# Appendix V5-8B

Near-field Plume Mixing Modelling and Water Quality Predictions for Discharges to Roberts Bay

# Memorandum

**Date:** March 9, 2016

**To:** John Roberts and Sharleen Hamm, TMAC Resources Ltd.

**From:** Mike Henry, ERM

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**Subject:** **Near-field Plume Mixing Modelling and Water Quality Predictions for Discharges to Roberts Bay**

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## 1. INTRODUCTION

TMAC Resources Ltd. (TMAC) plans to increase their production of ore at the Doris North Project, which is located 125 km from Cambridge Bay on the north coast of the Nunavut mainland. This will extend the life of the Doris Mine from two years to six years and will result in the interception of saline talik water during underground workings. A change in water management strategy will now move the discharge of mine (connate) and saline groundwater from the freshwater environment to the marine environment.

To account for the changes in Project design, TMAC submitted an application to the Nunavut Impact and Review Board (NIRB) and the Nunavut Water Board (NWB) in June 2015 to amend their current Doris Mine Project Certificate (Project Certificate No. 003) and Type A Water Licence (No. 2AM-DOH1323), part of which involved the assessment of discharging effluent to the marine environment (ERM 2015a). The following technical review comments were made by intervenors during the application review:

- KIA-8: Requested that plume modelling be conducted to predict the distance from the diffuser at which Canadian Council of Ministers of the Environment (CCME) water quality guidelines will be met in Roberts Bay, and predict the mixing zone size for three discharge scenarios (groundwater only, groundwater and TIA, TIA only) during the open water and under ice seasons.
- INAC 7 and INAC 9: Requested additional hydrodynamic modelling to address plume behaviour and mixing zones under variable effluent flow rates, composition, and environmental conditions.

In response to technical comments from the KIA, TMAC agreed to:

- conduct near-field mixing modelling to delineate mixing zone extent under a multiple discharge scenarios, and estimate the water quality therein for those parameters with marine CCME guidelines for the protection of marine and estuarine life.

Discussions with INAC during the technical session on January 27, 2016 resulted in the following commitment from TMAC:

- conduct far-field, three-dimensional dispersion modelling in Roberts Bay for the most sensitive water quality parameter (chromium) for one year of operations (Commitment#8).

The purpose of this memorandum is to present the near-field plume mixing modelling results and water quality predictions related to the proposed Doris Mine discharge into Roberts Bay. Modelling of the far-field dispersion of Doris Mine effluent in Roberts Bay is available in a complimentary report (ERM 2016).

The delineation of the near-field effluent mixing zones in Roberts Bay (extent and dilutions therein) was conducted using VISUAL PLUMES software (Frick et al. 2003), a USEPA-supported plume mixing model that is capable of simulating plume dispersion in stratified ambient flows from multi-port diffusers such as that proposed for the Doris North Project. It is an accepted effluent-dispersion model of Environment Canada (Environment Canada 2003), and is primarily used as a near-field model; that is, it applies to the region near the discharge structure (e.g., diffuser) in which the discharge plume is recognizable as separate from ambient waters and whose trajectory is dominated by the discharge rate, effluent density, and configuration of the discharge structure.

The potential for the effluent to affect water quality in Roberts Bay (and marine life therein) was assessed under a variety of discharge scenarios by comparing estimated mixing zone water quality concentrations against Canadian Council of Ministers of the Environment (CCME) water quality guidelines for the protection of marine and estuarine life (CCME 2016). The extent of the mixing plume where all marine water quality parameters were below CCME water quality criteria was considered to be safe for marine life in Roberts Bay.

Document Layout

This memo is structured as follows: Section 2 presents an outline of the Roberts Bay Discharge System, including the discharge streams and the location of the pipeline and diffuser in Roberts Bay; Section 3 describes the necessary dilution required for the effluent to meet all marine CCME water quality objectives in Roberts Bay, and thereby be safe for marine life (Problem Description); Section 4 describes the VISUAL PLUMES model and the diffuser configuration, effluent characteristics, and ambient conditions required for model inputs, and; Section 5 presents the results of the modelling exercise, subsequent plume water quality estimates; Section 6 summarizes the conclusions of the memorandum.

## 2. BACKGROUND

Under the current Doris North Project Certificate and Type A Water Licence, all mine and intercepted groundwater are to report to a Tailings Impoundment Area (TIA) and then discharged directly to Doris Creek, a fish-bearing stream that ultimately flows into Roberts Bay. The revised operational plan will encounter saline talik water under Doris Lake during underground workings, which, if discharged into Doris Creek, could affect water quality and fish and fish habitat because of elevated chloride concentrations. TMAC now proposes to discharge the saline groundwater to Roberts Bay via the Roberts Bay Discharge System where the saline effluent could be more effectively diluted within the marine environment and fully exchanged with Melville Sound.

The effects to water quality and marine life were previously assessed in the original amendment application, *Revisions to TMAC Resources Inc. Amendment Application No. 1 of Project Certificate No. 003 and Water Licence 2AM-DOH1323* (Document 4-1; ERM 2015a) using the broad-scale, time-stepped box model. The model used predicted water quality in the effluent together with baseline water quality and estimated flushing rates in Roberts Bay to predict resulting water quality in the inlet. Results of this exercise indicated that there would be no significant effects to the water quality in Roberts Bay due to marine discharge, and therefore no effects were predicted for marine life in the inlet. Through the technical review process, additional information was requested that addressed how the effluent behaved in the near-field environment (i.e., mixing zone). Specific information regarding the near-field mixing zone and resulting water quality therein are provided below.

## 2.1 Roberts Bay Discharge System

The Roberts Bay Discharge System has been described in detail elsewhere (SRK 2015a). Briefly, it consists of effluent streams from the TIA and saline groundwater that will be combined in a mixing box in the Mill Building near Doris Camp and pumped through a 5.6 km insulated pipe to the Roberts Bay Laydown Area at the Roberts Bay shoreline. The pipe will enter the marine environment through a Marine Outfall Berm and will travel approximately 2.2 km where it will terminate with a multi-port diffuser at the 40 m isobath (Appendices A1 and A2).

Saline talik water is expected to be encountered during the third year of active mining and workings within the talik will continue for four years. During this time, the TIA decant and saline groundwater will be discharged to Roberts Bay in a tri-modal, intermittent fashion. The saline groundwater will be discharged year-round and the TIA water will be combined with the groundwater and discharged only during the open-water season (June to September) when Roberts Bay flushing is greatest. Thus, only groundwater will be discharged during the ice-covered period (October to May) when inlet currents are negligible. The groundwater and combined TIA and groundwater discharge will occur over four years of operations. Several months following the end of operations, the TIA will be de-watered directly to Roberts Bay over an 18-month period after which no discharge will be released to Roberts Bay. Discharge will be intermittent and will be released when sufficient volume is available to pump at a constant rate to Roberts Bay.

The groundwater and TIA discharge will always be less dense than the ambient deep waters of Roberts Bay (see Section 4.2.1.2); therefore, the plume will be buoyant and will not interact with the seafloor. Appendix A3 shows a conceptual sketch of how the effluent and resulting plume will behave in the stratified waters of the bay. Briefly, the effluent will be discharged from ports on each side of the diffuser, with the less dense effluent being entrained into the Roberts Bay deep water through momentum and turbulent mixing. As momentum subsides, each buoyant plume will continue to rise through the stratified water column and will begin to merge as the plume density nears that of the ambient seawater. When density equilibrium is reached, the merging plume will reach its maximum rise, also known as the trapping depth, and will spread horizontally through the inlet with the deep water currents.

### 2.2 Design Objectives

The design objective of the Roberts Bay Discharge System is to ensure preservation of marine water quality within Roberts Bay, thereby protecting marine life and ecological function in the inlet. More specifically, concentrations of designated substances (arsenic, cadmium, chromium, mercury, silver, nitrate) must not exceed CCME marine water quality guidelines outside of a small mixing zone near the diffuser, and concentrations of substances designated by the Metal Mining Effluent Regulations (MMER; SOR/2002-222) must be below the requirements at the discharge point.

The multi-port diffuser will be a key infrastructure component in meeting these objectives as diffusers have the potential to achieve upwards of 100:1 dilution within metres of the outfall by increasing the entrainment of the effluent with the ambient deep waters. In the case of Roberts Bay, this will be beneficial for two reasons; first, the effluent will meet receiving water quality criteria much closer to the diffuser and will reduce the potential spatial zone of influence on marine organisms. Second, the density of the buoyant discharge will equilibrate much more quickly with the ambient water, reducing the rise of the plume in the water column. This will limit the effluent that will reach the more productive surface layer, and in the case of Roberts Bay, will confine the plume to the deep waters where past studies have shown that it will exchange freely with Melville Sound waters (Rescan 2012a; 2012b).

## 3. PROBLEM DESCRIPTION

To ensure that marine life is protected in Roberts Bay, the TIA and groundwater effluent must be diluted such that water quality concentrations in Roberts Bay will be less than CCME water quality guidelines for the protection of marine and estuarine life. Thus, water quality predictions were generated for those parameters with marine CCME guidelines using the near-field mixing modelling results as well as predicted effluent and measured baseline water quality data. Table 1 summarizes the comparison of predicted water quality concentrations in the TIA and groundwater (SRK 2015b; SRK 2016) with baseline concentrations in Roberts Bay to determine the dilution required to ensure that all water quality parameters will be below marine CCME guideline levels. VISUAL PLUMES was then used to predict if the required dilutions were achievable based on modelled dilutions near the diffuser.

As requested during the technical review of the amendment application (ID# KIA-8), water quality was evaluated using 75$^{th}$ percentile concentrations for both predicted TIA effluent (SRK 2016) and baseline Roberts Bay water quality. The 95$^{th}$ percentile concentrations were used for predicted groundwater concentrations (SRK 2015b). Deep-water concentrations (samples taken below the pycnocline) were used for Roberts Bay water quality as the effluent will be discharged into and is expected to be trapped within this layer.

For baseline chromium concentrations, the median level of 0.0005 mg/L was used as all baseline concentrations were below analytical detection (with multiple detection limits) and the 75$^{th}$ percentile concentration (0.05 mg/L) was greater than the predicted TIA and groundwater concentrations (Table 1). The use of the elevated 75th percentile detection limit concentration would have artificially diluted the chromium concentrations in Roberts Bay under each of the TIA and groundwater discharge scenarios. Baseline silver concentrations were also below analytical detection for every sample, however, the 75th percentile concentration was lower than the predicted TIA and combined TIA and groundwater discharge concentrations and the 0.001 mg/L level was retained in the analysis.

**Table 1. Predicted TIA and Groundwater and Baseline Roberts Bay Water Quality Concentrations for CCME Parameters.**

| | Water Quality Concentration (mg/L) | | | | | Effluent Dilution Required to Meet CCME (X:1) | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | TIA Only | Groundwater Only | TIA+GW | Roberts Bay | CCME Guideline | TIA | GW | TIA+GW |
| Nitrate | 1.02 | 0.93 | 0.98 | 0.0745 | 45 | 0.0 | 0.0 | 0.0 |
| Arsenic | 0.016 | 0.002 | 0.010 | 0.00137 | 0.0125 | 1.3 | 0.2 | 0.8 |
| Cadmium | 0.00040 | 0.00012 | 0.00028 | 0.000068 | 0.00012 | 3.4 | 1.0 | 2.3 |
| Chromium[a] | 0.0096 | 0.0009 | 0.0058 | 0.0005 | 0.0015 | 6.4 | 0.6 | 3.9 |
| Mercury[b] | 0.000081 | 0.000049 | 0.000067 | 0.0000018 | 0.000016 | 5.0 | 3.1 | 4.2 |
| Silver[a] | 0.0114 | 0.0001 | 0.0065 | 0.001 | 0.0075 | 1.5 | 0.0 | 0.9 |

*Note: 75th percentile concentrations were used for predicted TIA and baseline Roberts Bay data. 95th percentile concentrations were used for predicted groundwater data.*
[a] *all baseline chromium and silver concentrations in Roberts Bay were below analytical detection limits.*
[b] *75th percentile baseline concentration was calculated using only mercury samples that were analyzed at ultra-low detection limits (0.0000005 mg/L).*

The comparisons indicate the following:

- The greatest water quality concentrations for marine CCME parameters are always observed in the TIA effluent.
- Only minor dilution will be required to have all effluent concentrations meet CCME marine water quality guidelines. Chromium concentrations within the TIA effluent will require the greatest overall dilution at 6.4:1. All metals will require dilution at factors less than the 10× safety factor that are applied to CCME guidelines to be protective of the most sensitive marine organisms (based on species sensitivity distributions).
- Mercury will require the greatest dilution in the groundwater and TIA-groundwater combined scenarios, although the CCME guideline for mercury (0.000016 mg/L) is nearly an order of magnitude greater than baseline concentrations in Roberts Bay (0.0000018 mg/L).
- Nitrate will not require dilution and silver and arsenic will require only minor dilution and only when TIA effluent is discharged.
- Mercury is the only parameter that will require dilution (3.1:1) when only groundwater is discharged to Roberts Bay.

From Table 1 it can be surmised that if the TIA and groundwater effluent is diluted by more than 6.4:1 within the mixing zone in Roberts Bay then all water quality will be protective of marine life in the inlet.

## 4. MIXING ZONE MODEL

The VISUAL PLUMES model was used for the purposes of evaluating the near-field mixing zone characteristics and generating water quality predictions in Roberts Bay based on a variety of discharge scenarios (ground water and TIA effluent) and receiving environment conditions (ice covered/open water). The specific objectives of the near-field VISUAL PLUMES modelling exercise were to:

- Predict the distance from the diffuser at which the 6.4:1 dilution ratio will be met under multiple discharge scenarios so that all effluent water quality parameters will meet CCME water quality criteria that are protective of marine and estuarine life (i.e., 'CCME mixing zone');
- Predict the depth in the Roberts Bay where the discharge plume will be trapped (i.e., 'initial dilution zone') and dilutions achieved under multiple discharge scenarios; and
- Predict water quality concentrations within the trapped initial dilution zone for those parameters with marine CCME guidelines.

Mixing zone characteristics and water quality predictions were developed using the three-dimensional Updated Merge (UM3) model within VISUAL PLUMES (Frick et al. 2003). UM3 is a Langrangian plume model that simulates the overall average behaviour of the plume along a plume trajectory, and quantifies the rate at which mass is integrated into a plume in the presence of a current (i.e., forced entrainment). The model was run as steady state; that is, all inputs were deemed constant over time. Conservatism was applied to the modelling exercise, with maximum discharge rates and enriched water quality in the effluent and ambient waters used as model inputs.

### 4.1 Modelling Scenarios

The discharge to Roberts Bay will involve three discharge streams (groundwater, combined groundwater and TIA water, and TIA only water) of varying densities that will be pumped from the mixing box at a constant rate during the under-ice, moderately stratified season (October to May) and the ice-free, strongly stratified season (June to September). Five pumped discharge scenarios were modelled to represent the most important nominal operating conditions that could be encountered during the winter and summer seasons. These are outlined in Table 2 along with their effluent characteristics.

### 4.2 Model Inputs

VISUAL PLUMES requires three types of data inputs:

- The dimensions, depth, and configuration of the discharge structure (i.e., diffuser);
- A description of the effluent quality; and

- The properties and characteristics of the receiving environment, in this case, Roberts Bay.

**Table 2. Modelled Scenarios with Effluent Quantities and Thermohaline Characteristics**

| Case | Source of Water | Season | Effluent Pump Rate ($m^3/d$) | Effluent Salinity (ppt) | Effluent Temperature (°C) |
|---|---|---|---|---|---|
| **Winter Cases** | | | | | |
| 1a | Groundwater only (highest salinity) | Under ice (8 months) | 3,000 | 26.6 | 2.0 |
| 1b | Groundwater only (steady state) | Under ice (8 months) | 3,000 | 9.9 | 2.0 |
| 1c | TIA only (de-watering) | Under ice (8 months) | 4,000 | 0.2 | 2.0 |
| **Summer Cases** | | | | | |
| 2a | Groundwater (steady state) + TIA | Open water (4 months) | 7,000 | 4.2 | 7.4 |
| 2b | TIA discharge only (de-watering) | Open water (4 months) | 4,000 | 0.2 | 10.0 |

#### *4.2.1.1 Diffuser Configuration*

The model inputs for the diffuser configuration were based on previous designs (SRK 2015a). Specifically, the diffuser will be a 95-m long structure anchored at 40 m depth approximately 0.6 m above the seafloor. The diffuser will have 20 ports of 30 mm diameter staggered on either side of the diffuser spaced at 5 m intervals and discharging horizontally.

#### *4.2.1.2 Effluent Description*

The main effluent inputs included the discharge rate, density (salinity and temperature), and predicted water quality so that resulting mixing zone concentrations could be calculated.

<u>Discharge Rates</u>

The groundwater, TIA, and combined TIA and groundwater effluent streams were conservatively modelled as continuous discharges at the designed pump rates shown in Table 2. Groundwater will be pumped at a rate of 3,000 $m^3/d$ (35 L/s), TIA water at 4,000 $m^3/d$ (46 L/s), and TIA and groundwater combined discharge at 7,000 $m^3/d$ (81 L/s). In reality, pumping will be intermittent as discharge will only occur when there is sufficient water volume to support pumping for a least 6 continuous hours.

<u>Density</u>

The effluent sources will have different thermohaline characteristics thereby affecting the density of the discharge. The groundwater discharge will always be saline, with peak predicted chloride concentrations reaching 14,750 mg/L (salinity: 26.6 ppt)[1] during one month early in the operations phase (Figure 1; SRK 2015b). This is projected to decline rapidly to approximately 5,500 mg/L (salinity: 9.9 ppt) through most of operations (steady state). Plume mixing was modelled for each of the peak and steady state salinities during winter groundwater discharge, realizing that the peak salinity is a very conservative scenario as elevated levels are only anticipated to occur over a few months immediately after encountering the talik water.

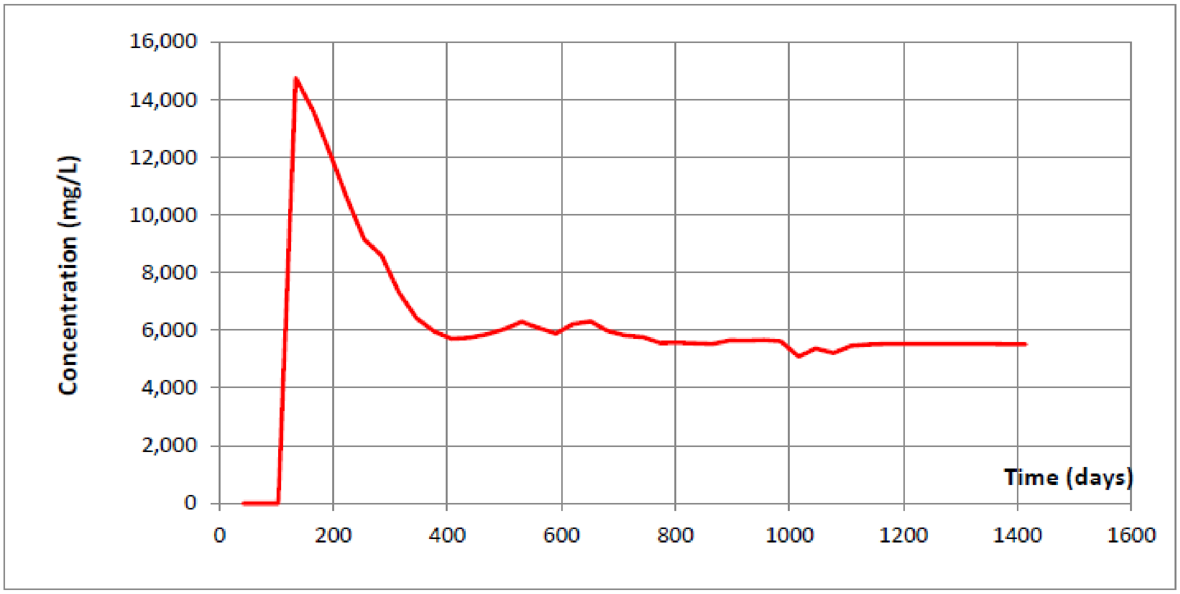


**Figure 1. Predicted Chloride Concentrations over Time associated with Mine Inflow (from SRK (2015b))**

The TIA water will be fresher with predicted chloride levels below 125 mg/L (salinity: 0.2 ppt; SRK 2016). Following operations, the TIA will be de-watered over an 18-month period during the under-ice and open-water seasons and will be the only water discharged into Roberts Bay during this time. For modelling purposes, 0.2 ppt was used for both the TIA under-ice and open-water de-watering scenarios (Table 2). During operations, the TIA water will also be combined with the saline groundwater (at steady state levels) and released into Roberts Bay during the open-water season over four consecutive years. The resulting salinity of 4.2 ppt was used in the modelling exercise for this scenario (Table 2).

Effluent temperature will also contribute to the overall density of the effluent, although far less so in the saline discharges. A temperature of 2°C was used for under-ice discharge scenarios (groundwater only discharge and TIA de-watering) as this will be the minimum temperature required to ensure the effluent will not freeze in the discharge system. TIA only discharge during the open-water season was modelled at 10°C based on average baseline measurements in the TIA (Rescan 2012c). The temperature for the combined TIA and groundwater effluent during the

[1] Based on regression of 2011 baseline salinity and chloride measurements from Roberts Bay deep waters ([Salinity, ppt] = [chloride, mg/L] × 0.0018).

open-water discharge was estimated at 7.4°C based on the 10°C summer TIA temperature and the 4°C groundwater temperature and their 4:3 mixing ratio in the mixing box.

Water Quality

Water quality inputs are considered to be conservative. The 75th percentile concentrations were used for TIA inputs based on SRK's sensitivity analysis of the TIA water quality predictions (SRK 2016), and 95th percentile concentrations were used for groundwater inputs as was done for SRK's *Doris North Project - Water and Load Balance Report* (SRK 2015c). A summary of the water quality inputs for the six water quality parameters with marine CCME guidelines is shown in Table 1.

##### *4.2.1.3 Ambient Conditions*

The existing ambient conditions of Roberts Bay were summarized in the original amendment application (ERM 2015a). The main inputs required in the model included physical water column structure (depth, salinity, and temperature), currents, and baseline Roberts Bay water quality. Discharge scenarios were modelled for both the open-water and under-ice periods (Table 2) to account for the seasonal differences in the aforementioned physical inputs.

Physical

The physical structure and circulation of Roberts Bay is determined by the presence or absence of ice. When ice covered, Roberts Bay is weakly stratified, with colder (-1.5°C), less saline water (25 to 27 ppt) overlying warmer (-0.2°C), more saline water (27 to 28 ppt), with a surface mixed layer depth ranging between 10 m to 35 m. Deep-water currents in Roberts Bay are usually less than 1 cm/s (Rescan 2012a). In open water, the bay is strongly stratified due to ice melt and riverine inputs, with a warmer (10°C), less saline (15 to 20 ppt) layer overlying a colder (-1°C), more saline (26 to 28 ppt) bottom layer, with a very stable pycnocline near 10 m. During this time, Roberts Bay circulation is dominated by winds (as opposed to riverine or tidal inputs), with the bay capable of being flushed several times with Melville Sound water over the open-water season (Rescan 2012a). Deep-water currents range between 1 cm/s to 25 cm/s, and are usually between 3 cm/s and 5 cm/s (Rescan 2012a).

For modelling purposes, data from representative thermohaline profiles were used as inputs from under-ice and open-water discharge scenarios (Table 3). The winter profile was taken on April 30, 2009, near the proposed diffuser location and the summer profile was collected on August 14, 2009. Ocean currents were set at 0 cm/s for under ice and 5 cm/s for open water. Tides were not considered as their contribution to the overall current structure in Roberts Bay is minimal (Rescan 2012a; 2012b).

Water Quality

Baseline water quality inputs included those parameters with CCME guidelines for the protection of marine and estuarine life (Table 1). The 75$^{th}$ percentile concentrations were used and were calculated from measurements collected at deep-water sites and from deep-water depths (below the pycnocline) in Roberts Bay. This rationale was adopted because this will be the region in the bay where effluent will be discharged and trapped and is more conservative as the greatest water quality parameter concentrations are usually found in the deep waters of Roberts Bay (Rescan 2010; 2011a; 2011b).

**Table 3. Baseline Thermohaline Profile Data Used in Modelling Scenarios**

| Under Ice (April 30, 2009) | | | Open Water (August 14, 2009) | | |
|---|---|---|---|---|---|
| Depth (m) | Salinity (ppt) | Temp (°C) | Depth (m) | Salinity (ppt) | Temp (°C) |
| 0.00 | 26.80 | -1.51 | 0.00 | 14.92 | 10.51 |
| 4.03 | 26.80 | -1.52 | 0.74 | 15.41 | 9.73 |
| 6.04 | 26.80 | -1.51 | 1.15 | 15.68 | 9.30 |
| 7.94 | 26.80 | -1.51 | 1.32 | 15.83 | 9.23 |
| 9.27 | 26.78 | -1.48 | 2.21 | 16.40 | 9.15 |
| 10.00 | 26.74 | -1.42 | 3.38 | 16.64 | 9.05 |
| 11.21 | 26.56 | -1.08 | 4.96 | 17.71 | 8.41 |
| 12.71 | 27.11 | -0.95 | 6.90 | 18.88 | 7.75 |
| 14.25 | 27.05 | -0.93 | 9.26 | 22.29 | 5.63 |
| 16.70 | 27.21 | -0.90 | 10.80 | 24.48 | 2.78 |
| 19.91 | 27.27 | -0.92 | 12.77 | 25.40 | 1.79 |
| 21.81 | 27.35 | -0.92 | 14.32 | 25.99 | 1.14 |
| 23.98 | 27.40 | -0.94 | 15.74 | 26.32 | 0.78 |
| 26.08 | 27.44 | -0.95 | 18.30 | 26.47 | 0.44 |
| 27.98 | 27.48 | -0.98 | 20.20 | 26.68 | 0.08 |
| 31.74 | 27.54 | -0.99 | 22.14 | 26.83 | -0.13 |
| 34.09 | 27.57 | -1.01 | 23.92 | 26.91 | -0.25 |
| 36.20 | 27.60 | -1.04 | 27.77 | 27.12 | -0.43 |
| 38.17 | 27.60 | -1.03 | 32.70 | 27.25 | -0.56 |
| 40.47 | 27.62 | -1.04 | 37.03 | 27.36 | -0.64 |
| - | - | - | 40.70 | 27.39 | -0.67 |

## 5. SIMULATION RESULTS AND DISCUSSION

Near-field discharge plume behavior was numerically simulated based on nominal operating conditions (groundwater only, TIA only, and combined TIA and groundwater discharge) that could occur during the winter (ice covered) and summer (open water) seasons. This resulted in a total of three simulated discharge cases in the winter and two in the summer.

### 5.1 Mixing Zone

The simulations showed that there will be tremendous dilution of the Doris Mine effluent as it passes through the diffuser into Roberts Bay (Table 4). The dilution of 6.4:1 required to ensure all water quality parameters are below CCME guideline levels in Roberts Bay is expected to occur within 1 m of the diffuser under all discharge scenarios (Table 4: column 8). This indicates that the discharge will be protective of marine life almost immediately after entering Roberts Bay.

**Table 4. Summary of Modelled Plume Mixing Zone Results for Under-ice and Open-water Discharge Scenarios**

| | Source of Water | Effluent Flow Rate ($m^3/d$) | Effluent Salinity (ppt) | Trapping Depth (m) | Horizontal Distance from Diffuser Port at Trapping Depth (m) | Minimum Average (Centreline) Dilution at Trapping Depth (X:1) | Horizontal Distance from Diffuser Port at which all CCME Met (Dilution of 6.4:1) (m) |
|---|---|---|---|---|---|---|---|
| **Under-ice Cases** | | | | | | | |
| 1a | Groundwater only (worst case) | 3,000 | 26.6 | 35.8 | 12.7 | 186 (142) | 0.76 |
| 1b | Groundwater only (steady state) | 3,000 | 9.9 | 29.5 | 5.2 | 294 (238) | 0.87 |
| 1c | TIA only (de-watering) | 4,000 | 0.2 | 27.5 | 5.7 | 361 (302) | 0.73 |
| **Open-water Cases** | | | | | | | |
| 2a | TIA only (de-watering) | 4,000 | 0.2 | 34.1 | 9.8 | 598 (471) | 0.75 |
| 2b | TIA + GW (steady state) | 7,000 | 4.2 | 34.1 | 12.5 | 446 (345) | 0.79 |

The plume trapping depths were estimated to be between 27.5 m and 35.8 m depth, or roughly 4 m to 13 m above the diffuser, with horizontal boundaries ranging from 5 m to 13 m (Table 4). Average plume dilutions were 186:1 to 598:1 within the vertical and horizontal plume boundaries. The trapping of the discharge plume far below the pycnocline (10 m depth) during each scenario suggests that nitrate will not be entrained into the more productive surface mixed layer, and will instead be advected from Roberts Bay into Melville Sound.

The greatest dilutions (> 400:1) were predicted to occur during the summer when the fresh TIA and brackish combined TIA and groundwater would be discharged. During this time, the discharge rates (port exit velocity) and ambient currents would be greatest, and the discharge would be most buoyant (TIA only and combined TIA and groundwater discharge) leading to enhanced entrainment and mixing of the plume into the surrounding Roberts Bay waters.

The lowest dilutions were predicted to occur under ice in winter when currents would be absent, discharge rates would be lowest, and the density differential between the effluent and ambient waters would be least (except TIA de-watering). The minimum calculated dilution (186:1) and trapping depth (35.8 m) corresponded to the highest salinity (least buoyant), groundwater discharge that would occur for a few months immediately after encountering saline talik water under Doris Lake.

### 5.2 Water Quality

Water quality concentrations were estimated at the trapping depth boundary using predicted dilutions from the near-field modelling exercise together with predicted effluent and baseline water quality data. Results showed that water quality at the extent of the mixing zone is expected to be far below CCME guidelines for the protection of marine and estuarine life (Table 5) and remain relatively unchanged from baseline levels (Table 6). Marine CCME water quality parameter concentrations were predicted to be greatest either during the under ice TIA de-watering discharge (arsenic, cadmium, chromium, silver), or during the short time when high salinity groundwater is discharged into an ice-covered Roberts Bay (mercury and nitrate). Nearly all water quality concentrations are expected to be within a few percentage points of baseline levels during each discharge scenario, except mercury that was estimated to be more than 10% of baseline levels (Table 6). However, the estimated mercury concentrations were nearly an order of magnitude lower its CCME guideline limit of 0.000016 mg/L. Given these results, the water quality is expected to be similar to baseline conditions following discharge and will be safe for marine and estuarine life in Roberts Bay.

**Table 5. Predicted Water Quality Concentrations in Mixing Zone (at Trapping Depth) for Groundwater and TIA Discharge Scenarios.**

| | | | Discharge Scenarios – Water Quality (mg/L) | | | | |
|---|---|---|---|---|---|---|---|
| Water Quality Parameter | CCME Guideline | Roberts Bay Baseline [a] | Groundwater (peak salinity) | Groundwater (steady state salinity) | TIA (under ice) | TIA (open water) | TIA+GW (open water) |
| Nitrate | 45 | 0.075 | 0.079 | 0.077 | 0.077 | 0.076 | 0.077 |
| Arsenic | 0.0125 | 0.0014 | 0.0014 | 0.0014 | 0.0014 | 0.0014 | 0.0014 |
| Cadmium | 0.00012 | 0.000068 | 0.000068 | 0.000068 | 0.000069 | 0.000069 | 0.000068 |
| Chromium | 0.0015 | 0.00050 | 0.00050 | 0.00050 | 0.00053 | 0.00052 | 0.00051 |
| Mercury | 0.000016 | 0.0000018 | 0.0000021 | 0.0000020 | 0.0000020 | 0.0000019 | 0.0000019 |
| Silver | 0.0075 | 0.0010 | 0.0010 | 0.0010 | 0.0010 | 0.0010 | 0.0010 |

[a] *Baseline concentrations were 75th percentile of deep water samples.*

**Table 6. Percent Increase of Predicted Mixing Zone Water Quality Concentrations (at Trapping Depth) over Baseline for Groundwater and TIA Discharge Scenarios.**

| | Discharge Scenarios – Water Quality (%) | | | | |
|---|---|---|---|---|---|
| Water Quality Parameter | TIA (open water) | Groundwater (steady state salinity) | TIA (under ice) | TIA (open water) | TIA+GW (open water) |
| Nitrate | 6.2 | 3.9 | 3.5 | 2.1 | 2.7 |
| Arsenic | 0.4 | 0.3 | 3.0 | 1.8 | 1.5 |
| Cadmium | 0.4 | 0.3 | 1.4 | 0.8 | 0.7 |
| Chromium | 0.4 | 0.2 | 5.0 | 3.0 | 2.4 |
| Mercury | 14.1 | 8.9 | 12.1 | 7.3 | 8.1 |
| Silver | -0.5 | -0.3 | 2.9 | 1.7 | 1.2 |

## 6. CONCLUSIONS

The results of the near-field modelling exercise indicate that tremendous dilutions (> 180:1) will attained within metres of the multi-port diffuser under all discharge scenarios, with all marine CCME water quality criteria predicted to be met within 1 m of the diffuser. The resulting plume will be buoyant and is expected to be trapped below the surface layer of Roberts Bay and will not interact with the seafloor. The water quality predictions validate previous findings from the original assessment (ERM 2015a) and follow-up technical review (e.g., ERM 2015b); that is, water quality in Roberts Bay will be similar to baseline conditions following discharge, and because concentrations will be far below existing CCME guidelines for the protection of marine and estuarine life, there will be no significant effects to marine life in the inlet.

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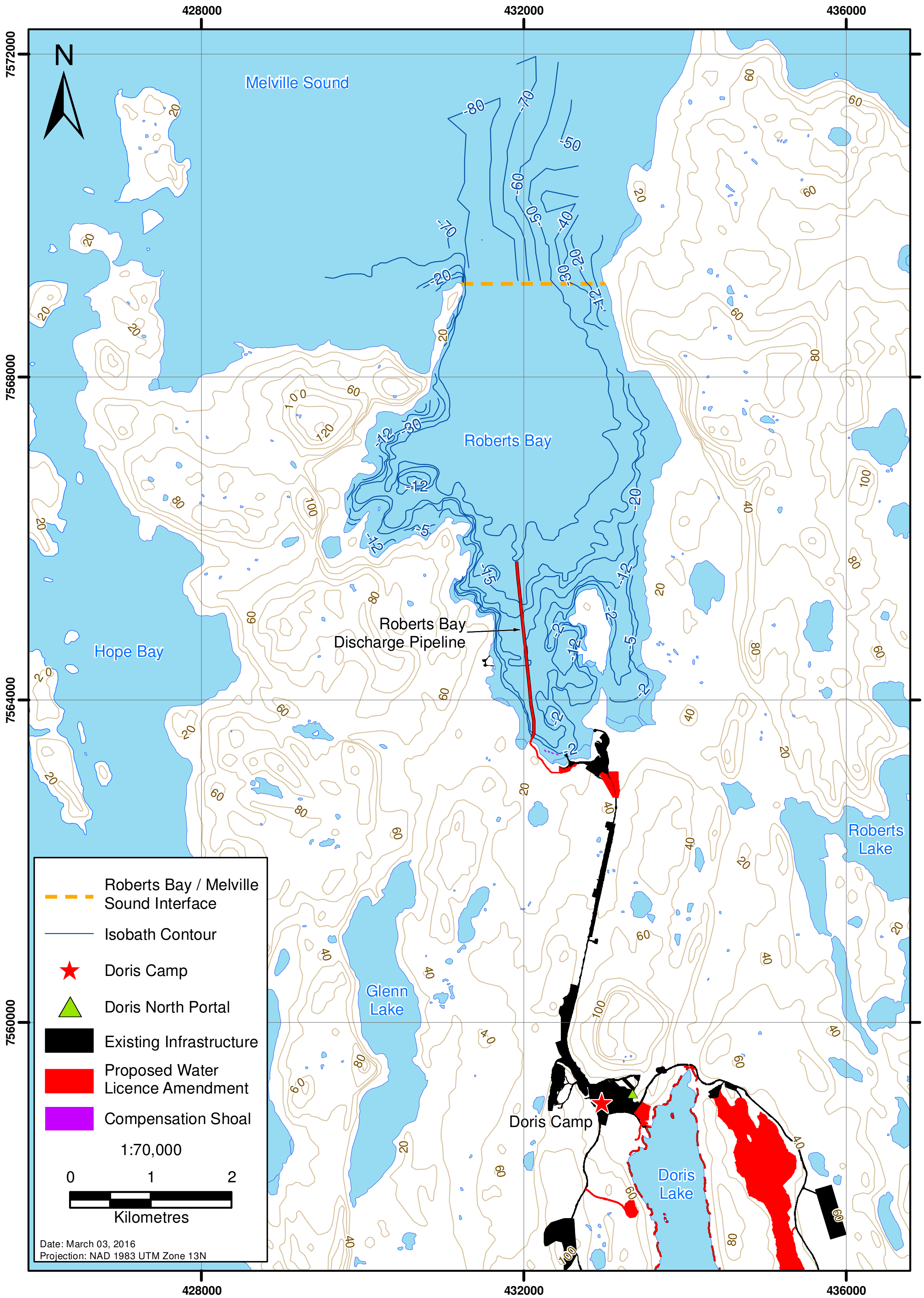
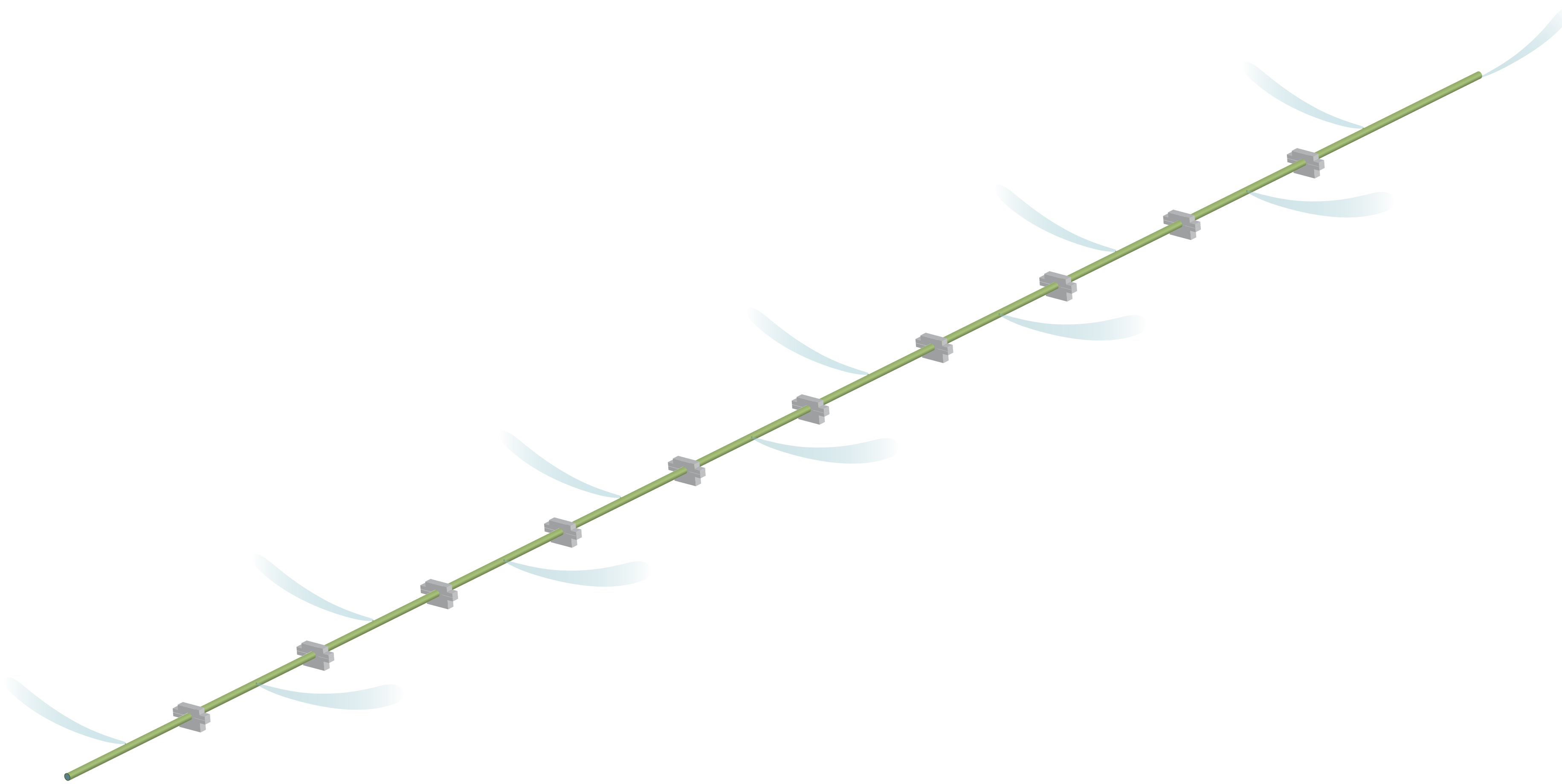
# Appendix A1
## Location of Doris North Project and Roberts Bay Discharge Pipeline



## Appendix A2

## Concept Sketch of One Half of the Diffuser showing the Discharge Plumes

ERM



*Note: Drawing not to scale.*

# Appendix A3

## Conceptual Sketch of Discharge Plume Behaviour in Roberts Bay