TETRA TECH

TECHNICAL MEMO

ISSUED FOR USE

To:	Colleen Prather, Permitting Technical Advisor Angie Arbaiza, Permitting Lead Michel Groleau, General Supervisor, Permitting and Regulatory Affairs	**Date:**	January 6, 2021
c:		**Memo No.:**	01
From:	Changheng Chen, Physical Oceanographer Aurelien Hospital, Group Manager	**File:**	ENG.ACLE03008-03
Subject:	Addendum to 3-D Hydrodynamic Modelling of Melvin Bay to Characterize the Long-Term Mixing and Transport of a Low TDS Effluent		

1.0 INTRODUCTION

Tetra Tech Inc (Tetra Tech) was engaged by Agnico Eagle Mines Limited (Agnico Eagle) to conduct 3-D circulation modelling in Melvin Bay, NU, to assess the dilutions resulting from a discharge through a proposed marine diffuser. In October 2020, Tetra Tech submitted a study report titled "*Meliadine Mine Waterline Addendum: Melvin Bay Hydrodynamic Modelling and Characterization of the Fate and Behaviour of the Discharged Saline Effluent*". This report presented the modelling framework, environmental input data and results corresponding to the discharge of a saline non-buoyant effluent (39,600 mg/L TDS), slightly denser than ambient ocean waters. A first addendum was conducted in November 2020 to assess the transport and mixing of a slightly buoyant effluent (14,861 mg/L TDS).

This technical memo serves as a second addendum to Tetra Tech's October 2020 study. This study focuses on the transport and mixing of a much buoyant effluent, with a TDS concentration estimated at 2,178 mg/L. This effluent corresponds to a discharge of CP1 waters directly into Melvin Bay instead of Meliadine Lake. While a discharge scenario of 100% surface contact water is unlikely, this scenario of low TDS water was investigated as part of the Adaptive Management Strategy developed by Agnico Eagle in response to interveners queries.

The same hydrodynamic model is used in this addendum study. However, this study focuses now on the release of a more buoyant effluent, composed of less saline water, and therefore less dense than ambient ocean waters, as compared to the effluent modelled in the October 2020 and November 2020 studies. Model forcing data, initial and boundary conditions, as well as model validation can be found in the Tetra Tech's October study. Characteristics of ocean current in the Melvin bay were also presented in Tetra Tech's October study.

This technical memo presents the effluent discharge configuration in Section 2. Section 3 shows the results of effluent accumulation over time, effluent concentration and temperature and salinity changes due to the effluent discharge in Melvin Bay. Conclusions of this study are given in Section 4.

OQM CERTIFIED

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2.0 DISCHARGE CONFIGURATION

This addendum investigates the transport and mixing of a buoyant effluent in Melvin Bay. The effluent flow is conservatively estimated at 20,000 m^3/d from June through October. The discharge rate is well above the projected mean daily flow rates for each month over mine operations (i.e., 2020 to 2028) and represents a conservative scenario. The 3-D hydrodynamic model is run through the discharge season (i.e., open water) from early June to late October. While the effluent discharge stops at the end of October, the simulation continues for an extra month, i.e., through November, with no effluent discharge to allow an investigation on the timeline for the system to recover from the effluent discharge. Effluent is discharged at the proposed diffuser location as from Tetra Tech's previous diffuser design study (545789 m E and 6963370 m N) and at a depth of 20 m Chart Datum.

The effluent temperature in each month is set to be 3 °C higher than the monthly mean air temperature from the meteorological forcing data, representing the potential heating of the effluent during overland transport through the covered pipeline. Salinity of the effluent is 2.18 PSU and is conservatively converted from a TDS concentration of 2,178 mg/L, which corresponds to a diversion of the flow from Meliadine Lake to Melvin Bay and a low TDS content (email communication with Agnico Eagle, November 26, 2020). Table 1 summarizes the discharge rate, temperature, salinity and density of the effluent. The effluent density (ranging between 1000.9 kg/m^3 and 1001.7 kg/m^3) is consistently lower than the ambient ocean water density, which ranges from around 1,024 kg/m^3 to 1,027 kg/m^3 depending on the ambient seawater temperature and salinity.

Table 1. Effluent Monthly Discharge Rates and Temperature

Month	June	July	August	September	October	November
Discharge Rate (m3/d)	20,000	20,000	20,000	20,000	20,000	0
Temperature (°C)	8.40	14.27	13.21	6.50	1.00	-
Salinity (PSU)	2.18	2.18	2.18	2.18	2.18	-
Density (kg/m^3)	1001.55	1000.90	1001.05	1001.66	1001.67	-

3.0 RESULTS

3.1 Effluent Accumulation

A total volume of about 3,060,000 m^3 of effluent is discharged between June and October. As a comparison, the amount of water present in the bay at any given time exceeds 50,000,000 m^3, without accounting for the thousands of cubic meters of water exchanged daily through tides.

The amount of effluent remaining in the model domain is primarily determined by discharge rate, as well as metocean conditions (i.e., current in the embayment and water exchange between Melvin Bay and Hudson Bay through tides). The specific concentrations of both chloride and TDS in the effluent are held constant during the discharge season.

The amount of effluent present within the domain and its percentage of the total released effluent as a function of time are shown in Figure 3.1. Effluent in the water body within Melvin Bay first increases greatly and then fluctuates around a mean level in each subsequent month in response to effluent exiting the model boundary and metocean conditions. It is worth noting that the maximum quantity of effluent reaches a maximum of about 0.12 Mm³ in the embayment that contains over 50 Mm³ of water.

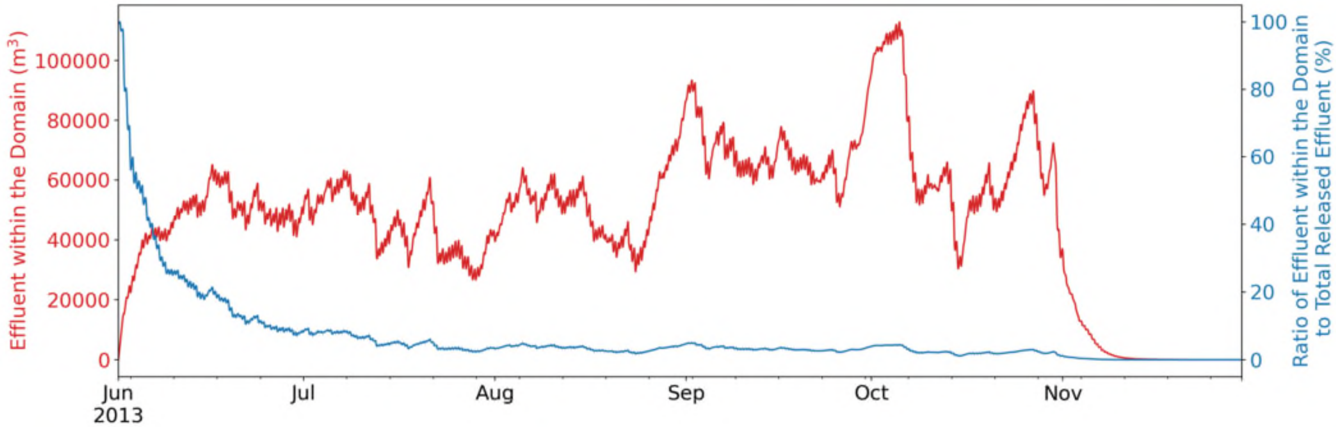

Figure 3.1. Effluent Present within Melvin Bay (red curve) and Ratio of Effluent (blue curve) within the Bay to Total Released Effluent as a Function of Time

The tidal conditions in Melvin Bay shows significant flushing capacity. The system recovers to a pre-effluent-discharge state at a great speed after the discharge stops by the end of October:

- There is about 0.03% of the total released effluent (589 m³ out of 3,060,000 m³) that is still present in Melvin Bay 10 days after the discharge being stopped.
- By November 20, i.e., almost three weeks after the discharge stopped, there is about 0.001% of the total released effluent (23 m³) that still remains in Melvin Bay. In comparison, there was about 55 m³ effluent left by November 20 in the system in Tetra Tech's October study, where a nonbuoyant effluent was discharged at the same rate of 20,000 m³/d. While similar, this difference can be explained by the nature of the effluent: buoyant effluent tends to rise to the surface, where current speed is relatively stronger and exhibits higher flushing capability as shown in the Tetra Tech's October study. Note that October and November were considered open water and did not include ice formation in this simulation.

3.2 Effluent Concentration

The different constituents of the effluent are represented as a passive tracer, which has an initial concentration of 1 (m³/m³). A target tracer concentration value of 0.09 was identified at the 100-m mixing zone (Tetra Tech October 2020 study), corresponding to a target dilution of 11:1.

This target concentration is met at all time at the 100-m mixing zone. Knowing that the dash line of Figure 3.2 represents the target/threshold concentration, the maximum concentration is well below the target concentration during the whole model simulation period. The maximum tracer concentration at the edge of the mixing zone is around 0.018 (about 55:1 dilution) throughout the discharge season. The concentration value reaches near 0 about 20 days after the effluent discharge stops on October 30.

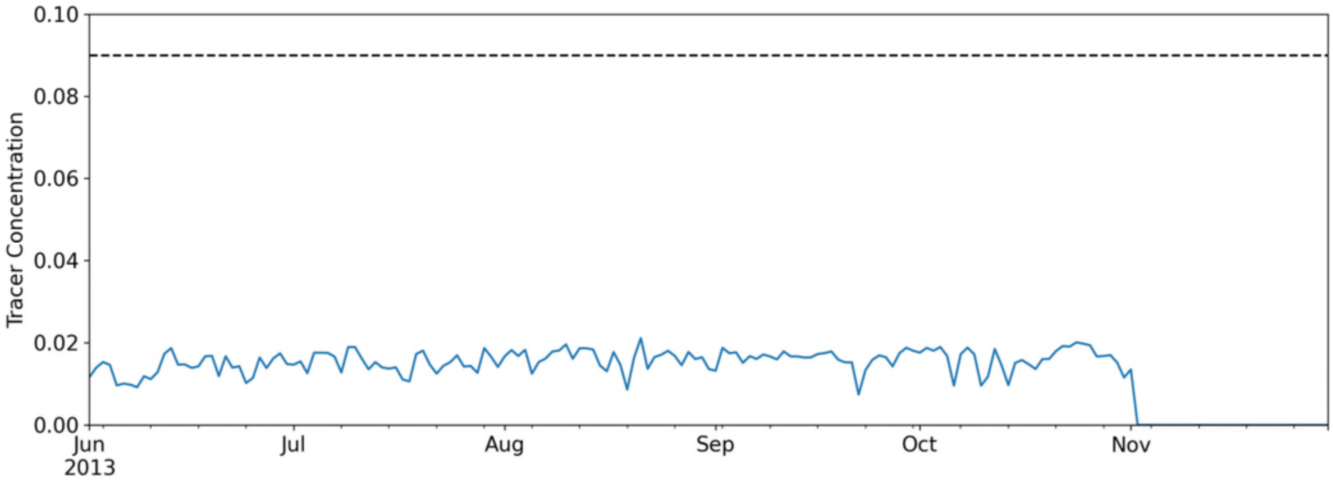

Figure 3.2. Time Series of Daily Maximum Effluent Concentration at the 100-m Mixing Zone (Dash Line Indicating the Threshold Concentration Value 0.09 Corresponding to a Dilution of 11:1)

Figure 3.3 illustrates the spatial distribution of the effluent in a plan view. The monthly mean of maximum concentration throughout the water column in October is displayed. The legend was selected to reflect the threshold concentration as red color. As one can observe, the entire bay appears in blue, indicating tracer concentration much smaller than the threshold concentration. Value probing shows that while still well below the concentration threshold of 0.09 (corresponding to dilution of 11:1), maximum tracer concentration tends to be slightly higher in the vicinity of the diffuser during the discharge season, as one could expect.

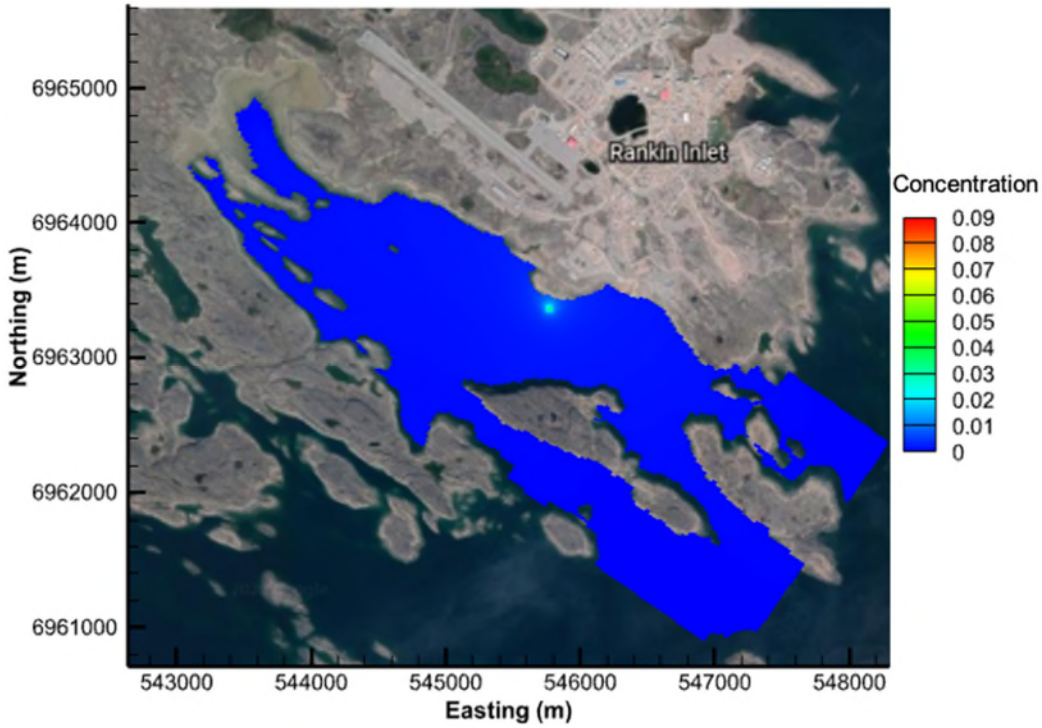

Figure 3.3. Monthly Mean of Maximum Effluent Concentration in October

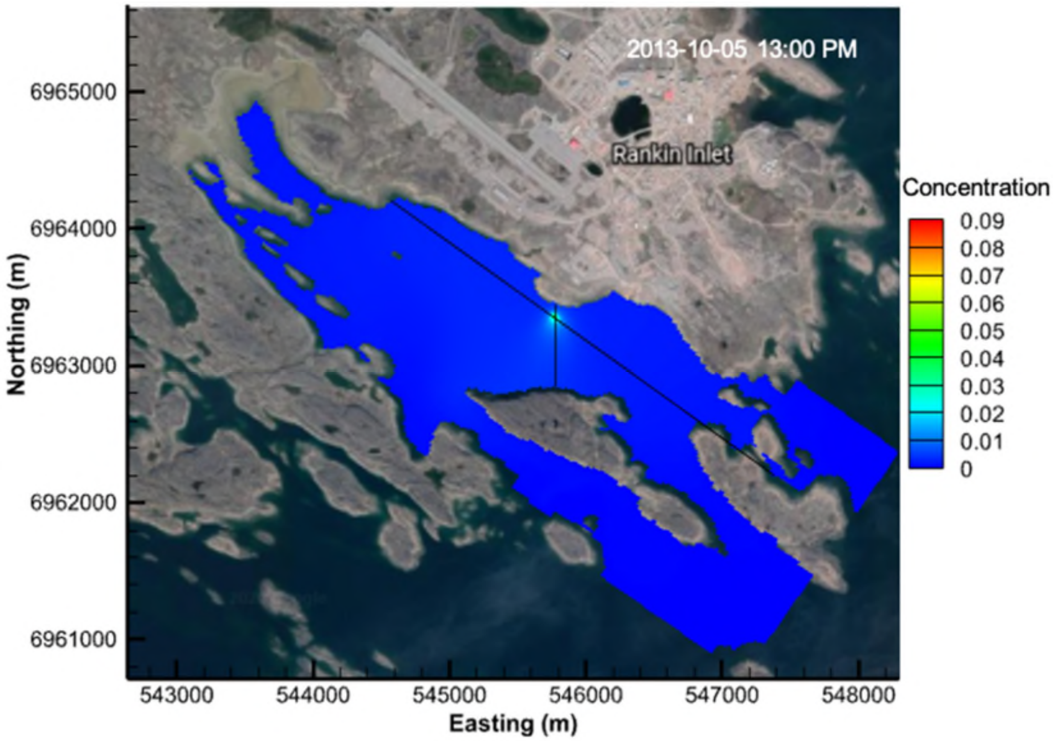

Figure 3.4. Instantaneous Maximum Effluent Concentrations on October 5 at 13:00 PM. Vertical line denotes the cross section plotted in Figure 3.5 (a), and slanted line in (a) is the cross section plotted in Figure 3.5 (b).

October 5 is identified as the period with the largest quantity of effluent within the bay (refer to Figure 3.1) and is shown in Figure 3.4. Snapshot of the maximum concentration on October 5 at 13:00 PM identifies relatively higher concentrations on the coastal side of the diffuser. Note that since concentrations are still well below the threshold concentration (0.09 corresponding to an 11:1 dilution), the figure appears in uniform blue color, indicating very low effluent concentrations and a compliance with guidelines.

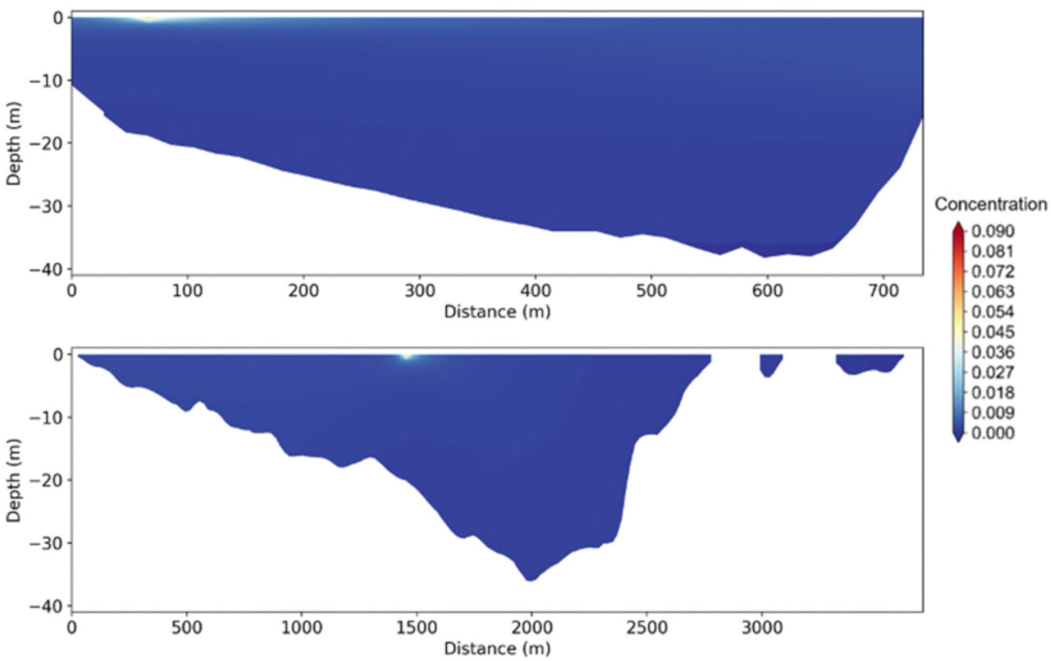

Figure 3.5. Vertical Profiles of Tracer Concentration at the Cross Sections Shown in Figure 3.4 on October 5 at 13:00 PM

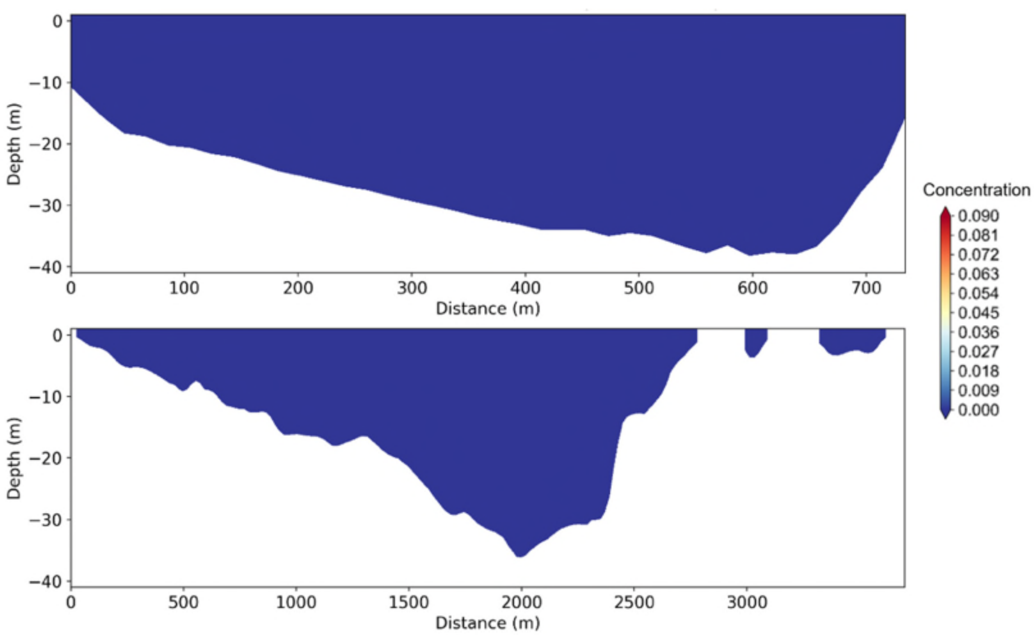

Figure 3.6. Vertical Profiles of Tracer Concentration at the Cross Sections Shown in Figure 3.4 on November 5 at 00:00 AM

Figures 3.5 and 3.6 show vertical profiles of tracer concentration taken on October 5 (maximum quantity of effluent within the bay) and November 5 (5 days following the end of discharge). Similar to other graphs, the legend was established so as to present red colors when reaching the threshold concentration. As one can observe, most transects are blue, even near the diffuser, indicating a strong immediate mixing. Figure 3.5 shows that the buoyant effluent tends to rise to the surface and accumulates in the top layers, where concentration is still well below the target concentration.

To summarize, the target dilution value of 11:1 (i.e., concentration value of 0.09) is met at all time at the 100-m mixing zone during the discharge season. The system recovers to a pre-effluent-discharge state at a great speed after the discharge stops by the end of October.

3.3 Temperature and Salinity

As presented in Tetra Tech's October 3-D modelling study, temperature and salinity changes due to effluent discharge at the 100-m mixing zone should not exceed 0.5 °C and 4 PSU, respectively. Figures 3.7 and 3.8 show the time series of temperature and salinity changes at the 100-m mixing zone, respectively. These changes represent the difference between the simulation containing the effluent discharge and the base case, when no discharge occurs. The base case is presented in Tetra Tech October 2020 report. The magnitude of the maximum change in the background seawater temperature/salinity is below 0.3 °C / 0.2 PSU, confirming a compliance with guidelines/regulation. In addition, Figure 3.9 shows the time series of percentage change in salinity at the 100-m mixing zone, which are well below 1% throughout and post the effluent discharge season.

Changes in surface temperature and salinity are negligible throughout the discharge season (figures not shown). The maximum increase/decrease in temperature/salinity are found near the surface at the diffuser location, i.e., within the 100-m mixing zone, where it is +0.31 °C in temperature and -0.18 PSU in salinity.

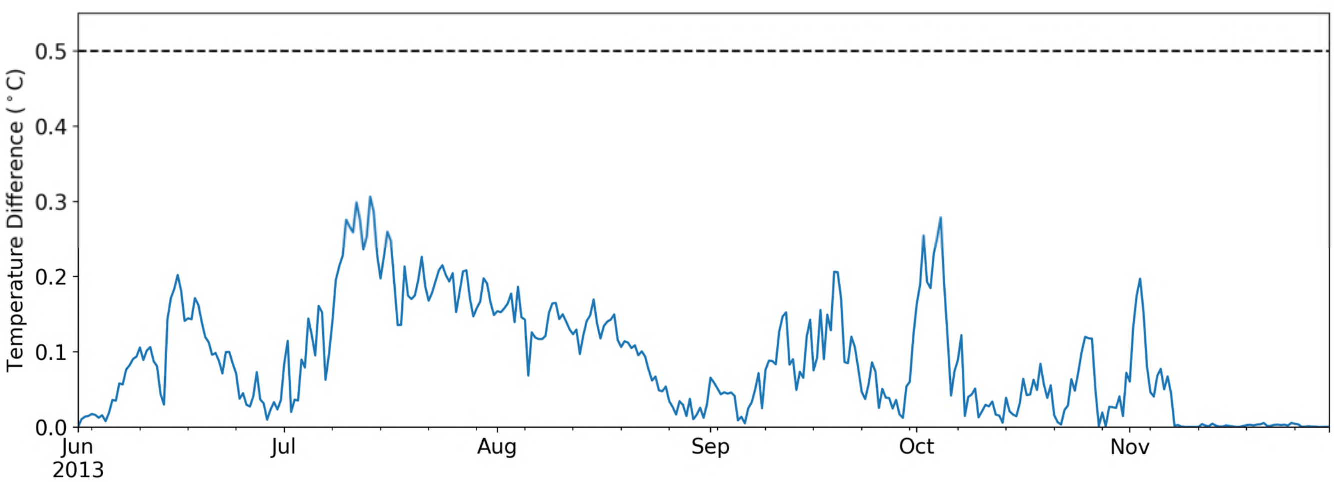

Figure 3.7. Time Series of the Magnitude of Maximum Temperature Change Relative to Ambient at the 100-m Mixing Zone (Dash Line Indicating the 0.5 °C Maximum Target Temperature Change)

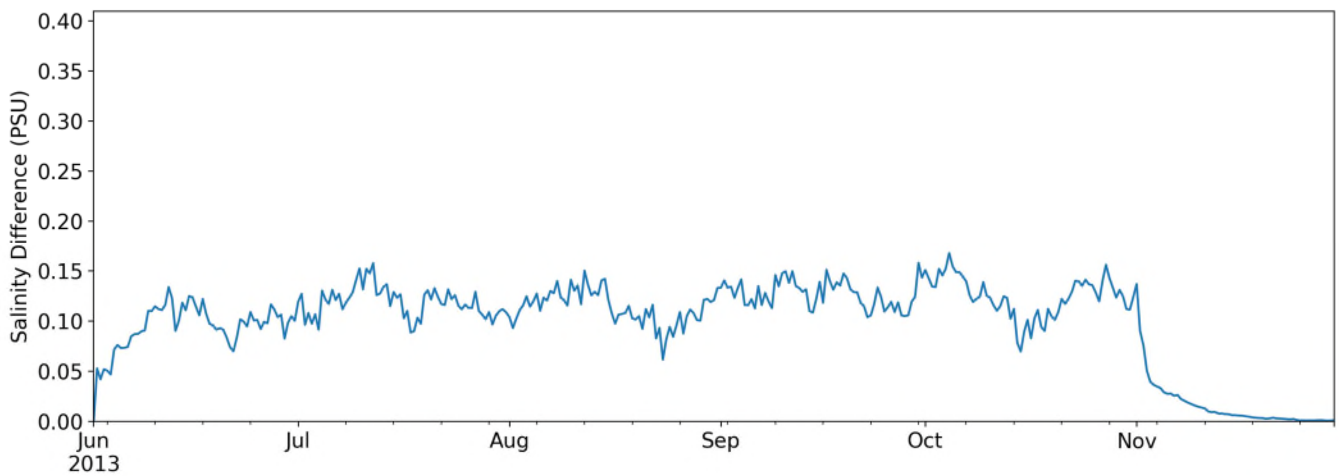

Figure 3.8. Time Series of the Magnitude of Maximum Salinity Change Relative to Ambient at the 100-m Mixing Zone (Maximum Target Salinity Change is 4 PSU)

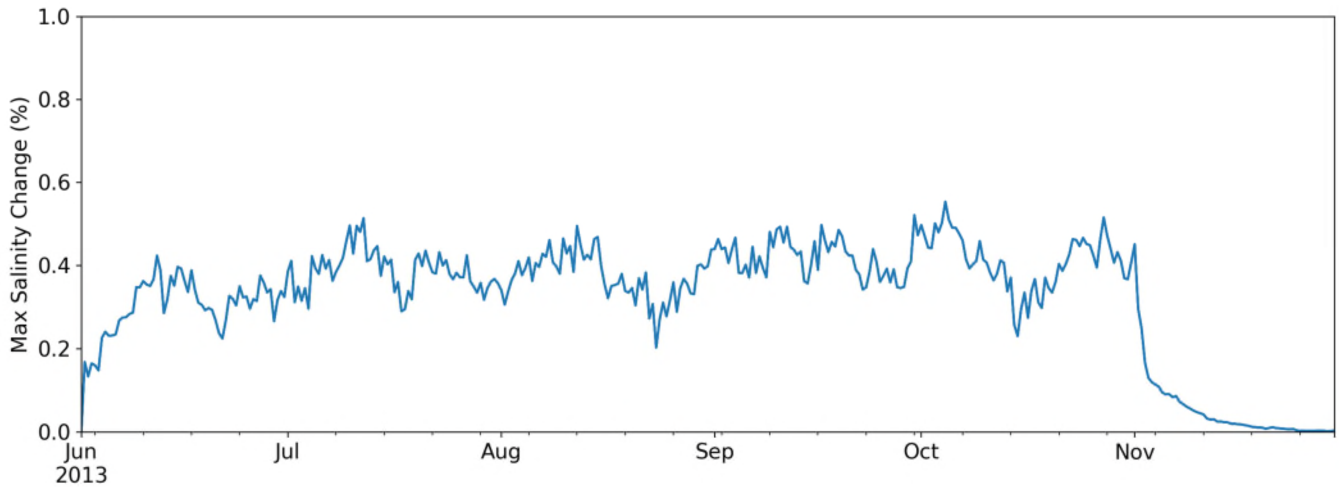

Figure 3.9. Time Series of the Maximum Salinity Percentage Change Relative to Ambient at the 100-m Mixing Zone

4.0 CONCLUSIONS

This study investigates the transport and mixing of a discharged buoyant effluent in Melvin Bay. It serves as a second addendum to Tetra Tech's October 2020 study titled "*Meliadine Mine Waterline Addendum: Melvin Bay Hydrodynamic Modelling and Characterization of the Fate and Behaviour of the Discharged Saline Effluent*". Effluent is discharge at the proposed diffuser location and at a depth of 20 m. The discharge season is from June to October. The 20,000 m^3/d discharge rate is well above the projected mean daily flow rates for each month over mine operation (i.e., 2020 to 2028) and therefore represents a very conservative scenario. A very low TDS concentration of 2,178 mg/L is chosen to represent a diversion flow from Meliadine Lake to Melvin Bay. While this scenario is unlikely, it was investigated as part of the Adaptive Management Strategy.

The main conclusions are aligned with Tetra Tech's October main study and Tetra Tech's November addendum:

- The receiving embayment will not fluctuate by more than +/- 10% with respect to chloride or salinity from the effluent discharge; specifically, the target dilution factor of 11:1 or target concentration of 0.09 at the 100 -m mixing zone is always satisfied during or post the discharge season;
- Temperature and salinity changes due to effluent discharge are well below the regulated threshold values (i.e., 0.5 ºC change and 4 PSU change respectively) at the 100-m mixing zone throughout the discharge season. In other words, the release of the effluent has a very little impact on the ambient temperature and salinity at the edge of the mixing zone. Salinity changes are below 1% all the times at the edge of the mixing zone;
- Based on simulated conditions, the system takes slightly less than 20 days following the end of the discharge to recover to a near pre-effluent-discharge state (less than 0.001% of total released effluent remains in the domain)
- Note: in the simulation, October and November were considered as open water conditions and did not include ice formation. The maximum increase of temperature was found in the surface layers since the plume was buoyant within the mixing zone and below 0.31 °C in October. The maximum decrease in salinity was found at similar locations and around 0.18 PSU in October.

  The potential impact of the plume on ice formation comes at two levels: i) as the freezing temperature of sea water increases with the decrease in salinity, the plume discharge could potentially accelerate very locally the ice formation (typical salinity levels around 28-32 PSU with a reduction of 0.15 PSU at most due to the discharge); but ii) as the water temperature could slightly increase by up to 0.3 °C, the plume discharge could on the other hand slightly delay very locally the formation of ice. Since the plume discharge is mostly scheduled to occur during open water conditions, the impact on ice formation is deemed minimal. Furthermore, the integrity of the ice once formed will not be at risk because there will be no discharge over the winter, and the bay will quickly return to pre-discharge conditions due to flushing of the bay at the end of each annual discharge phase; and
- The Melvin Bay metocean conditions lead to very efficient flushing capacity of the study area that easily satisfies the various regulations and guidelines on effluent discharge of all the studied cases.

The main difference between this addendum study and Tetra Tech's October main study is that the effluent used in this simulation is buoyant and therefore tends to rise to the surface. Higher concentration of effluent is observed in the surface layer, but its value stays well below the threshold concentration within and at the edge of the mixing zone during and post the discharge season.

The main difference between this addendum and Tetra Tech's November first addendum is that the effluent used in this study is more buoyant. The maximum temperature and salinity changes at the 100-m mixing zone are larger: 0.2 °C / 0.1 PSU in the first addendum which investigated an effluent with a 14.861 mg/L TDS and 0.3 °C / 0.2 PSU in this second addendum (effluent with a TDS concentration of 2,178 mg/L). While the time series of maximum effluent concentration at the 100-m mixing zone in the two addendums are comparable: both are well in agreement with the target dilution of 11:1 throughout the discharge season.

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We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

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Enclosure: Limitations on the Use of this Document

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HYDROTECHNICAL

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