality objective, and an analysis of uncertainty.

The proposed site specific water quality objective is in units of mg/L of dissolved copper, whereas the existing CCME interim WQG is presented in units of mg/L total copper. The BLM predicts WQVs in terms of dissolved concentrations because the concentration of dissolved metal is generally believed to better approximate the toxic fraction than does the concentration of total metal (USEPA 2003a).

As part of the sensitivity analysis, predicted operational-stage water quality in Doris Outflow was used to investigate the effect of tailings discharge water on the calculated site-specific WQVs. Predicted tailings water chemistry increased the mean site-specific WQV from 8.0 µg/L to between 8.5 and 9.0 µg/L, indicating that tailings discharge in the receiving water will likely reduce the concentration of copper bound to the biotic ligand (and therefore reduce the observed toxicity for a given dissolved water concentration).

A conservative site-specific water quality objective for dissolved copper of 4.1 µg/L is recommended for the site. The recommended water quality objective was determined by calculating individual WQVs from independent monitoring events conducted at Doris Outflow between June and September 2003/2004 (June to September is the proposed period of tailing water discharge; RL&L/Golder 2003; Golder 2004). The input parameters represent baseline conditions and therefore (as shown above) represent a more conservative water quality objective than one estimated once tailings water discharge to Doris Outflow commences. Calculated WQVs (from the individual monitoring events) approximated a normal distribution. The recommended water quality objective for the site was calculated by subtracting two standard deviations from the calculated mean. Despite naturally occurring changes in the background water quality, the recommended water quality objective (4.1 µg/L) is predicted to be a reasonably conservative site-specific objective for copper. Uncertainties associated with the calculated site-specific water objective for copper have been mitigated by including conservative assumptions.

TABLE OF CONTENTS

SECTION PAGE

1.0 Introduction ... 1
- 1.1 Background Information ... 1
- 1.2 Scientific Basis for Modeling Copper Toxicity ... 4
- 1.3 The USEPA BLM ... 6
- 1.4 Objective ... 7
- 1.5 Technical Approach ... 7

2.0 Methodology ... 8
- 2.1 Model Input Parameters ... 8
- 2.2 Sensitivity Analysis ... 8
- 2.3 Modeling Approach ... 8

3.0 Results and Discussion ... 15
- 3.1 Sensitivity Analysis ... 15
  - 3.1.1 Predicted WQVs and Recommended Site-specific Water Quality Objective Based on 2003/2004 Doris Outflow Data ... 15
  - 3.1.2 Predicted WQVs Based on Predicted Discharge ... 20
- 3.2 Model Limitations and Uncertainty ... 22

4.0 Conclusions ... 23

5.0 Limitations ... 24

6.0 References ... 25

7.0 Closure ... 27

LIST OF FIGURES

Figure 1 Water Bodies Associated with the Doris North Project. ... 2

Figure 2 Conceptual Diagram of the Biotic Ligand Model (BLM), Showing Complexation Within the Water Column and Competition for Gill Binding Sites (after Pagenkopf et al. 1983). ... 5

Figure 3 Model Input Parameters as a Function of Seasonality. ... 11

Figure 4 Association of Copper with the Gill as a function of Individual Input Parameters (Sensitivity Analysis). ... 16

Figure 5 Calculated Site-specific Copper WQVs as a Function of Individual Input Parameters (Sensitivity Analysis). ... 17

Figure 6 Sensitivity Analysis using Minimum and Maximum Recorded Values for Each Input Parameter. ... 18

Figure 7 Calculated Site-specific Copper WQVs as a function of Seasonality. ... 19

Figure 8 Predicted Site-specific Copper WQVs in Doris Outflow for Eight Different Discharge Scenarios. ... 21

LIST OF TABLES

Table 1 Input Parameters for -50% to +50% Sensitivity Analysis for Dissolved Organic Carbon (DOC). 9
Table 2 Input Parameters for Max/Min Sensitivity Analysis................................. 10
Table 3 Input Parameters Based on Baseline Measurements in Doris Outflow (the Receiving Water)... 13
Table 4 Input Parameters for Predicted Discharge Conditions in the Doris Outflow. 14

1.0 INTRODUCTION

1.1 Background Information

Miramar Hope Bay Ltd. (MHBL) has applied for a development permit to operate a gold mine in the Doris Lake watershed, 5 km from the Arctic coast in Nunavut. According to the current mine plan, mining will occur underground, and processing (crushing and the production of concentrate) will occur on-site. Mine tailings will be discharged to Tail Lake. A frozen core dam at one end of the lake will regulate discharge of tailings water to the receiving environment. Tailings discharge will consist of mill tails, treated sewage and mine runoff. Regulated discharges from the tailings impoundment will flow into Doris Creek (also called Doris Outflow; Figure 1) and then continue to flow down gradient to Little Roberts Lake, to Roberts Creek for 1 km, and ultimately to the Arctic Ocean at Roberts Bay.

The current mine plan indicates that the mine has an anticipated two year lifespan, after which time there will be no further discharge of tailings to Tail Lake; consequently, due to the catchment of precipitation, concentrations of mine related contaminants including copper in the lake should begin to decrease after mining ceases.

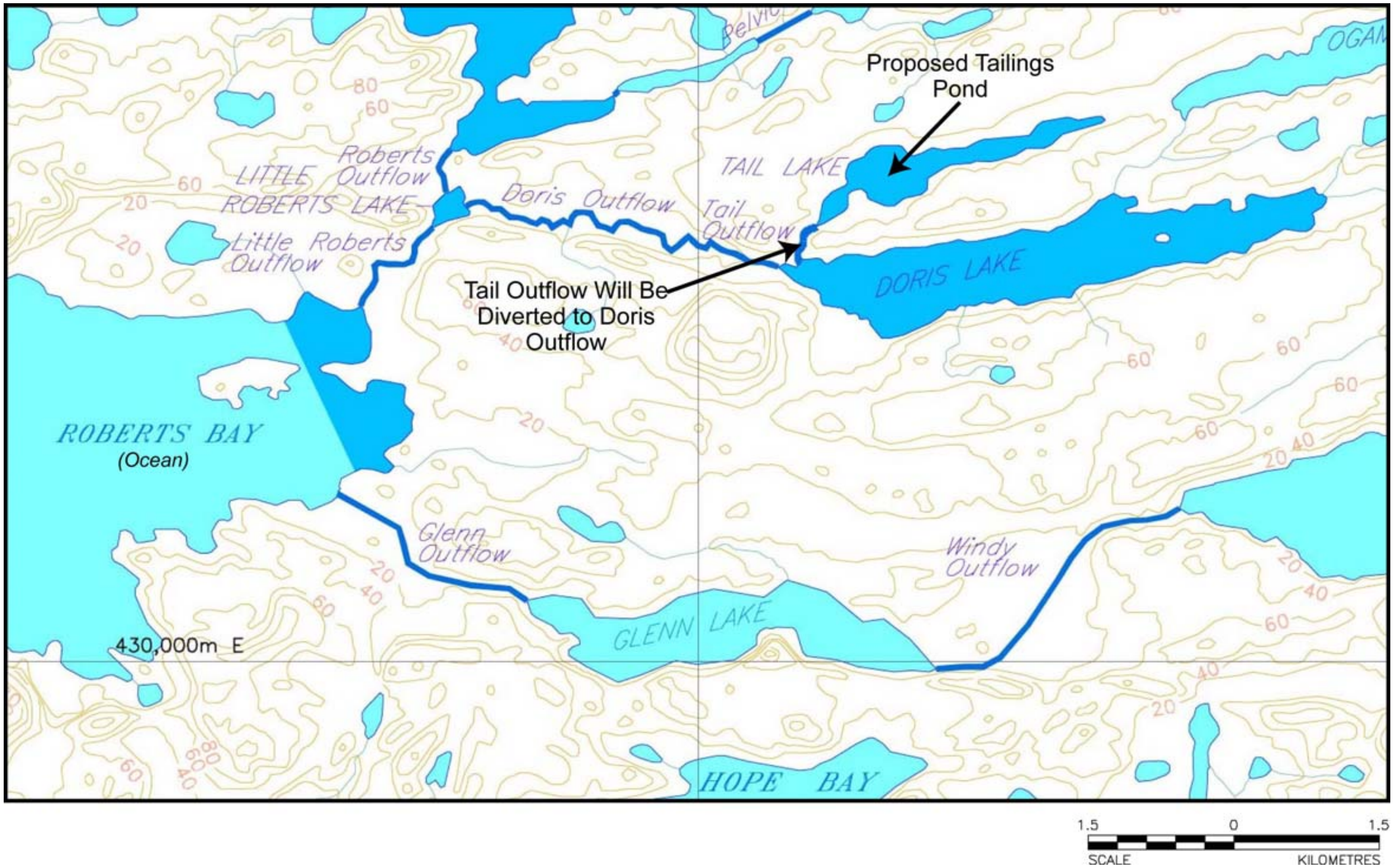
The proposed tailings water discharge will be into Doris Outflow immediately above the falls, located approximately 500 m downstream lake outlet. These falls act as a barrier for fish migrating upstream in Doris Outflow. Discharge water is expected to be well mixed as it passes over the falls.

Surface water in the Doris North area has naturally elevated concentrations of copper. Mean total and dissolved copper concentrations are as follows:

	Total Copper (µg/L ± one standard deviation	Dissolved Copper (µg/L ± one standard deviation
Tail Lake	1.07±0.22	1.07
Doris Lake	1.34±0.23	1.41±0.11
Doris Outflow	1.29±0.16	1.29±0.07
Little Roberts Lake	1.52±0.13	1.34
Little Roberts Outflow	1.43±0.28	1.33±0.21
Roberts Outflow	1.38±0.25	1.16±0.17

Mean background concentrations of copper are only marginally lower than the Canadian Council of Ministers of the Environment (CCME) interim water quality guideline (WQG) for copper. The interim WQG is hardness dependent, for hardness ranging from 0 to 120 mg/L (which is representative of hardness in the Doris Lake watershed), the interim

Figure 1: Water Bodies Associated With The Doris North Project



WQG is 2 μg/L (CCME, 1999). The naturally elevated background concentrations of copper increase the probability that discharge of incremental quantities of copper (i.e., from the tailing impoundment) to the system would result in an exceedance of the CCME interim WQG. Although copper is not a common by-product of gold mining operations, the elevated copper concentrations in ore deposits in the area result in an increased amount of copper becoming solubilized during the milling process.

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> *Environmental quality guidelines should not be regarded as blanket values for national environmental quality. Variations in environmental conditions across Canada will affect environmental quality in different ways. Therefore, the users of EQG may need to consider local conditions and other supporting information (e.g., site-specific background concentrations of naturally occurring substances) during the implementation of EQGs.* ***Science-based site-specific criteria, guidelines, objectives, or standards may therefore differ from the Canadian EQGs recommended in this document*** (at Introduction, Canadian Environmental Quality Guidelines, p. 2; emphasis added).
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> *In order to apply this scientific information, for example to recommend site-specific water quality objectives, many factors such as the local water quality, resident biotic species, local water demands, and other elements have to be considered* (at Introduction, Chapter 4, Canadian Water Quality Guidelines for the Protection of Aquatic life, p.2).

WQGs are intended to be used as screening values. Concentrations below the WQG indicate conditions that are highly unlikely to result in ecological effects. Concentrations above the WQG indicate conditions that may or may not result in ecological effects, but in order to resolve potential risks, further investigation is required. The freshwater WQGs are designed to be protective of aquatic organisms for all freshwater water bodies across Canada. In order to be protective of organisms living in very diverse freshwater habitats, conservative considerations are incorporated into the WQGs (i.e., they are intended to be overprotective). In addition, the CCME WQG for copper is an "interim WQG", which means that available toxicity data did not meet the minimum requirements of quantity and/or quality in order for a WQG to be derived (CCME 1999). The guideline has been used by CCME since 1987. However, since 1987 there has been considerable scientific research in the area of copper toxicity and, as a result, copper is currently on the CCME list of substances that have priority for the derivation of WQGs (CCME 1999). Due to the small amount (and quality) of data on which they are based, interim guidelines have an associated amount of uncertainly and are typically more conservative than finalized WQGs (i.e., they are overprotective).

Since 1987, the approach for deriving regulatory guidelines for copper (and other metals) has evolved in most jurisdictions. Regulatory agencies (in Canada, the European Union, and the US) have realized that the toxicity of metals in natural surface waters is often a function of site-specific water quality parameters (e.g., CCME 1999; USEPA 2003a). In the 1990s, regulatory agencies provided protocols for deriving site-specific water quality objectives[1] for metals that were a function of water hardness and pH (USEPA 2002). More recently, regulatory agencies have become aware of the importance of other water quality parameters in modifying the toxicity of dissolved metals. Currently, agencies in the US and Canada are considering the inclusion of additional site-specific water quality parameters into the derivation of site-specific water quality objectives (USEPA 2003a).

The purpose of this document is to derive a realistic, yet environmentally protective site-specific water quality objective for copper in Doris Creek, taking into consideration site-specific factors.

1.2 Scientific Basis for Modeling Copper Toxicity

Only a portion of copper in surface water will be in a form that can result in ecological effects. This portion of copper is referred to as free copper, whose toxic potency is mostly due to two ionic forms: Cu^{2+} and $CuOH^{+}$.

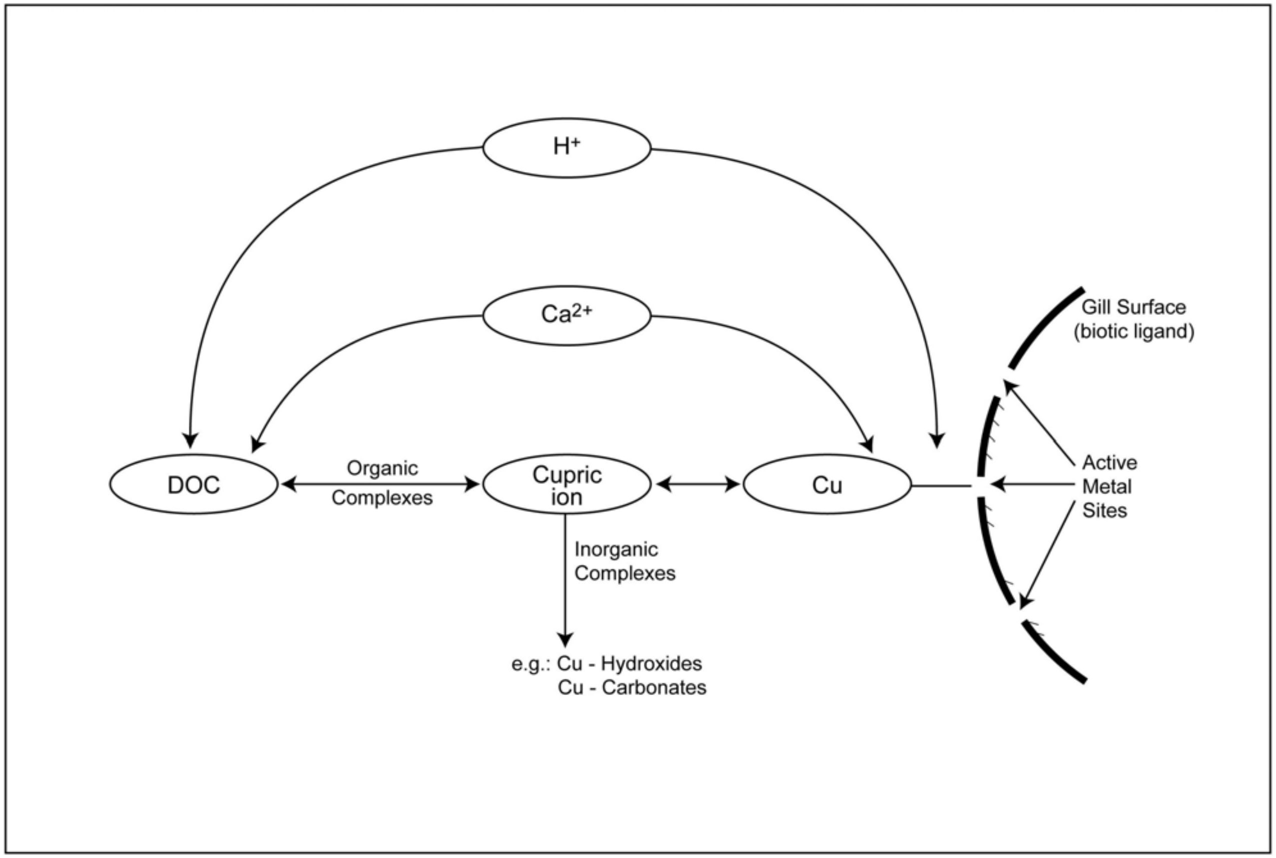
Copper (like other metals in aqueous solution) readily interacts with other components of water (e.g., organic carbon, carbonates, sulphides, chloride) and forms numerous metal species (Figure 2). Some of the metal species are soluble and therefore have the potential to interact with biological organisms, these metal species are termed bioavailable. Other metal species are not readily soluble and therefore do not readily interact with biological organisms; in other words, they are not bioavailable.

Metal speciation models provide an approach for predicting the speciation of copper in a given receiving environment knowing the site-specific water chemistry (Chapman et al. 2003). Metal speciation models utilize thermodynamic information (e.g., dissociation constants) of the various chemical species.

Copper toxicity is a function of copper bioavailability, but it is also a function of competition of copper ions for binding sites on respiratory surfaces (e.g., gills of fish; Figure 2). The main mechanism for acute toxicity to aquatic organisms is interaction and interference with the sodium channels on the gill surface (DiToro et al. 1991; Chapman et al. 2003). These channels play a crucial part in maintaining the ion balance within aquatic

[1] Note: consistent with CCME 1999, the term "site-specific water quality objective" is used in this document to represent a numerical value that is considered protective of designated water use at a specified site. Also consistent with CCME 1999, the term "guideline", as used in this report, represents a value that is protective at all sites.

Figure 2: Conceptual diagram of the Biotic Ligand Model (BLM), showing complexation within the water column and competition for gill binding sites between copper and other positively charged ions (after Pagenkopf et al. 1983).



organisms. Besides copper, H^+, Ca^+, Na^+ and K^+ are able to bind at these sites and will compete with copper; therefore, an increased concentration of H^+, Ca^+, Na^+ or K^+ in water should result in lower observed toxicity for a given dissolved copper concentration.

Biotic ligand models (BLMs) take metal speciation modeling one step further and predict the level of Na^+ channel interactions based on site-specific water quality. Regulatory agencies have been investigating the application of BLMs as a tool for better regulation of metals in the aquatic environment (USEPA 2003a). In order for BLMs to work, the relationship between acute toxicity and concentration of copper bound to the gill (or "biotic ligand") must be known. This relationship has only presently been established for a few key aquatic species (e.g., rainbow trout, fathead minnow, *Daphnia magna* and *Ceriodaphnia*) for acute toxicity; however, work is ongoing on other aquatic species and for chronic toxicity (Niyogi et al. 2004; Chapman et al. 2003).

1.3 The USEPA BLM

USEPA has recently published a draft document outlining a protocol for deriving site-specific water quality objectives (criteria) for copper in surface waters. As part of this draft protocol, USEPA has utilized a BLM based primarily on the CHESS (Chemical Equilibrium in Soils and Solution) model (Santore and Driscoll 1995) but which also utilizes algorithms from the Windemere Humic Aqueous Model (WHAM) to describe interactions between copper and dissolved organic carbon (Santore et al. 2001; Paquin et al. 2002).

The BLM can be run in either "toxicity" or "speciation mode". In speciation mode, the user inputs dissolved copper concentration and site-specific water quality parameters, and the model estimates the concentrations of free copper, active copper and copper associated with the gill (Cu^{2+} and $CuOH^+$). In "toxicity mode" the user enters only site-specific water quality parameters, and the model predicts dissolved water concentrations that would result in 50% mortality of test organisms (LC_{50}) for selected aquatic organisms. The gill concentration that results in mortality of 50% of test organisms is referred to as the LA_{50}. In speciation mode the LA_{50} equals the sum of Cu-gill and CuOH-gill complexes. The LA_{50} varies for different aquatic organisms, but is constant within a given fish or aquatic invertebrate species, irrespective of site-specific water quality parameters.

The USEPA's approach for deriving a site-specific objective requires the development of a LA_{50} protective of 95% of aquatic organisms tested. To derive the LA_{50}, USEPA compiled toxicity data meeting certain predefined quality criteria. Water quality data associated with these tests were used to calculate a distribution of LA_{50} by running the BLM model in speciation mode. The derived LA_{50}s were then used to calculate a normalized LC_{50} based on a single set of "normal" water quality data provided by USEPA. From the distribution of LC_{50}s, the concentration protective of 95% of aquatic organisms was then calculated. Using this number and the same normalized water quality parameters utilized earlier, the LA_{50} protective of 95% of aquatic organisms was calculated.

The LA_{50} protective of 95% of aquatic organisms is input manually to calculate a FAV (final acute value) using site-specific water quality parameters. A CMC (criterion maximum concentration), an acute toxicity guideline, is calculated from the FAV by dividing by two. The factor of two accounts for the maximum two-fold error observed in the model predictions when compared to actual data (Santore et al. 2001). A CCC (criterion continuous concentration), a chronic toxicity guideline, can then be derived from the CMC by dividing by an acute to chronic factor. Based on literature investigation, USEPA adopted an acute to chronic ratio of 3.22 for copper. In this report, we derive CCCs and adopt these as water quality values (WQVs). The term WQV has been created to account for the fact that the receiving environment changes seasonally and therefore a single model output cannot be adopted as the site-specific water quality objective. Instead, a distribution of WQVs was calculated, and then a single recommended site-specific water quality objective was selected using the distribution.

The proposed site specific water quality objective is in units of mg/L of dissolved copper, whereas the existing CCME interim WQG is presented in units of mg/L total copper. The BLM predicts WQVs in terms of dissolved concentrations because the concentration of dissolved metal is generally believed to better approximate the toxic fraction than does the concentration of total metal (USEPA 2003a).

1.4 Objective

The purpose of this document is to describe the derivation of an environmentally protective, site-specific water quality objective for copper in Doris Creek (the receiving environment) taking into consideration site-specific factors.

1.5 Technical Approach

The technical approach involved the following steps:

1) Sensitivity analysis of the USEPA copper BLM. The goal of the sensitivity analysis was two-fold:

   a) Explore the sensitivity of the model to various input parameters,

   b) Explore model behavior with the addition of tailings water to the receiving environment.

2) Derivation of a site-specific water quality objective for Doris Outflow utilizing the BLM.

3) Discussion of the limitations of the approach taken to derive a site-specific water quality objective and the steps that were taken to address the limitations.

2.0 METHODOLOGY

2.1 Model Input Parameters

Input parameters required for running the USEPA BLM model are temperature (deg C), pH, DOC, K^+, Na^+, Mg^{2+}, alkalinity, sulphate, chloride and hardness. These parameters were derived from data collected from Doris Outflow between July and September 2003 and between June and September 2004 (RL&L/Golder 2003; Golder 2004). Only water quality collected between the months of June and September were utilized in the model, as these would best approximate natural water quality conditions during the period of planned discharge.

2.2 Sensitivity Analysis

As a first investigative iteration, the mean values of all individual input parameters from the 2003 and 2004 data were calculated. Then a range of input values from -50% to +50% was calculated for each of the input parameters (Table 1). Finally, multiple model iterations were run whereby a single input parameter was varied from -50% through to +50%, while remaining parameters were held constant at their respective arithmetic means (the “base-case” condition). The model was run both in speciation and toxicity mode so that the sensitivity of the predicted gill binding of copper (which is proportional to toxicity), and predicted site-specific WQV derivations to various input parameters could be assessed.

As a second sensitivity analysis iteration, the maximum and minimum measured input parameters for the 2003 and 2004 data sets were input to the model while keeping the other parameters constant (Table 2). This second sensitivity analysis incorporated a greater degree of site relevance as it considered actual variance in the input parameters.

2.3 Modeling Approach

The utility of running the model in a probabilistic manner was explored. Input data were plotted as a function of time, as an exploratory approach to assess whether the input data co-varied. The results of this assessment indicated that many of the input parameters co-vary (Figure 3) and therefore it would be misleading to follow a typical probabilistic approach, which assumes that input parameters vary independently following probability distributions. Co-variance of input parameters is not unusual in aquatic systems that undergo defined seasonal changes (Hobbie 1973). For the Doris North Project, the observed changes to the physical water quality basically reflect the freeze/thaw cycle. Water quality is primarily a function of source; water from thawing snow flowing over the surface of the ground will have a different chemistry than water originating from the active layer (the layer of soil above the permafrost that thaws later in the summer).

Table 1: Input Parameters for -50% to +50% Sensitivity Analysis for Dissolved Organic Carbon (DOC).
(data shown in model import format, each row represents a distinct model simulation)

Scenario[1]	Temp (deg C)	pH	DOC (mg/L)	HA (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	LA_{50} (nmol/g wet)
- 50%	5.12	7.55	2.83	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
- 45%	5.12	7.55	3.11	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
- 40%	5.12	7.55	3.39	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
- 35%	5.12	7.55	3.67	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
- 30%	5.12	7.55	3.96	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
- 25%	5.12	7.55	4.24	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
- 20%	5.12	7.55	4.52	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
- 15%	5.12	7.55	4.80	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
- 10%	5.12	7.55	5.09	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
- 5%	5.12	7.55	5.37	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
Base Case	5.12	7.55	5.65	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
+ 5%	5.12	7.55	5.93	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
+ 10%	5.12	7.55	6.22	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
+ 15%	5.12	7.55	6.50	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
+ 20%	5.12	7.55	6.78	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
+ 25%	5.12	7.55	7.06	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
+ 30%	5.12	7.55	7.35	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
+ 35%	5.12	7.55	7.63	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
+ 40%	5.12	7.55	7.91	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
+ 45%	5.12	7.55	8.19	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412
+ 50%	5.12	7.55	8.48	10	7.28	6.195	29.05	2.16	2.812	60.5	26.35	0.001	0.0412

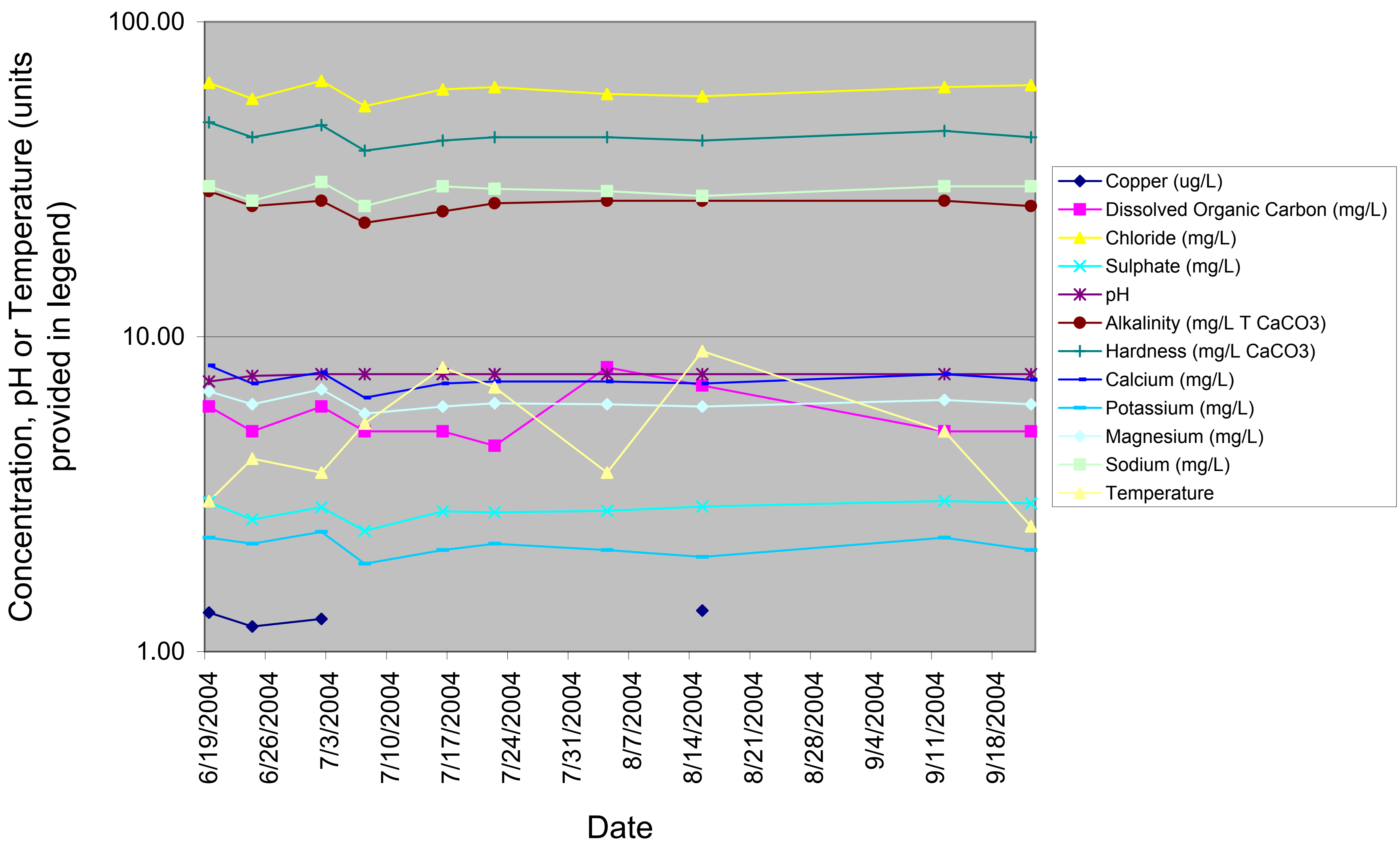
1. The percentage by which the mean measured DOC concentration in Doris Creek was varied during the sensitivity analysis.

Table 2: Input Parameters for Max/Min Sensitivity Analysis.
(data shown in model import format, each row represents a distinct model simulation)

Scenario[1]		Temp (deg C)	pH	DOC (mg/L)	HA (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	LA_{50} (nmol/g wet)
Temp	Min	2.5	7.55	5.65	10	7.28	6.20	29.1	2.16	2.81	60.5	26.35	0.001	0.041
Temp	Max	9	7.55	5.65	10	7.28	6.20	29.1	2.16	2.81	60.5	26.35	0.001	0.041
pH	Min	5.12	7.2	5.65	10	7.28	6.20	29.1	2.16	2.81	60.5	26.35	0.001	0.041
pH	Max	5.12	7.6	5.65	10	7.28	6.20	29.1	2.16	2.81	60.5	26.35	0.001	0.041
DOC	Min	5.12	7.55	4.5	10	7.28	6.20	29.1	2.16	2.81	60.5	26.35	0.001	0.041
DOC	Max	5.12	7.55	8	10	7.28	6.20	29.1	2.16	2.81	60.5	26.35	0.001	0.041
Ca	Min	5.12	7.55	5.65	10	6.4	6.20	29.1	2.16	2.81	60.5	26.35	0.001	0.041
Ca	Max	5.12	7.55	5.65	10	8.1	6.20	29.1	2.16	2.81	60.5	26.35	0.001	0.041
Mg	Min	5.12	7.55	5.65	10	7.28	5.70	29.1	2.16	2.81	60.5	26.35	0.001	0.041
Mg	Max	5.12	7.55	5.65	10	7.28	6.80	29.1	2.16	2.81	60.5	26.35	0.001	0.041
Na	Min	5.12	7.55	5.65	10	7.28	6.20	26.0	2.16	2.81	60.5	26.35	0.001	0.041
Na	Max	5.12	7.55	5.65	10	7.28	6.20	31.0	2.16	2.81	60.5	26.35	0.001	0.041
K	Min	5.12	7.55	5.65	10	7.28	6.20	29.1	1.9	2.81	60.5	26.35	0.001	0.041
K	Max	5.12	7.55	5.65	10	7.28	6.20	29.1	2.4	2.81	60.5	26.35	0.001	0.041
SO4	Min	5.12	7.55	5.65	10	7.28	6.20	29.1	2.16	2.42	60.5	26.35	0.001	0.041
SO4	Max	5.12	7.55	5.65	10	7.28	6.20	29.1	2.16	3.01	60.5	26.35	0.001	0.041
Cl	Min	5.12	7.55	5.65	10	7.28	6.20	29.1	2.16	2.81	54	26.35	0.001	0.041
Cl	Max	5.12	7.55	5.65	10	7.28	6.20	29.1	2.16	2.81	65	26.35	0.001	0.041
Alk	Min	5.12	7.55	5.65	10	7.28	6.20	29.1	2.16	2.81	60.5	23	0.001	0.041
Alk	Max	5.12	7.55	5.65	10	7.28	6.20	29.1	2.16	2.81	60.5	29	0.001	0.041

1. Maximum and minimum measured concentrations of individual input parameters (background water quality chemistry data from Doris Creek). Other parameters held constant at the sample mean.

Figure 3: Model Input Parameters as a Function of Seasonality.



Consequently, the chosen modeling approach involved calculating WQVs from individual monitoring events separately in a deterministic manner and plotting the compilation of predicted WQVs over the span of the anticipated discharge period (Table 3). The WQV calculations involved field collected data from 2003 and 2004 monitoring events (RL&L/Golder 2003; Golder 2004). Older data were not used because of uncertain accuracy caused by collection by different investigators using different sampling approaches and different analytical laboratories.

A recommended site-specific water quality objective was derived from the distribution of WQVs derived from 2003/2004 data. A WQV representing the lowest 2.5 percentile of the WQV distribution was calculated by subtracting two standard deviations from the mean WQV. The lowest 2.5 percentile WQV was selected as the recommended site-specific water quality objective because it represents a conservative WQV (i.e., 97.5 % of the time when WQVs are calculated using the BLM and site-specific water chemistry data, the calculated WQV will be higher).

As an additional investigative iteration, predicted water chemistry in Doris Outflow (SRK 2004) during tailing pond water discharge was used to assess the effect that tailings water would have on the calculated WQVs. SRK modeled eight possible discharge scenarios (Table 4). The predicted water chemistry was not used to determine the recommended site-specific water quality objective because:

- the available evidence indicated that the introduction of tailings pond water would result in a less conservative site-specific water quality objective;
- there was additional uncertainty in the predicted water chemistry; and,
- the predicted water chemistry does not reflect variability due to seasonal effects.

Table 3: Input Parameters Based on Baseline Measurements in Doris Outflow (the Receiving Water).
(data shown in model import format, each row represents a distinct model simulation)

Scenario[1]	Temp (deg C)	pH	DOC (mg/L)	HA (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	LA_{50} (nmol/g wet)
7/28/2003	5.12	7.5	5.2	10	6.4	5.9	28.8	2.2	0.90	53	23	0.001	0.041
8/28/03	5.12	7.8	4.9	10	7.2	6.4	28.8	2.2	2.30	52.3	24	0.001	0.041
9/05/03	5.12	7.4	5.2	10	7.3	6.1	28.4	2.2	2.00	54.2	24	0.001	0.041
6/19/2004	3.00	7.2	6.0	10	8.1	6.7	30	2.3	2.98	64	29	0.001	0.041
6/24/2004	4.10	7.5	5.0	10	7.1	6.1	27	2.2	2.63	57	26	0.001	0.041
7/2/2004	3.70	7.6	6.0	10	7.7	6.8	31	2.4	2.87	65	27	0.001	0.041
7/7/2004	5.30	7.6	5.0	10	6.4	5.7	26	1.9	2.42	54	23	0.001	0.041
7/16/2004	8.00	7.6	5.0	10	7.1	6.0	30	2.1	2.79	61	25	0.001	0.041
7/22/2004	6.90	7.6	4.5	10	7.2	6.2	30	2.2	2.77	62	27	0.001	0.041
8/4/2004	3.70	7.6	8.0	10	7.2	6.1	29	2.1	2.80	59	27	0.001	0.041
8/15/2004	9.00	7.6	7.0	10	7.1	6.0	28	2.0	2.89	58	27	0.001	0.041
9/12/2004	5.00	7.6	5.0	10	7.6	6.3	30	2.3	3.01	62	27	0.001	0.041

1. Date when baseline chemistry data was collected from Doris Creek.

Table 4: Input Parameters for Predicted Discharge Conditions in the Doris Outflow.
(data shown in model import format, each row represents a distinct model simulation)

Scenario	Temp (deg C)	pH	DOC (mg/L)	HA (%)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SO4 (mg/L)	Cl (mg/L)	Alkalinity (mg/L)	S (mg/L)	LA_{50} (nmol/g wet)
Base Case	5.12	7.55	5.65	10	7.28	6.2	29	2.2	2.8	61	26	0.001	0.041
SRK Case 1	5.12	7.55	5.65	10	25	7.3	41	3.6	5.5	85	28	0.001	0.041
SRK Case 2	5.12	7.55	5.65	10	25	7.3	41	3.6	5.5	85	28	0.001	0.041
SRK Case 3	5.12	7.55	5.65	10	34	7.4	49	5.0	7.2	87	29	0.001	0.041
SRK Case 4	5.12	7.55	5.65	10	18	7.3	41	3.3	4.5	78	28	0.001	0.041
SRK Case 5	5.12	7.55	5.65	10	20	7.3	43	3.8	4.8	75	28	0.001	0.041
SRK Case 1B	5.12	7.55	5.65	10	26	7.3	41	3.6	5.6	86	28	0.001	0.041
SRK Case 3B	5.12	7.55	5.65	10	27	7.3	49	4.4	6.0	89	29	0.001	0.041
SRK Case 5B	5.12	7.55	5.65	10	17	7.3	42	3.6	4.4	73	28	0.001	0.041

[shaded] concentrations derived from water quality modeling (SRK 2004).
Other parameters represent the mean background receiving environment concentrations. Both pH and DOC are expected to change little with introduction of tailings pond water. However, if pH and DOC do change the change will be upwards; therefore, the calculated WQVs based on the input data above represent a conservative estimate.

3.0 RESULTS AND DISCUSSION

3.1 Sensitivity Analysis

The sensitivity analysis provides the modeler and reviewer with an enhanced appreciation for how the model behaves, often providing additional confidence in the predictions of the model as well as providing an indication of what will happen in the environment as a result of changing individual parameters. Generally, the model is sensitive to changes in only a small number of the input parameters. It is important to know which parameters the model is most sensitive to so that the investigator can ensure that these data are of adequate quality.

The results of varying the individual parameters from -50% through to +50% are shown in Figure 4 and Figure 5. These results show that the model is most sensitive to changes in DOC, followed by pH, then the proportion of humic acid in the DOC, and then the concentration of sodium ions. All other parameters appear to have little effect on either the predicted gill concentration of copper or the derived site-specific objective. However, with the exception of magnesium, all input parameters tend to be positively correlated with the BLM calculated WQV. Consequently, the effect of increasing most input parameters is to result in a predicted decrease of copper binding at the gills and therefore an increase in the calculated WQV.

The results of the sensitivity analysis utilizing minimum and maximum individual parameters show that pH and DOC are the only parameters that will likely be responsible for variance in predicted site-specific WQVs at the Doris North site (Figure 6). For the rest of the parameters, both the model sensitivity to the individual parameter and the actual variance of the parameter in the 2003/2004 data set are sufficiently low that they will be responsible for little of the expected variance in predicted site-specific WQVs. However, the introduction of tailings water will have some effect on water quality. Therefore, it is possible that other input parameters (e.g., anions and cations) may account for more variance in the WQV. The potential influence of tailings water on the calculated WQV is explored in Section 3.1.2

3.1.1 Predicted WQVs and Recommended Site-Specific Water Quality Objective Based on 2003/2004 Doris Outflow Data

The predicted WQVs based on point estimates of input data collected in 2003 and 2004 (n = 12; RL&L/Golder 2003; Golder 2004), indicate that the calculated WQVs can vary between 5.44 µg/L and 12.15 µg/L between June and September (Figure 7). Generally, the calculated WQVs appear to increase from June to the beginning of August, and then decrease again into September. These results indicate that the predicted gill binding of

Figure 4: Association of Copper with the Gill as a Function of Individual Input Parameters (Sensitivity Analysis).

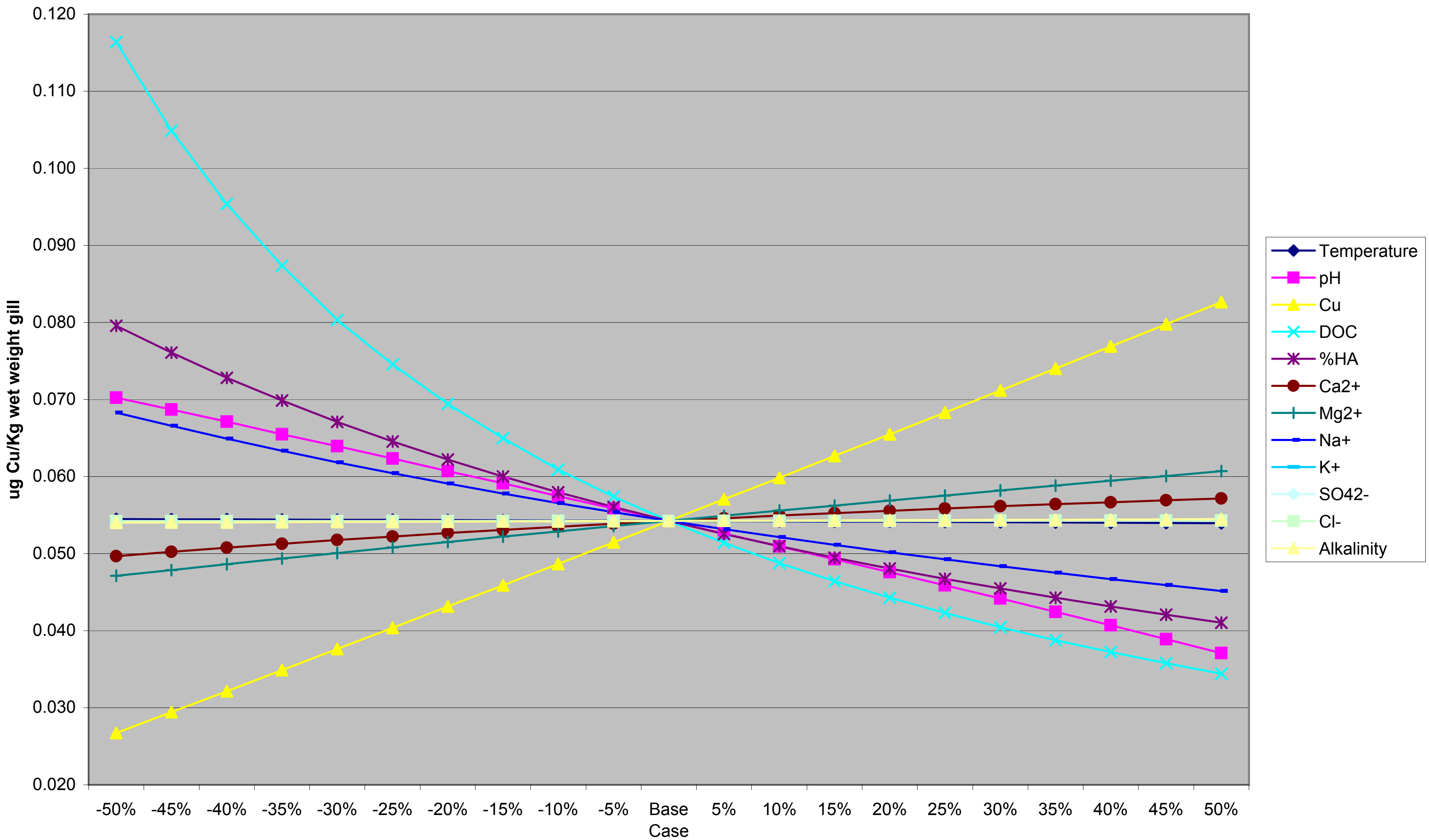


Figure 5: Calculated Site Specific WQVs as a Function of Individual Input Parameters (Sensitivity Analysis).

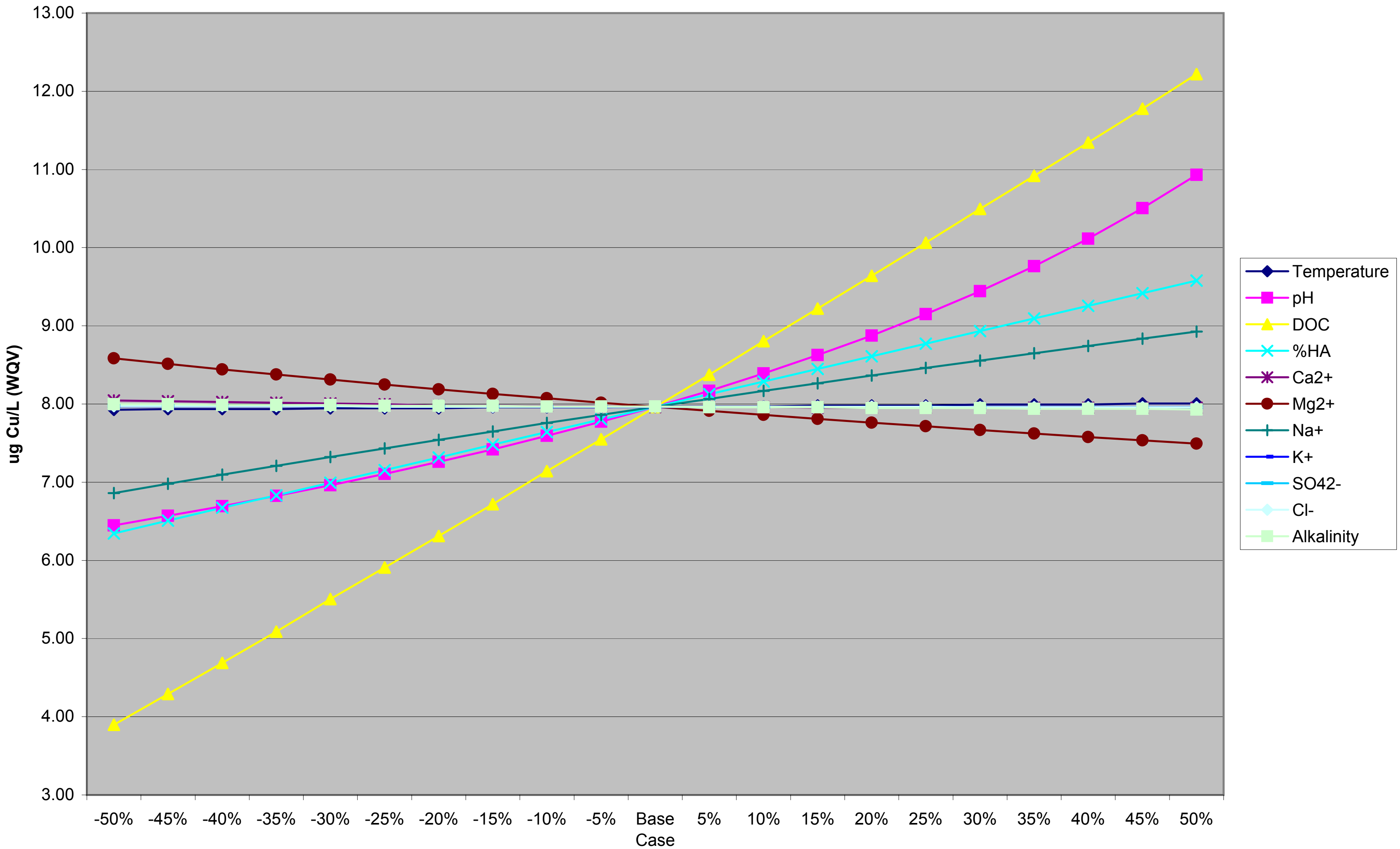


Figure 6: Sensitivity Analysis using Minimum and Maximum Recorded Values For Each Input Parameter

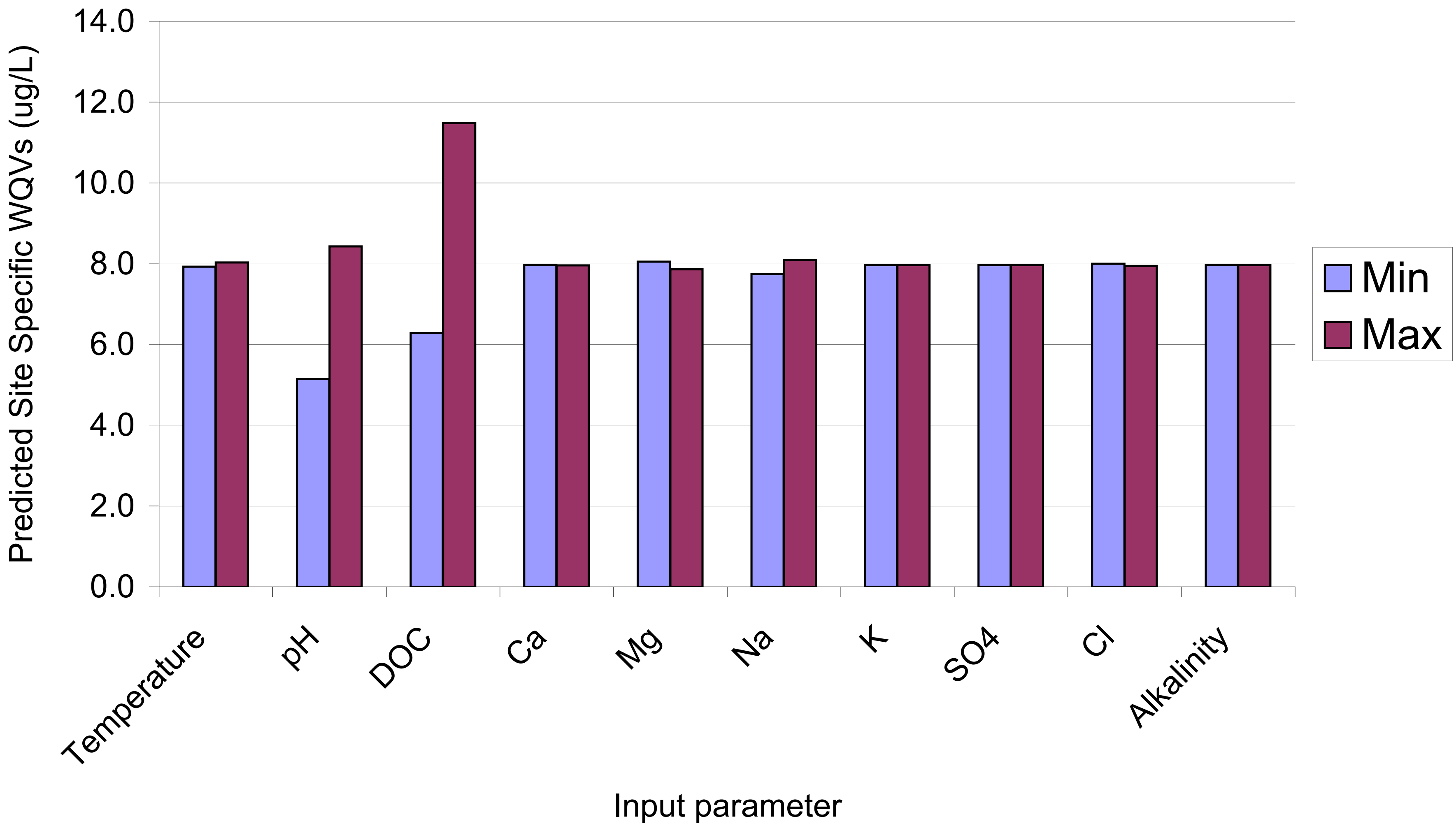
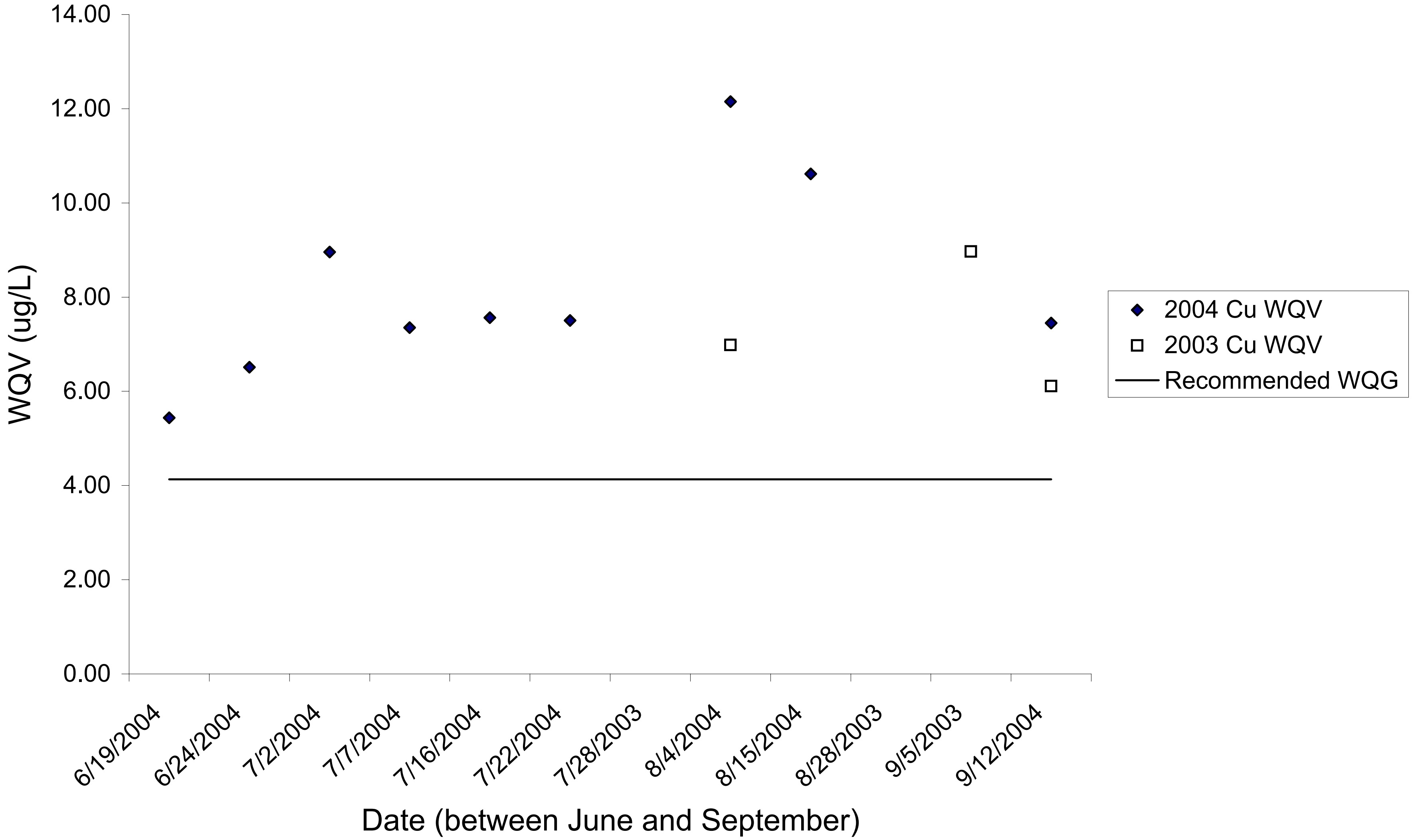


Figure 7: Calculated Site Specific Copper WQVs as a Function of Seasonality.



copper will be highest soon after thaw and as the Doris Outflow is freezing up in the autumn. The mean WQV based on background receiving water chemistry was 8.0 µg/L dissolved copper.

To derive a recommended site-specific water quality objective that is protective under most (if not all) water quality conditions (from June to September), it was important to select a calculated site-specific water quality objective that was located at the low end of the distribution of calculated WQVs. Choosing the lowest calculated WQV would unlikely be sufficiently conservative as it was unknown whether the actual worst-case conditions were captured in the 2003 or 2004 sampling events. Instead, a site-specific water quality objective was calculated that would be lower than 97.5% of possible calculated WQVs based on the distribution of WQVs. The Shapiro-Wilks test was used to confirm that the data were statistically normally distributed (USEPA, 2003b). The recommended site-specific water quality objective was calculated by subtracting two standard deviations from the mean WQV and was calculated to be 4.1 µg/L (depicted in Figure 7 as a line).

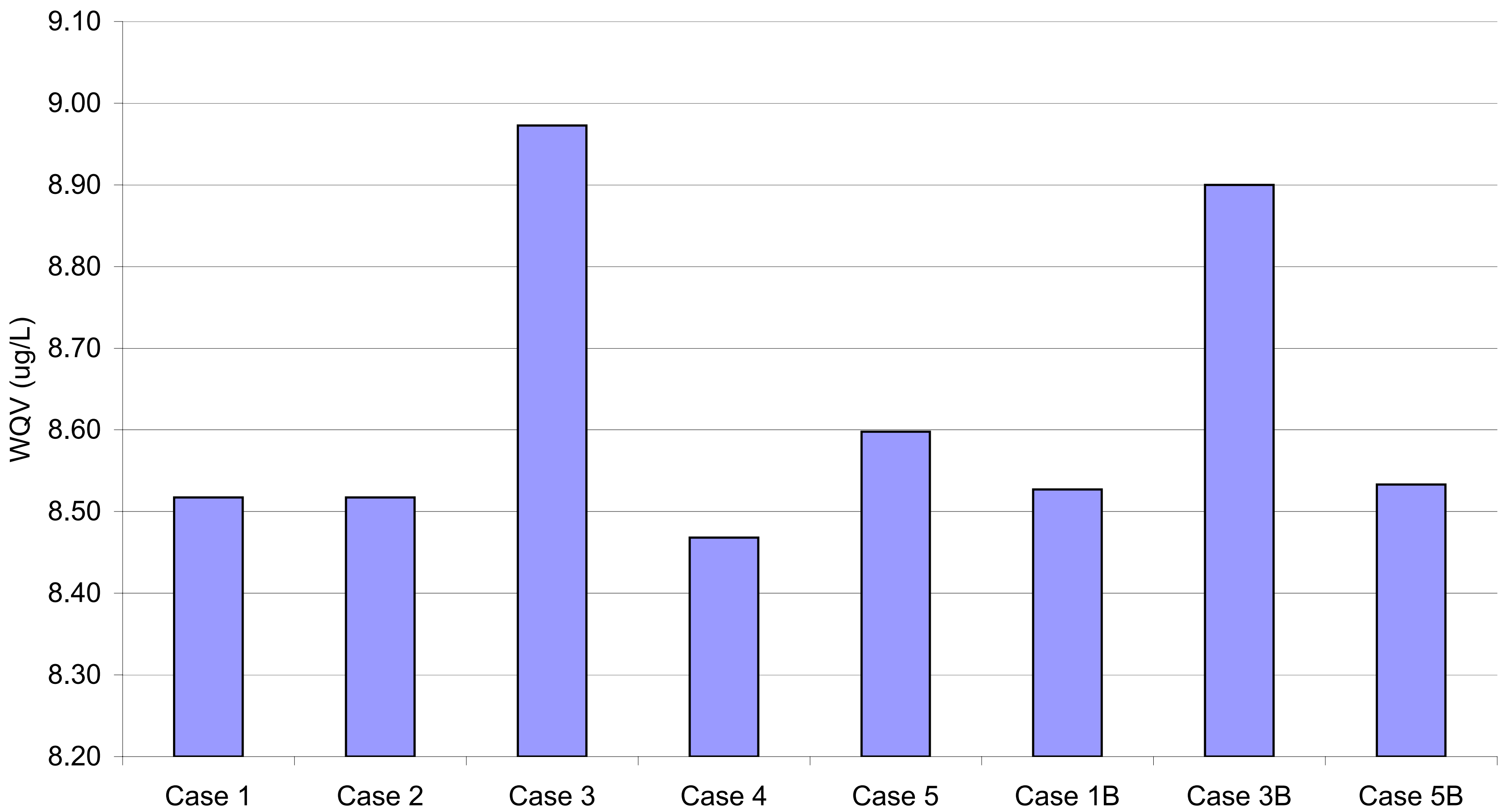
3.1.2 Predicted WQVs Based on Predicted Discharge

Water quality modeling performed by SRK indicates that the concentrations of most water quality parameters are likely to increase in Tail Lake (the tailing pond) during milling and processing (J. Chapman, SRK, pers. comm., November 9th, 2004). Consequently, any discharge from Tail Lake will only increase these parameters in the receiving environment (Doris Outflow). As was demonstrated in the sensitivity analysis, increasing most water quality parameters reduces the predicted toxicity of dissolved copper, resulting in an increase in the predicted WQV. Eight different discharge scenarios were modeled based on data provided by SRK (i.e., Case 1, 2, 3, 4, 5, 1B, 3B and 5B; SRK 2004).

As an additional level of conservatism, predicted increases in DOC in the tailings pond outflow and subsequent increases in DOC concentrations in Doris Outflow were not included in the BLM simulations. The increase in DOC has been estimated as an additional 0.3 mg/L (J. Chapman, SRK, pers. comm., November 9th, 2004), which would further reduce copper toxicity.

In all cases, the inclusion of Tail Lake discharge resulted in the BLM predicting a slightly larger WQV than the mean (also called base-case) WQV (8.0 µg/L; Figure 8). The larger predicted WQV indicates that the addition of Tail Lake discharge reduces binding of copper with the biotic ligand at the gill and thus reduces bioavailability of copper in Doris Creek. WQVs for the site also did not vary substantially between the eight cases

Figure 8: Predicted Site Specific Copper WQV in Doris Creek for Eight Different Discharge Scenarios.



Conservatively assumes no increase in organic carbon or pH in the receiving environment provided by SRK (Figure 8). The minimum predicted site-specific water quality objective was 8.5, the maximum predicted site-specific water quality objective was 9.0, and the coefficient of variation was estimated to be 2.2 %.

3.2 Model Limitations and Uncertainty

The application of biotic ligand models to deriving site-specific water quality objective is relatively new (USEPA 2003a). There are sufficient data to validate the models for key freshwater aquatic species; however, the number of aquatic species is relatively small and presently limited to acute toxicity endpoints (Hydroqual 2003).

The model used in this report is part of a draft copper objective derivation protocol document created by the USEPA. Canadian regulators are expected to similarly apply BLMs to site-specific water quality objective development, however to date this has not occurred.

To address the above limitations and uncertainties, a conservative approach has been taken:

1. The LA_{50} (and therefore the LC_{50}) was chosen to be protective of 95 % of test species, including plants, fish and aquatic invertebrates.
2. It was assumed that organisms will be exposed to mine effluent on a chronic basis.
3. Acclimation and adaptation, which could both ameliorate copper toxicity, have not been considered. Copper is an essential element and as such is regulated in biological organisms. Generally organisms living in habitats with elevated background concentrations of copper have an enhanced ability to regulate copper (Bossuyt et al. 2003; McGeer et al. 2002; Grosell et al. 1997). Consequently, organisms currently living in the Doris North watershed will likely be able to tolerate higher concentrations of copper than organisms raised in low-copper conditions (Bossuyt and Jenssen 2003; Grosell et al. 1997).
4. The assumption was made that receiving water quality parameters will remain the same as pre-mine conditions. As demonstrated earlier, the addition of tailings water will increase most water quality parameters resulting in lower copper bioavailability and thus also in lower toxicity.
5. A site-specific dissolved copper site-specific water quality objective was derived using USEPA's current water hardness-based equation for deriving copper site-specific water quality objective (USEPA 2002). The formula is as follows: (dissolved copper concentration) = $\exp\{0.8545\ [\ln\ (43.8)] + (-1.702)\}$ The calculated WQC for dissolved copper was 4.42 µg/L, which agrees well with the WQC derived using the BLM approach.

4.0 CONCLUSIONS

A protective site-specific water quality objective of 4.1 µg/L dissolved copper was derived for receiving waters associated with tailings water discharge from Tail Lake. This site-specific water quality objective is based on appropriate baseline water quality chemistry in Doris Outflow (measured in the summers of 2003 and 2004). The selected site-specific water quality objective equals the mean calculated WQV minus two standard deviations. This represents a reasonable lower bound (and therefore conservative) estimate of possible WQVs.

5.0 LIMITATIONS

This report has been prepared for the use of Miramar Hope Bay Ltd. for the proposed Doris North Project, and provides a site-specific water quality objective for copper in Doris Outflow (the receiving environment). Any use of this report by any party for any purpose other than that stated is the responsibility of that party. Golder Associates Ltd. disclaims responsibility for consequential financial effects on transactions or property values, or requirements for follow-up actions and costs.

The report is based on data and information collected during investigation programs conducted by Golder Associates Ltd. and others. It is based solely on the conditions on the subject Site encountered at the time of these Site investigations as supplemented by a review of historical information and data obtained by Golder Associates Ltd.

The assessment of the environmental conditions at this Site has been made using the results of chemical analysis of discrete surface water samples over a limited amount of time. The Site conditions between sampling events have been inferred based on conditions observed at the time of sampling. Additional study, including further surface water sampling, can reduce the inherent uncertainties associated with this type of study.

The services performed as described in this report were conducted in a manner consistent with the level of care and skill normally exercised by other members of the engineering and science professions currently practicing under similar conditions, subject to the time limits and financial and physical constraints applicable to the services.

The content of this report is based on information collected during Site baseline monitoring programs, our present understanding of the Site conditions, and our professional judgment in light of such information at the time of this report. This report provides a professional opinion and, therefore, no warranty is either expressed, implied, or made as to the conclusions, advice and recommendations offered in this report. This report does not provide a legal opinion regarding compliance with applicable laws. With respect to regulatory compliance issues, it should be noted that regulatory statutes and the interpretation of regulatory statutes are subject to change.

The findings and conclusions made in this document are valid only as of the date of the report, and are specific to Doris Outflow.

If new information is discovered in future work which indicates that one or more of the assumptions made in this report are not correct, Golder Associates Ltd. should be requested to re-evaluate the conclusions of this report, and to provide amendments as required.

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7.0 CLOSURE

We trust that the report, Doris North - Site-specific Water Quality Objective For Copper, meets your expectations. If you have any concerns or questions, please do not hesitate to contact the undersigned below.

Yours very truly,

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