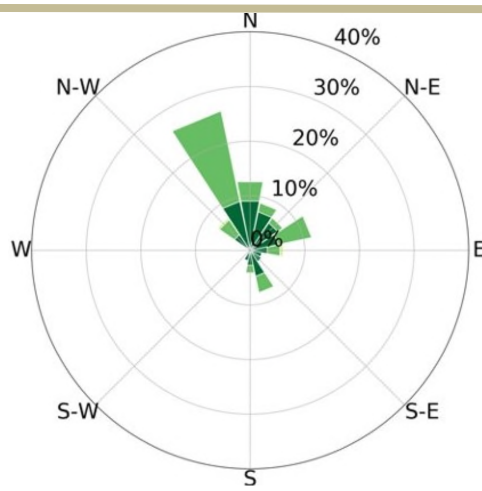
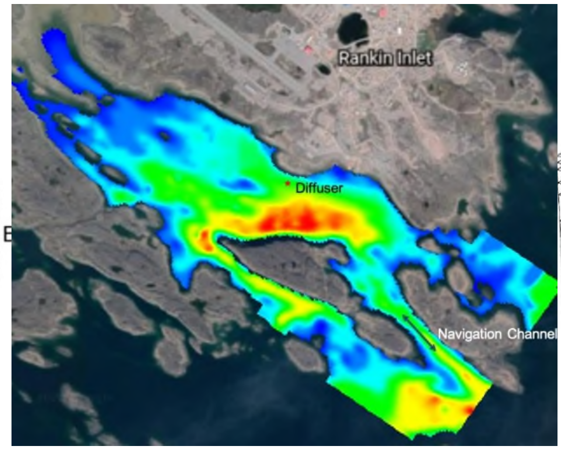
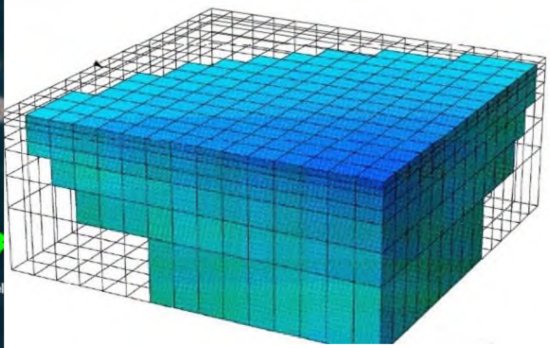
Meliadine Mine Waterline Addendum:

Melvin Bay Hydrodynamic Modelling and Characterization of the Fate and Behaviour of the Discharged Saline Effluent







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Agnico Eagle Mines

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EXECUTIVE SUMMARY

Tetra Tech Canada Inc. (Tetra Tech) is retained by Agnico Eagle Mines Ltd. (Agnico Eagle) to conduct a three-dimensional hydrodynamic modelling of Melvin Bay near Rankin Inlet, Nunavut, in support of the waterline amendment with the design of the Melvin Bay diffuser. This proposed diffuser would be part of the Meliadine Mine operations, located north-west of Rankin Inlet. A waterline would convey the water from the mine site down to a coastal facility located near Rankin Inlet's airport and along the shores of Melvin Bay.

As part of the proposed diffuser design in Melvin Bay conducted in April 2020 by Tetra Tech, the US-EPA Visual Plumes model was used to assess dilutions of the effluent in the near-field. The April 2020 outcome was that efficient dilutions were achieved in the near-field.

This present work now investigates the fate and behaviour of the discharged effluent over the entire Melvin Bay: the potential accumulation of the effluent concentration over time, as well as the effluent dispersion due to spatially- and temporally-varying ocean currents in the vicinity of the diffuser are part of this study. Effluent is discharged at the proposed diffuser location and at a depth of 20 m. The discharge season is from June to October. Three scenarios of different discharge rates (6,000 m^3/d, 12,000 m^3/d and 20,000 m^3/d) are modelled. The 20,000 m^3/d discharge rate is well above the projected mean daily flow rates for each month over mine operations (i.e., 2020 to 2028) and therefore represent a very conservative scenario.

The main results are:

- The modelling results confirm the outcomes of the 2-D Visual Plumes model conducted in April 2020: an effective and rapid dilution of the effluent, allowing to reach the target dilution of 11:1 by the edge of the mixing zone;
- Ocean current conditions identified during this study confirm the assumptions taken during the April 2020 study;
- 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 regulated 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 respectively at the 100-m mixing zone throughout the discharge season;
- The currents in the embayment are mainly tidal driven, vertically coherent and follow the isolines;
- Water exchange across isolines and depths is limited;
- Direction of currents at the diffuser is mainly northwest or southeast towards the seabed, while the surface current has a wider range of directions due to wind effect;
- At the diffuser, the monthly mean maximum surface current speed varies from 0.15 m/s to 0.22 m/s, while the monthly maximum speed at the depth of 20 m varies from 0.04 m/s to 0.11 m/s;
- Cross-isoline and -depth effluent advection is limited due to the characteristics of the currents;
- Maximum tracer concentration increases/decreases as the discharge rate increases/decreases;

- 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 0.002% of total released effluent remains in the domain) in the scenario of 20,000 m^3/d discharge rate, 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 the studied base case.

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LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of Agnico Eagle Mines and their agents. Tetra Tech Canada Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than Agnico Eagle Mines, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this document is subject to the Limitations on the Use of this Document attached in the Appendix or Contractual Terms and Conditions executed by both parties.

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) is retained by Agnico Eagle Mines Ltd. (Agnico Eagle) to conduct a three-dimensional hydrodynamic modelling of Melvin Bay near Rankin Inlet, Nunavut, in support of the waterline amendment with the design of the Melvin Bay diffuser. This proposed diffuser would be part of the Meliadine Mine operations, located north-west of Rankin Inlet. A waterline would convey the water from the mine site down to a coastal facility located near Rankin Inlet's airport and along the shores of Melvin Bay.

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This report first presents the model configuration in Section 2 and shows the model validation in terms of water level and currents in Section 3. Section 4 describes the scenarios investigated as part of this study. Section 5 presents the results on the characteristics of ocean currents at the diffuser, effluent accumulation in the bay. The conclusion of this study is drawn in Section 6.

2.0 MODEL CONFIGURATION

2.1 Model Overview

Tetra Tech's proprietary three-dimensional hydrodynamic and sediment transport model, H3D, is used to carry out this study. The same H3D model was used as part of the design of the now-existing diffuser in Meliadine Lake.

The H3D model is an implementation of the numerical model developed by Backhaus (1983; 1985), which has had numerous applications to the European continental shelf, (Duwe et al., 1983; Backhaus and Meir Reimer, 1983), Arctic waters (Kampf and Backhaus, 1999; Backhaus and Kampf, 1999) and deep estuarine waters (Stronach et al., 1993). Locally, H3D has been used to model the temperature structure of Okanagan Lake (Stronach et al., 2002), the transport of scalar contaminants in Okanagan Lake, (Wang and Stronach, 2005), sediment movement and scour/deposition in the Fraser River, circulation and wave propagation in Seymour and Capilano dams, salinity movement in the lower Fraser River and recent coastal ocean modelling along the entire BC coast, in the Gulf of the St Lawrence and in the Bay of Fundy (Hospital et al, 2019).

The H3D model forms the basis of the model developed by Saucier and co-workers for the Gulf of St. Lawrence (Saucier et al., 2003), and has been applied to the Gulf of Mexico (Rego et al., 2010). H3D and its hydrocarbon transport and weathering module have been used in environmental assessment applications before the appropriate regulatory agencies. H3D was used to do oil spill modelling for the environmental and engineering assessments for the proposed Gateway project involving oil shipment out of Kitimat. The modelling work forms part of the information package submitted to the National Energy Board. Similarly, H3D was used to assess the fate of accidental fuel spills arising from a proposed jet fuel terminal in the Fraser River. Recent National Energy Board applications were linked with H3D simulating currents and oil spill as part of the Energy East and Trans Mountain projects.

2.2 Grid

H3D is a three-dimensional hydrodynamic model, which means that the model is discretized in both horizontal and vertical directions: each cell covering the Melvin Bay domain is divided in different vertical layers throughout the water column to capture various coastal and oceanic processes. Figure 2.1 illustrates a typical 3-D model grid.

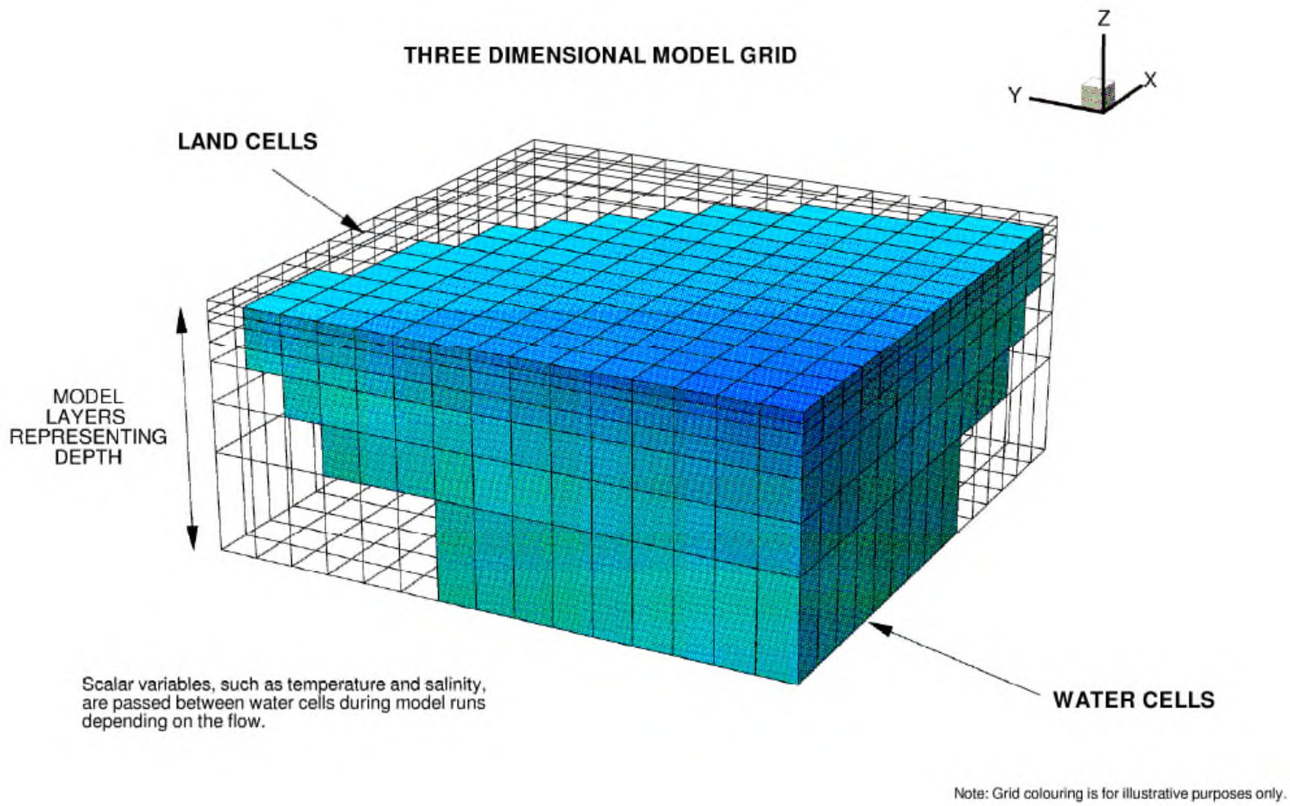

Figure 2.1. Typical 3-D Hydrodynamic Model Grid

The model domain covers the entire Melvin Bay, extends southeastward with open boundaries in Hudson Bay to allow water exchange between the interior of the Bay and the open ocean (Figure 2.2). The model has a grid resolution of 20 m by 20 m and 16 vertical layers. Bathymetry in the vicinity of the proposed diffuser and nautical charts are interpolated onto the model grid, creating a 3- D model domain, as shown in Figure 2.2.

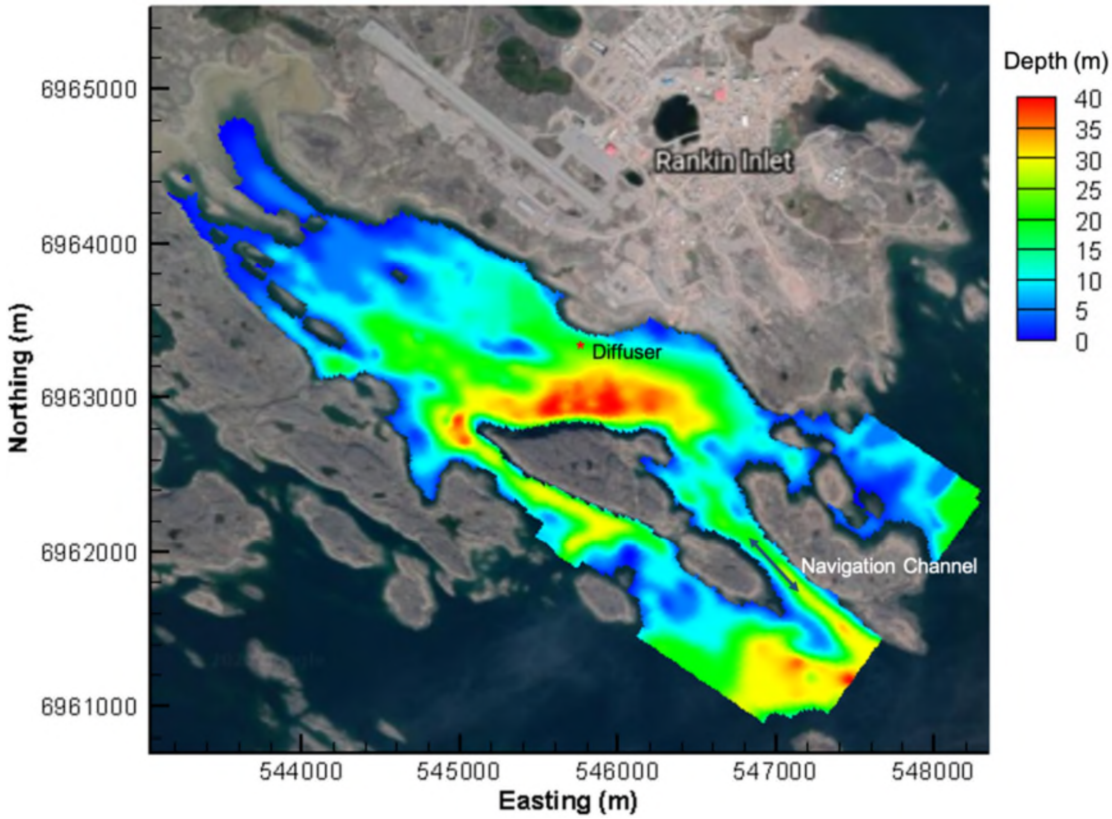

Figure 2.2. Bathymetry of the Model

2.3 Tidal and Atmospheric Forcing

It is understood that tidal conditions are the main drivers for currents in Melvin Bay. Tidal variables are extracted from the TOPEX Poseidon database, allowing to provide tidal information at the open boundaries of the model.

Wind-driven current is an integral part of the surface circulation in the bay. Meteorological forcing, such as air temperature, solar radiation and relative humidity, influences sea water temperature and potentially affects stratification. Both wind and meteorological forcing data are extracted from ECCC weather station location at Rankin Inlet airport. Over 30 years of data were collected (1981 to present) and a statistical analysis was conducted to determine a representative year, i.e. a year which adheres well to the average wind conditions.

Figure 2.3 presents the outcome of the statistical analysis. The top panel shows a statistical distribution of wind speed: the red line indicates the average conditions, while the yellow (year 2013) and green (year 2014) lines show two years very close to average conditions. The lines in light grey represent all other years on record. Similarly, the bottom panel presents wind roses with the left panel showing the rose for the entire period of record and the right panel presenting the rose corresponding to year 2013. The full period of record wind rose clearly indicates that the predominant wind direction is coming from the northwest and the north. This predominant direction is also well observed in year 2013.

As a result, the selected period for the simulation time is year 2013, both being very close to average conditions.

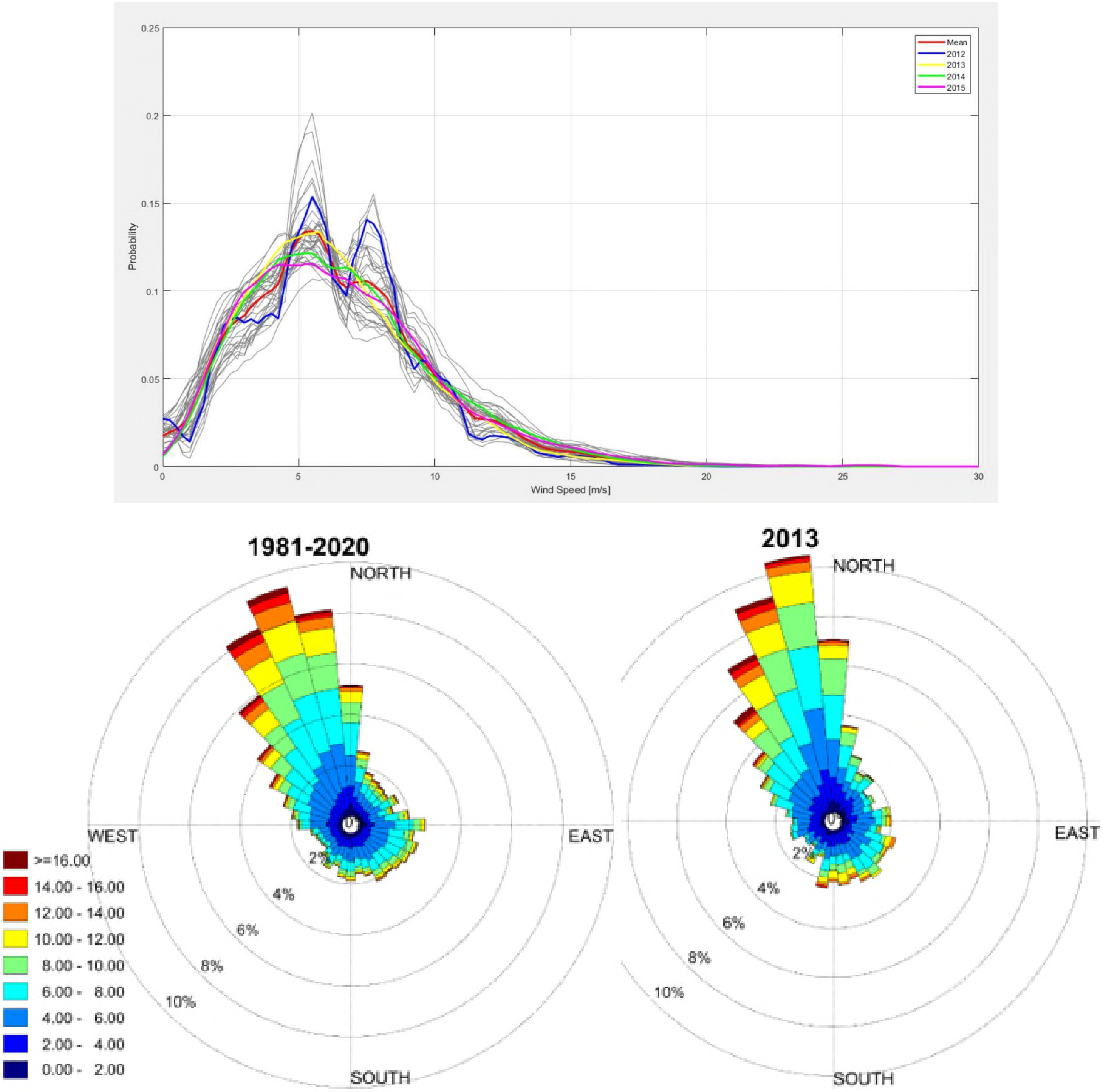

Figure 2.3. Wind Speed Statistical Distribution (Top Panel) and Wind Roses (Bottom Panel: Left 1981-Present and Right: year 2013)

2.4 Initial and Open Boundary Conditions

Therefore, following the selection of the representative year, the model was run mostly during the open water season, spanning from June to November 2013. The ambient (i.e. ocean) initial temperature and salinity are 1.16 °C and 30.5 PSU, respectively. The initial conditions correspond to the mean temperature and salinity in June 2013 from the HYCOM forecasting system (www.hycom.org). Since ocean waters are exchanged daily between Melvin

Bay and Hudson's Bay, monthly-varying temperature and salinity conditions were applied to the open boundary of the model. These temperature and salinity conditions were set to correspond to HYCOM monthly means. As a result, the temperature and salinity in the interior of the embayment fluctuate with changes at the open boundaries and in meteorological forcing.

3.0 MODEL VALIDATION

The model is validated in terms of water level and ocean currents. Temperature and salinity in the H3D model were modulated by those from the HYCOM model. The accuracy of reproduction of temperature and salinity in Melvin Bay in H3D is essentially the same to, if not better than, that of the HYCOM model, as H3D has a much higher resolution of 20 m, compared to HYCOM presenting a resolution of 0.04° (>4 km) in the Melvin Bay area.

3.1 Water Level

There is no available observational data of water level from 2013 in Melvin Bay to the best of our knowledge. Water level in the Melvin Bay from H3D is validated against predictions from Fisheries and Oceans Canada (DFO). Tidal analysis is carried out using DFO's predictions of water level at Rankin Inlet from 2018 to 2020 (https://www.waterlevels.gc.ca/eng/data/table/2018/wlev_sec/5100?pedisable=true#s0). Water level at Rankin Inlet in 2013 is hindcast using the DFO tidal analysis result. In parallel, the 3-D hydrodynamic model is run and both water level curves are compared and shown in Figure 3.1.

Phases of tidal water level from H3D are in perfect sync with the prediction from DFO's dataset. There is a slight mismatch of water level at low tide. It is worth mentioning that the DFO predictions are based on only 3-year long dataset and do not represent actual observed water level but are only predictions. The validation for the water level, acknowledging the limitations with DFO dataset, is deemed very good, as the phase is near-perfect and the amplitude correctly reproduced.

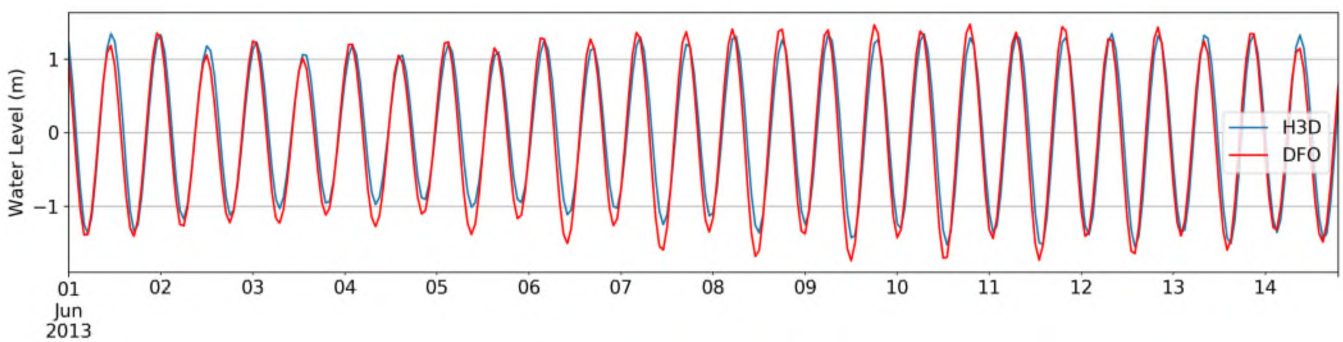

Figure 3.1. Water Levels from H3D and Predictions based on DFO's Dataset

3.2 Ocean Currents

Nautical chart indicates that the maximum current speed within the navigation channel (entering Melvin Bay) is about 0.5 knots. The model reproduces well such current. Figure 3.2 shows a snapshot in time when the flood current entering the navigation channel reaches a maximum speed of about 0.25 m/s in agreement with the nautical chart indication. Further analysis of current at the diffuser and the navigation channel locations is given in Section 5.1.

Figure 3.3 presents a statistical analysis of currents in the navigation channel and over the water column. The current through the navigation channel tends to be vertically coherent (barotropic). The median velocity throughout the water column is around 0.1 m/s. The maximum speed in the top layers are slightly higher and can reach up to 0.35 m/s.

Current rose is a direct way to show the general current direction and speed during a certain period of time. The circular format of the current rose shows the direction the current flows to and the length of each "spoke" around the circle shows how often the current flows to that direction. The different colors of each spoke provide details on the speed. As shown in the current rose plot, the current direction at the navigational channel is controlled by the topography of the narrow channel and follows isolines (Figure 3.4). Current in the middle and bottom layers flow northwestward 50% of the time and southeastward in the rest of the time, confirming the main driver for water exchanges in Melvin Bay is tidal. Surface current shifts around the NW-SE direction slightly, due to wind effects. The “spokes” of flood and ebb currents in the current roses are like mirror-images, indicating comparable, if not equal, flood and ebb current speeds.

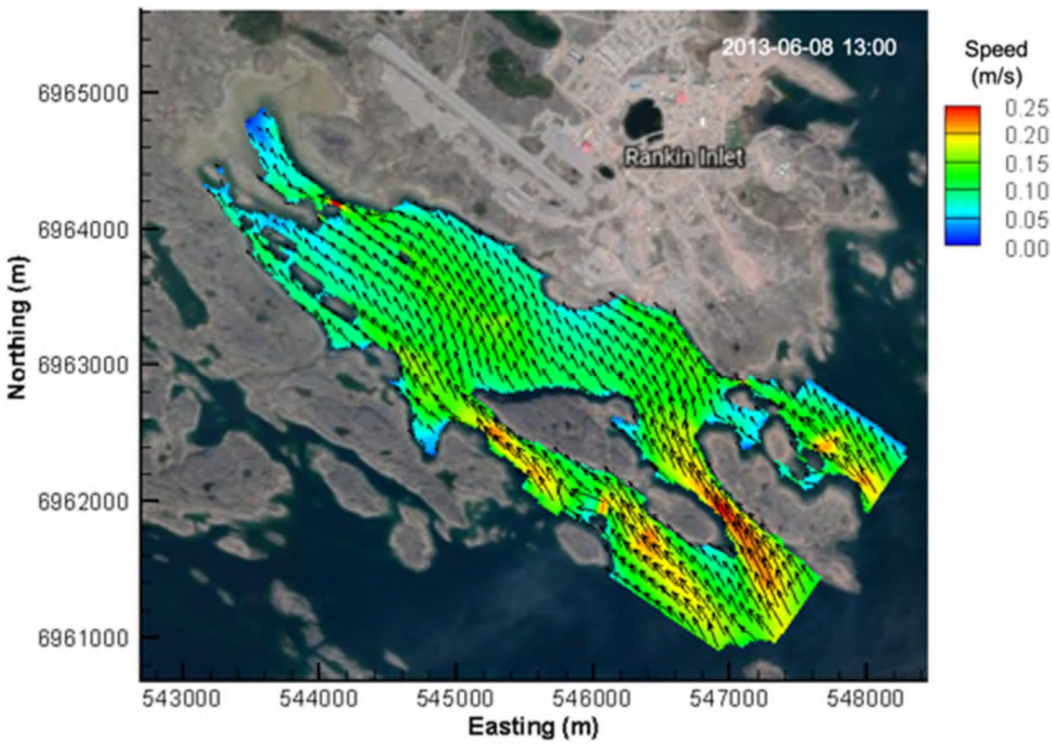

Figure 3.2. Surface Flood Current in the Model Domain at 13:00 PM on June 8, 2013

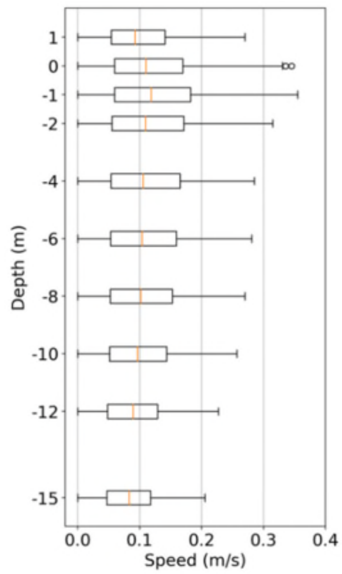

Figure 3.3. Boxplot of Current Speed throughout the Water Column in the Middle of the Navigational Channel from June to October 2013

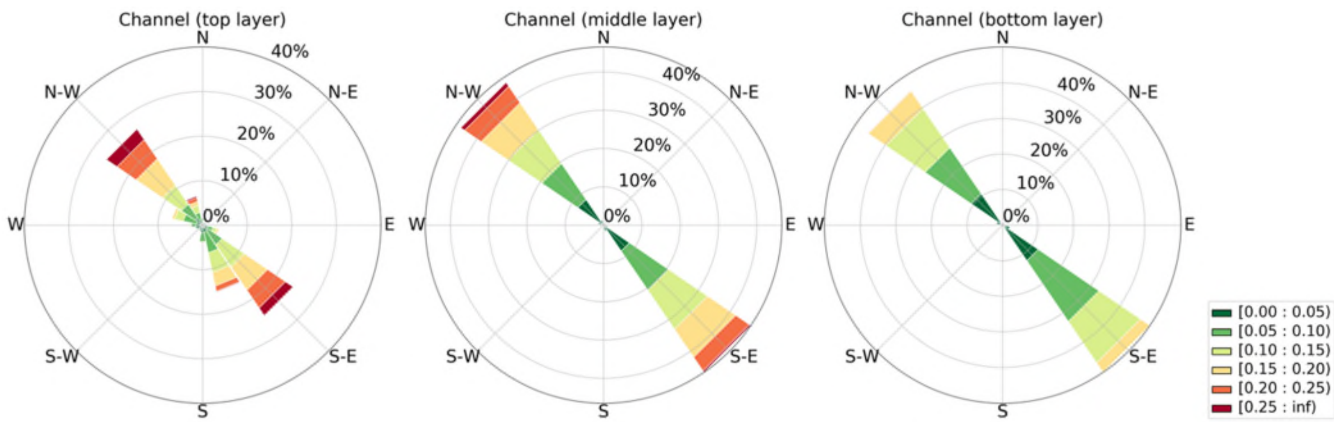

Figure 3.4. Current Roses Representing Surface, mid-Water Column and near Seabed Currents in the Middle of the Navigation Channel from June to October 2013

4.0 DISCHARGE CONFIGURATION

This study investigates various scenarios based on different saline effluent flow rates, concentrations, and time of release.

This present report investigates three discharge scenarios. As part of the waterline amendment, an increase in saline effluent flow is proposed between 6,000 m^3/day and 12,000 m^3/day with a potential maximum at 20,000 m^3/day. Therefore, each scenario investigates an effluent discharge rate of 6,000, 12,000 and 20,000 m^3/d, respectively. The 20,000 m^3/d 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 very conservative scenario. The 3-D model is run through the discharge season (i.e. open water) from June to October. While the effluent discharge stops at the end of October, the model continues running an extra month, i.e. 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.

Table 4.1 Effluent Monthly Discharge Rates and Temperature

Month		June	July	August	September	October	November
Scenario 1	Discharge Rate (m^3/d)	6,000	6,000	6,000	6,000	6,000	0
Scenario 2		12,000	12,000	12,000	12,000	12,000	0
Scenario 3		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)		39.6	39.6	39.6	39.6	39.6	-

The effluent monthly discharge rates are selected to cover a wide range of discharge scenarios. 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 waterline. Salinity of the effluent is 39.6 PSU and is conservatively converted from a TDS concentration of 39,600 mg/L.

5.0 RESULTS

5.1 Currents

Ocean currents are a critical factor in the ability of the effluent to properly disperse and reduce accumulation over time. This section presents the statistics of ocean currents in the vicinity of the diffuser. Statistics of current speed through the water column are given as monthly means. Monthly current speed and direction distributions are shown as current roses.

5.1.1 Statistics of Current Speeds

Monthly boxplots of current speed throughout the water column at the diffuser are shown in Figure 5.1. Monthly mean vertical structure of current speed is consistent through June to October. As expected, the current speed diminishes with depth. Maximum speed is observed near the surface with speed around 0.15 to 0.22 m/s. Maximum speed near the seabed where the diffuser would be installed (at 20 m depth) varies from 0.04 to 0.11 m/s from month to month. Current speed tends to be uniform at depths deeper than 6 m. Descriptive statistics of current speed at the top, middle and bottom layers are given in Table 5.1

The table confirms the adequacy of current speed selected as part of the April 2020 study.

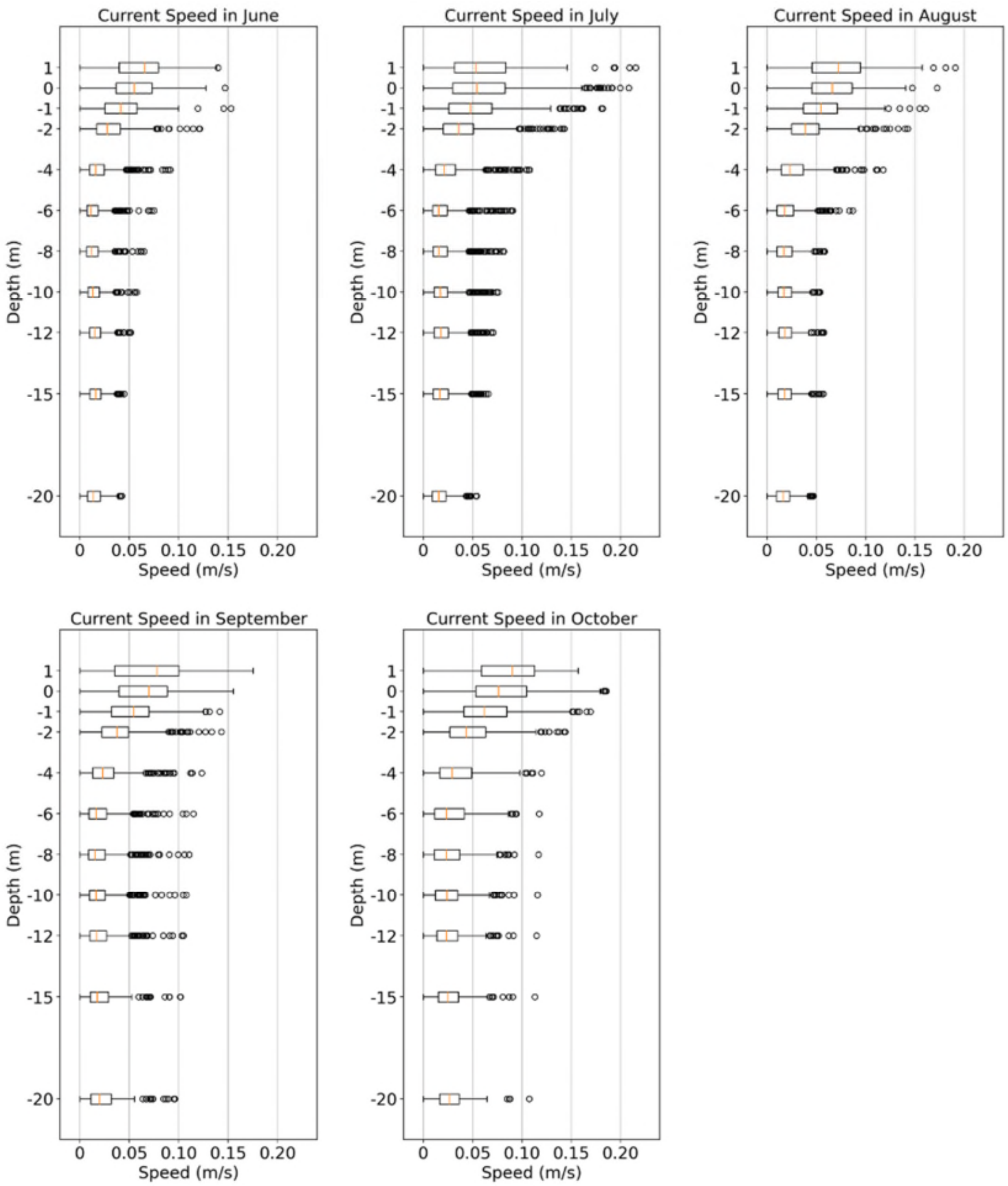

Figure 5.1. Monthly Boxplot of Current Speed throughout the Water Column at the Diffuser

Table 5.1 Monthly current speed statistics at the diffuser

Month	Layer	Speed (m/s)						
		Mean	Standard Deviation	Minimum	25th Percentile	50th Percentile	75th Percentile	Maximum
June	Surface	0.05	0.03	0	0.03	0.05	0.07	0.15
	middle	0.01	0.01	0	0.01	0.01	0.02	0.06
	bottom	0.01	0.01	0	0.01	0.01	0.02	0.04
July	Surface	0.06	0.04	0	0.04	0.05	0.08	0.22
	middle	0.02	0.01	0	0.01	0.02	0.02	0.08
	bottom	0.02	0.01	0	0.01	0.02	0.02	0.05
August	Surface	0.06	0.03	0	0.04	0.06	0.08	0.19
	middle	0.02	0.01	0	0.01	0.02	0.02	0.06
	bottom	0.02	0.01	0	0.01	0.02	0.02	0.05
September	Surface	0.06	0.03	0	0.04	0.06	0.08	0.18
	middle	0.02	0.02	0	0.01	0.02	0.03	0.11
	bottom	0.02	0.01	0	0.01	0.02	0.03	0.10
October	Surface	0.07	0.04	0	0.05	0.07	0.09	0.19
	middle	0.03	0.02	0	0.01	0.02	0.04	0.12
	bottom	0.03	0.01	0	0.02	0.03	0.04	0.11

5.1.2 Current Roses

Current in the embayment is mainly driven by tides. Wind also plays a non-negligible role in surface currents. The current is also influenced by topographic features, such as continental slope, islands and undersea mountains/hills (one being located just south-west of the proposed diffuser terminus). Monthly current roses of the current at the surface, in the middle of the water column and at the bottom (i.e. near the seabed) are shown in Figures 5.2 to 5.6. These currents are extracted at the diffuser location.

Currents at the diffuser location are complex due to changes in wind, the presence of bottom topographic slope, and the turbulent nature of the local flow. The surface currents do not show a consistent direction through June to October. Though it is predominantly northwestward during flood tides for June and July. Surface current in other months is sporadic and flows towards all directions. In the middle and lower layers, ebb currents tend to have a more consistent direction than flood current, and flow more consistently towards the east to southeast directions from June to August. Moreover, at the middle and bottom layers the ebb current is not necessarily stronger than the flood current as shown by the similar color range of the spokes that represent them.

The roses confirm that, with ocean currents heading in various directions throughout the water column with speeds ranging between a few cm/s up to almost 20 cm/s, the proposed diffuser site is adequate for enhanced mixing.

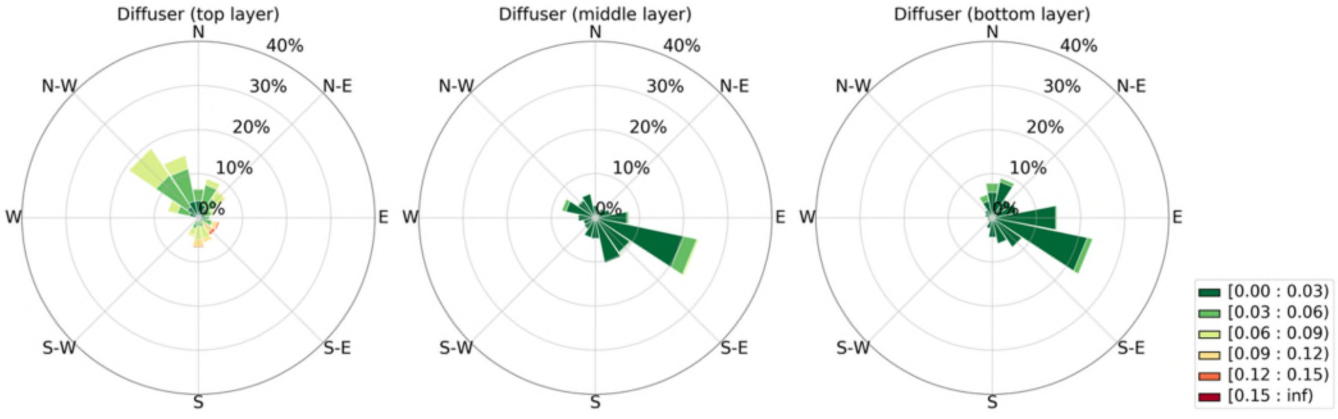

Figure 5.2. Current Roses of the Current in the Surface, Middle and Bottom Layers at the Diffuser in June

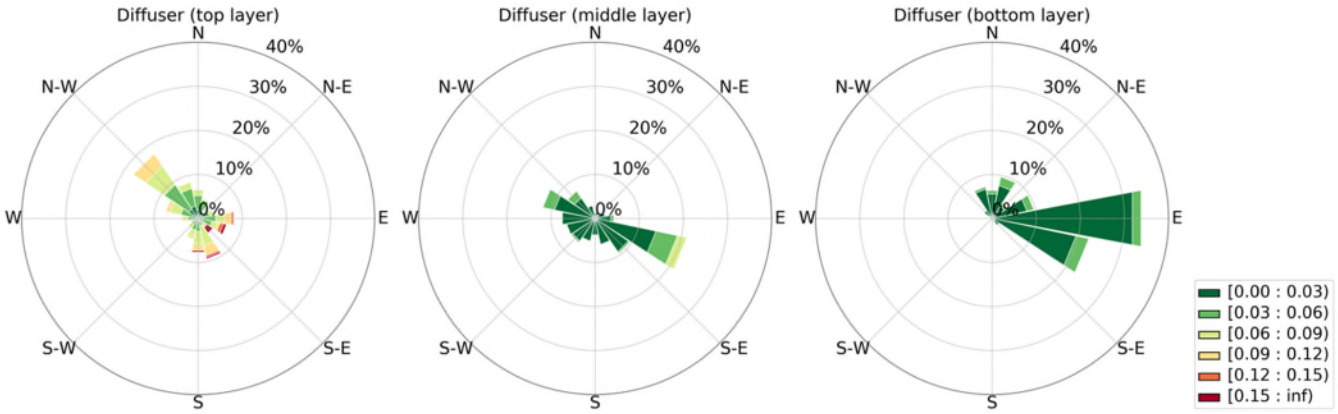

Figure 5.3. Current Roses of the Current in the Surface, Middle and Bottom Layers at the Diffuser in July

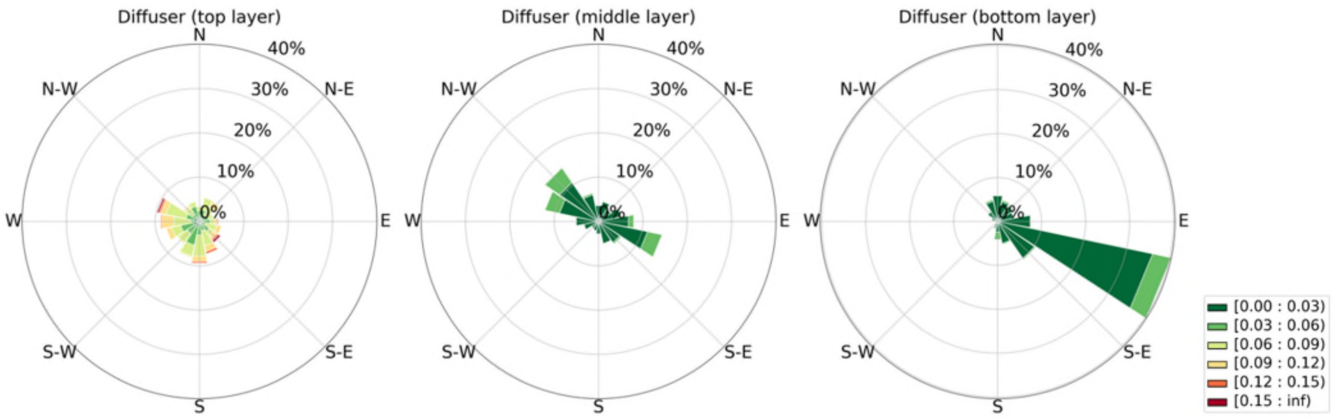

Figure 5.4. Current Roses of the Current in the Surface, Middle and Bottom Layers at the Diffuser in August

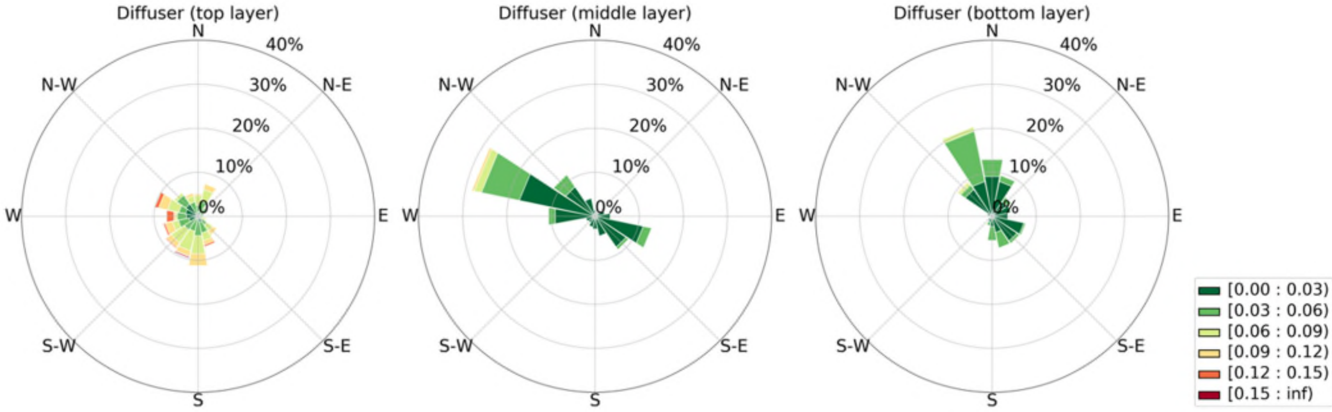

Figure 5.5. Current Roses of the Current in the Surface, Middle and Bottom Layers at the Diffuser in September

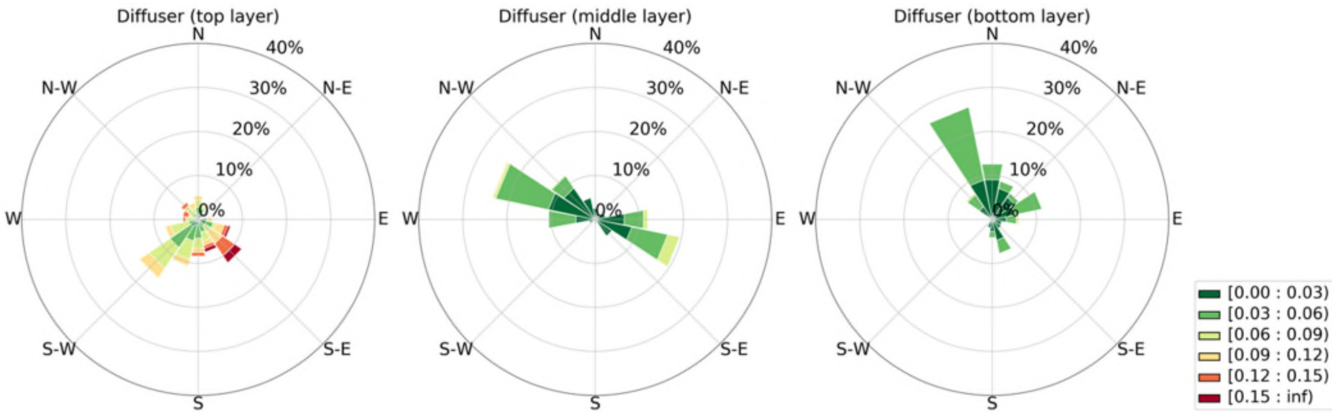

Figure 5.6. Current Roses of the Current in the Surface, Middle and Bottom Layers at the Diffuser in October

5.2 Effluent Accumulation and Concentration

A total of about 918,000 m^3, 1,836,000 m^3 and 3,060,000 m^3 effluent are discharged between June and October in the three scenarios, respectively. As a comparison, the amount of water in the bay exceeds 50,000,000 m^3, without accounting for the thousands of cubic meters of water exchanged daily through tides. It is worthwhile to mention that effluent accumulation and concentration values change close to linearly with the discharge rates. As a result, the following discussion in this section only shows the most extreme scenario that has a discharge rate of 20,000 m^3/d and a total discharge amount of 3,060,000 m^3 throughout the whole discharge season.

5.2.1 Effluent Accumulation in the Domain

The amount of effluent 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 the tides). The specific concentrations of both chloride and TDS 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 5.7. 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 0.1 Mm^3 in the embayment that contains over 50 Mm^3 of water.

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 less than 0.05% of the total released effluent (1,484 m^3 out of 3,060,000 m^3) that is still present in Melvin Bay by November 10. By November 20, there is less than 0.002% of the total released effluent (55 m^3) that remains in Melvin Bay. Note that October was considered open water and did not include ice formation in this simulation.

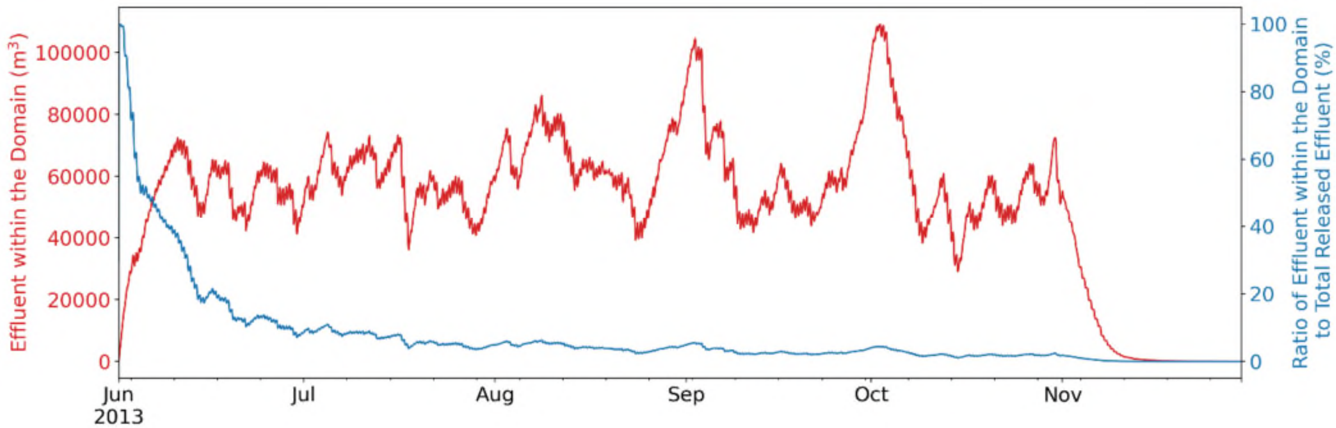

Figure 5.7. Effluent within Melvin Bay (red curve) and Ratio of Effluent (blue curve) within the Bay to Total Released Effluent as a Function of Time

5.2.2 Effluent Concentration

A conservative target dilution of 11:1 was identified at the 100-m regulated mixing zone (Tetra Tech February 2020 diffuser design study). This target dilution is the threshold value that is required to comply with the British Columbia Ministry of the Environment guideline for chloride (2017), which states:

"Human activities should not cause the chloride of marine and estuarine waters to fluctuate by more than 10% of the natural chloride expected at that time and depth."

This guideline is modelled after the Canadian Council of Minister of the Environment - Canadian Water Quality Guidelines, where the interim guideline for marine salinity (CCME 1996) states that human activity should not cause salinity to fluctuate by more than 10% of the natural level expected at that time and depth.

The different constituents of the effluent are represented as a passive tracer, which has an initial concentration of 1. Following the effluent release, this tracer becomes dispersed, mixed and advected based on ocean currents and water column properties. The target dilution of 11:1 corresponds to a target concentration value of 0.09 in the modelling results. Results of the dispersion of the tracer will permit calculation of WQ constituents based on End of Pipe (EoP) concentration (assuming conservatism of mass – no chemical transformation, uptake, precipitation, etc.).

The target concentration of 0.09 is met at all time at the 100-m regulated mixing zone. Knowing that the dashed line of Figure 5.8 represents the target/threshold concentration, the maximum concentration is well below the target concentration during the whole model simulation period. As one can expect, the largest tracer concentration is observed within the 100-m regulated mixing zone of the diffuser (red curve). Note that the blue curve represents the curve to comply with regulation, i.e. concentrations at the edge of the mixing zone. The tracer concentration and effluent discharge rate have a positive correlation. The tracer concentration at the edge of the mixing zone is around 0.005 throughout the discharge season. The concentration value reaches near 0 about 20 days after the effluent discharge stops on October 30.

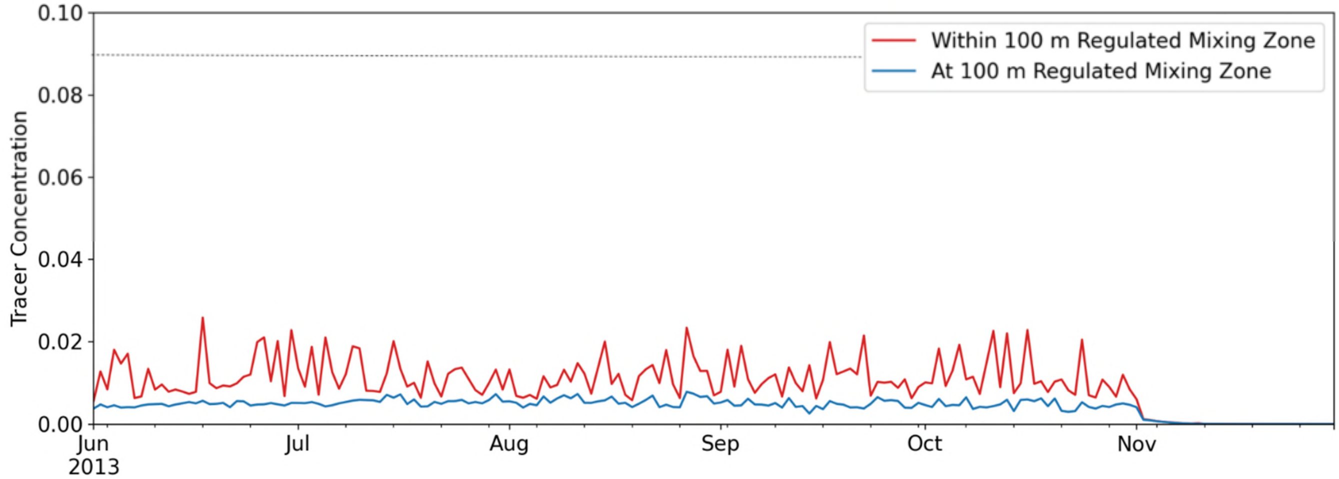

Figure 5.8. Time series of Daily Maximum Tracer Concentration within and at the 100-m Regulated Mixing Zone. The dash line indicates the threshold concentration value 0.09.

Figure 5.9 presents the monthly mean of maximum concentration in July. The legend was selected in order to reflect the threshold concentration as red color. As one can observe, the entire bay appears in blue, indicating tracer concentrations much smaller than the threshold concentrations. Value probing allows to determine that, while still well below the concentration threshold of 0.09, maximum tracer concentration tends to be slightly higher in the vicinity and the northwest area of the diffuser during the effluent discharge season.

October 2 was identified as the period with the largest quantity of effluent within the bay, as shown in Figure 5.7. Snapshot of the maximum concentration on October 2 at 09:00 AM identifies relatively higher concentration at the deep depths south of the diffuser (Figure 5.10a). Note that since concentrations are still well below the threshold concentration, the figure appears in uniform blue color. The corresponding depths at which the maximum concentration is observed shows that effluent has not been advected and redistributed to all water depths across the domain (Figure 5.10b). As the current below the surface tends to follow the isolines, water exchange across the isolines is hindered. This causes the maximum concentration southwest of the diffuser to be confined to the deeper layers.

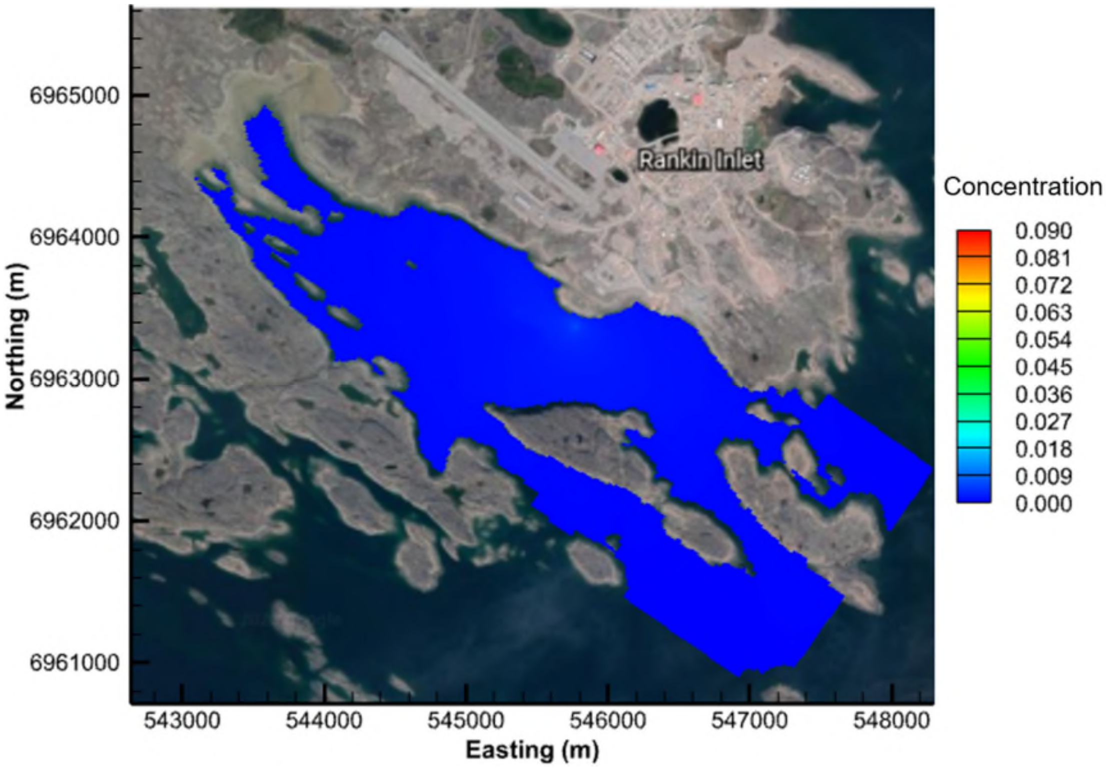

Figure 5.9. Monthly Mean of Maximum Tracer Concentration in July

Figure 5.11 presents the maximum effluent concentration throughout the water column 20 days following the end of the discharge. Effluent is still present within the bay (about 55 m^3) but in extremely low concentration (Figure 5.11a). Effluents located in the bottom layer tend to take a longer time to be flushed out, as the effluent is confined within closed isolines and the currents in the bottom layer are relatively weaker. That being said, effluent at these depths is almost flushed out of the embayment by November 20 (Figure 5.11b), since only 55 m^3 is left present.

Figures 5.12 and 5.13 show vertical profiles of tracer concentration taken on October 2 (maximum quantity of effluent within the bay) and November 20 (20 days following the end of the discharge). Similar to the 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. Value probing indicates that the vertical profiles show that effluent redistribution across both isolines and depths is limited during effluent discharge season. It is likely due to the fact that the currents below the surface are vertically coherent and follow the isolines most of the time. Surface currents tend to flow towards a wider range of directions due to wind effects.

To summarize, the target dilution of 11:1, corresponding to the concentration value of 0.09, is met at all time at the 100-m regulated mixing zone during the discharge season. In fact, this criterion is readily met at the edges of the grid cell (20-m wide, 20-m wide and 5-m high) at the depth of 20 m, where the diffuser sits. The system recovers to a pre-effluent-discharge state at a great speed after the discharge stops by the end of October. There is less than 0.05% of the total released effluent (1,484 m^3 out of 3,060,000 m^3) that is still present in system by November 10. By November 20, there is less than 0.002% of the total released effluent (55 m^3) that exists in the system.

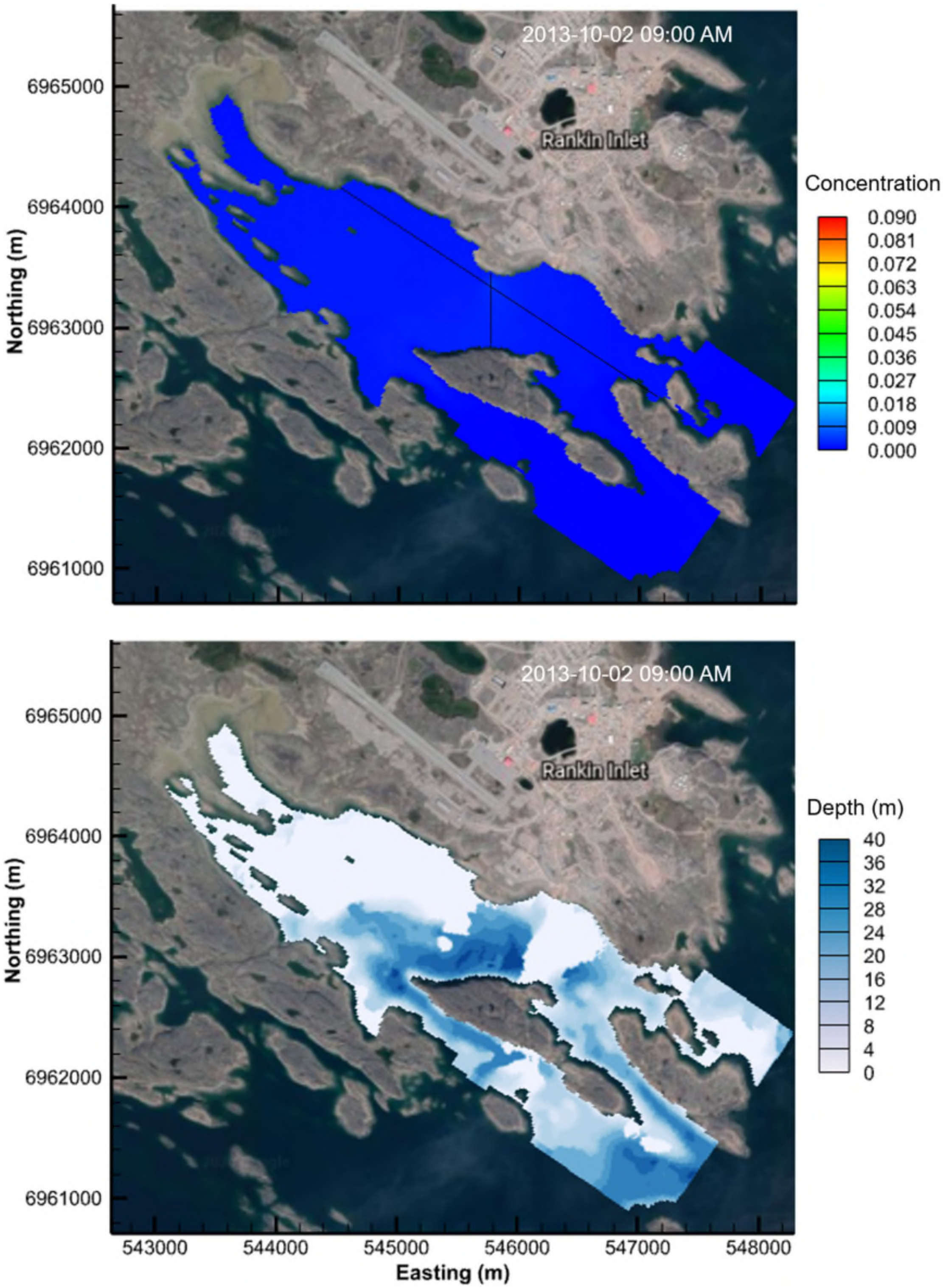

Figure 5.10. (a) Instantaneous Maximum Tracer Concentrations within the Water Columns and (b) the Corresponding Depths at Which the Maximum Tracer Concentrations Are Observed on October 2 at 09:00 AM. Vertical line in (a) is the cross section plotted in Figure 5.12(a), and slanted line in (a) is the cross section plotted in Figure 5.12(b).

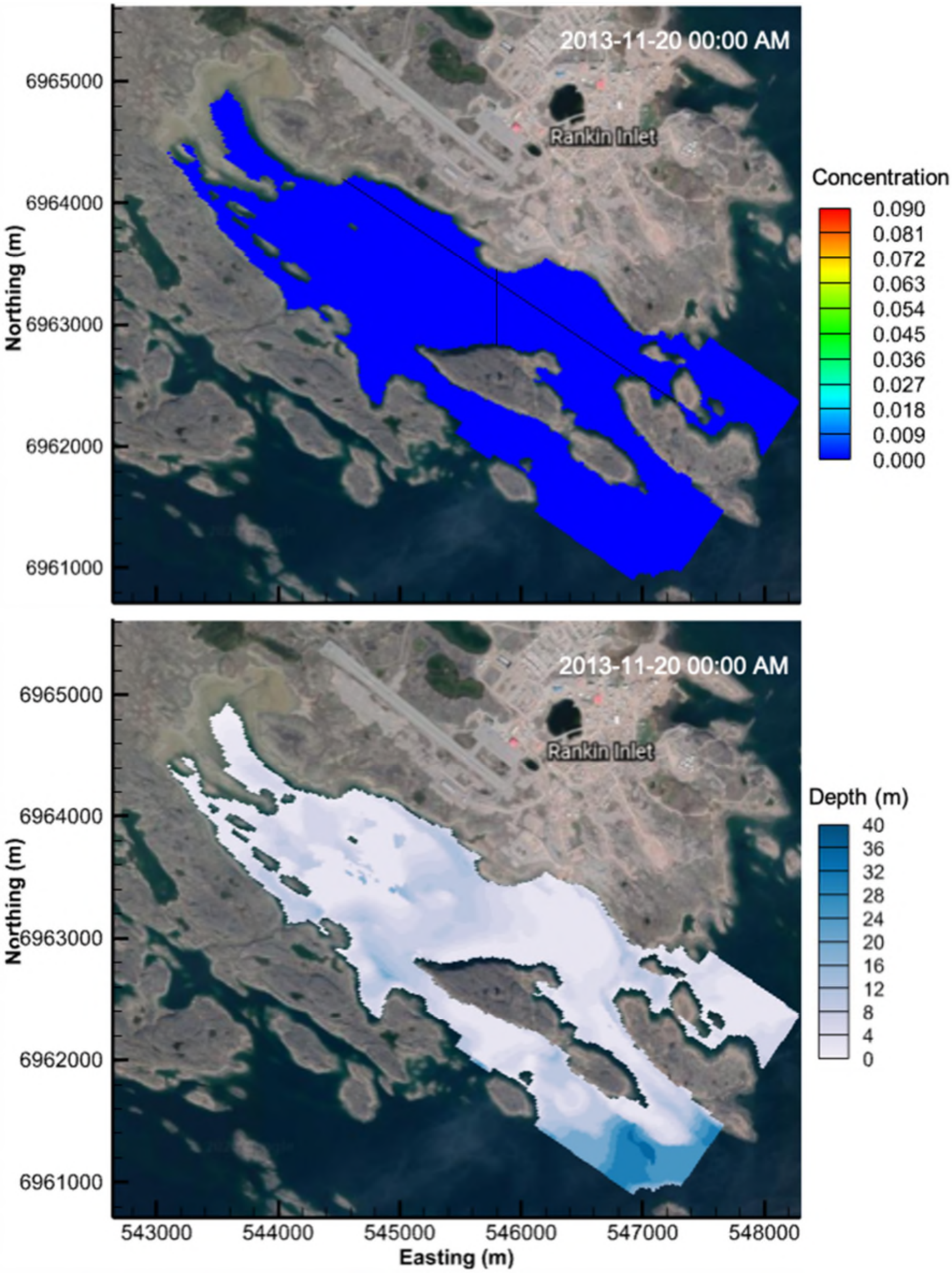

Figure 5.11. (a) Instantaneous Maximum Tracer Concentrations within the Water Columns and (b) the Corresponding Depths at Which the Maximum Tracer Concentrations Are Observed on November 20 at 00:00 AM. Vertical line in (a) is the cross section plotted in Fig. 13(a), and slanted line in (a) is the cross section plotted in Fig. 13(b).

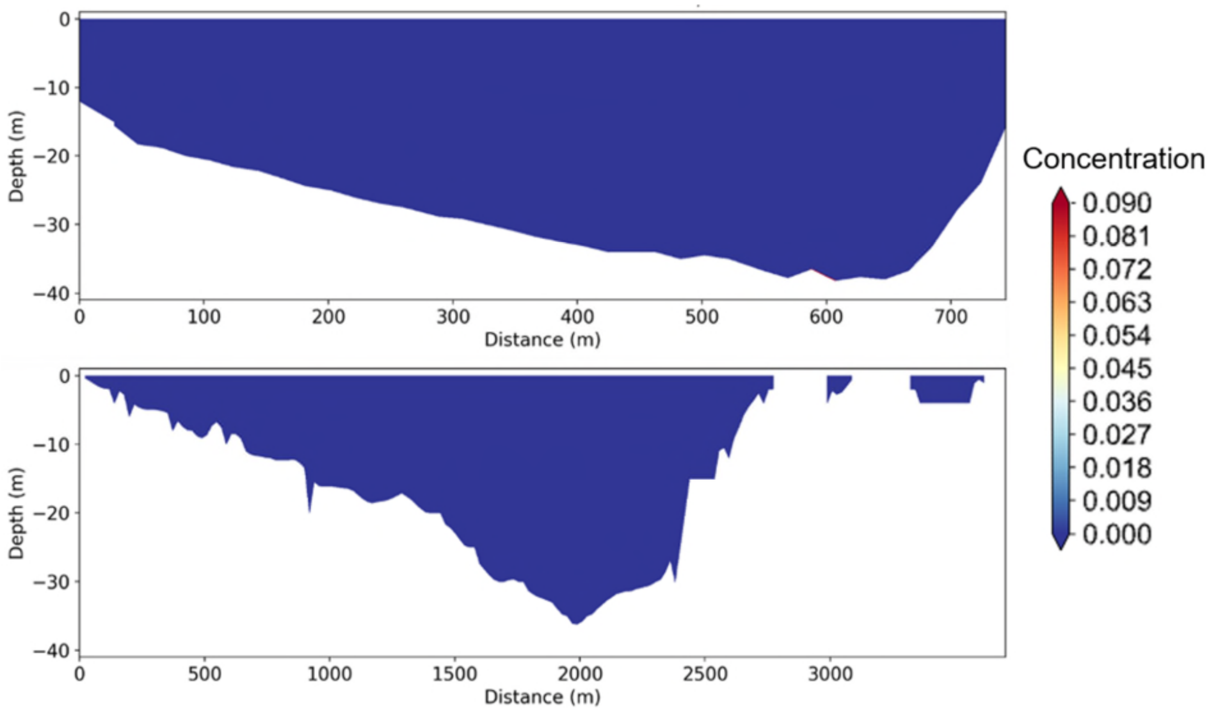

Figure 5.12. Vertical Profiles of Tracer Concentration at the Cross Sections Shown in Figure 5.12 on October 2 at 09:00 AM

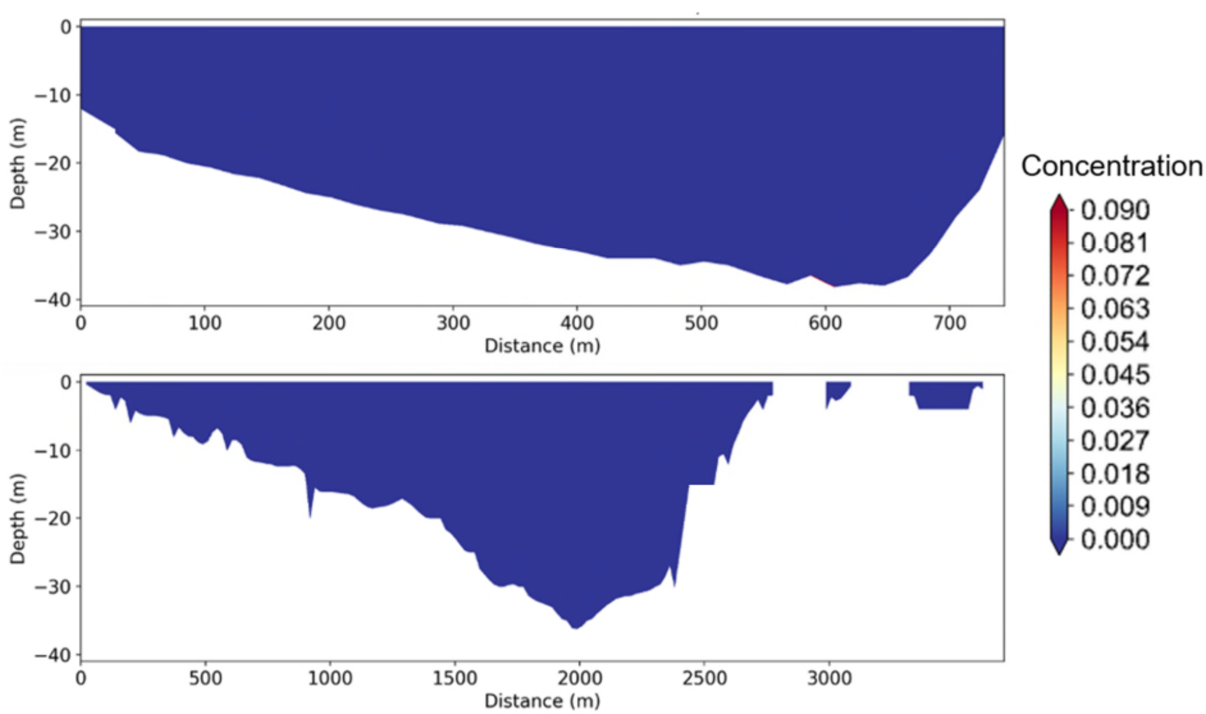

Figure 5.13. Vertical Profiles of Tracer Concentration at the Cross Sections Shown in Figure 5.13 on October 5 at 00:00 AM

5.3 Temperature and Salinity

Temperature change at the 100-m regulated mixing zone due to effluent discharge is required to comply with the British Columbia Ministry of the Environment guideline for temperature (2017):

"Max of +/- 1 degree change from ambient background temperature. Hourly rate of change up to 0.5 degrees."

Figure 5.14 shows the time series of temperature change at the 100-m regulated mixing zone of the three discharge scenarios. The magnitude of the maximum change in the background seawater temperature is below 0.3°C throughout the discharge season, which is well below the threshold value of 0.5 °C. As expected, higher discharge rate leads to greater changes in the ambient temperature.

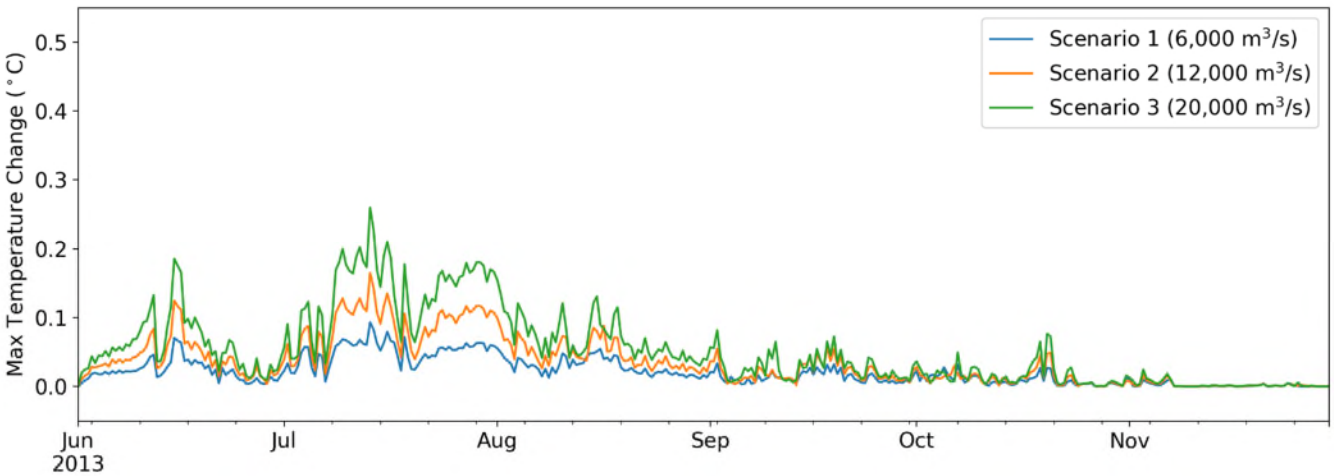

Figure 5.14. Time Series of the Magnitude of Maximum Temperature Change at the 100-m Regulated Mixing Zone of the Three Discharge Scenarios

Similarly, salinity change at the 100-m regulated mixing zone due to effluent discharge is required to comply with the Department of Environment guideline for salinity (1972):

"24-hour change in salinity should not exceed 4 parts per thousand if natural salinity is 13.5 to 35 parts per thousand (PSU)."

Figure 5.15 shows the time series of salinity change at the 100-m regulated mixing zone of the three discharge scenarios. The magnitude of the maximum change in the background seawater salinity is below 0.07 PSU throughout the discharge season, which is well below the threshold value of 4 PSU. As expected, higher discharge rate leads to greater changes in the ambient salinity.

Changes in surface temperature and salinity are negligible throughout the discharge season. Figure 5.16 shows the time mean of surface temperature and salinity change from June to October. The maximum increase in both temperature and salinity is found at the diffuser location, where it is 0.034 °C in temperature and 0.038 PSU in salinity.

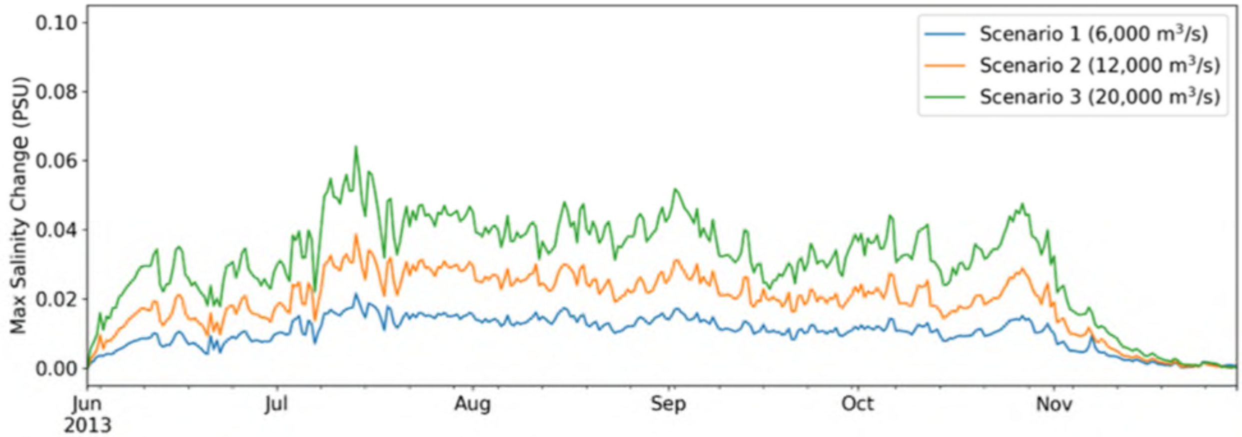

Figure 5.15. Time Series of the Magnitude of Maximum Salinity Change at the 100-m Regulated Mixing Zone of the Three Discharge Scenarios

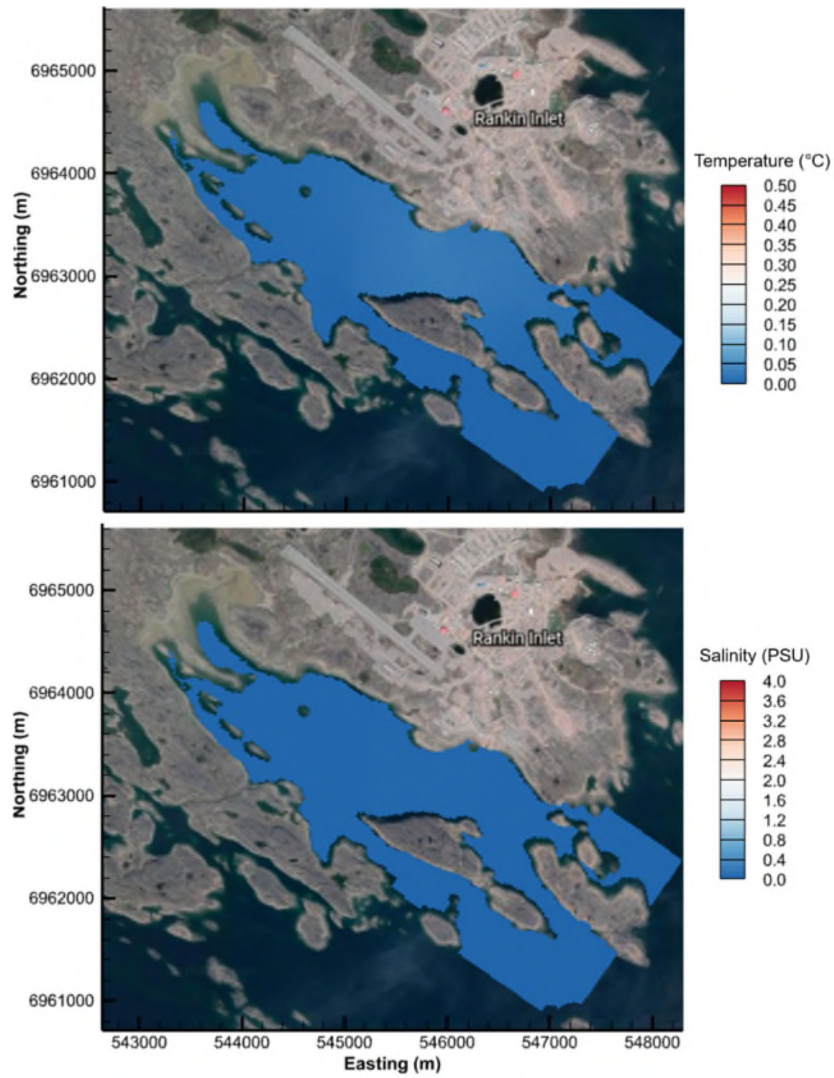

Figure 5.16. Time Mean of Surface Temperature (upper panel) and Salinity Change from June to October due to Effluent Discharge of Scenario 3 (20,000 m^3/d)

6.0 CONCLUSION

This modelling study investigates the fate and behaviour of discharged effluent in Melvin Bay, as part of the Meliadine Mine Waterline Amendment. Effluent is discharged at the proposed diffuser location and at a depth of 20 m. The discharge season is from June to October. Three scenarios of different discharge rates (6,000 m^3/d, 12,000 m^3/d and 20,000 m^3/d) are modelled. The 20,000 m^3/d discharge rate is well above the projected mean daily flow rates for each month over mine operations (i.e., 2020 to 2028) and therefore represent a very conservative scenario. The 3-D model is run an extra month after the discharge season ends to study the timeline for the system to recover towards its initial conditions.

The main results are:

- The modelling results confirm the outcomes of the 2-D Visual Plumes model conducted in April 2020: an effective and rapid dilution of the effluent, allowing to reach the target dilution of 11:1 by the edge of the mixing zone;
- Ocean current conditions identified during this study confirm the assumptions taken during the April 2020 study;
- 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 respectively at the 100-m mixing zone throughout the discharge season;
- The currents in the embayment are mainly tidal driven, vertically coherent and follow the isolines;
- Water exchange across isolines and depths is limited;
- Direction of currents at the diffuser is mainly northwest or southeast towards the seabed, while the surface current has a wider range of directions due to wind effect;
- At the diffuser, the monthly mean maximum surface current speed varies from 0.15 m/s to 0.22 m/s, while the monthly maximum speed at the depth of 20 m varies from 0.04 m/s to 0.11 m/s;
- Cross-isoline and -depth effluent advection is limited due to the characteristics of the currents;
- Maximum tracer concentration increases/decreases as the discharge rate increases/decreases;
- 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 0.002% of total released effluent remains in the domain) in the scenario of 20,000 m^3/d discharge rate, 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 the studied base case.

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7.0 CLOSURE

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

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APPENDIX A

LIMITATIONS ON THE USE OF THIS DOCUMENT

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HYDROTECHNICAL

This report incorporates and is subject to these “General Conditions”.

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The Report is intended for the sole use of TETRA TECH’s Client (the “Client”) as specifically identified in the TETRA TECH Services Agreement or other Contract entered into with the Client (either of which is termed the “Services Agreement” herein). TETRA TECH does not accept any responsibility for the accuracy of any of the data, analyses, recommendations or other contents of the Report when it is used or relied upon by any party other than the Client, unless authorized in writing by TETRA TECH.

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Where TETRA TECH submits both electronic file and hard copy versions of the Report or any drawings or other project-related documents and deliverables (collectively termed TETRA TECH’s “Instruments of Professional Service”), only the signed and/or sealed versions shall be considered final. The original signed and/or sealed version archived by TETRA TECH shall be deemed to be the original. TETRA TECH will archive the original signed and/or sealed version for a maximum period of 10 years.

Both electronic file and hard copy versions of TETRA TECH’s Instruments of Professional Service shall not, under any circumstances, be altered by any party except TETRA TECH. TETRA TECH’s Instruments of Professional Service will be used only and exactly as submitted by TETRA TECH.

Electronic files submitted by TETRA TECH have been prepared and submitted using specific software and hardware systems. TETRA TECH makes no representation about the compatibility of these files with the Client’s current or future software and hardware systems.

1.3 STANDARD OF CARE

Services performed by TETRA TECH for the Report have been conducted in accordance with the Services Agreement, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Report. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Report.

If any error or omission is detected by the Client or an Authorized Party, the error or omission must be immediately brought to the attention of TETRA TECH.

1.4 ENVIRONMENTAL AND REGULATORY ISSUES

Unless expressly agreed to in the Services Agreement, TETRA TECH was not retained to investigate, address or consider, and has not investigated, addressed or considered any environmental or regulatory issues associated with the project.

1.5 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Services Agreement, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

1.6 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Report, TETRA TECH may have relied on information provided by persons other than the Client.

While TETRA TECH endeavours to verify the accuracy of such information, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

1.7 GENERAL LIMITATIONS OF REPORT

This Report is based solely on the conditions present and the data available to TETRA TECH at the time the Report was prepared.

The Client, and any Authorized Party, acknowledges that the Report is based on limited data and that the conclusions, opinions, and recommendations contained in the Report are the result of the application of professional judgment to such limited data.

The Report is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present at or the development proposed as of the date of the Report requires a supplementary investigation and assessment.

It is incumbent upon the Client and any Authorized Party, to be knowledgeable of the level of risk that has been incorporated into the project design, in consideration of the level of the hydrotechnical information that was reasonably acquired to facilitate completion of the design.

The Client acknowledges that TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.8 JOB SITE SAFETY

TETRA TECH is only responsible for the activities of its employees on the job site and was not and will not be responsible for the supervision of any other persons whatsoever. The presence of TETRA TECH personnel on site shall not be construed in any way to relieve the Client or any other persons on site from their responsibility for job site safety.