Stantec

Memo

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File:	121414584	Date:	September 29, 2017

Reference: Far-field Dispersion Modelling of Treated Effluent Discharge at the Existing Weir in Boat Harbour, Pictou, Nova Scotia

INTRODUCTION

KSH Solutions Inc. (KSH) engaged Stantec Consulting Ltd. (Stantec) to complete a preliminary receiving water study in Pictou Harbour, Nova Scotia. The objective of the study was to address the requirement of a new effluent pipeline and outfall for a wastewater treatment plant for Northern Pulp Nova Scotia Corporation (NPNS).

Following reviews and discussions on the preliminary results presented in the report by Stantec (2017), KSH would like to further understand the effluent dispersion characteristics and the corresponding potential environmental effects, using similar effluent quality as that in the 2017 study, for effluent discharged into Boat Harbour and through the existing weir structure (**Figure 1**). The weir currently separates Boat Harbour from the Pictou Road area of the Northumberland Strait and prevents any tidal intrusion into Boat Harbour. In response to this request of KSH in August 2017, Stantec conducted additional far-field dispersion modelling using the Mike 21 coupled model. The modelling conditions and results for the additional work to characterize the dispersion of effluent for existing conditions are outlined in this technical memorandum.

MODELING CONDITIONS

The numerical model, available data sources, domain and boundary conditions are presented in Section 2 in Stantec's report (Stantec 2017). The differences from the previous modelling outfall discharge are described as follows:

- In the previous modelling (Stantec 2017), Boat Harbour was assumed to be connected to Pictou Road estuary by a navigation channel and was incorporated in the model domain as the future scenario with re-introduction of tidal influence to Boat Harbour. The present modelling assumes the effluent to be discharged through the existing weir structure into the tidal estuary and where the weir prevents tidal flows into Boat Harbour. Therefore, Boat Harbour is not included in the Stantec 2017 model domain and a model boundary is set at the weir structure.
- The bathymetry in the channel downstream of the weir structure to Pictou Road estuary/Northumberland Strait is based on the Canadian Hydrographic Service nautical chart no. 4437. **Figure 2** presents the currently available elevation contours (light blue points) and the shoreline contours (yellow points).
- The computational domain, generated bathymetry and boundary setups for modelling of the existing conditions are presented in **Figure 3**. The generated mesh system for the model contains

8,808 nodes and 16,358 elements. Finer mesh (in metres) is produced in the vicinity of the channel, estuary, shorelines and harbour areas.

The effluent quality to be discharged at the existing weir boundary, which should be as close as possible to those previous model for comparative purposes, are provided by KSH in consultation with NPNS (KSH 2017) and based on the following assumptions:

- Discharge flow rate is set to 1.23 m^3/s at the weir, which includes a 0.98 m^3/s daily maximum flow of the effluent into Boat Harbour and a 25% increase due to groundwater discharge and surface runoff into Boat Harbour from the surrounding watershed. An increase of 25% in flow between effluent discharge to and weir overflow leaving Boat Harbour was based on year over year measuring flow at both locations by NPNS.

- Total dissolved solids (TDS) concentration of the discharge at the weir for modelling is set to 3200 mg/L, which is reduced from the TDS of 4000 mg/L in the effluent due to the additional 25% fresh water inflow into Boat Harbour and based on the assumption that TDS in the groundwater discharge and surface runoff is negligible.

- Temperature of the discharge at the weir in July is set to 21°C for modelling, which is based on temperature measurements by NPNS at the weir during July.

Model settings and parameters for discharge at the existing weir are summarized below in **Table 1**. The effluent is assumed to be discharged at a single point from the weir location and at a constant arbitrary effluent parameter concentration of 100 mg/L, as previously assessed (Stantec 2017). Effluent transport is simulated by the MIKE 21 model in the particle tracking module (PT) which is dynamically coupled with the hydrodynamic circulation module (HD). This dilution modeling of the effluent does not take into account any decay coefficients or settling/buoyancy effects of the effluent quality and therefore the modelling results are conservative, and similar for comparative purposes to the modelling conditions in Stantec (2017).

Reference: Far-field Dispersion Modelling of Treated Effluent Discharge at the Existing Weir in Boat Harbour

Table 1 Summary of Conditions and Assumptions Used in the Hydrodynamic and Particle Tracking 2D Modelling for Existing Conditions

Feature	Characteristics	Comments
General Model Settings		
Model Domain	8808 nodes and 16358 elements	
Coupled Modules	Hydrodynamic (HD), Temperature/Salinity (TS), and Particle Tracking (PT)	
Simulation Period	A full month from July 1 to 31, 2016	
Simulation Time Step	60 seconds	
Assumptions	no decay and no dispersion in the Particle Tracking module	most conservative approach
Outfall Discharge Location		
At the weir	Easting 528115.5 m, Northing 5057523.5 m	approximate location at the existing weir structure
Effluent Properties at the Weir		
Discharge Rate	1.23 m^3/s	daily maximum based on information provided by KSH (in consultation with NPNS)
Temperature	21 °C	assumed for July summer condition, based on information provided by KSH (in consultation with NPNS)
TDS	3200 mg/L	based on information provided by KSH (in consultation with NPNS)
Concentration	Arbitrary effluent parameter concentration: 100 mg/L	assumed arbitrary concentration at discharge for calculation of dilution ratios and easy visualization of the plume
Boundary and Ambient Conditions		
Predicted Tides	Tidal range 1.91 m (from -1.11 m to 0.8 m) including spring and neap tides	this tidal range is less than the normal tidal range of 2.11 m in the Pictou Harbour area
Measured Winds	Peak and mean wind speeds in July 2016 are 10.83 m/s and 3.75 m/s respectively	based on wind records at Caribou Point (AUT), NS
East River Discharge	1.64 m^3/s	based on ENSR 1999 study
Ambient Water	Temperature: 14 °C	based on ENSR 1999 study
	Salinity: 27.5 practical salinity unit (psu)	based on ENSR 1999 study

MODELING RESULTS

Current Circulation

A time series plot and a directional rose plot of the current speeds at the mid-channel between the weir and Pictou Road estuary are presented in **Figure 4** over the simulation period for July 2016. The circulation pattern in the channel indicates that:

- Flood currents towards the weir (in the south direction) are stronger than ebb currents towards Pictou Road estuary (in the north direction).
- In 80% of the simulation time, the current speeds are lower than 0.05 m/s.
- There exist strong hydrodynamic interactions between the flood and ebb currents, resulting in the water in the channel area fluctuating in a wide range of directions.
- The water in the channel area cannot be easily flushed out to the Pictou Road open water due to the effect of the narrow channel and channel opening.

Effluent Dispersion

An arbitrary effluent parameter was assumed to be discharged at a constant arbitrary concentration of 100 mg/L from a single point at the existing weir. Simulated effluent transport is presented in time series of effluent concentrations, spatial snapshots of the effluent plume for various stages of neap and spring tides, and cumulative effects with time by the end of the 30-day simulation period starting on July 1 and ending on July 31, 2016. As described above, a conservative approach was used in the model where no degradation or decay of the arbitrary effluent parameter was taken into consideration.

The spatial distribution of the effluent plume at various stages of a typical neap tide cycle on July 13 are illustrated in **Figure 5** to **Figure 8**. The spatial distribution of the effluent plume at various stages of a typical spring tide cycle on July 21 and July 22 are presented in **Figure 9** to **Figure 12**. Current vectors and circulation patterns are presented in the plots as well to provide supporting information of the current-driven forcing on effluent transport.

The effluent transport is dominated by current flows and circulation patterns, and the effluent plume is normally transported to and accumulated in areas with lower circulation velocities and eddies. The simulated results indicate that the effluent plume discharge from the weir location is highly constrained in the channel area during the time of the simulation period, which is due to the fact of poor water exchange conditions in this area. When the effluent plume drifts out of the channel area into Pictou Road, the plume typically moves back and forth along the south shoreline of Pictou Road before eventually mixing with the open water in Northumberland Strait. The plume concentration remains relatively high along the south shoreline with effluent intrusion into Pictou Harbour.

Figure 13 presents the predicted spatial distribution of the effluent dilution factors over the one-month simulation period in July. The results indicate that lower dilution factors, suggesting the potential presence of higher effluent concentrations in the receiving environment, occur in areas of the channel, Pictou Road estuary, and the south shoreline in Northumberland Strait.

Reference: Far-field Dispersion Modelling of Treated Effluent Discharge at the Existing Weir in Boat Harbour

CONCLUSIONS

Preliminary effluent dispersion analysis at the existing weir location was undertaken using the Mike 21 hydrodynamic models. The modelling results for effluent dispersion indicate that the potential effluent impact on the surrounding environment of Pictou Road estuary is higher than the modelled discharge of the effluent in Northumberland Strait by Stantec (2017). The cumulative effects by the end of the one-month simulation period for the discharge at the existing weir location indicate that the highest dilution factor achieved in the channel and in Pictou Road estuary is 10 (**Figure 13**), which is considered low and insufficient for effluent mixing with the ambient water.

CLOSURE

This memorandum has been prepared for the sole benefit of KSH Solutions Inc. and Northern Pulp Nova Scotia Corporation. This memorandum may not be used by any other person or entity without the express written consent of Stantec Consulting Ltd., KSH Solutions Inc. and Northern Pulp Nova Scotia Corporation.

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The information and conclusions contained in this memorandum are based upon work undertaken by trained professional and technical staff in accordance with generally accepted engineering and scientific practices current at the time the work was performed. Conclusions and recommendations presented in this memorandum should not be construed as legal advice.

The conclusions presented in this memorandum represent the best technical judgment of Stantec Consulting Ltd. based on the data obtained from the work. If any conditions become apparent that differ from our understanding of conditions as presented in this memorandum, we request that we be notified immediately to reassess the conclusions provided herein.

This memorandum was prepared by Shelton Liu (Ph.D., P.Eng.), reviewed by Sam Salley (M.Sc.) and independently reviewed by Sheldon Smith (MES., P.Geo.).

STANTEC CONSULTING LTD.

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Attachment: **Appendix A** – ***Figures 1*** to ***13***

Reference: Far-field Dispersion Modelling of Treated Effluent Discharge at the Existing Weir in Boat Harbour

REFERENCES

KSH Solutions Inc. (KSH). 2017. Email communication with Stantec Consulting Ltd. on July 31, 2017.

Stantec Consulting Ltd. (Stantec). 2017. Preliminary Receiving Water Study for Northern Pulp Effluent Treatment Plant Replacement, Pictou Harbour, Nova Scotia. Final Report prepared for KSH Solutions Inc. August 11, 2017.

APPENDIX A

Figures

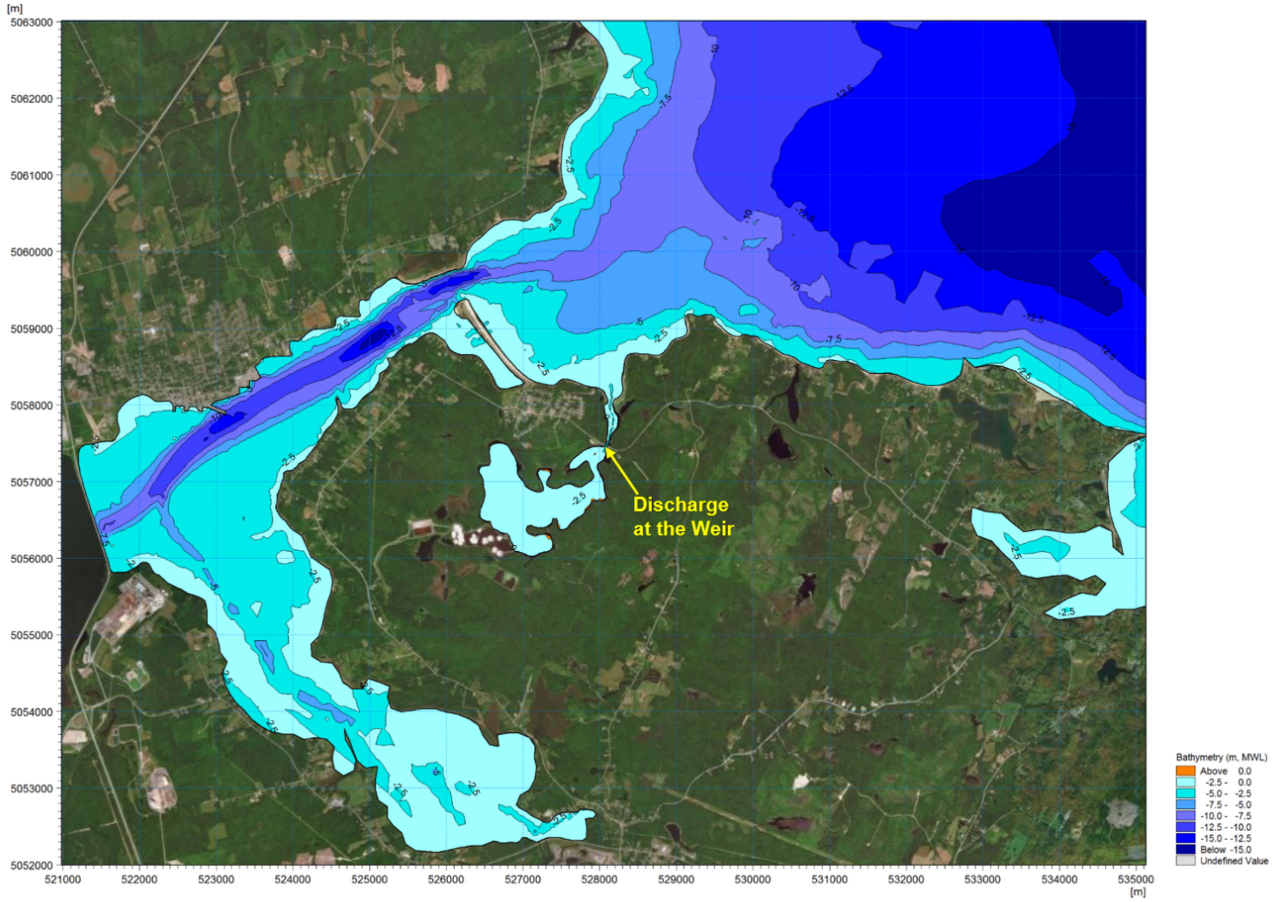


Figure 1 Boat Harbour Outfall Location Applied for Effluent Dispersion Modelling

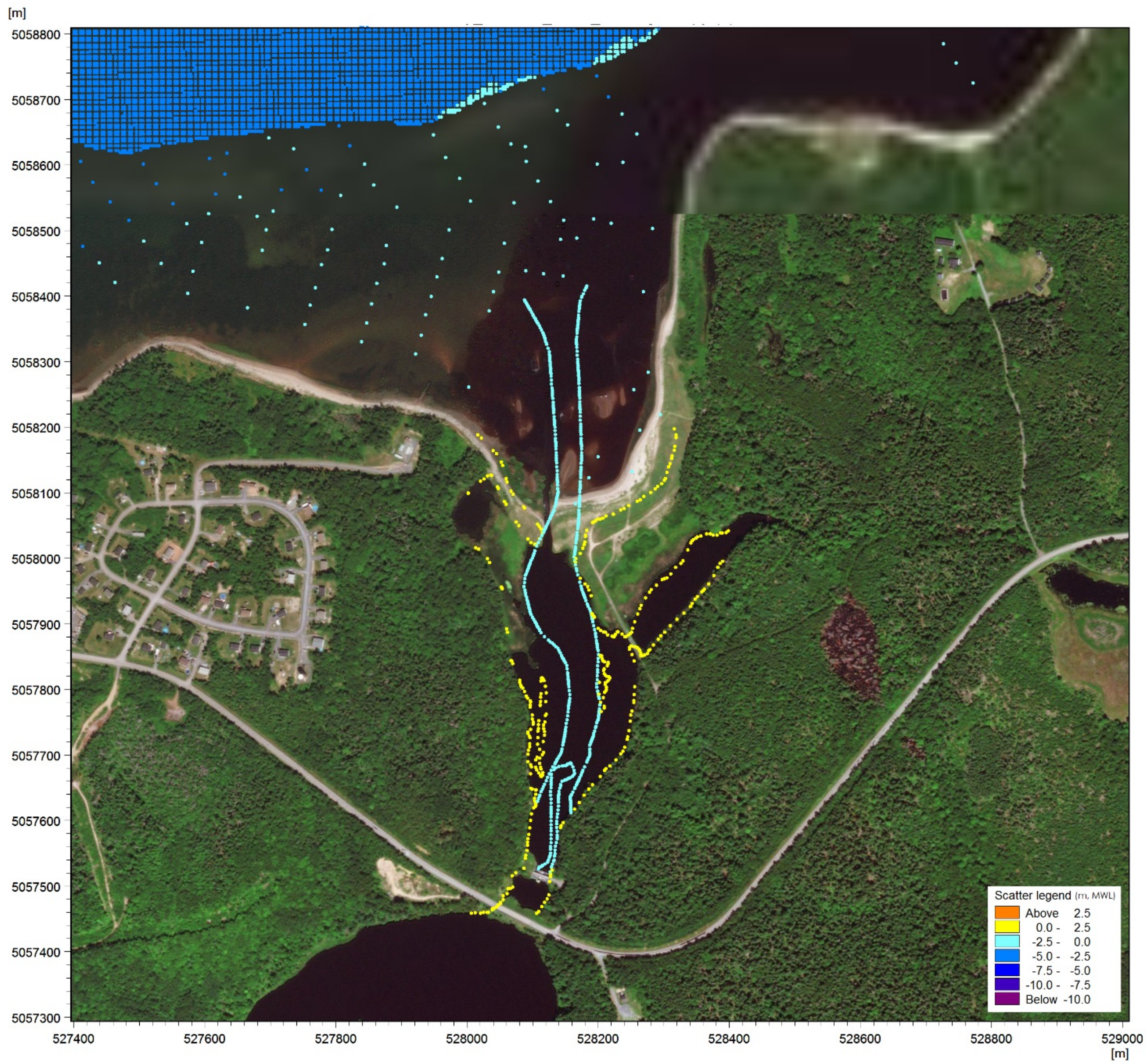


Figure 2 Available Bathymetric Data and Extent in the Channel between the Existing Weir and the Pictou Road Estuary

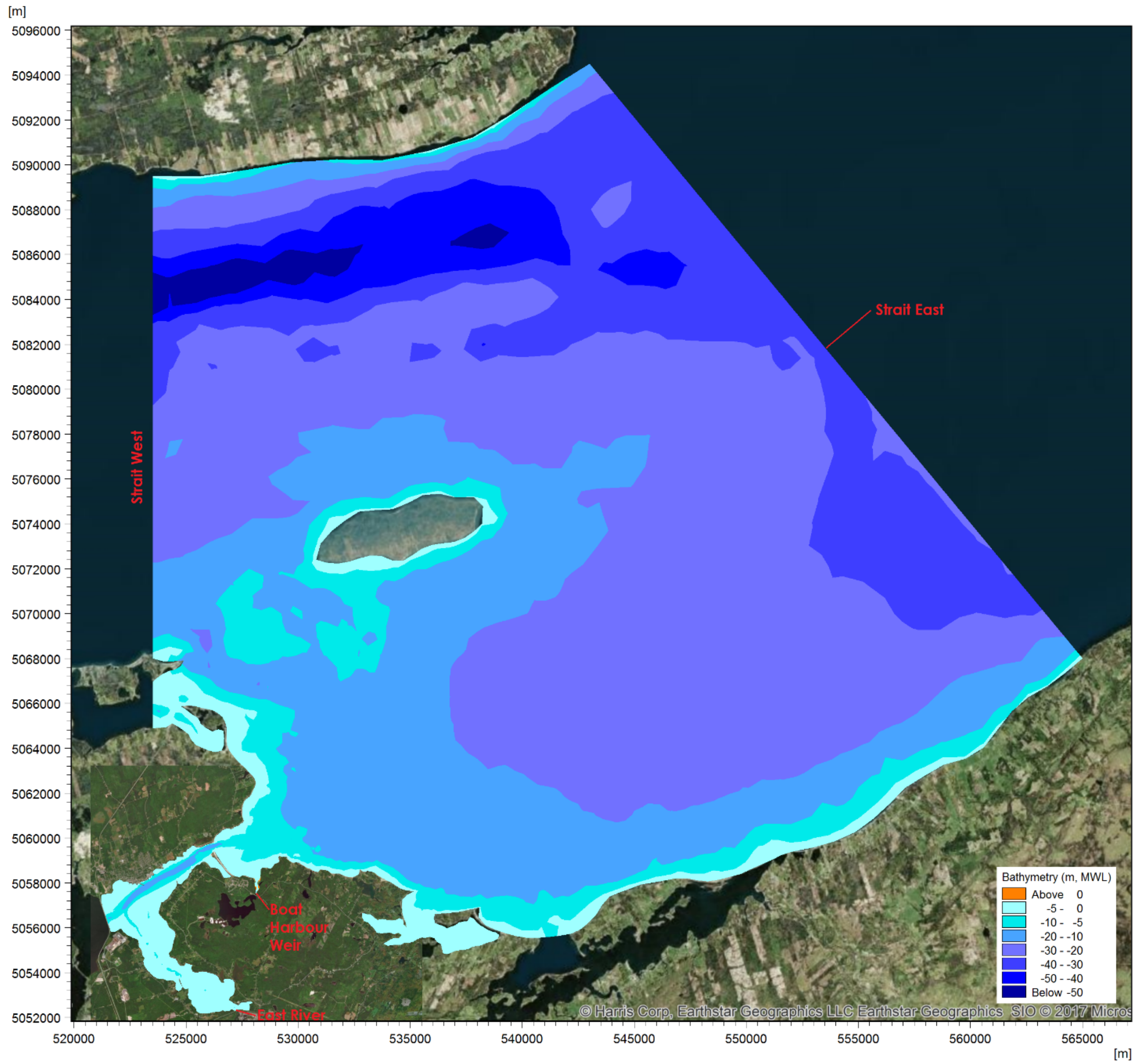
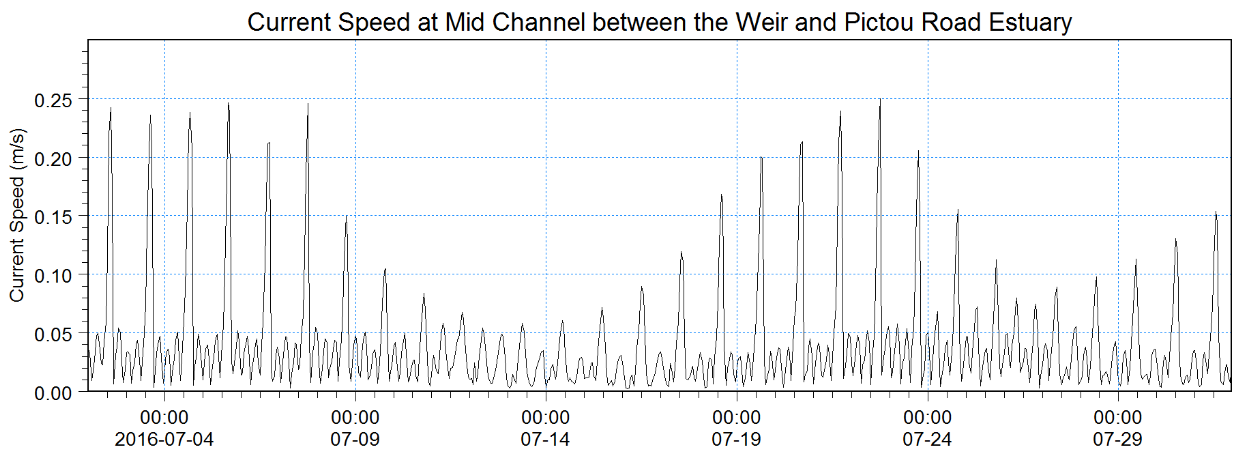


Figure 3 Computational Domain and Boundaries



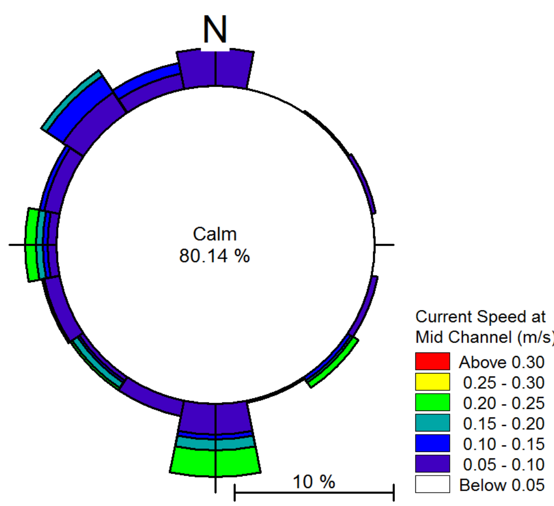


Figure 4 Current Speeds and Current Directions at Mid-channel Between the Weir and Pictou Road Estuary

Stantec

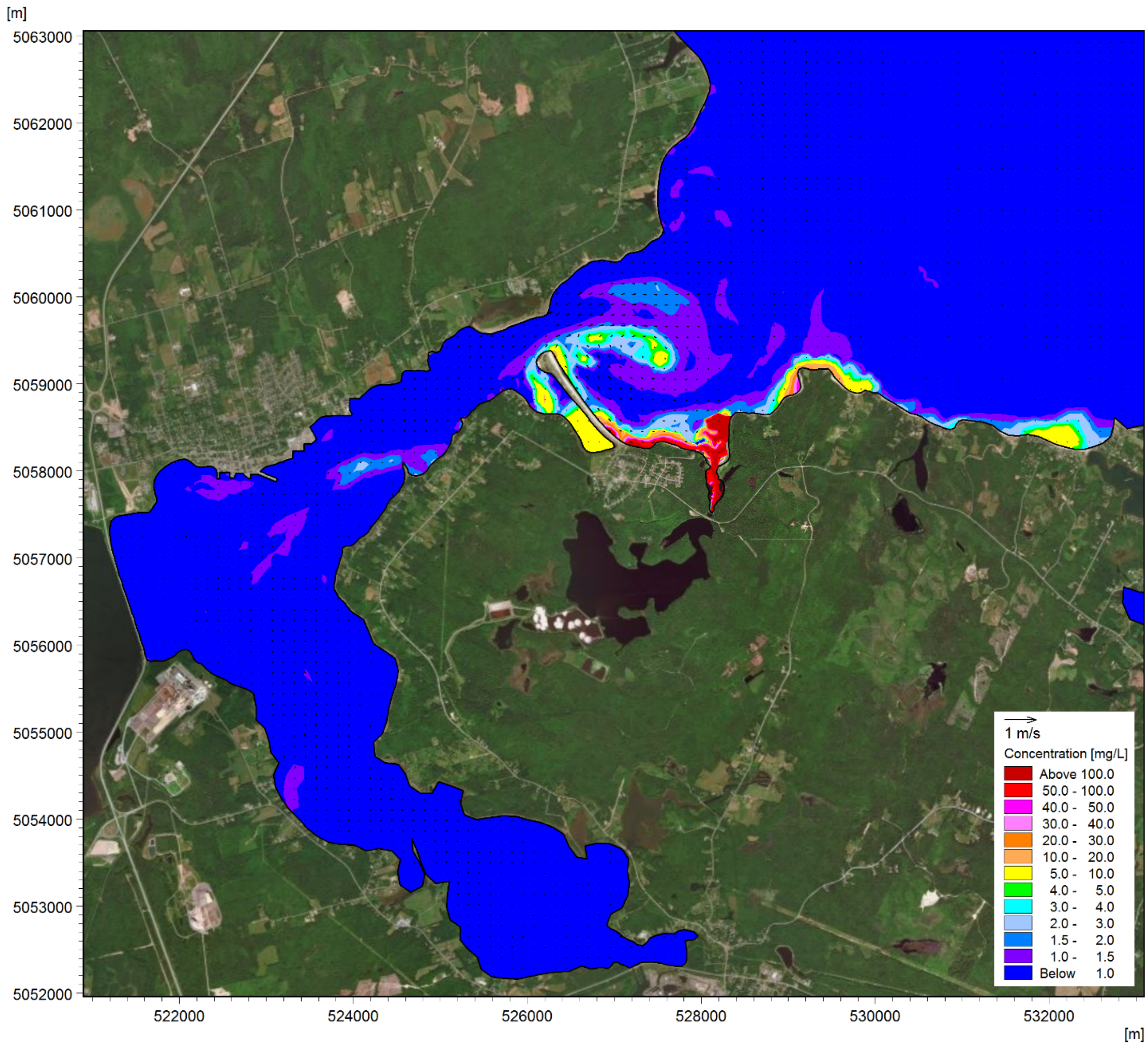


Figure 5 Simulated Currents Circulation and Effluent Concentrations for Typical Neap Tide - Slack Low Tide at 10:00 hr, July 13

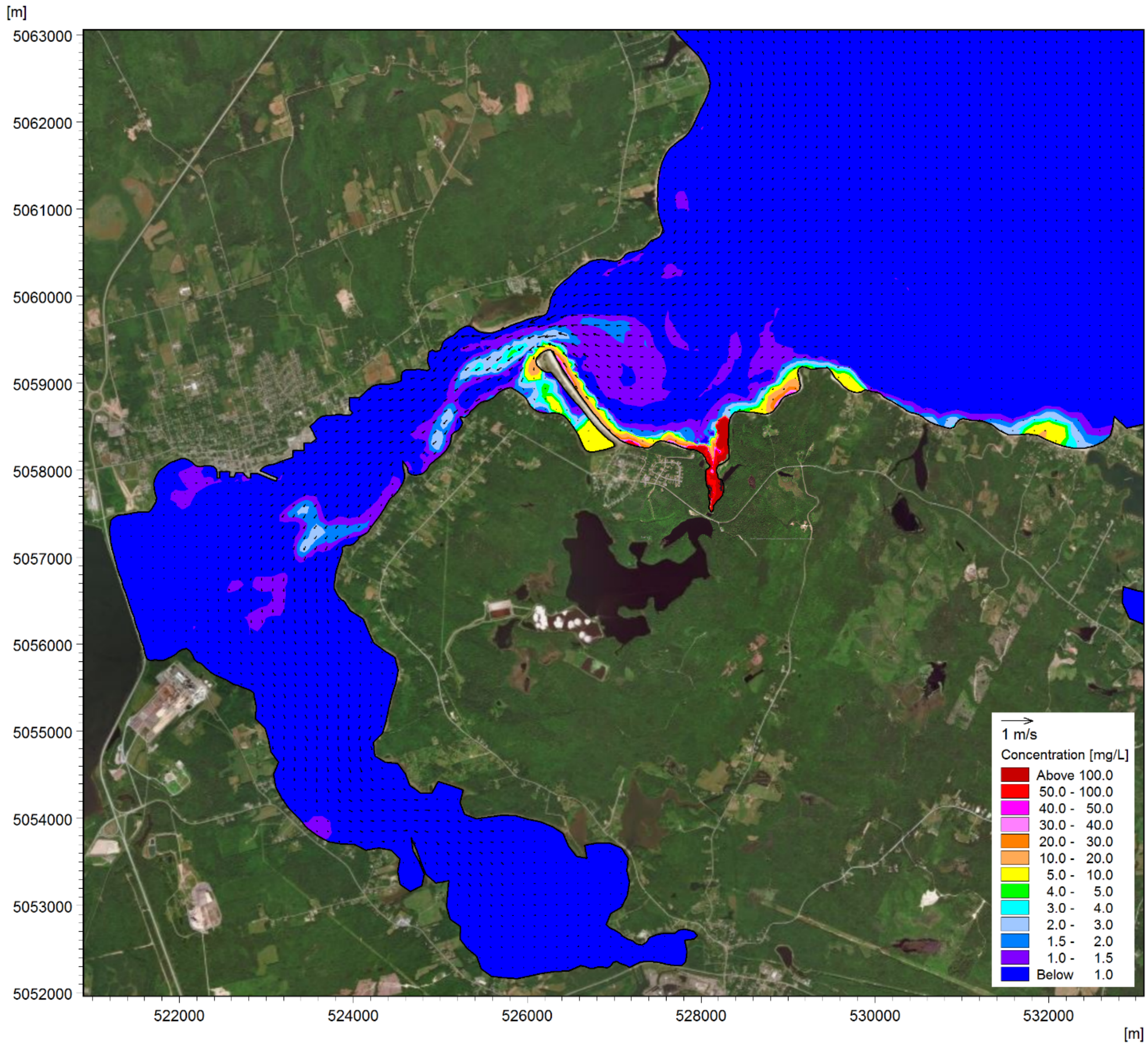


Figure 6 Simulated Currents Circulation and Effluent Concentrations for Typical Neap Tide - Flood Tide at 14:00 hr, July 13

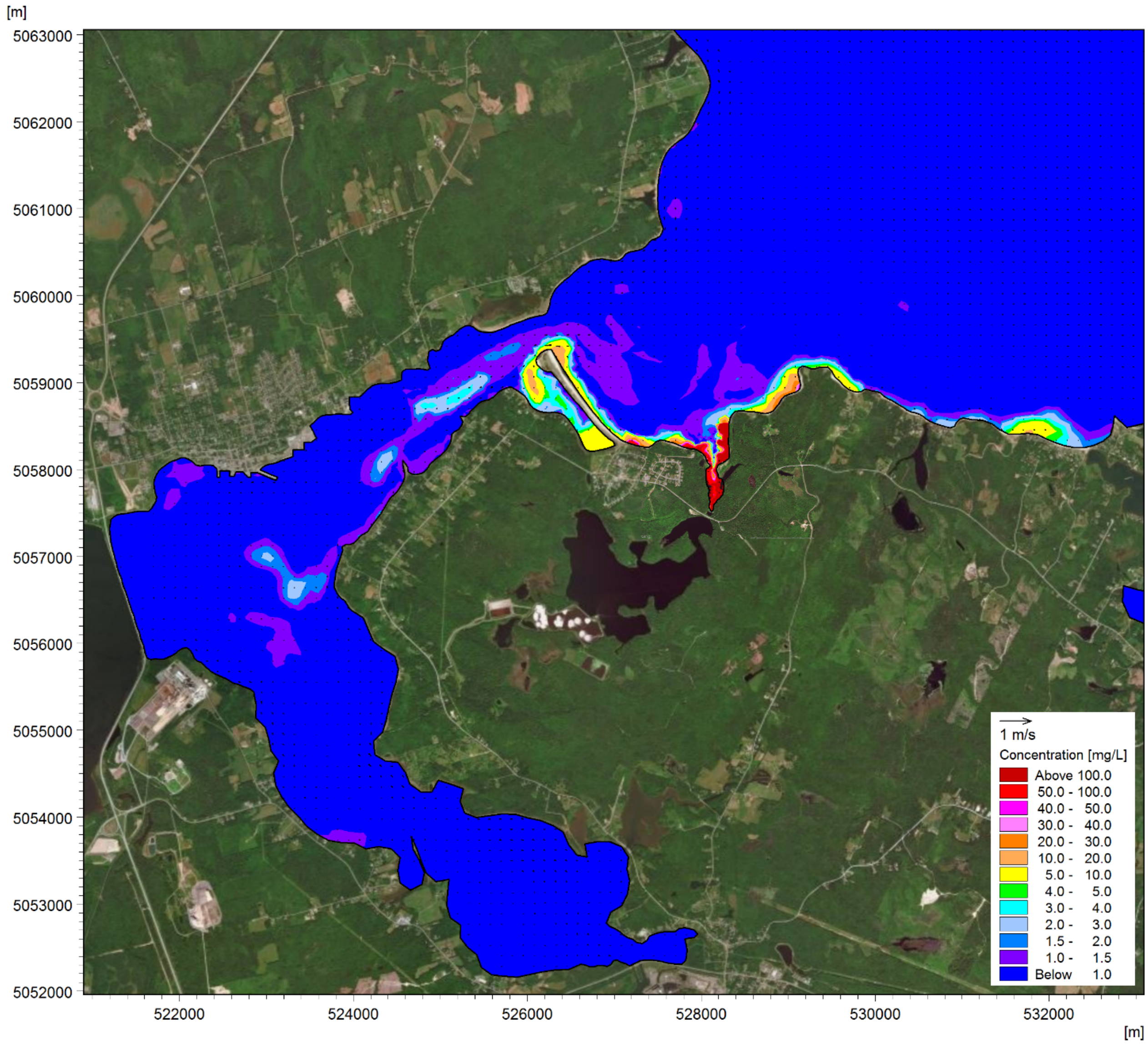


Figure 7 Simulated Currents Circulation and Effluent Concentrations for Typical Neap Tide - Slack High Tide at 17:00 hr, July 13

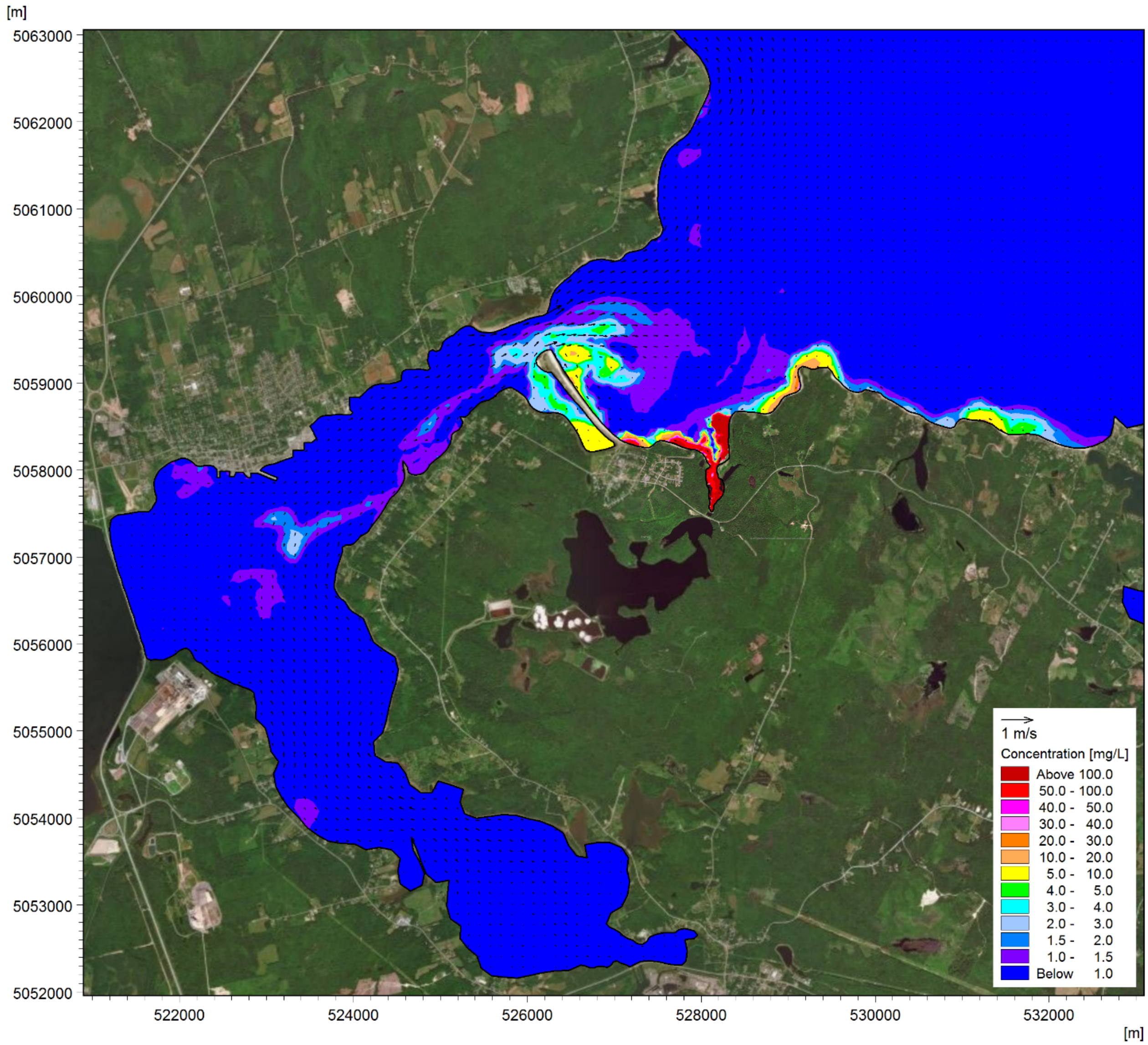


Figure 8 Simulated Currents Circulation and Effluent Concentrations for Typical Neap Tide - Ebb Tide at 20:00 hr, July 13

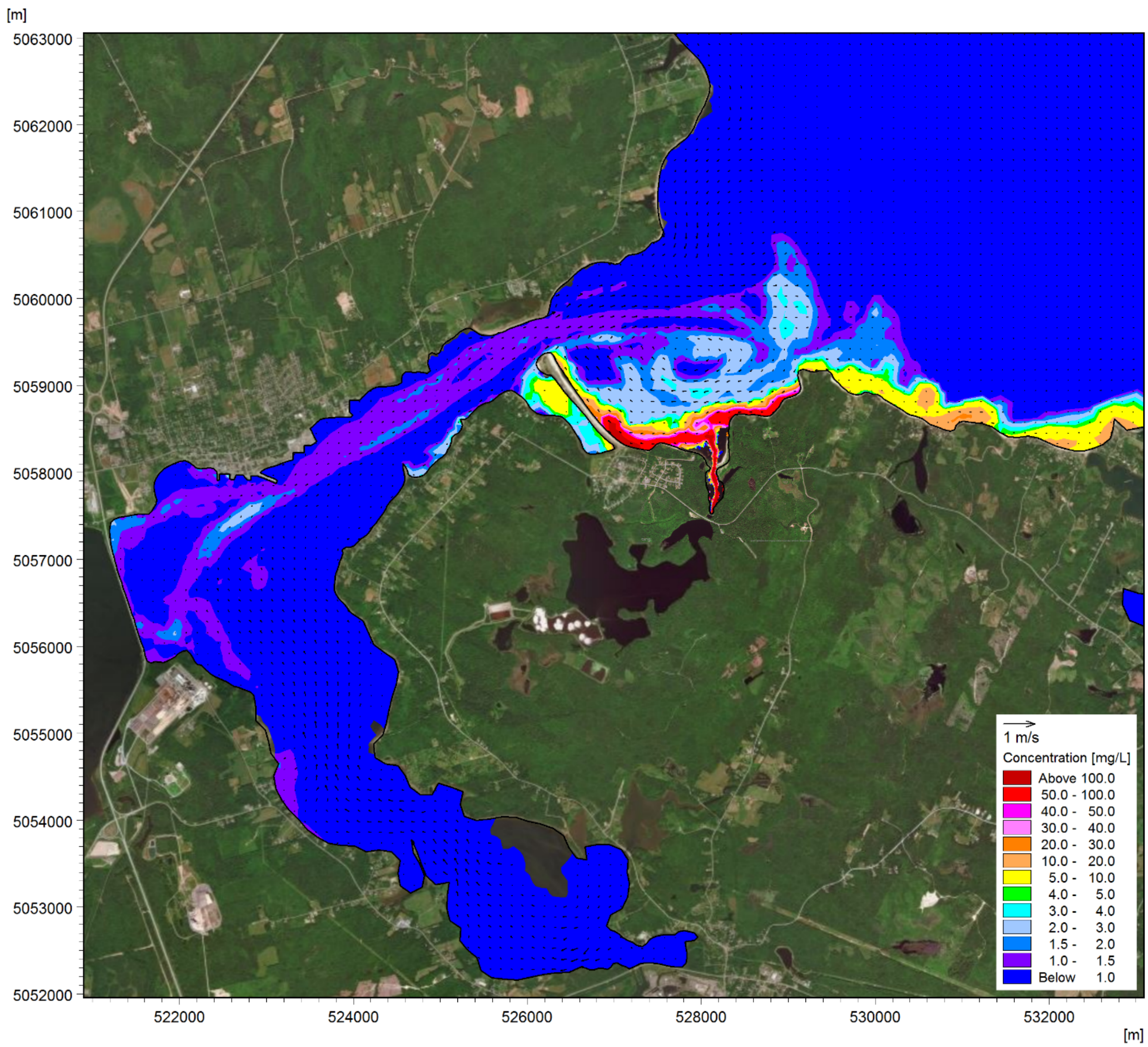


Figure 9 Simulated Currents Circulation and Effluent Concentrations for Typical Spring Tide - Slack Low Tide at 17:00 hr, July 21

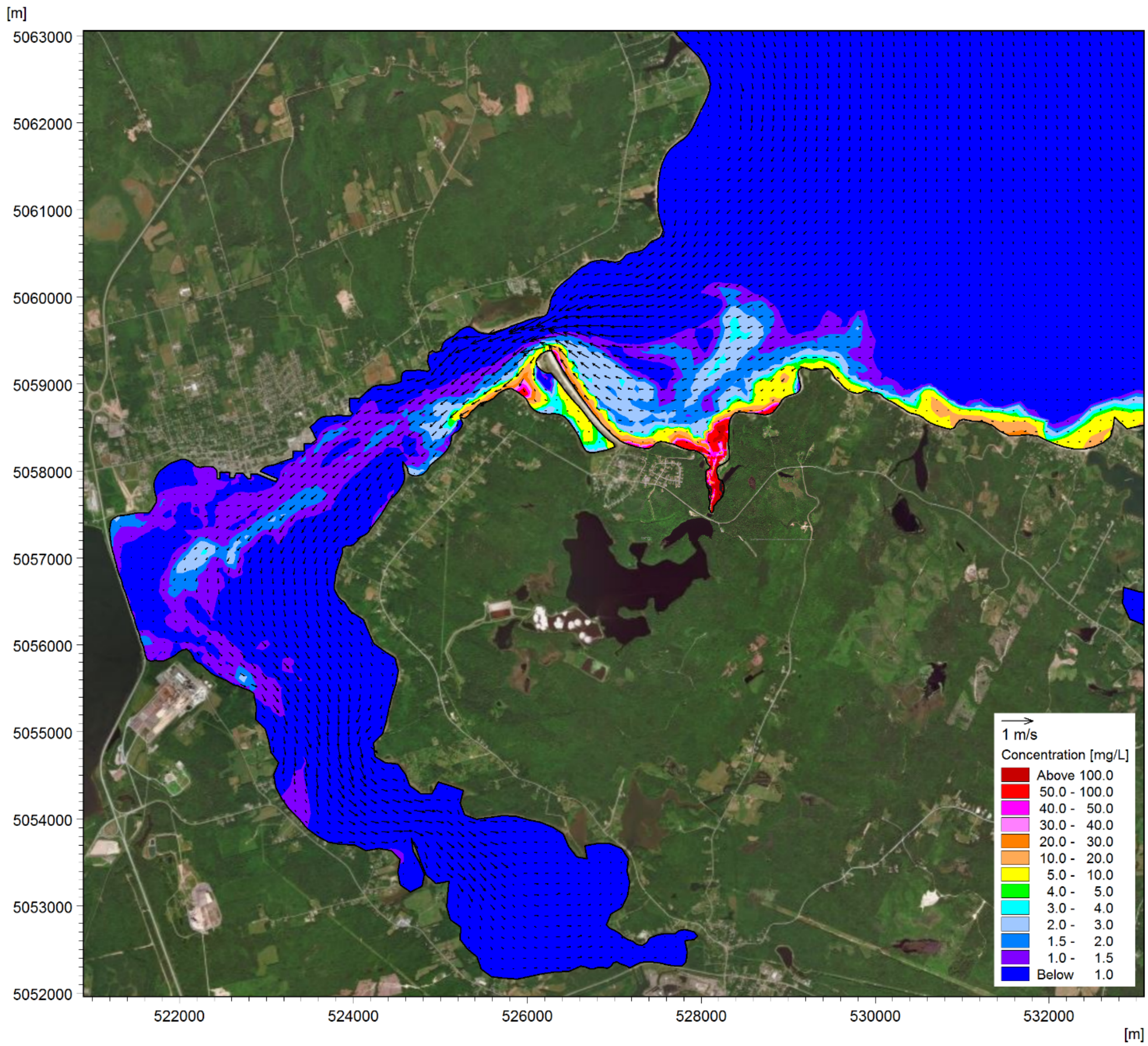


Figure 10 Simulated Currents Circulation and Effluent Concentrations for Typical Spring Tide – Flood Tide at 21:00 hr, July 21

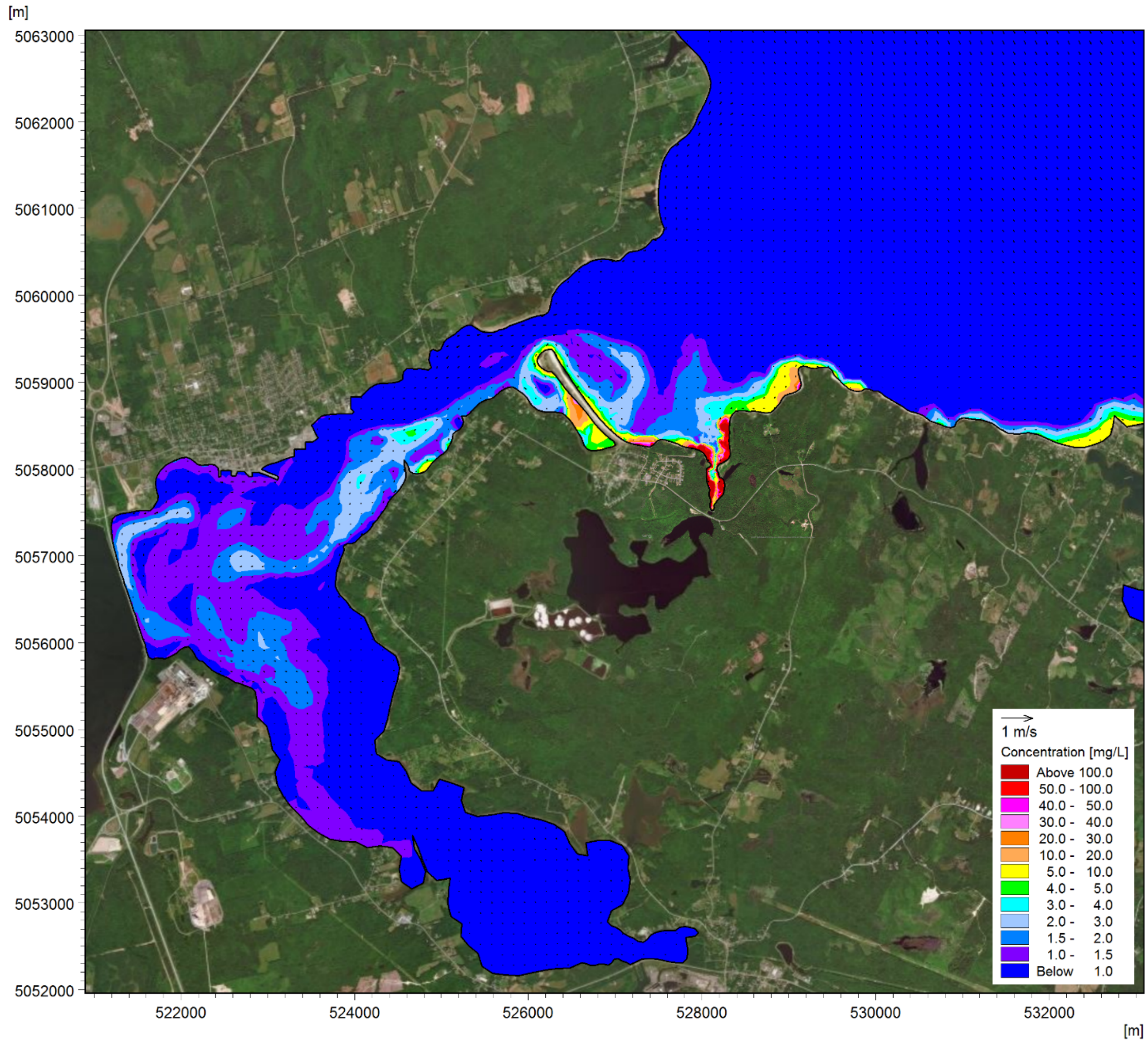


Figure 11 Simulated Currents Circulation and Effluent Concentrations for Typical Spring Tide – Slack High Tide at 11:00 hr, July 22

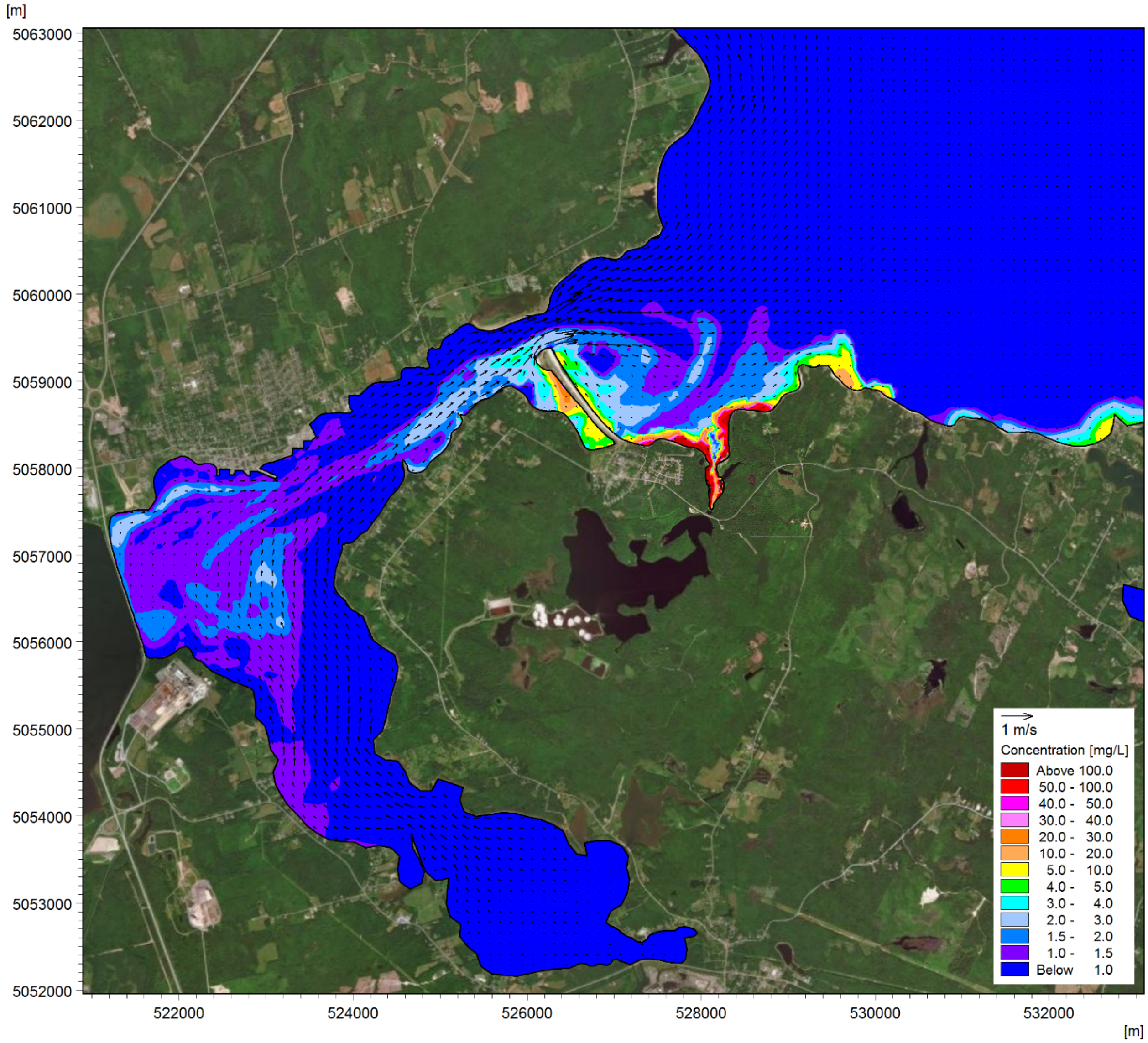


Figure 12 Simulated Currents Circulation and Effluent Concentrations for Typical Spring Tide – Ebb Tide at 14:00 hr, July 22

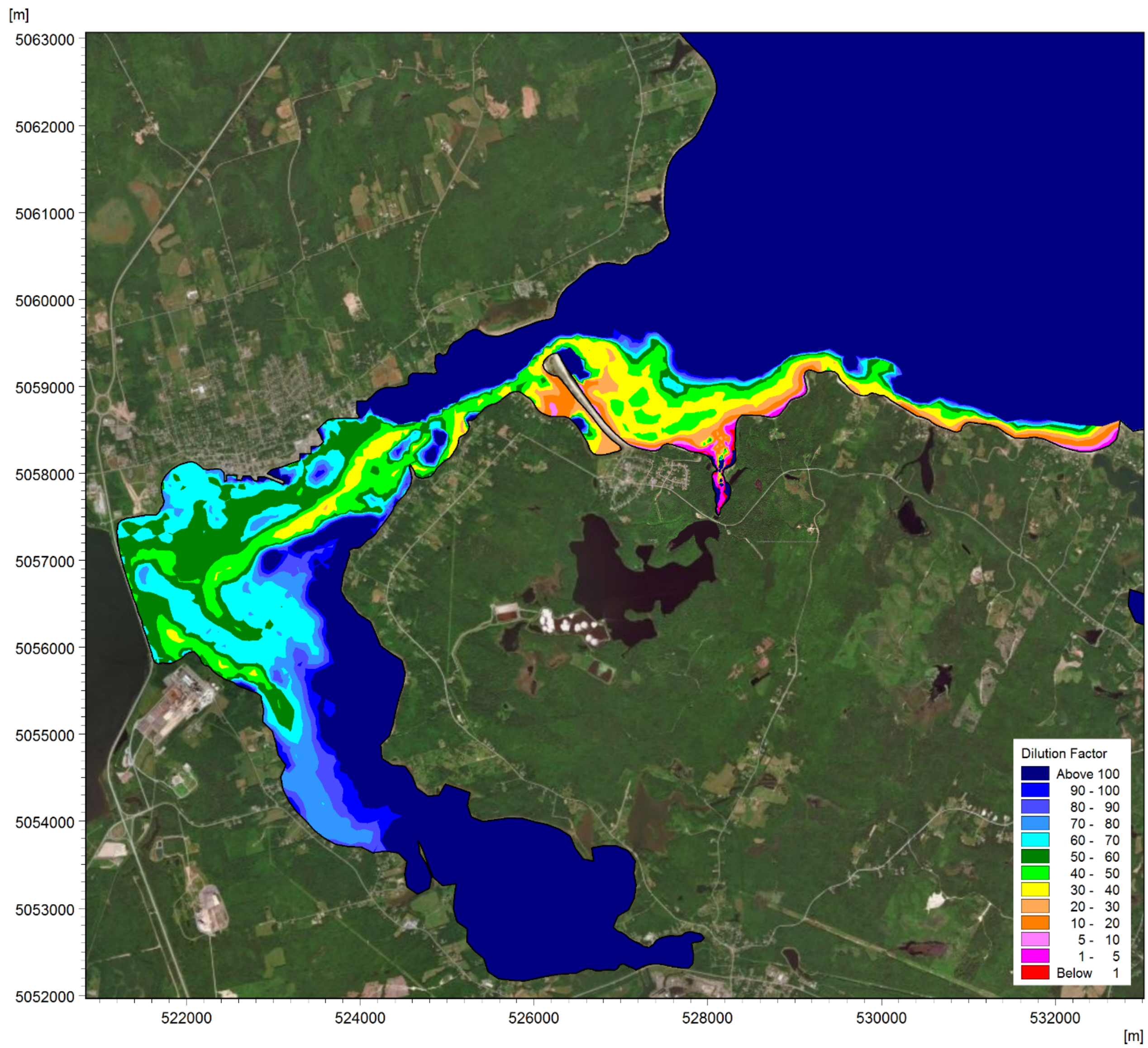


Figure 13 Spatial Distribution of Simulated Effluent Dilution Factor at the End of a One-Month Simulation Period (assuming no particle degradation over the simulation period)

Northern Pulp Effluent Treatment Facility Replacement Project: Updated Receiving Water Study, Caribou, Nova Scotia

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September 27, 2019

Sign-off Sheet

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Executive Summary

Stantec Consulting Ltd. (Stantec) was retained by Northern Pulp Nova Scotia (NPNS) to undertake a Receiving Water Study (RWS) to address the environmental requirements of a new outfall discharge in the marine water offshore of Caribou Harbour in Northumberland Strait. The dispersion characteristics of the treated effluent discharge were investigated by hydrodynamic dispersion modellings, with the 2018 RWS report submitted as Appendix E1 to the Environmental Assessment Registration Document (EARD) filed on February 7, 2019. A review of the EARD for the Replacement Effluent Treatment Facility Project (the Project), including the RWS report in Appendix E1, resulted in the issuance of Terms of Reference (TOR) by Nova Scotia Environment for the submission of a Focus Report. Section 4.2 of the TOR required an update to the RWS for the Focus Report with baseline water quality data collected for Caribou Harbour and additional information requirements noted in Addendum 3.0 of the TOR. This report addresses these TOR requirements to update the RWS.

To update the RWS, a field program was implemented to collect sediment and water quality data, water column profiles, and time-series measurements over a month in May-June 2019 for currents, waves, water levels, and temperature in the Caribou area of Northumberland Strait. These data indicate weak stratification of the water column for temperature, salinity, and currents in the area of the proposed outfall location and support the use of the 2-dimensional (2D) model used in the 2018 RWS (Stantec 2018), and were also used to calibrate and validate the numerical models for this updated RWS. The measured water current data also revealed significantly higher velocities than those predicted in the 2018 RWS which led to improved dilutions in every scenario by comparison to 2018.

In this study, the mixing and dispersion of the treated effluent discharged from the NPNS wastewater treatment plant into the marine water offshore Caribou Harbour in Northumberland Strait were simulated by two numerical approaches: a MIKE 21 2D hydrodynamic coupled model for prediction of the far-field effluent dispersion, and the 3-dimensional (3D) CORMIX model for prediction of the near-field mixing and end-of-pipe configurations.

The MIKE 21 Coupled Model simulated the effluent dispersion under integrated hydrodynamic and environmental conditions of tidal currents, wind forcing, waves, air heat exchange, density flows, and effluent discharges to investigate the accumulative characteristics of effluent concentrations and dilution factors in a spatial domain. The hydrodynamic dispersion models were conducted in a time domain over an entire month in July 2019 for the summer conditions and in February 2019 for the winter conditions with ice cover. The effluent discharge was assumed as a single point discharge and no diffuser at the outfall, and the effluent was assumed to have no decay in dispersion, both of which were considered to represent a conservative scenario. The key conclusions based on the effluent dispersion modelling results are summarized as follows:

- The hydrodynamic model simulated the dynamic process of circulation currents, water temperature and density, and predicted their variation ranges at the outfall location for two seasons.

For the summer conditions:

- The current speeds ranged from 0.03 to 0.85 m/s, with a mean value of 0.41 m/s. The flood currents are typically predominant in the northwest direction and the ebb currents are predominant in the southeast direction. The strong currents at the outfall site are beneficial for effluent mixing and dispersion driven by currents.
- The water temperatures ranged from 15.2 to 22.5 ºC. The temperature increase over time is dominated by air heat exchange.
- The water salinity varied with effluent freshwater and tidal cycles in a small range from 29.5 to 29.8 ppt.
- As a function of water temperature and salinity, the resulting water density decreased from 1021.90 to 1020.01 kg/m^3.

For the winter conditions:

- Current speeds ranged from 0.01 to 0.78 m/s, with a mean value of 0.38 m/s. The current magnitude is slightly less than that for summer conditions.
- Without the dynamic effects of air heat exchange on the water surface, the magnitude of water temperature variation overtime was in a small range from 1.03 to 1.33 ºC.
- The water density varied in a small range from 1023.54 to 1023.84 kg/m^3, which is higher than that for summer conditions.

* The hydrodynamic dispersion model simulated the dynamic process of effluent concentrations, and provided the following model results:
  - Driven by circulation currents, the effluent plume from the outfall discharge dispersed primarily southeasterly during ebb tides and northwesterly during flood tides.
  - The effluent plumes were well-mixed and dispersed in the receiving water (i.e., entrainment was not observed). By the end of the one-month simulation period, no effluent concentration buildup was found in the harbour basins, along the shorelines and in the entire model domain.
  - The dilution factor in most of the model domain was above 100 for both the summer and winter conditions.
  - A lowest mean dilution factor of 441 was achieved at the edge of 100 m radius from the outfall location for the summer conditions.
  - A lowest mean dilution factor of 337 was achieved at the edge of 100 m radius from the outfall for the winter conditions. The difference between the high summer and winter mean dilution factors does not give rise to appreciable differences between the two seasons for an arbitrary effluent concentration.

The CORMIX model was used for the 3-dimensional (3D) near-field hydrodynamic modelling of the CH-B outfall location with a diffuser containing three ports. The mixing zone was defined as the 100-m distance from the outfall pipe.

Three modelling scenarios, representative of summer open-water conditions, were modelled. Scenarios differ by ambient current velocity, maximum effluent flow rate, and some effluent parameters.

Scenario A utilizes average current velocities for July 2019, maximum expected effluent quality and effluent flow rate of 85,000 m^3/day or 0.984 m^3/s. The dilution ratio is 252 times at 10 m from the ports and 427 times at the end of the mixing zone (i.e., at 100 m), which is a much higher dilution ratio than 144 times predicted in the 2018 RWS (Stantec 2018) with similar effluent quality. Scenario B is the most conservative scenario as it utilizes slack velocity for July 2019, Pulp and Paper Effluent Regulation (PPER) draft limits and effluent flow rate of 85,000 m^3/day or 0.984 m^3/s. The dilution ratio is 51 times at 5 m from the ports and 146 times at the end of the mixing zone (i.e., at 100 m). Scenario C utilizes slack velocity for July 2019, PPER draft limits and reduced effluent flow rate of 50,000 m^3/day or 0.579 m^3/s. The dilution ratio is 78 times at 5 m from the ports and 219 times at the end of the mixing zone (i.e., at 100 m).

The results of the near-field modelling show that for all scenarios the proposed effluent discharge limits for AOX, TN, TP, colour, BOD, COD, TSS, water temperature, DO, pH, salinity, cadmium, total dioxins, phenanthrene, total resin acids, total fatty acids and total pulp and paper phenols are anticipated to meet compliance at the end of the mixing zone for applicable federal water quality guidelines and/or background conditions.

Using CORMIX the maximum effluent concentration which can be assimilated by the receiving environment to meet the CCME limits at the 100 m mixing zone was back-calculated. The results for Scenarios A, B and C for parameters with CCME limits indicate that the receiving environment has substantial assimilative capacity. Thus, total nitrogen in the effluent discharged can reach 6,532 mg/L to 19,152 mg/L (depending on the scenario) to comply with the CCME limit. TSS can reach 731 mg/L to 2,139 mg/L and cadmium can reach 5.3 mg/L to 15.5 mg/L in the effluent discharged to comply with the CCME limits. Other parameters (temperature, pH, salinity and DO) also showed a similar pattern of compliance with the CCME limits at the end of the mixing zone.

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ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
AOX	Adsorbable Organic Halides
AST	Atlantic Standard Time
BOD	Biochemical Oxygen Demand
CCME	Canadian Council of Ministers of the Environment
CD	chart datum
CHS	Canadian Hydrographic Service
COD	Chemical Oxygen Demand
CORMIX	Cornell Mixing Zone Expert System
DFO	Fisheries and Oceans Canada
DO	Dissolved Oxygen
EARD	Environmental Assessment Registration Document
ECCC	Environment and Climate Change Canada
GD	geodetic datum
HD	Hydrodynamic module
HHWLT	higher high water large tide
LAT	lowest astronomical tide
LNT	lowest normal tide
LLWLT	lower low water large tide
MWL	mean water level
NAD	North American Datum
NPNS	Northern Pulp Nova Scotia
ppt	parts per thousand
psu	practical salinity unit
PT	Particle Tracking module
RWQO	Receiving Water Quality Objective
RWS	Receiving Water Study
TCU	True Colour Units
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorus
TS	Temperature/Salinity module
TSS	Total Suspended Solids
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
WQG	Water Quality Guideline

1.0 INTRODUCTION

1.1 PROJECT BACKGROUND

Northern Pulp Nova Scotia (NPNS)'s kraft mill located on Abercrombie Point near the town of New Glasgow, Nova Scotia has been in operation since 1967. The mill produces bleached kraft market pulp at a rate of 280,000 to 300,000 air-dry tonnes per year (ADt/y).

The mill's process effluent is treated currently in the wastewater treatment plant located in the western portion of an area known as Boat Harbour, about 3.5 km east of the mill across the East River. The treatment system consists of constructed sedimentation basins and an aerated stabilization basin equipped with baffle curtains. Effluent flows through the large Boat Harbour basin prior to release to the Northumberland Strait through a weir in Boat Harbour.

As a result of the *Boat Harbour Act* that came into effect on May 11, 2015, the use of the present Boat Harbour treatment facility will be prohibited after January 30, 2020. This will require the mill to install a new wastewater treatment plant, including a new effluent outfall.

An area offshore of Caribou Harbour and off Caribou Point in Northumberland Strait was identified as the outfall location. The pipeline route to this area would have both a land-based and marine-based path after leaving the mill site; into Pictou Harbour along the causeway, and then coming on land roughly following Highway 106 to the Caribou Ferry Terminal, and then in the vicinity of the terminal an outfall pipe would be extended parallel to the ferry route to a deeper water location.

Stantec Consulting Ltd. (Stantec) was retained by NPNS to conduct hydrodynamic modelling and a Receiving Water Study (RWS) in the vicinity of Caribou Harbour to investigate the dispersion characteristics of the treated effluent and address the environmental requirements of the new outfall discharge in the marine water offshore of Caribou Harbour. Hydrodynamic modelling and an investigation for the dispersion of the effluent plume were undertaken for this new outfall in Northumberland Strait off Caribou Point, with the 2018 RWS report submitted as Appendix E1 to the Environmental Assessment Registration Document (EARD) filed on February 7, 2019. A review of the EARD for the Replacement Effluent Treatment Facility Project (the Project), including the RWS report in Appendix E1, resulted in the issuance of Terms of Reference (TOR) by Nova Scotia Environment for the submission of a Focus Report. Section 4.2 of the TOR required an update to the RWS for the Focus Report with baseline water quality data collected for Caribou Harbour and additional information requirements noted in Addendum 3.0 of the TOR. This report addresses these TOR requirements to update the RWS.

1.2 OBJECTIVES

The key objective of the present receiving water study is to assess the effluent discharge at the selected outfall location CH-B with marine baseline data collected in the Caribou and Northumberland areas and the effluent dispersion characteristics in the local and regional areas that will meet the regulatory requirements. The specific work to achieve this objective includes:

- Conducting far-field hydrodynamic modelling using a MIKE 21 Coupled Model developed by the Danish Hydraulic Institute and provide local and regional effluent dispersion characteristics.
- Conducting near-field modelling and effluent mixing using a CORMIX (Cornell Mixing Zone Expert System) model to provide recommendations on preferred outfall design, including diffuser configuration and orientation, and to model water quality within the mixing zone.

1.3 STUDY AREA

The study area encompasses Caribou Harbour, Pictou Island, the Northumberland Strait and Pictou Harbour with complex ocean currents, tides, winds and waves. The study area (Figure 1), comprising an area 58.8 km x 42.5 km (Table 1), corresponds to the hydrodynamic model domain that was selected large enough to eliminate model boundary effects. The size of the study area was based on:

- The geographic extent of available bathymetry data sources;
- Location of available oceanographic information including the observed tides, currents, and winds; and
- The extent of potential hydrodynamic influences on hydrodynamics and effluent dispersion.

Table 1 Coordinates of the Study Area

Vertex	Coordinates (UTM NAD83 Zone 20)	
	Easting (m)	Northing (m)
Southwest (SW)	506200	5052000
Northwest (NW)	506200	5094500
Northeast (NE)	565000	5094500
Southeast (SE)	565000	5052000

Figure 1 Study Area and Location Map

2.0 FAR-FIELD MODELLING

2.1 METHOD AND AVAILABLE DATA

As part of the modelling work, a two-dimensional (2D) model was used to simulate far-field effluent dispersion at the selected discharge location CH-B and to provide indications of the potential cumulative effects on sensitive marine habitat and areas of important socio-economic value.

A recommended modelling practice for receiving water studies is to simulate the dispersion behavior in the coastal hydrodynamic environments using a combined modelling approach of a 2D coastal hydrodynamic model for far-field mixing and a CORMIX model for near-field mixing. Based on Stantec's experience associated with marine water quality modelling and Environmental Impact Assessment (EIA) studies, a suitable 2D modelling tool for meeting the objectives of this study is the MIKE 21 model, which is a globally recognized modelling tool for coastal and estuarine environmental processes.

2.1.1 MIKE 21 Coupled Model

The Danish Hydraulic Institute MIKE 21 Coupled Model was applied to simulate various aspects of the integrated hydrodynamic processes of tidal circulations, wind and air climates, wind waves, outfall discharge, and density currents to predict the changes of key water quality parameters for the marine water. The MIKE 21 Coupled Model consists of a Hydrodynamic (HD), a Temperature/Salinity (TS), a Spectra Wave (SW) and a Particle Tracking (PT) modules. Descriptions of these computational modules used in this study are provided below.

- The MIKE 21 Hydrodynamic (HD) Module — simulates unsteady flow taking into account density variations, bathymetry, and external forcings in rivers, lakes, estuaries and coastal areas. The model solves the continuity, momentum, temperature, salinity, and density equations. Water density varies with temperature and salinity. The HD Module is the basic computational component of the modelling system. The HD module was used to simulate reciprocal interactions among currents and effluent dispersion by coupling with the other modules.

- The MIKE 21 Temperature and Salinity (TS) Module — invoked in the HD Module via specification of the density. The TS module activates additional transport equations for temperature and salinity. The calculated temperature and salinity are fed back to the hydrodynamic equations through buoyancy forcing induced by density gradients.

- The SW Module — a third generation spectral wind-wave model that simulates the growth, decay, and transformation of wind-generated waves and swells in offshore and coastal areas. The model includes the following physical phenomena: wave growth by action of wind, non-linear wave-wave interaction, dissipation due to white-capping, dissipation due to bottom friction, dissipation due to breaking, refraction, and shoaling due to depth variation; and wave-current interaction.
- The MIKE 21 Particle Tracking (PT) Module — simulates transport and fate of dissolved and suspended substances.

The models are implemented using a flexible mesh (an unstructured triangular grid) that allows for different spatial resolution as needed. Generally, a flexible mesh system is generated with horizontal mesh sizes varying in size from hundreds of metres to metres, where finer resolution is used in the vicinity of project infrastructure, environmentally sensitive areas, and in areas required to represent the changes of nearshore bathymetry and shoreline topography.

The models are firstly calibrated using available physical oceanographic data (e.g., waves, water levels, currents, water temperature, salinity) from historical observations and Project field surveys in the study area, and then applied to Project exercises for defined modeling scenarios. Key objectives of this 2D modelling include:

- to understand the hydrodynamics and current circulation patterns in the study area;
- to characterize the dispersion patterns, extent and dilution factors of the discharged effluent; and
- to provide hydrodynamic information required for CORMIX near-field dispersion modelling.

2.1.2 Physical Oceanography

2.1.2.1 Data Sources

The physical oceanographic and hydrometric data were collected and compiled to develop parameters for defining the model domain and boundary conditions of the hydrodynamic model. The data sources consist of public open sources, the previous and 2019 Project field surveys/measurements, and the relevant Project environmental studies and engineering designs. Table 2 and Figure 1 Study Area and Location Map provide a summary of the available data and information collected, including the 2019 field program.

Table 2 Available Data Sources

Parameter	Data Sources
Seabed bathymetry	• Canadian Hydrographic Service (CHS) bathymetric survey in 2015 – 2016 (provided by CHS) • CHS nautical charts (4404, 4437, 4443 and 4445) • Caribou Harbour bathymetric survey in June 2019 (along navigation channel) by CSR GeoSurveys Ltd. (CSR) • LiDAR 2016 data from CHS that covers the shoreline topography and near-shore bathymetry in the surrounding area of Caribou Harbour • Boat Harbour bathymetric survey conducted in 2006 by CSR • Bathymetric and topographic survey in the East River conducted in 2009 by CSR
Tide and Water Level	• DFO Canadian Tides and Water Levels Data Archive (DFO no date (n.d.)) • NPNS Project field measurements at ADCP, Skinner and Arisaig stations in Figure 1 (conducted from May 24 to June 28, 2019 by Stantec)
Water Current and Wave	• NPNS Project field measurements at ADCP station in Figure 1 (conducted from May 24 to June 28, 2019 by Stantec)
Wind and Air Temperature	• Environment and Climate Change Canada (ECCC) Climate Archive for station Caribou Point (AUT), NS
Marine Water Temperature and Salinity	• NPNS Project field measurements in and offshore Caribou Harbour (conducted by Stantec in May and June 2019) • DFO Ocean Data Inventory database outside Caribou (DFO ODI, n.d.) • Previous studies (ENSR, 1999)
East River Discharge	• Previous studies (ENSR, 1999)
Sea Ice	• DFO Gulf 2013 Ice Survey

The modelling was conducted in a time domain using time-series records with overlapping periods of time to meet the model requirements. In this study, the datum and time references were standardized for consistency as follows:

- The horizontal datum refers to North America Datum of 1983 (NAD83) UTM Zone 20, and the vertical datum refers to the mean water level (MWL) at Pictou Harbour, NS.
- The units are in metres, and the time refers to Atlantic Standard Time (AST).

2.1.2.2 Bathymetry

The seabed elevations for the study area were obtained from various data sources as summarized in Table 2. A combined bathymetry was developed for use for the present hydrodynamic modelling study. The horizontal resolutions of the bathymetric data sets are 2 m in the Caribou navigation channel (2019 sounding survey), 5 m along the shorelines of Caribou Harbour (LiDAR that covers the shoreline topography and near-shore bathymetry to about 6 m water depth), 5 m to 10 m in Pictou Harbour and Pictou Road areas, and 50 m in offshore waters in the Northumberland Strait.

Figure 2 presents the extent of bathymetry information used in the model which includes all the available bathymetric surveys, LiDAR and nautical charts.

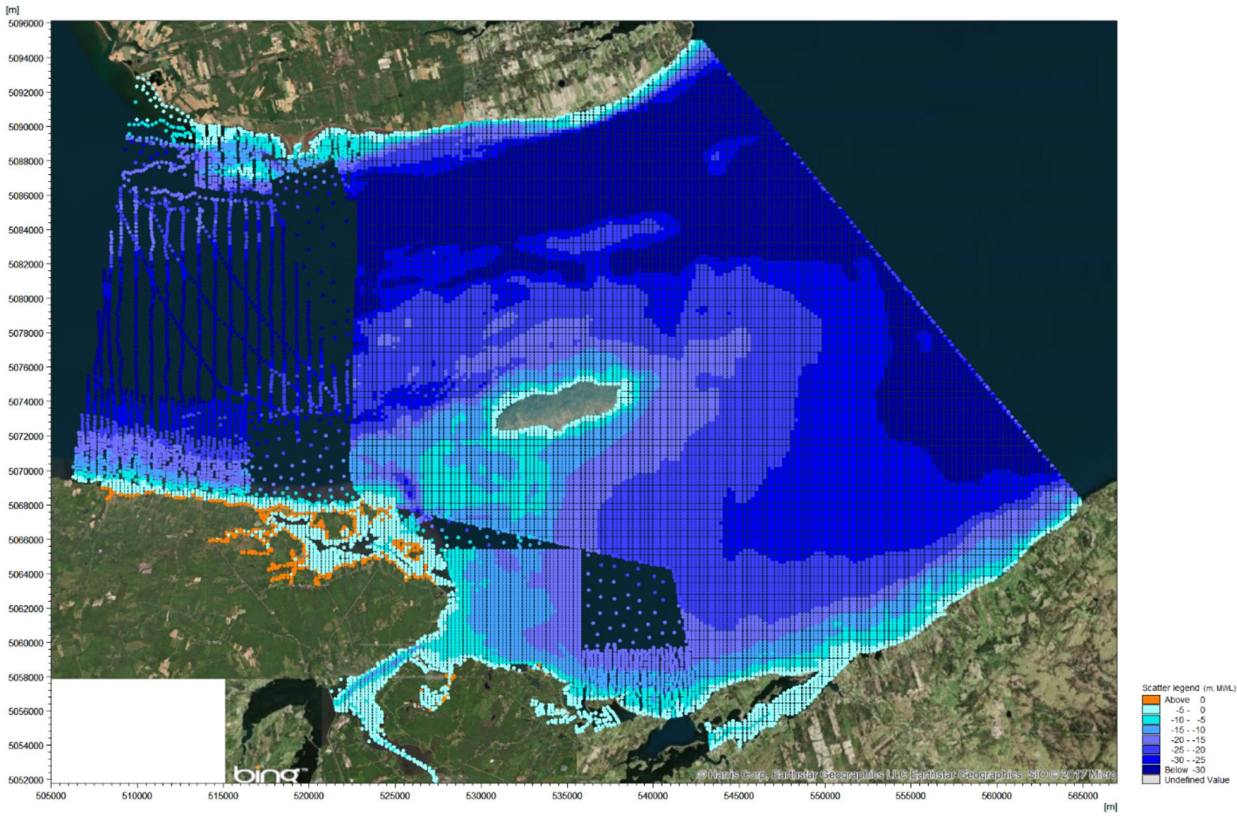


Figure 2   Available Bathymetric Data and Extent Covering the Study Area

2.1.2.3 Water Levels and Tide Constituents

Tides in the Pictou Harbour area are mixed by two dominant tidal components; a semi-diurnal (twice daily) component and a diurnal (daily) component (ENSR, 1999). The combination of semi-diurnal and diurnal tidal components results in the "mixed" tides in which relatively larger and smaller tides occur alternatively over time with successive highs and lows of unequal heights. The tides also have a bi-weekly spring-neap tide cycle in which the spring tidal ranges are about double those of neap tides.

Water levels due to astronomical tides are available from the Canadian Hydrographic Service (CHS), Fisheries and Ocean Canada (DFO). The tidal levels at Pictou Harbour are summarized in Table 3. The tidal range is 2.11 m between the Highest Astronomical Tide (HAT) and the Lowest Astronomical Tide (LAT). Chart Datum (CD), defined as the Lowest Normal Tide (LNT), is 1.19 m below the Mean Water Level (MWL).

The CHS maintains tidal stations and publishes historical water-level measurements (DFO website http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/twl-mne/inventory-inventaire/index-eng.htm). Table 4 presents the available tidal data at the CHS stations located within the Project study area. The data were used as reference information for tidal analysis and prediction of tidal levels.

As part of the Project field survey programs conducted in May and June 2019, two water level gauges were deployed at Skinner Cove and Arisaig (Figure 1) to collect the water level variations at the model west and east boundaries, respectively. One bottom-mounted Acoustic Doppler Current Profiler (ADCP) was deployed offshore Caribou Harbour in the Northumberland Strait (Figure 1) to measure the water level, current, wave and water temperature in the vicinity of outfall location CH-B. The station information and measured data records are shown in Table 5.

Table 3 Tide Levels at Pictou Harbour

Tides	Water Level above Chart Datum (m, CD)	Water Level above Mean Water Level (m, MWL)
Highest Astronomical Tide (HAT)	2.10	0.91
Higher High Water, Large Tide (HHWLT)	2.06	0.87
Higher High Water, Mean Tide (HHWMT)	1.72	0.53
Mean Water Level (MWL)	1.19	0.00
Lower Low Water, Mean Tide (LLWMT)	0.50	-0.69
Lower Low Water, Large Tide (LLWLT)	0.06	-1.13
Lowest Astronomical Tide (LAT)	-0.01	-1.20

Table 4 CHS Stations and Available Tidal Records in the Study Area

Station Name	Station #	Coordinates		Available Data Records
		Easting (m)	Northing (m)	
Pictou Harbour, NS	1630	523361.00	5058908.00	1957/01/01 to 1996/03/11
Wood Islands, PEI	1680	519375.51	5088522.56	2004/03/ 01 to 2006/12/31

Table 5 Water Level Measurements in the 2019 Field Program

Station Name	Coordinates		Available Data Records
	Easting (m)	Northing (m)	
Skinner	496509	5071198	2019/05/24 to 2019/06/05
Arisaig	564456	5067627	2019/05/24 to 2019/06/27
ADCP	526402	5067601	2019/05/24 to 2019/06/27

To provide appropriate tide level prediction at the model offshore boundaries in the Northumberland Strait, a tidal constituent analysis was conducted. This analysis was based on the water level measurements at Skinner and Arisaig stations that contains data for 12 days and 34 days respectively. As the measured raw data were scattered with measuring noises, the data sets were smoothed for use of constituent analysis. The analyzed major tide constituents are listed in Table 6; accuracy of the values depend mainly on the quality of the measured data and the duration of data records. The constituents are used for the prediction of tidal levels at offshore boundaries in the following hydrodynamic modelling for simulation time that is beyond the field measurement period.

Verification plots of measured versus predicted water levels are presented in Figure 3. Good agreement between the measured and predicted water levels are achieved in terms of both the magnitude and phase of tidal cycles including all the spring and neap tides.

Table 6 Analyzed Tide Constituents at Skinner and Arisaig Stations

Constituents	Skinner		Arisaig	
	Amplitude (m)	Phase (deg.)	Amplitude (m)	Phase (deg.)
M2	0.5784	-23.82	0.3549	-52.42
S2	0.1134	38.37	0.0909	-10.13
K1	0.2042	-86.33	0.1898	-82.61
O1	0.2228	-102.3	0.1965	-110.68
F4	0.0717	179.78	0.1197	93.38
F6	0.0554	-86.55	0.0913	-58.24

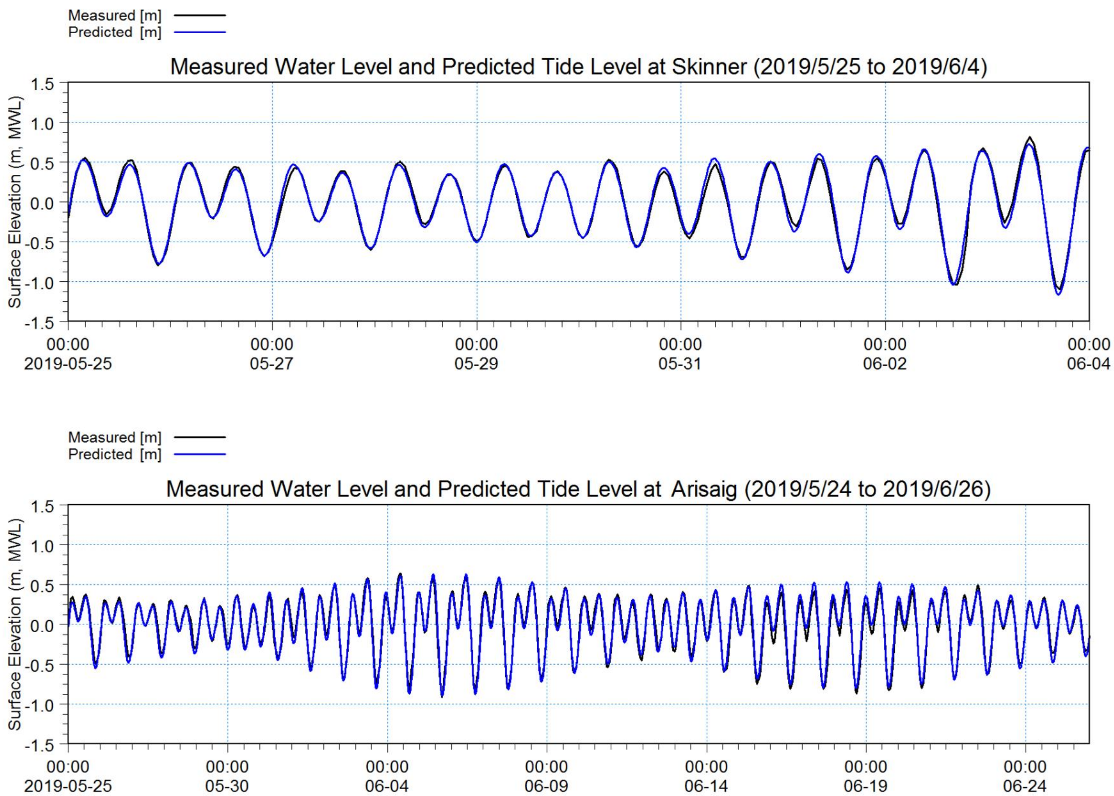


Figure 3 Comparison of Measured and Predicted Water Levels at Skinner and Arisaig

2.1.2.4 Climate

Climate data near the Project site were available from the National Climate Data and Information Archive, Environment and Climate Change Canada (ECCC). The Caribou Point (AUT) climate station of ECCC is located approximately 2.8 km north of Caribou Harbour (Figure 1) with the available data records shown in Table 7.

The hourly wind rose plot within the record period from 1994 to 2016 is presented in Figure 4, which indicates that the wind climate in the study area is dominated by winds from the northwest and west. The recorded maximum wind speed was 95 km/hr (26.4 m/s) on March 7, 1997, with a wind direction from the northwest (320°). Year-round wind variations are typically stormy during the winter season and calm during the summer season.

Figure 5 illustrates the time series of measured hourly wind, air temperature and relative humidity from the climate station for a period from January to July 2019. These data sets are used as domain wind and air heat forcings for model calibration and model runs.

Table 7 Environment and Climate Change Canada Climate Station at Caribou Point, NS

Station Name	Station #	Coordinates		Available Data Records (hourly)
		Easting (m)	Northing (m)	
Caribou Point (AUT)	8200774	524623.09	5068171.84	from 1994/01 to 2019/08

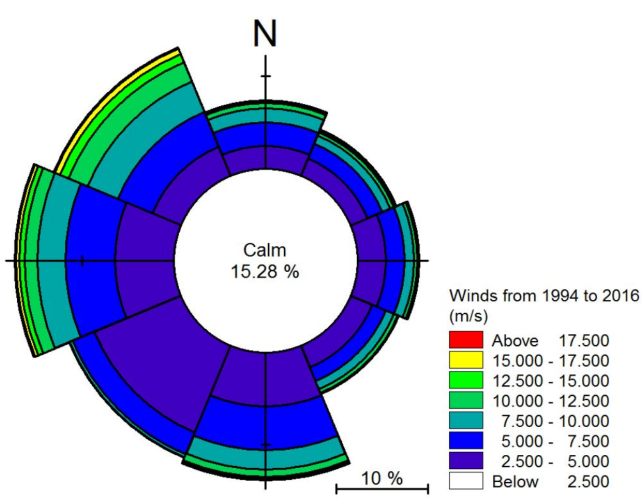


Figure 4 Wind Rose Plot at Caribou Point for a Period from 1994/01 to 2016/12

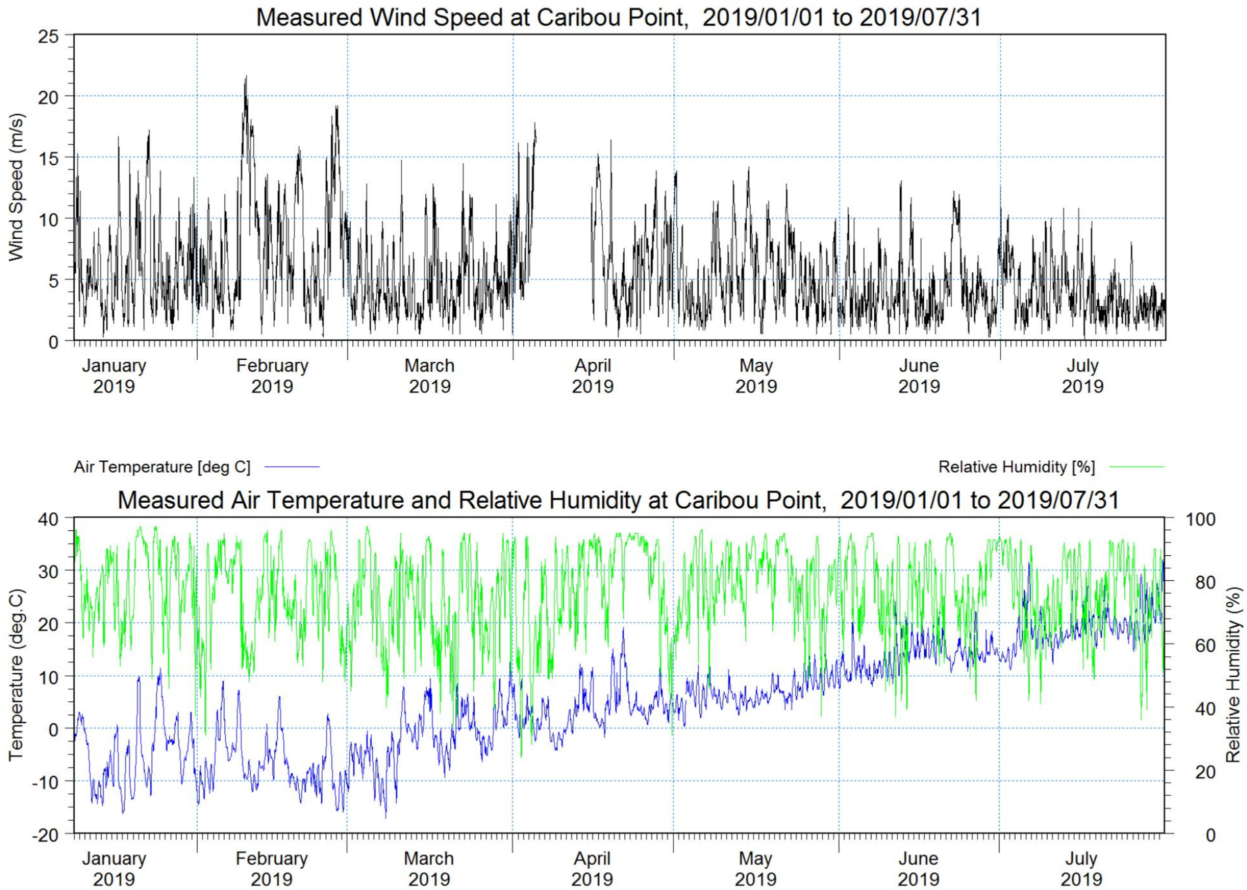


Figure 5 Measured Hourly Wind, Air Temperature and Relative Humidity at Caribou Point from 2019/01 to 2019/07

2.1.2.5 Currents and Waves

Site-specific water current, wave and marine water quality data were collected from the NPNS Project field program in May and June 2019.

Vessel-mounted ADCP

Current transects were measured for the water column using a vessel-mounted ADCP, including a transect during the flood tide on May 24, 2019 and a transect during the ebb tide on May 25, 2019. Figure 6 illustrates the start and end points of transect profiles.

Figure 7 provides the measured current transect profiles in the vicinity of outfall location CH-B during the flood tide on May 24, 2019. The current profiles for the water column at locations of 250 m inshore from CH-B, approximately at CH-B, and 250 m offshore from CH-B (Figure 8) indicate that:

- Velocity profiles show weak stratification from near the water surface to seabed. At the CH-B location, for instance, the velocities over the water column are within a range from 0.35 m/s to 0.65 m/s.
- Direction profiles show homogeneous distribution from near the water surface to seabed. The current directions are predominantly towards the northwest over the entire profile.

Figure 9 presents the measured current transect profiles during the ebb tide on May 25, 2019. The current profiles of the water column at locations of 250 m inshore from CH-B, approximately at CH-B, and 250 m offshore from CH-B (Figure 10) indicate that:

- Velocity profiles show weak stratification from near the water surface to seabed. At the CH-B location, for instance, the velocities over the water column are within a range from 0.55 m/s to 0.85 m/s.
- Direction profiles show homogeneous distribution from near the water surface to seabed. The current directions are predominantly towards the south-southeast over the entire profile.

Bottom-mounted ADCP

A bottom-mounted ADCP was moored approximately 490 m northwest of CH-B (see Figure 1) to measure the time-series variations of currents and waves for a period from May 24 to June 27, 2019. These data sets were used for calibrating the hydrodynamic model in the following model calibration sections.

A close-up of time-series measurements over a 48-hr period at this ADCP station in Figure 11 also illustrates the weak stratification of current velocities and directions in the water column, including the change in the direction of currents associated with the tides approximately every 6 hours (lower panel in Figure 11).

Figure 6 ADCP Transect Start and End Points Surveyed in May 2019

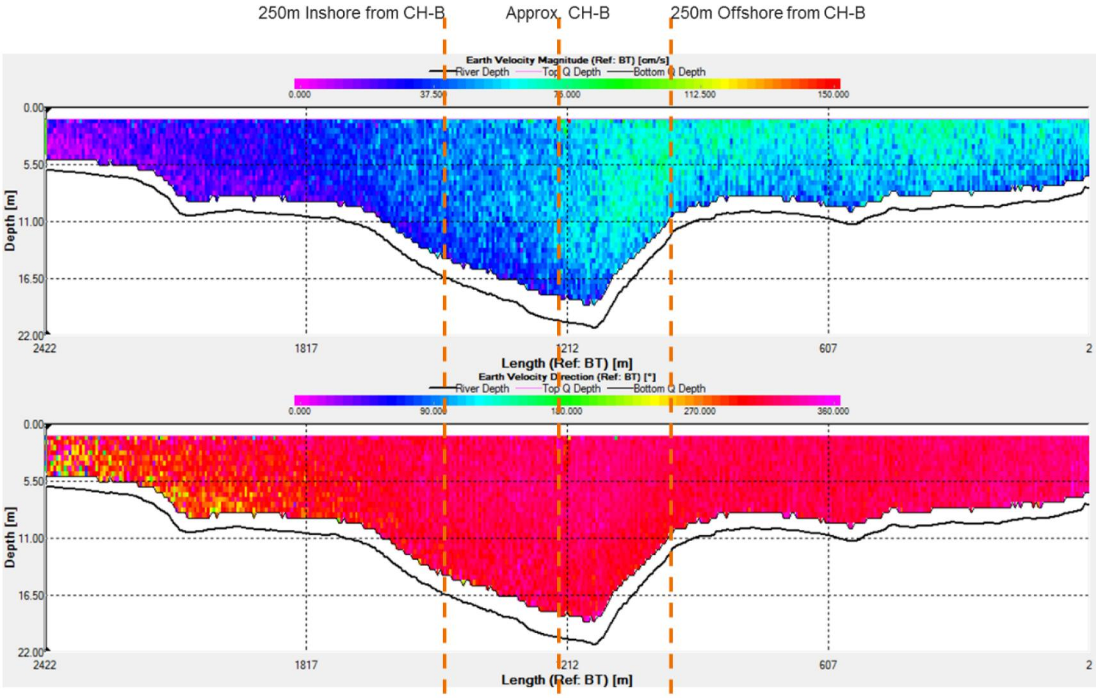


Figure 7 **Transect Profiles of Current Magnitude (upper panel) and Direction (lower panel), during the Flood Tide on May 24, 2019**

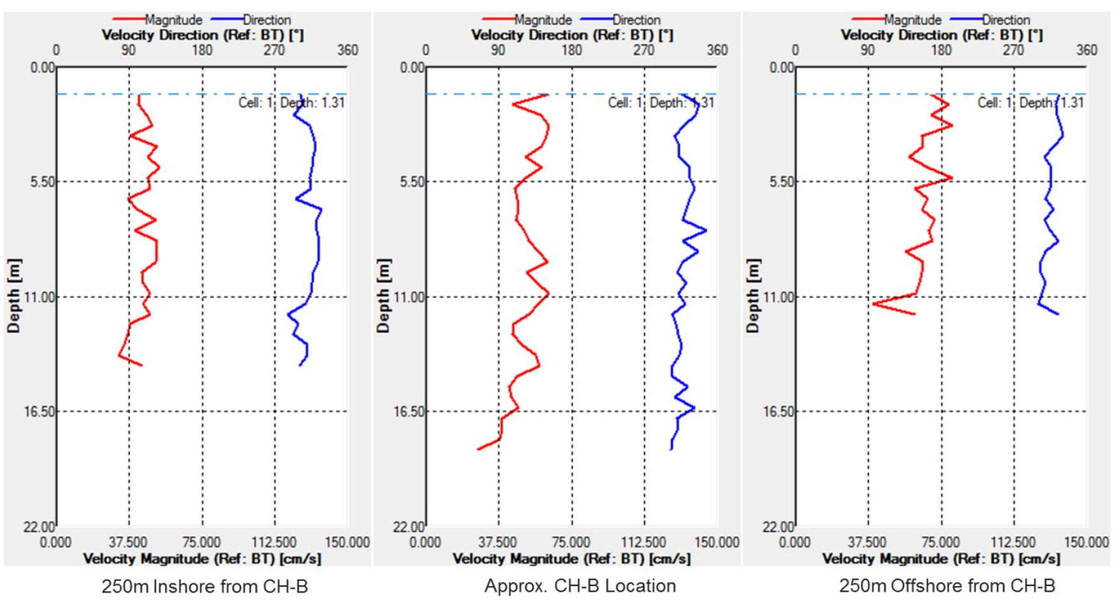


Figure 8 **Current Profiles of the Water Column during the Flood Tide on May 24, 2019**

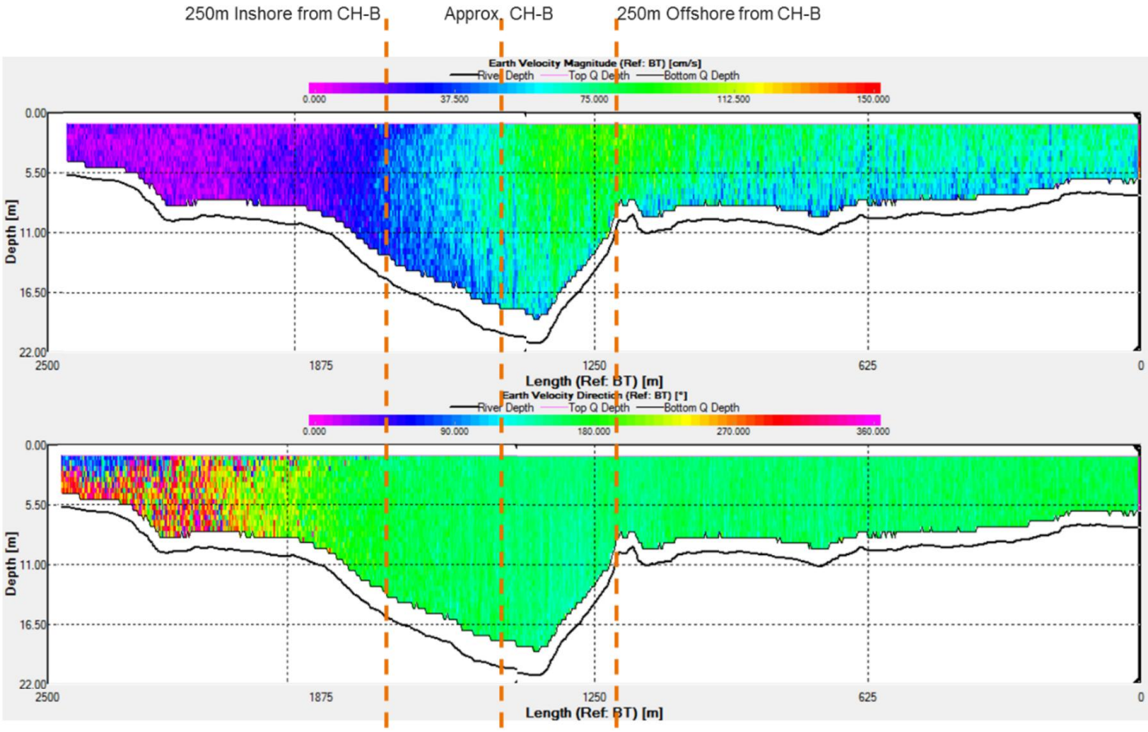


Figure 9 Transect Profiles of Current Magnitude (upper panel) and Direction (lower panel), during the Ebb Tide on May 25, 2019

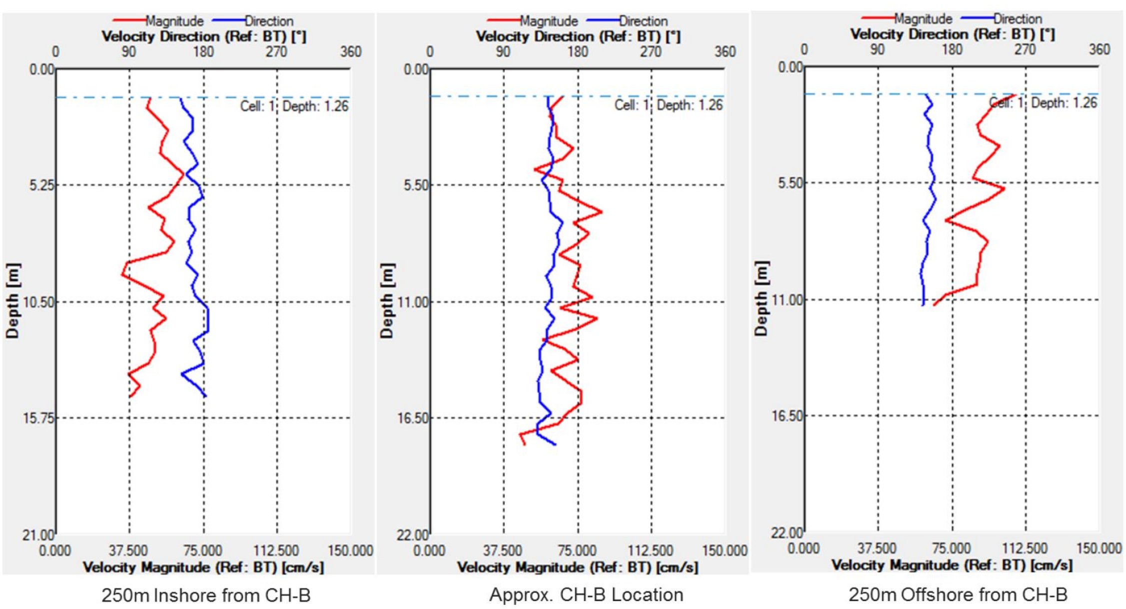


Figure 10 Current Profiles of the Water Column during the Ebb Tide on May 25, 2019

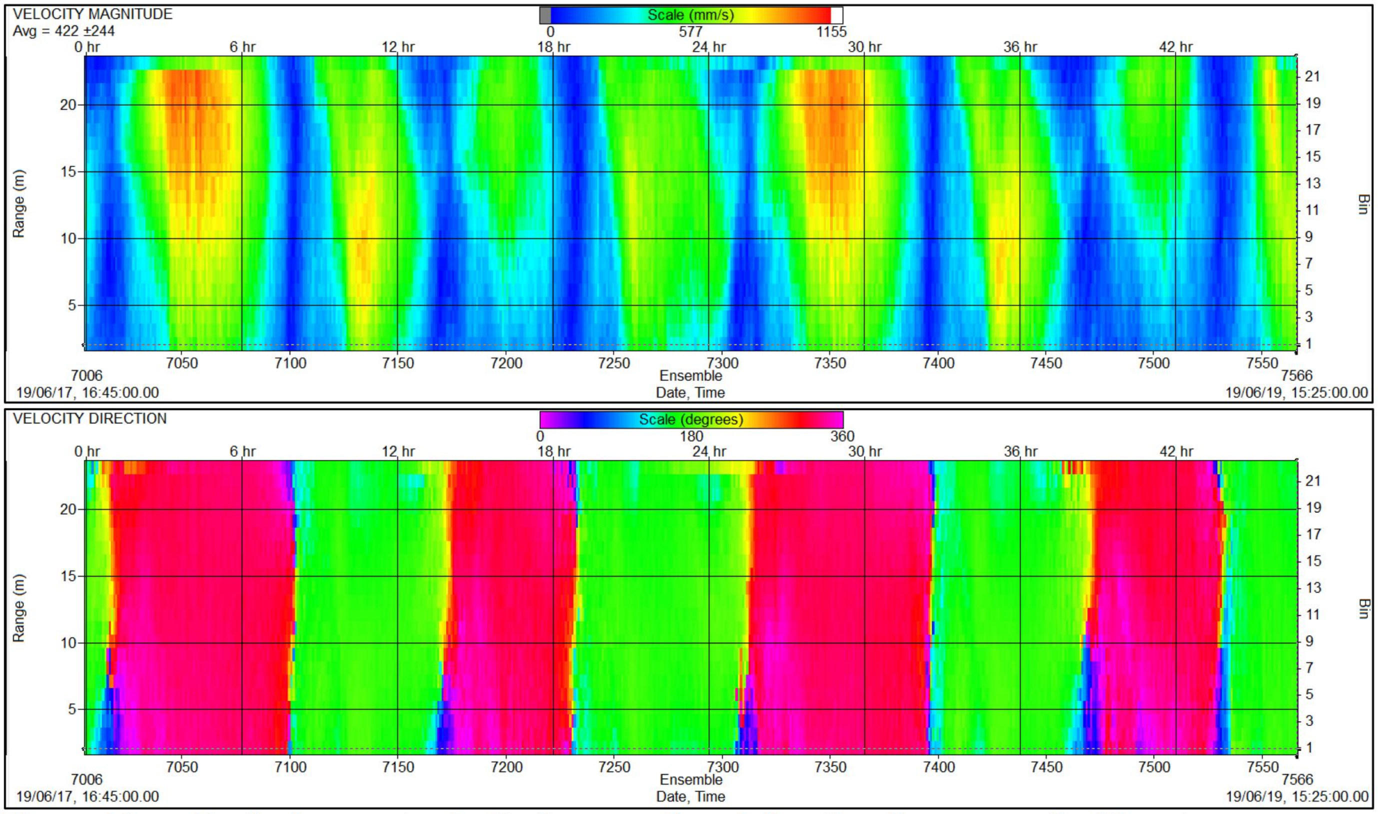


Figure 11 **Vertical current velocity (top panel) and direction (lower panel) with water depth at the ADCP station over a 48-hr period in June 2019 showing weakly stratified conditions from near-surface to near-bottom of the water column (Bin 1 is towards the ADCP instrument on the bottom and Range is from the seabed).**

2.1.2.6 Water Temperature and Salinity

Project Field Survey

During the 2019 Project field program, temperature and salinity profiles of the water column were measured in the vicinity of outfall CH-B during flood and tides on May 24 and May 25. Figure 12 is a location map of the surveyed profiles (P).

Figure 13 illustrates the measured temperature profiles for both the downcast and upcast of the instrument through the water column in the vicinity of outfall CH-B during the flood tide on May 24 (Profile 1, Profile 2 and Profile 3) and May 25 (Profile 4), as well as during the ebb tide on May 25 (Profile 11). It is observed that:

- Temperature difference between water surface and seabed is less than 0.5˚C.
- Temperature profiles show weak stratification from water surface to seabed.

Figure 14 similarly presents the measured salinity profiles during the flood tide on May 24 (Profile 1, Profile 2 and Profile 3) and May 25 (Profile 4), as well as during the ebb tide on May 25 (Profile 11). It is observed that:

- Salinity difference between water surface and seabed is less than 0.5 parts per thousand (ppt).
- Salinity profiles show weak stratification from the water surface to seabed.

Vertical profiles for temperature and salinity were also measured in the water column in the area of the CH-B outfall during an ebb tide on June 28, 2019. Temperature and salinity were relatively homogenous throughout the water column, ranging from 12.6˚C to 12.9˚C and 28.8 to 29.0 ppt, respectively.

The bottom-mounted ADCP also had a temperature sensor to measure the time-series variations of water temperature near the seabed from May 24 to June 27, 2019. This data set was used to calibrate the hydrodynamic model.

Together with the water level gauge deployments at Skinner and Airsaig in May and June 2019, water temperature was also recorded at these two stations with available records from May 25 to June 5 for Skinner and from May 25 to June 27 for Arisaig (Figure 15). These data sets were used to define the temperature boundary conditions for model calibration.

DFO Historical Data

DFO Ocean Data Inventory database (DFO n.d.) maintains historical measurements on marine water temperature at offshore Caribou Point (Easting 525658 m, Northing 5068546 m). This station contains monthly temperature records from 2007 to 2011 at a water depth of 9 m, which is about mid-depth at the site. The statistics of minimum, maximum and mean values are shown in Figure 16, with data gaps in February and Mach. This data set was referenced as the seasonal temperature variations for setting up the model domain and boundary conditions for marine water temperature.

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Disclaimer: The map is for illustrative purposes to support this Stantec project; questions can be directed to the issuing agency.

Figure 12 Water Quality Survey in May 2019 at the Outfall Location

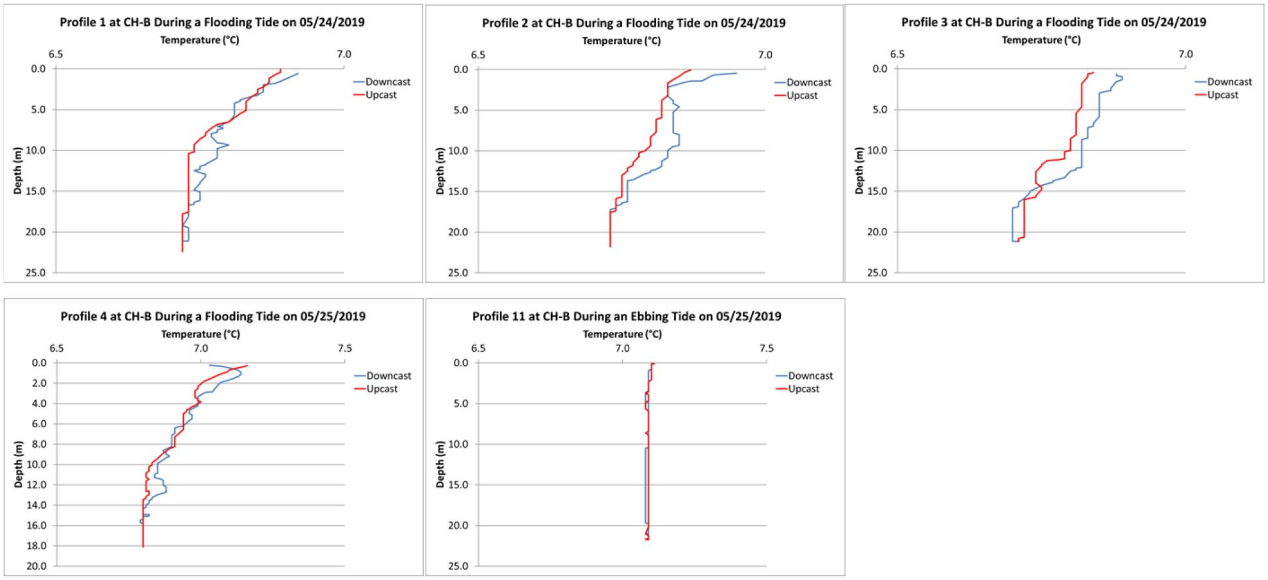


Figure 13 Temperature Profiles of the Water Column during Flood and Ebb Tides Measured in May 2019

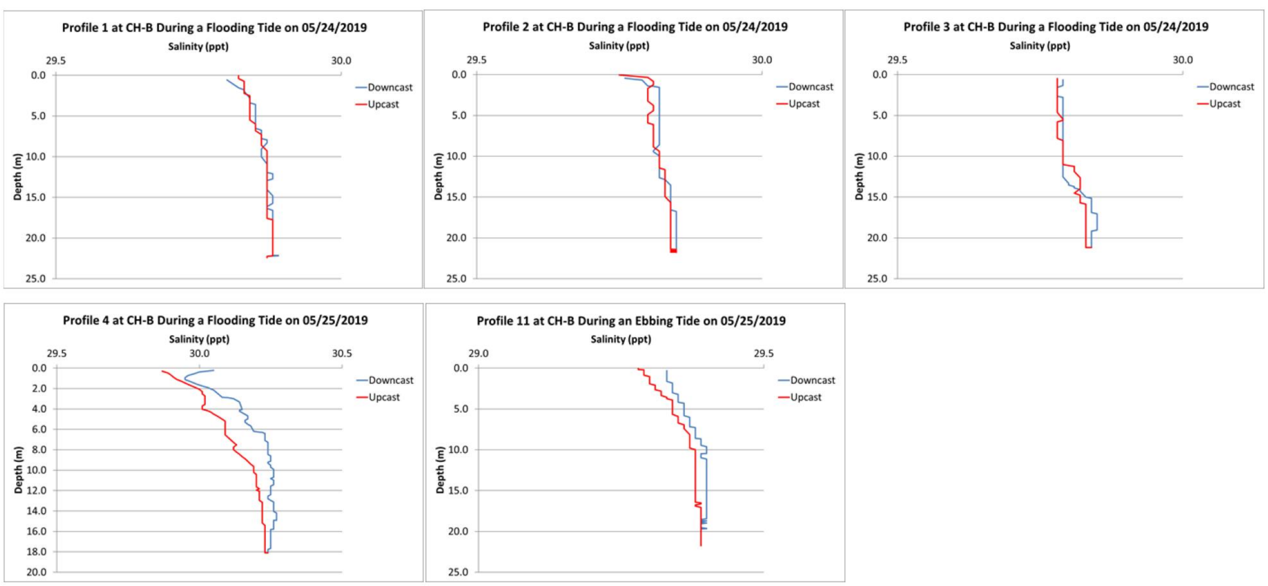


Figure 14 Salinity Profiles of the Water Column during Flood and Ebb Tides Measured in May 2019

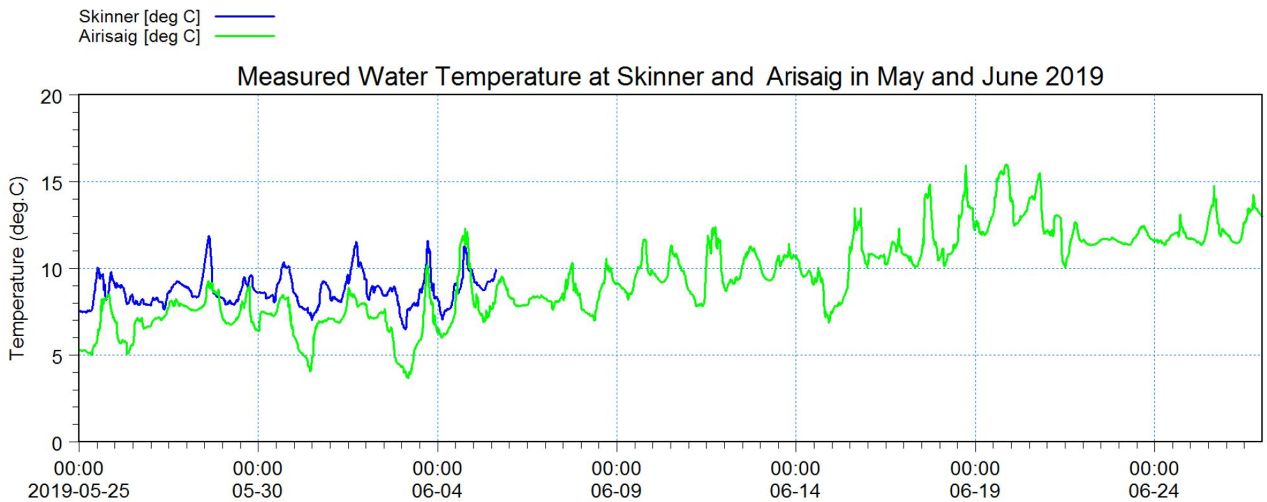


Figure 15 Field Measurement of Water Temperature at Skinner and Arisaig

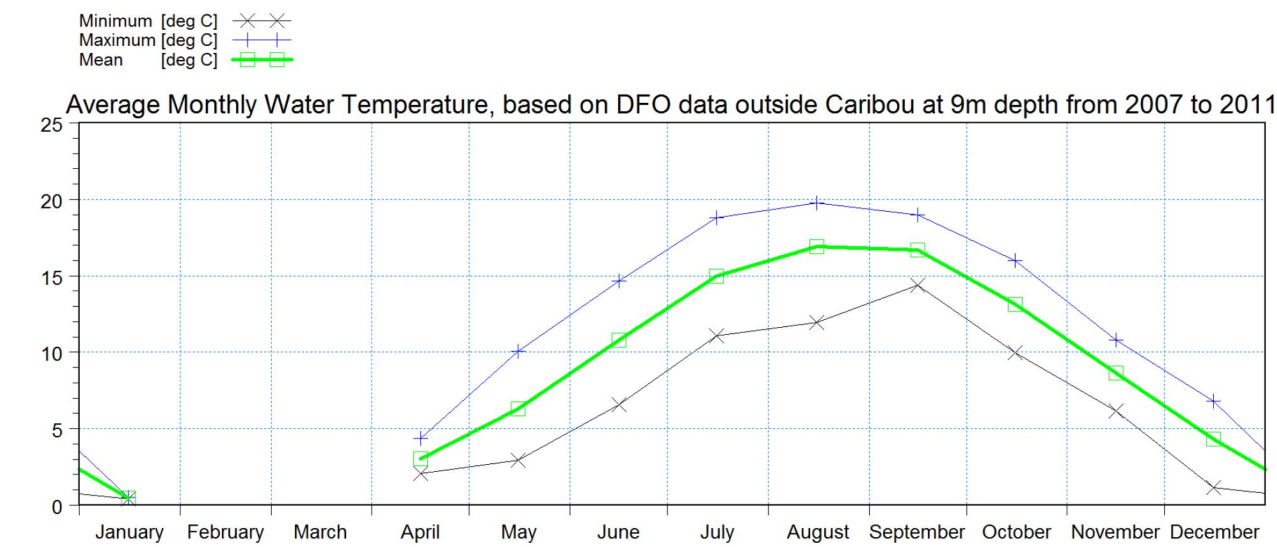
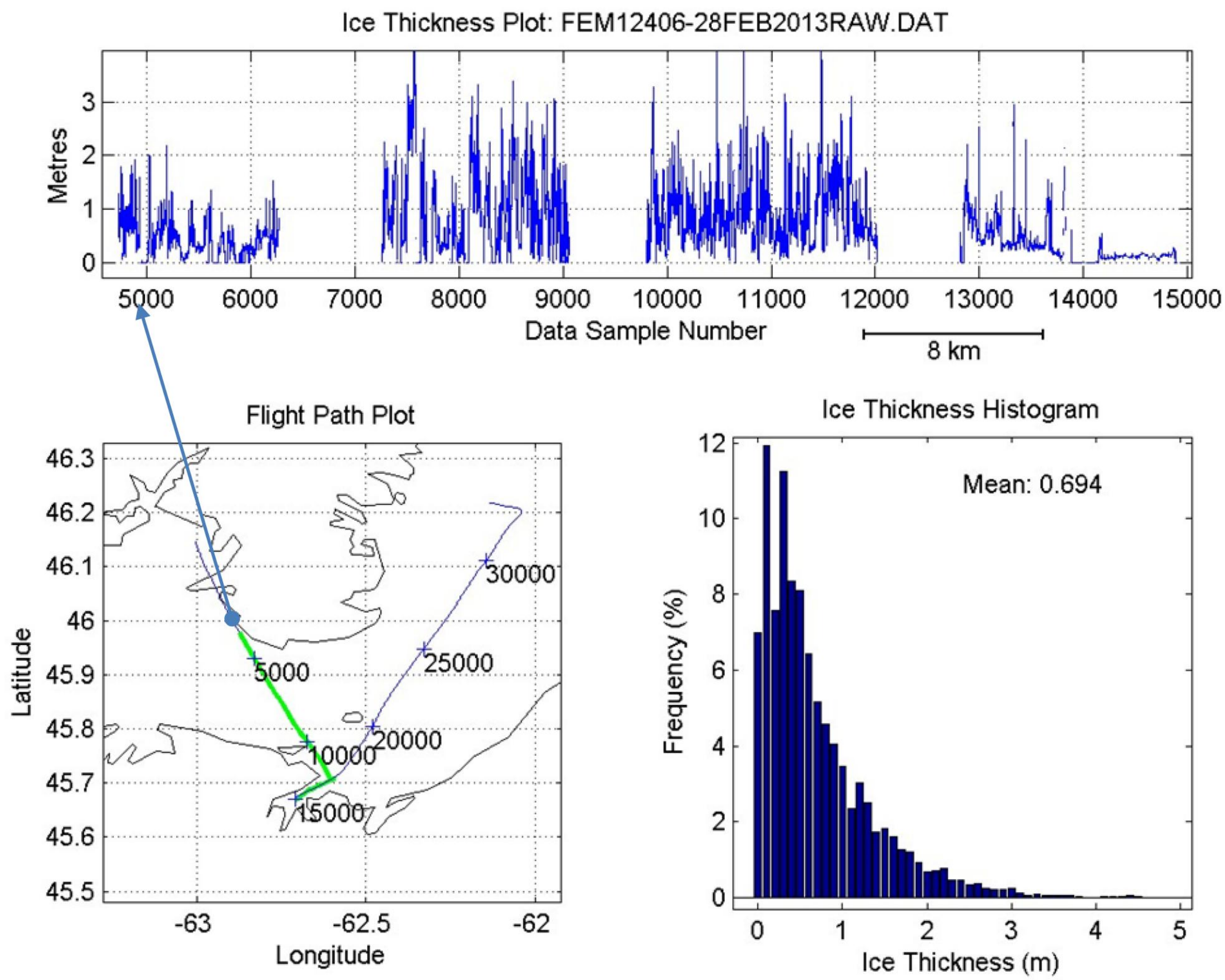


Figure 16 Measured Marine Water Temperature at DFO Station Offshore Caribou Point

2.1.2.7 Sea Ice

The marine waters of Caribou Harbour and Northumberland Strait are covered by sea ice during the winter seasons. Sea Ice Climate Altas, published by the Canadian Ice Service for a climatological time period of 30 years from 1981 to 2010, indicates that the marine waters freeze up in December and break up in April.

DFO conducted a helicopter ice survey from the Northumberland Strait into Pictou Harbour on February 28, 2013; the mean ice thickness offshore Caribou Harbour was approximately 0.7 m (Figure 17).



Source: DFO Helicopter Ice thickness survey into Pictou Harbour (ftp://starfish.mar.dfo-mpo.gc.ca/pub/ocean/seaice/Helicopter_Data/Gulf2013/7%20Gulf%202013%20Pictou%20large%20floe/)

Figure 17 Surveyed Ice Thickness in the Northumberland Strait on February 28, 2013

2.2 MODEL SETUP AND CALIBRATION

2.2.1 Approach and Model Setup

Water levels, currents, waves, and temperature and salinity with environmental forcings of tides, winds, and air heat in the model domain of the study area were simulated using the integrated MIKE 21 hydrodynamic model. This 2D model was appropriate for the study area based on weakly stratified currents and water column properties as note in Section 2.1.2. A model mesh system was developed using a range of mesh sizes, varying from coarse mesh offshore to fine resolution of elements in the vicinity of the outfall discharge. The model was calibrated using the Project field measurements collected in 2019 to allow for appropriate offshore boundary conditions and domain forcings, which established the modelling basis and investigation of the effluent transport for the outfall discharge from the CH-B location. The model setup and calibration were implemented as following:

- Model setup, which involves defining model domain, generating computational element meshes, and specifying model parameters and boundary conditions.
- Coupling HD, TS, and SW modules in the hydrodynamic model for selected calibration scenarios. A coupled hydrodynamic model was developed to simulate the physical oceanographic conditions under the complex forcings of tide, current, wind, wave, air heat, and water temperature and salinity.
- Model calibration, which involves calibrating key parameters through a series of model runs to reproduce historical events and to compare the model results with the measured water levels, waves, currents, and water temperature.

Figure 1 illustrates the defined model domain, which covers 58.8 km along the east-west axis and 42.5 km along the north-south axis, including Caribou Harbour, the Northumberland Strait, Pictou Island and Pictou Harbour. A well-structured model bathymetry and generated mesh system is essential for obtaining reliable modelling results, especially in the shallower waters near the coast and in the outfall discharge areas. The elevation scatter points from the field bathymetric surveys, nearshore LiDAR, CHS digital charts, together with a high-resolution aerial photo, were used to develop the seabed bathymetry and shoreline features.

Figure 18 presents the generated flexible mesh system (which contains 14,771 nodes and 27,731 elements) and seabed bathymetry contours. The mesh density of the computational domain generally increases from offshore to near-shore, and finer mesh was produced in the areas surrounding the outfall location, harbour, channels, and shorelines. The computational mesh was derived through an iterative process of refining and smoothing the mesh density to ensure proper model convergence and accuracy of the numerical solution over a full range of water levels, waves and ocean currents.

The model domain was established with the following open boundaries:

- Coastal Shoreline Boundary - the shoreline boundary was defined as solid, with no water current transmission.

- Offshore the Northumberland Strait Boundaries - these boundaries were set to allow for sufficient space for water current circulation and wave growth in the Northumberland Strait water bodies. The boundary conditions were predicted tide levels, and the water temperature and salinity assumed were based on the Project field surveys and a literature review. All these parameters were applied as constant values along the model boundary and varied in time.

Forcings over the model domain are defined as follows:

- Wind forcing - hourly wind records (wind speed and direction) at the ECCC Caribou Point (AUT) station were used. Wind parameters were applied as constant values in the domain and varied in time.
- Air heat on water surface - hourly air temperature and relative humidity records at the ECCC Caribou Point (AUT) station were used to simulate heat exchange between air and water body. Air temperature and humidity were applied as constants in the domain and varied in time. The heat exchange modelling also requires input data of air clearness. As the clearness data are not available from the climate station, it was assumed as a constant value in domain and in time.
- Bed resistance - Manning's roughness, related to seabed roughness, is applied and varied in the domain. The roughness was a calibration parameter.
- Water density - water density is applied as a function of temperature and salinity and calculated in the Temperature/Salinity (TS) Module, varying in time and domain.
- Coriolis forcing - Coriolis forcing is included in the modelling and varied in the domain.

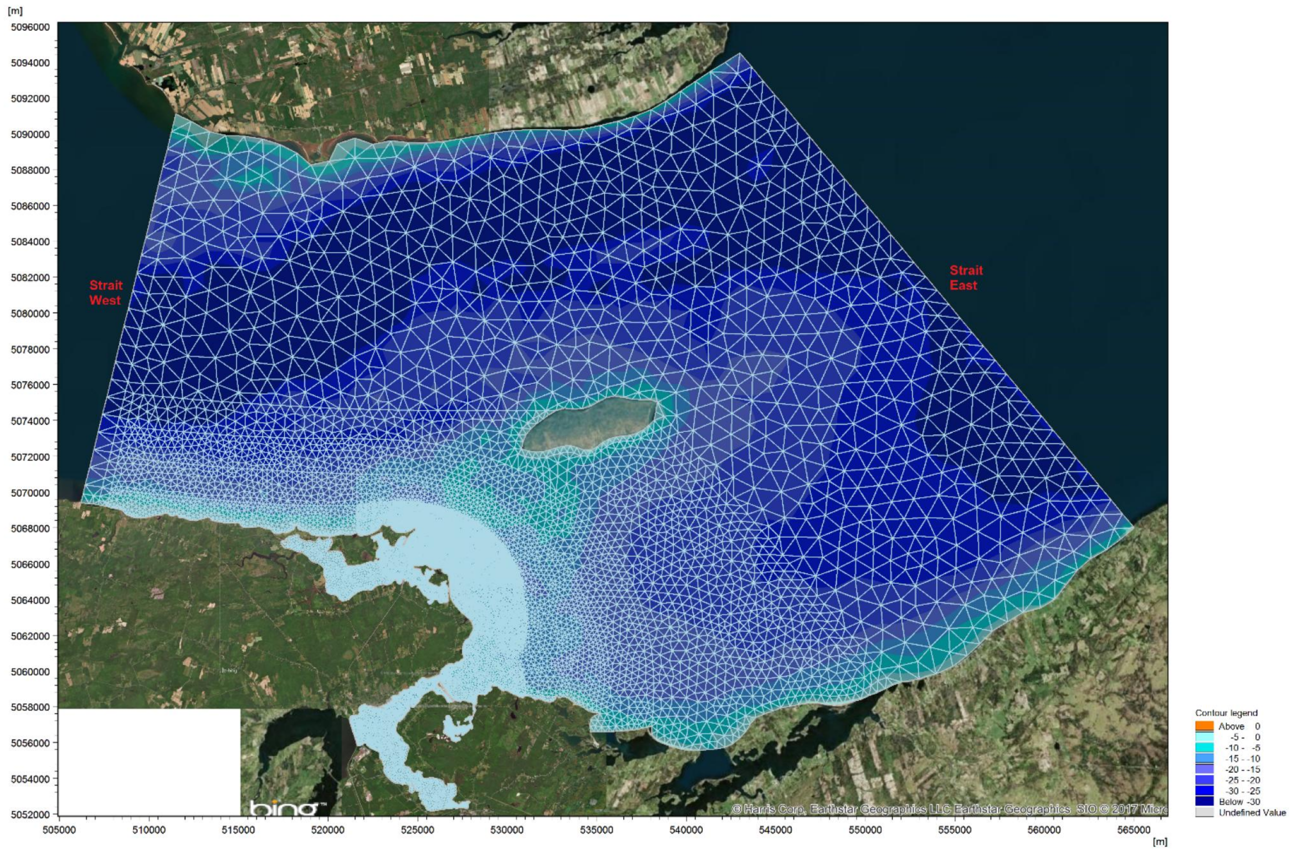


Figure 18 Computational Domain, Mesh System, and Boundaries

2.2.2 Model Calibration

The key hydrodynamic components required for calibration are tidal levels, currents and waves. The MIKE 21 Coupled Model was calibrated using the available field measurements from 2019, as described in Section 2.1.2.1. The approach for calibrating the HD and SW coupled model was a stepwise process as follows:

- Waves were calibrated in the SW wave module. The SW model simulates wind generated waves, which were compared with the measured waves at the ADCP station.
- Currents were calibrated in the HD module using the field measurements at the ADCP station.
- Model parameters, including simulation time steps, solution convergence criteria, bed roughness, and dry/wet depth, were adjusted to improve model performance and predictions.

Model calibration was conducted for a simulation period of one-month from 2019/05/25 to 2019/06/26, of which the first one day was to establish initial conditions in the model domain. The model calibration scenario was selected based on considerations of the available data sources that have overlapped period of time and minimum data gaps. The calibration used model sensitivity test runs and adjusted model parameters until the modelling results achieved good agreement with the measured records.

2.2.2.1 Spectral Wave Model

The MIKE 21 SW model simulates wind-driven waves and the process of wave generation, growth, propagation, and transformation. The wave model was conducted using the hourly winds measured at the ECCC Caribou Point station (Figure 5); the wind speeds demonstrated significant seasonal variations corresponding to calm in summer and stormy in winter. During the simulation period of the calibration scenario, there were several events that had wind speed larger than 10 m/s, and the wind speeds ranged from 0.56 to 13.06 m/s, with a mean speed 4.23 m/s. The prevailing winds were from the northwest.

Verification plots of measured versus simulated wave heights are presented in Figure 19. Responding to wind forcing in the domain, the simulated wind-driven waves reproduced the measured stormy and calm conditions well in terms of magnitude and timing of peaks. Statistics of the measured and simulated wave heights are summarized in Table 8, and show good agreement.

The following parameters were calibrated in the SW module:

- Sensitivity of simulation time steps. The time step was tested in the range from 15 to 180 seconds to investigate its effect on model convergence, stability and computing time. A smaller time step requires less iterations at each time step but increases computing time over the whole simulation period. A time step of 60 seconds was adopted in this study.
- No adjustments were applied to the originally recorded wind speed and direction.
- Adjustment of bottom friction. Increase of the bottom friction coefficient usually leads to increased energy dissipation and thus decreased wave heights. Bottom friction in the wave model was defined using a Nikuradse roughness (kn) and the calibrated roughness was a value of kn=0.03 m.
- Steepness induced dissipation. Two dissipation coefficients control the rate of steepness-induced energy dissipation, also known as “white capping”. Model testing runs showed little sensitivity to the parameters of white capping, so the default values by the software were adopted.
- To capture small waves with short wave periods, the maximum peak frequency of wave spectra was set to 2 Hz, i.e., the cut-off wave period was set to 0.5 second.

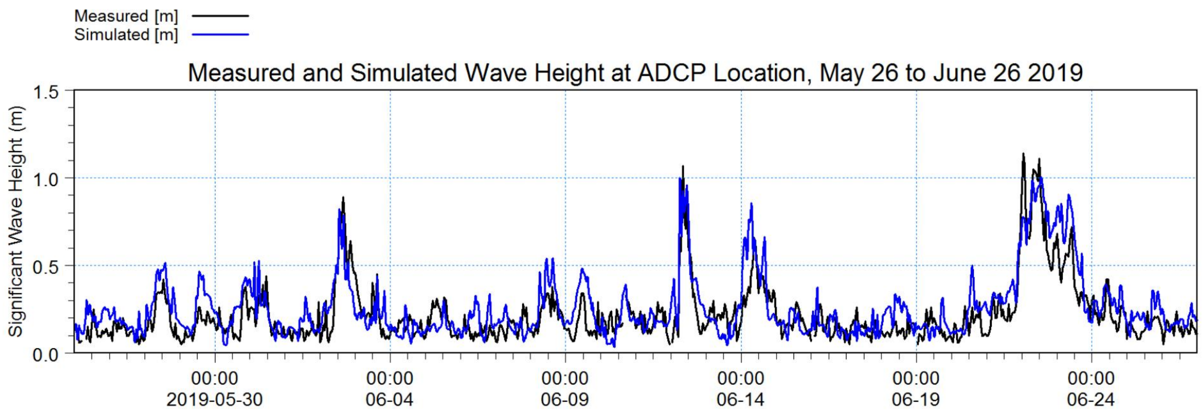


Figure 19 Measured and Simulated Waves at the ADCP Location

Table 8 Statistics of Measured and Simulated Significant Wave Heights

	Minimum (m)	Maximum (m)	Mean (m)	Standard Dev.
Measured	0.05	1.11	0.23	0.17
Simulated	0.02	1.05	0.25	0.18

2.2.2.2 Hydrodynamic Model

The hydrodynamic model coupled with the wave model, comprises the integrated effects of tidal circulation, wind, air temperature, and water temperature and salinity. This HD model was calibrated by comparing with field measurements, thus enabling the model to reproduce the site hydrodynamic circulation of currents in the area of outfall location.

Conditions applied as inputs in the model domain and at model boundaries included:

- Wind and air temperature. Hourly wind and air temperature records at ECCC Caribou Point (Figure 5) were applied on the model domain, constant in domain and varied in time. During the simulation period, air temperature varied in a range from 5.6 ºC to 24 ºC with a mean value of 12.9 ºC, and the relative humidity in a range from 37 to 95% with a mean value of 76%.

- Tide level prediction. Tidal levels at the offshore boundary were predicted using the tide constituents in Table 6 derived from the field measurements at Skinner and Arisaig.

- Marine water temperature and salinity. By selecting baroclinic density, which is a function of temperature and salinity, the TS module was invoked in the HD model to integrate the effect of water density. The TS module sets up additional transport equations for temperature and salinity, and feeds back to the hydrodynamic equations through buoyancy forcing induced by density gradients. Temperature boundary condition was defined using the field measurement at Skinner and Arisaig (Figure 15), while salinity was set to 29.8 ppt referred to the field profile measurements in May 2019 (Figure 14).

Through a systematic model run process, the following key parameters were calibrated:

- Time Step. The choice of time step requires consideration of numerical stability and solution accuracy. The time step was tested in the range of 15 seconds to 180 seconds. This allowed model stability and accuracy to be determined over this range. A time step of 60 seconds was ultimately chosen for all model runs.
- Courant number. The numerical stability and computing time depend not only on the number of nodes in the mesh and the simulation time step, but also the resulting Courant numbers (which needs to be less than 1). Sensitivity model runs were conducted with various critical Courant numbers from 0.6 to 1.0, of which a small critical Courant number resulted in a significant increase of computing time. A critical Courant number of 0.8 was adopted in this study.
- Flood and dry. The dry, flood and wet depths were set to 0.01, 0.05 and 0.1 m respectively.
- Bed resistance. The bed resistance value was tested in range from 20 to 50 $m^{1/3}/s$, and the calibrated valued was 33 $m^{1/3}/s$ in the model domain.
- Eddy viscosity. The eddy viscosity value can range from 0.28 to 1.0 m^2/s. The default setting for the eddy viscosity is a coefficient of 0.28 and no adjustments to the default value were required to obtain agreement between predicted and field measurements

The modelling results are compared with field ADCP measurements of water level, current and water temperature as follows.

Modelling results were compared with measured water levels at the ADCP station as illustrated in Figure 20 and Table 9. Good agreement between simulated and measured water levels was achieved in terms of the variation in phases and magnitudes of tidal cycles.

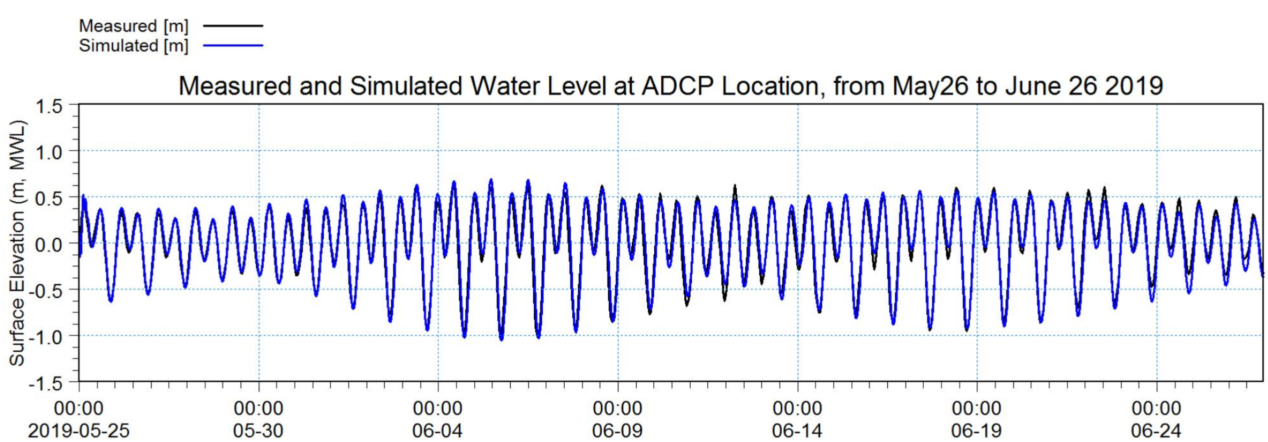


Figure 20 Measured and Simulated Water Levels at the ADCP Station

Table 9 Statistics of Measured and Simulated Water Levels

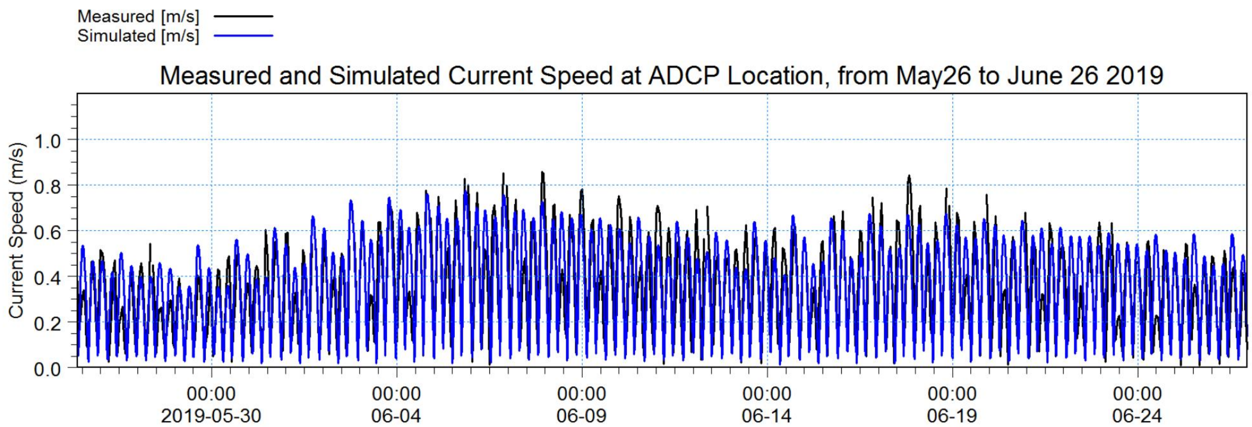
	Minimum (m)	Maximum (m)	Mean (m)	Standard Dev.
Measured	-1.05	0.64	0.00	0.38
Simulated	-1.06	0.68	0.00	0.38

Comparisons of measured and simulated current speed and direction at the ADCP station are shown in Figure 21 and in Table 10. Simulated current magnitudes and phases captured well the variation of measured values through the tidal cycles from neap tide to spring tide. Good agreement is achieved between simulated and measured currents. Differences between the simulated and measured currents are attributed to the fact that the simulated values are depth-averaged as the result of the 2D model and the measured values are taken as the mean value of bin measurements from surface to seabed at 1-m depth intervals.

The depth-averaged mean and maximum current velocities simulated by the 2D model for the 2018 RWS (Stantec 2018) are 0.1 m/s and 0.27 m/s, respectively, which are substantially lower than the currents measured (mean 0.35 m/s and maximum 0.86 m/s) or simulated (mean 0.36 m/s and maximum 0.77 m/s) for this updated RWS (see Table 10). Therefore, the current-driven mixing processes and effluent dispersion for the 2018 RWS investigation were lower and underestimated, producing conservative results.

Simulated water temperatures at the ADCP station are compared with the measurements in Figure 22 for the time series variations. In general, modeling results captured fairly well the field measurements in both the magnitudes and the variation patterns (phases), and agreed well with DFO's historical records. The discrepancy between the model simulated and the field measured data is considered to be due to the following reasons:

- Modelling of water temperature changes depends primarily on the environmental forcings of air heat exchange which requires inputs of air temperature, relative humidity (%) and air clearness index (%). Since the clearness data from the ECCC climate station at Caribou Point were not available, the parameter of air clearness was set to a constant value of 70 %.
- The ADCP temperature was measured near the seabed.
- The DFO monthly mean temperature was based on historical records from 2007 to 2011 measured at a water depth of 9 m. The DFO station is also located approximately 1.2 km northwest of the ADCP station.



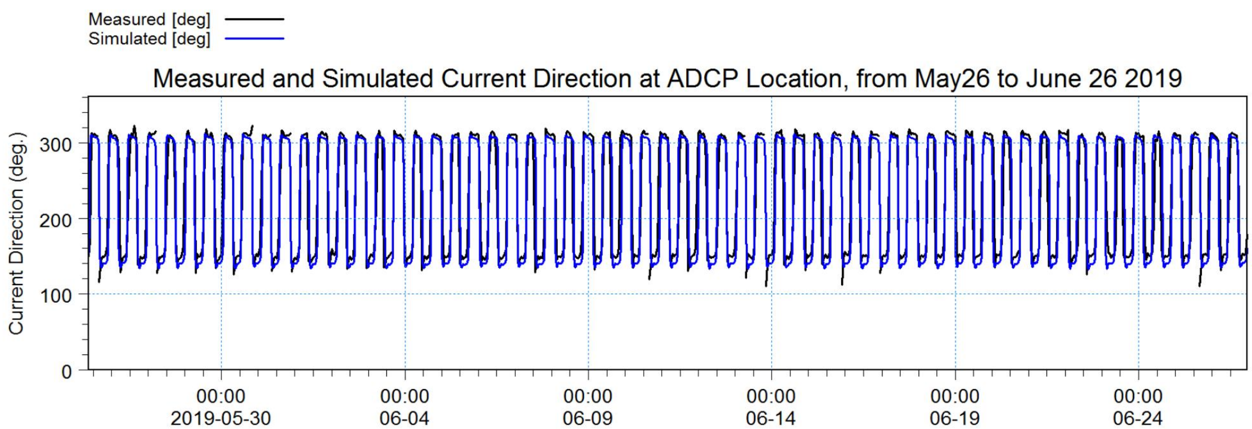


Figure 21 Measured and Simulated Currents (Speed and Direction) at the ADCP Station

Table 10 Statistics of Measured and Simulated Current Speed

	Minimum (m/s)	Maximum (m/s)	Mean (m/s)	Standard Dev. (m/s)
Measured	0.01	0.86	0.35	0.20
Simulated	0.00	0.77	0.36	0.18

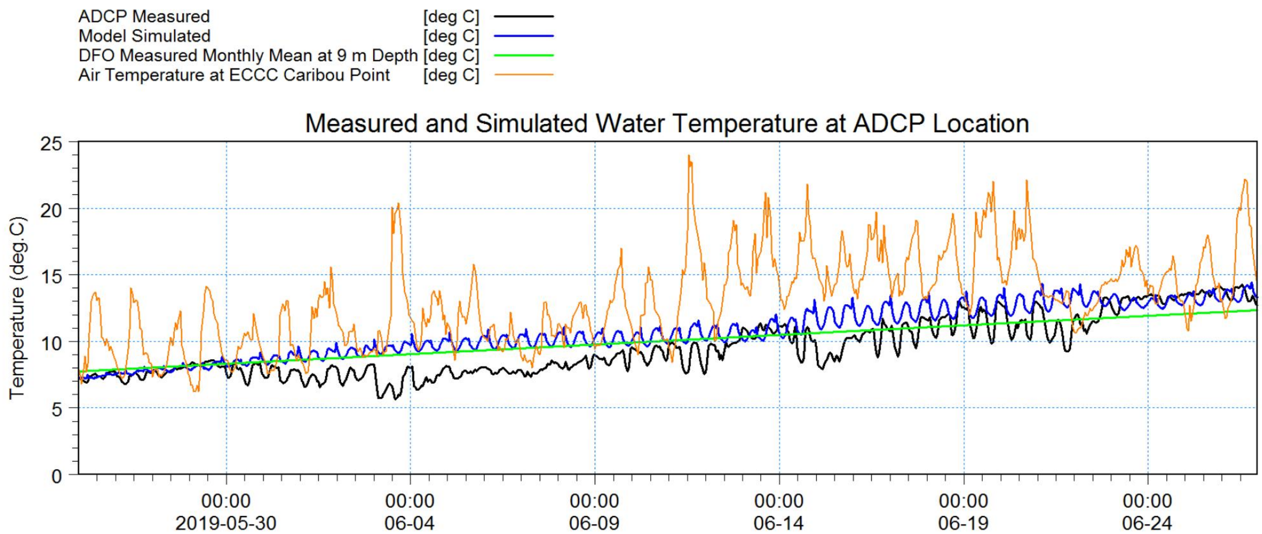


Figure 22 Measured and Simulated Water Temperature at the ADCP Station

2.3 MODELLING AND RESULTS

2.3.1 Modelling Conditions

2.3.1.1 Approaches

The objectives of the hydrodynamic dispersion modelling are to quantify the mixing, dispersion, and cumulative effects of the effluent discharges from the proposed outfall location and surrounding areas. This is to be achieved through further integrating a particle tracking (PT) module into the calibrated hydrodynamic model and carrying out the fully coupled hydrodynamic model for a one-month simulation period to characterize the circulation patterns and indications of effluent transport. The following approach and steps were undertaken:

- incorporating proposed outfall location into the model;
- defining modelling scenarios and conditions;
- developing a fully coupled hydrodynamic model of HD, TS, SW, and PT modules; and
- applying the model to the defined scenarios to investigate the dispersion features of the effluent discharged from the outfall location.

The outfall will be located in a water depth of 20 m MWL and will provide allowance for ship navigation, outfall pipe/diffuser structures, and minimum potential for ice scouring. The proposed outfall is located offshore Caribou Harbour in Northumberland Strait at a water depth of 20.3 m MWL (526737 m E / 5067239 m N), as shown in Figure 23. This outfall is similar in location to CH-B in Stantec (2018), but was moved by about 130 m to be situated in the bottom of the channel and after the June 2019 bathymetric survey was conducted. This outfall location is still referred to as CH-B in this report.

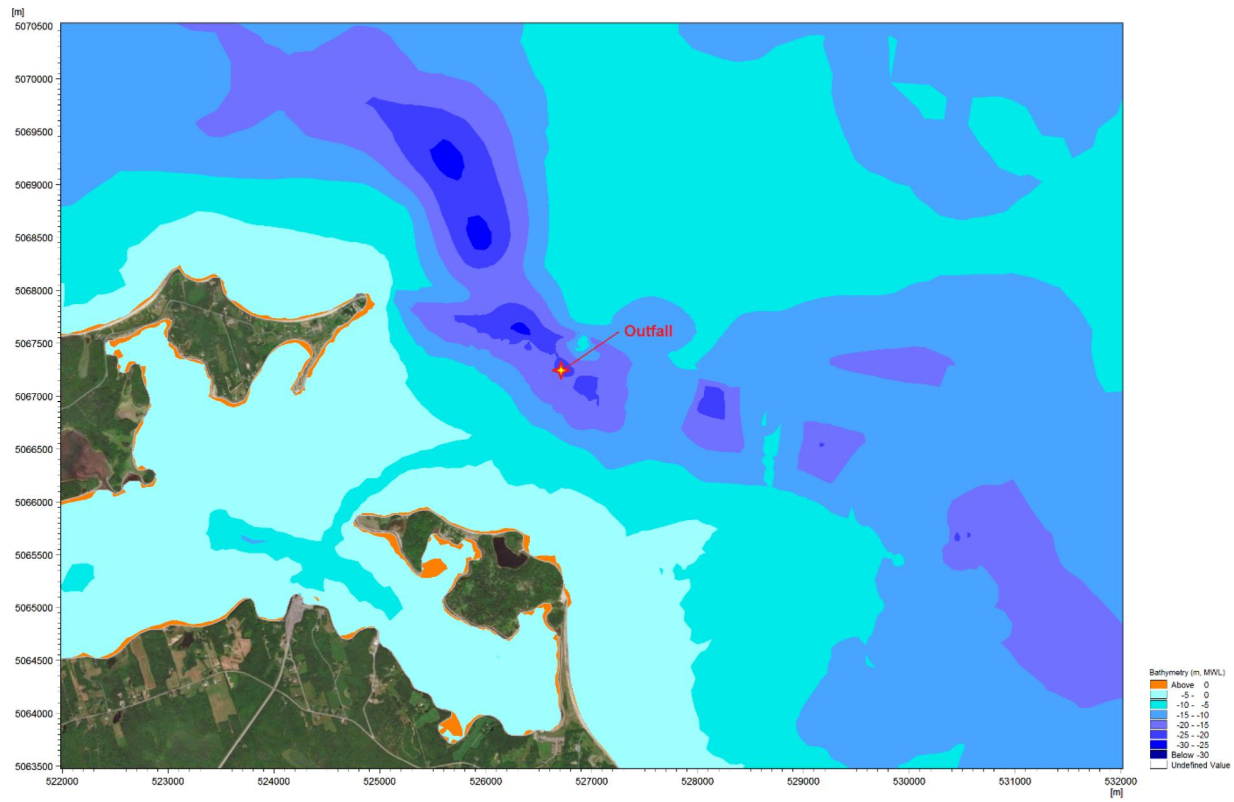


Figure 23 Outfall Location and Bathymetry in the Study Area

2.3.1.2 Modelling Scenario and Conditions

Model scenarios were defined based on consideration of available datasets that would provide good coverage to represent typical summer and winter environmental conditions. The key factors determining the model scenarios were:

- A one-month simulation period with continuous hydrometric and environmental data records required to provide sufficient representative inputs for modelling purposes
- Typical tidal cycles, including spring tides and neap tides
- Site-specific climate data for wind and air temperature
- Field measurement records on ambient water temperature and salinity

Therefore, July 2019 was selected as a summer scenario to reflect a relevant open-water period with warmer ambient waters and less wind-driven surface currents for potential effects of reduced surface mixing of the effluent, and February 2019 was selected as a winter scenario to include ice and ice cover to eliminate wind-driven surface mixing. The two scenarios will be able to envelop the year-round physical oceanographic and hydrodynamic environments for modelling effluent dispersion.

The general conditions and assumptions applied in the modelling are summarized in Table 11. The assumptions include no decay of effluent quality, which is a conservative modelling approach that would represent an exaggerated condition, given that normally some decay is anticipated to occur.

Key model output parameters are surface elevations, currents, waves, water temperature and salinity, and effluent concentration.

Table 11 Summary of Conditions and Assumptions Used in the Hydrodynamic Dispersion Modelling

Feature	Characteristics	Comments
General Model Settings		
Model Domain	14771 nodes and 27731 elements	
Coupled Modules	Hydrodynamic (HD), Temperature/Salinity (TS), Spectral Wave (SW) and Particle Tracking (PT)	The coupled model integrated the effects of tide, wind, wave, heat, marine water quality, and effluent discharge
Simulation Period	A full month from July 1 to 31, 2019 for summer conditions; A full month from February 1 to 28, 2019 for winter conditions;	
Simulation Time Step	60 seconds	
Assumptions	no decay	As a conservative approach
Outfall Discharge Location		
Northumberland Strait (CH-B)	Easting 526737 m, Northing 5067239 m	At a water depth 20.3 m MWL (Figure 23)
Effluent Properties		
Discharge Rate	85,000 m^3/day / 0.984 m^3/s	Provided by KSH Solutions
Parameter	Temperature: • 37 °C for summer condition • 25 °C for winter condition	Provided by KSH Solutions
	Total Dissolved Solids: 2000 mg/L	Provided by NPNS as conservative concentration (typical mill effluent 900 – 1500 mg/L)
	Concentration: 100 mg/L	Assumed arbitrary concentration at discharge for calculation of dilution ratios and easy visualization of the plume
Boundary and Ambient Conditions		
Tide	Predicted tidal levels at the west (near Skinner Cove) and the east (near Arisaig) boundaries in Northumberland Strait	Predictions are based on the constituents derived from the field water level measurements (Table 6, Figure 24)
Climate	Measured hourly wind, air temperature and relative humidity	Figure 5, measured at ECCC climate station at Caribou Point (AUT), NS
Wave	Wind-generated waves	Simulated from the wave model
Ambient Water	Temperature: • Time varying temperature (Figure 16) for summer conditions • 1.0 °C (constant) for winter condition	Assumed based on DFO's monthly records (Figure 16)
	Salinity: 29.8 ppt	Assumed based on field survey in May and June 2019
Ice Cover	Ice thickness 0.7 m (for winter modelling scenario only)	Assumed based on DFO's survey (Figure 17)

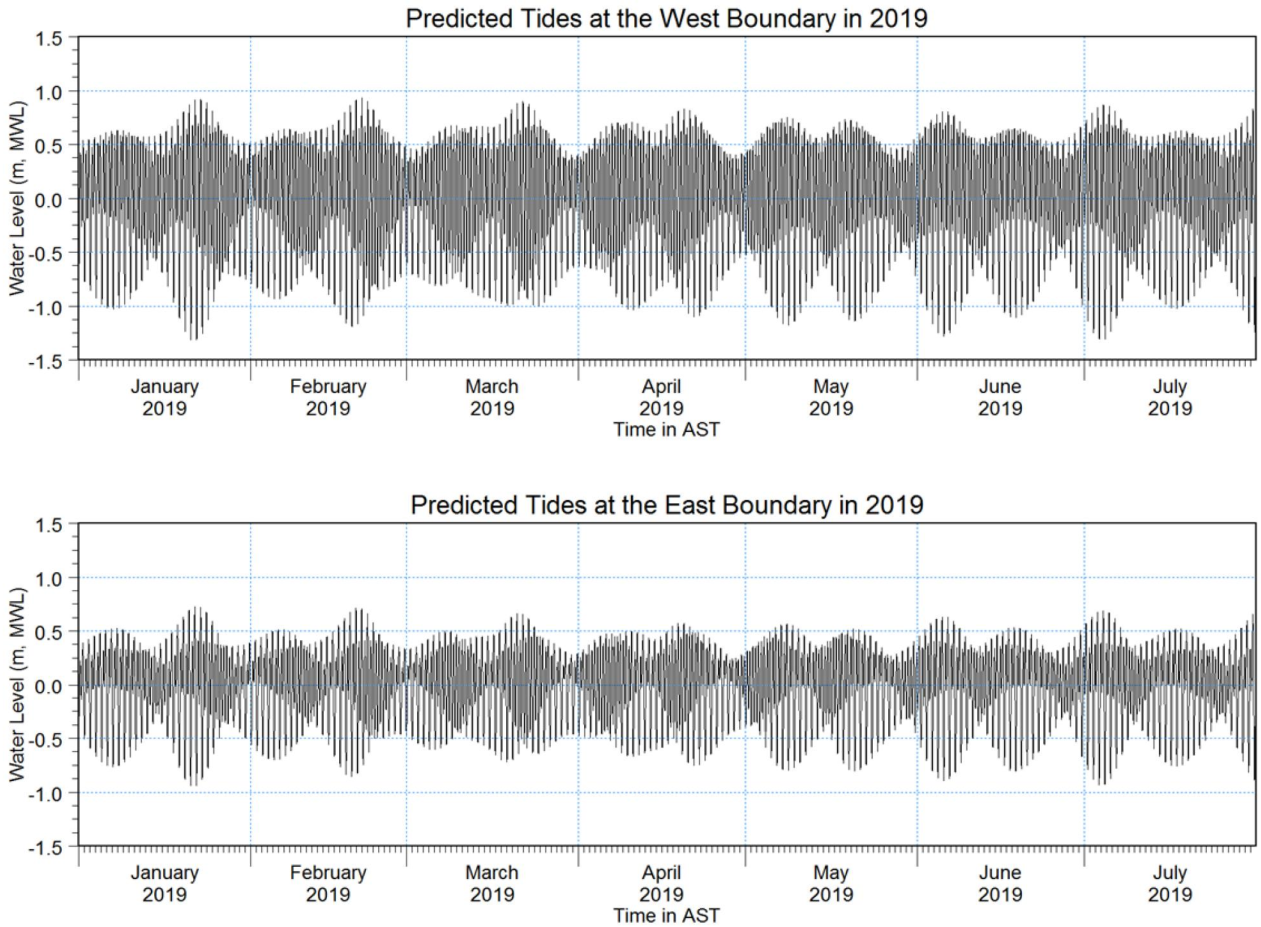


Figure 24 Predicted Water Levels at the West (Skinner) and East (Arisaig) Offshore Boundaries for Northumberland Strait in 2019

2.3.2 Summer Scenario

2.3.2.1 Wave

Simulated wind-generated waves at the outfall location are shown in Figure 25 for the one-month period in July. As a result of fetch limitation by the shoreline on the southwest direction of the outfall, wave growth by the southwest winds is limited, and the outfall site experiences waves predominantly from the northwest. The significant wave heights are in a range from 0.0 to 1.13 m with a mean value of 0.22 m.

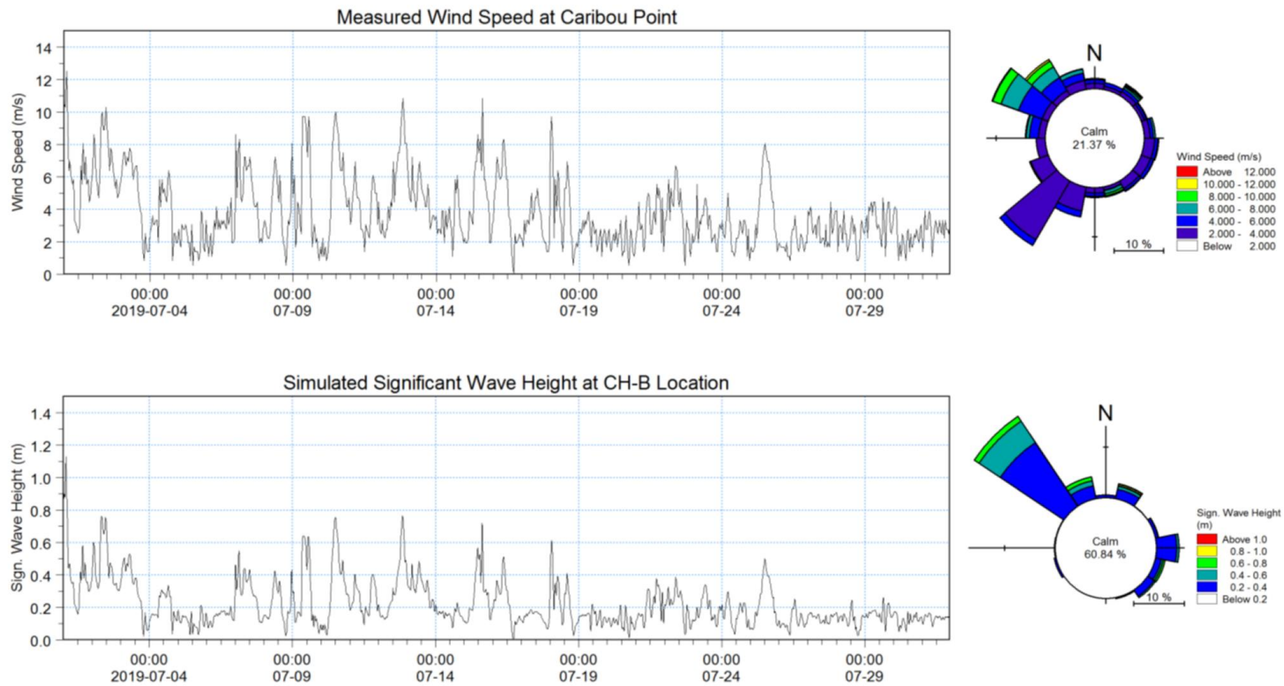


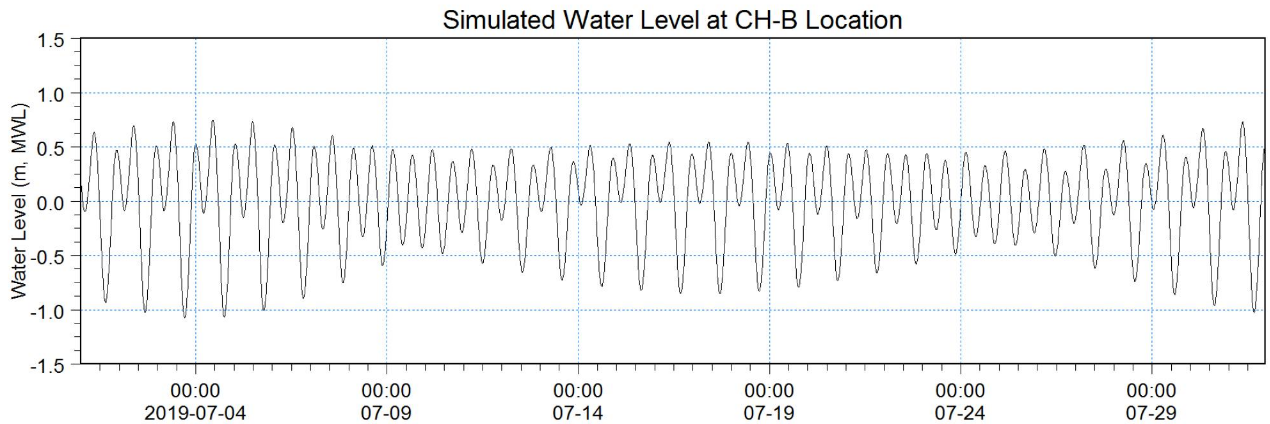
Figure 25 Simulated Wind and Waves at the Outfall Location in July 2019

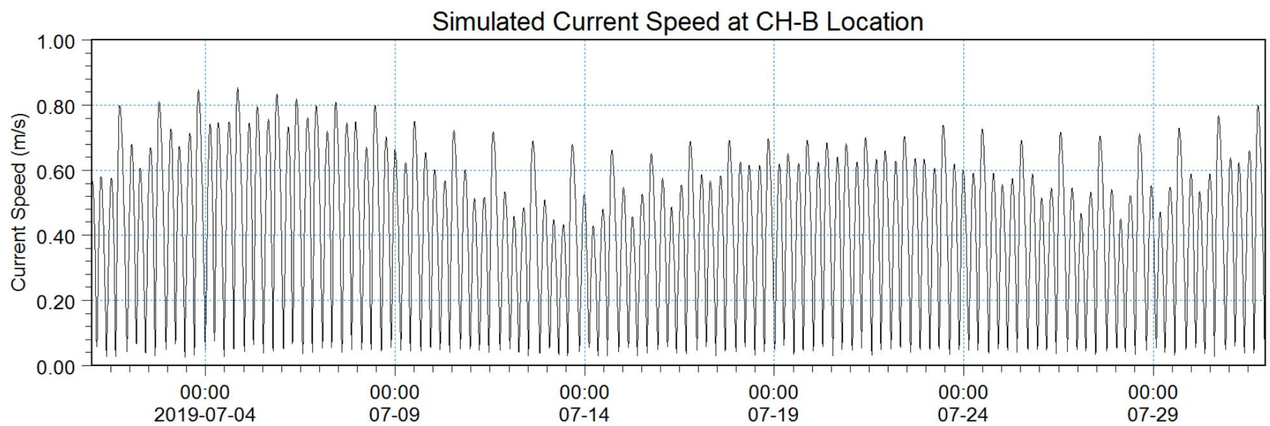
2.3.2.2 Water Level and Currents

Current flows in coastal areas depend strongly on tidal circulation, wind- and wave-generated surface currents, nearshore bathymetry, and shoreline topographic features. Current velocity is the predominant factor causing effluent transport and dispersion.

Figure 26 presents the time-series of water levels and current speeds, and the direction rose plot of currents (towards) at the outfall discharge location over the simulation period for July 2019, where:

- Water levels vary from -1.07 to 0.75 m (MWL), with a tidal range of 1.82 m. The mean value of water level variation is 0.00 m;
- Current speeds vary in a range from 0.03 to 0.85 m/s, with a mean value of 0.41 m/s;
- The circulation pattern indicates currents typically are predominant in the northwest direction for flood currents, and in the southeast direction for ebb currents.





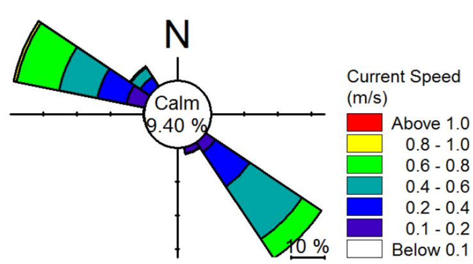


Figure 26 Simulated Water Levels and Currents at the Outfall Location in July 2019

2.3.2.3 Water Temperature and Salinity

Figure 27 presents the simulated time series for water temperature, salinity and density at the outfall location in July, which indicate that:

- The water temperature experiences the dynamically integrated effects of the marine water, air heat exchange, effluent warm water and tidal cycles. The temperature increase over time is dominated by air temperature and relative humidity. The water temperature varies in a range from 15.2 to 22.5 ºC;
- The water salinity varies with the dynamically integrated effects of effluent freshwater and tidal cycles in a range from 29.5 to 29.8 ppt;
- As a function of water temperature and salinity, the resulting water density decreases from 1021.90 to 1020.01 kg/m^3.

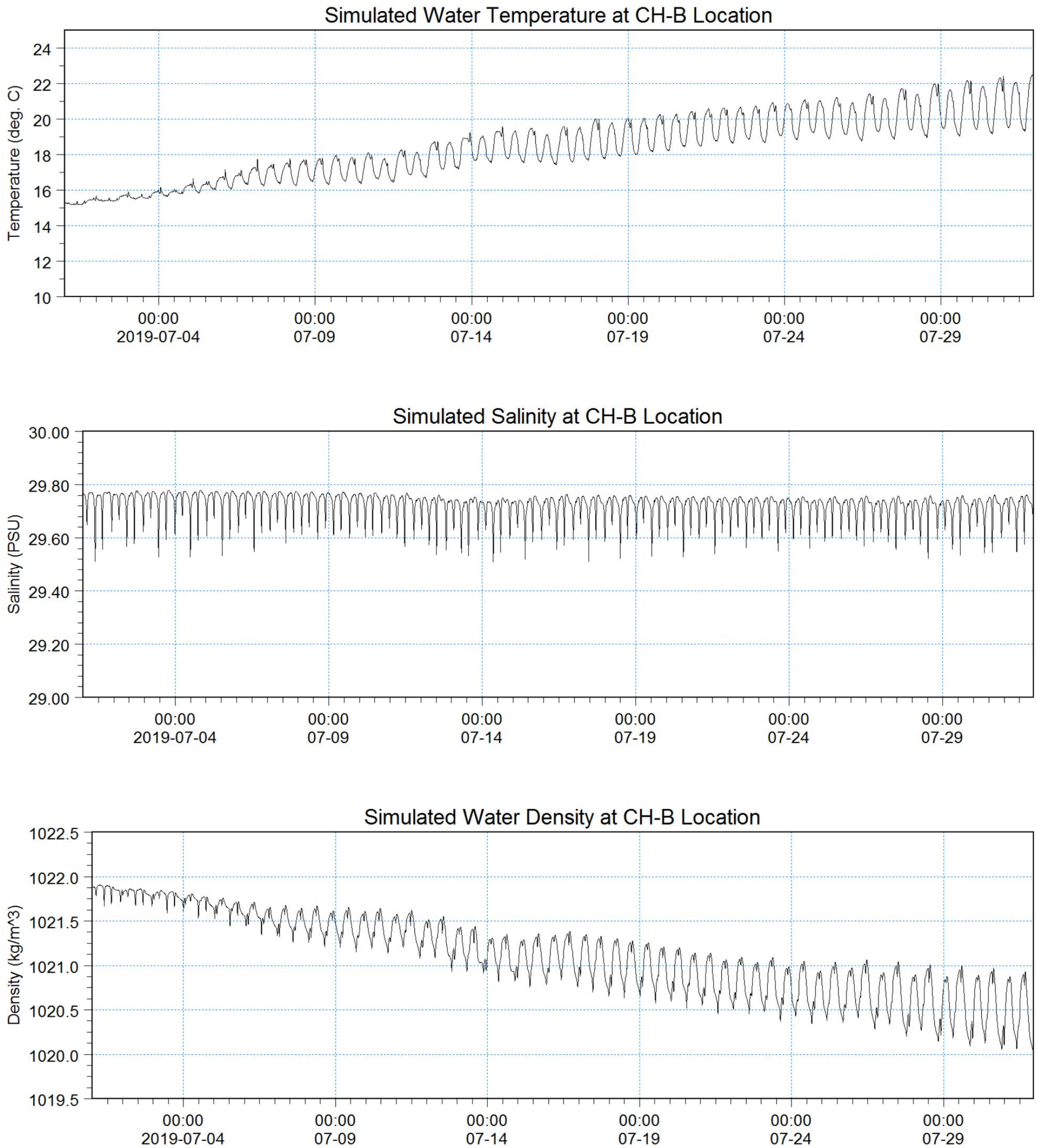


Figure 27 Simulated Water Temperature, Salinity and Density at the Outfall Location in July 2019

2.3.2.4 Effluent Dispersion

An arbitrary effluent parameter was assumed to be discharged at a single point discharge from the end-of-pipe outfall location and at a constant arbitrary concentration of 100 mg/L. Effluent transport was simulated in the PT module which was dynamically coupled with the HD, TS, and SW modules. Results are presented in snapshots of the effluent plume for typical ebb and flood tides, the accumulative concentrations and corresponding dilution ratios achieved by end of the simulation period, time series of effluent concentrations, and average dilution ratios achieved at 100 m radius locations. No decay of the effluent parameter was taken into consideration in the model, which is a conservative approach.

The scale for arbitrary concentration of the effluent on the figures used to present the effluent dispersion results for the Pictou Harbour RWS (Stantec 2017) and for the 2018 Caribou Harbour RWS (Stantec 2018) was based on the full scale for the arbitrary concentration of 100 mg/L. However, at this scale, effluent concentrations were not visible for this updated RWS as shown on Figure 28. Therefore, due to improved dispersion, a lower concentration scale was used for all subsequent figures and to be able to see any effluent dispersion.

Figure 29 to Figure 32 illustrate the simulated spatial concentration contours of effluent plume at various stages of a typical spring tide cycle on July 4, and Figure 33 to Figure 36 present the effluent plume at various stages of a typical neap tide cycle on July 10. Current vectors and circulation patterns are presented in the plots as well to provide supporting information of the current-driven forcing on effluent transport. The effluent dispersion corresponding to the advection of currents are dominated by the circulation patterns. The simulated results indicate that:

- the predominant offshore currents in the vicinity of the outfall discharge flow southeasterly during ebb tides and northwesterly during flood tides;
- the effluent plumes driven by circulation currents are transported correspondingly in the southeast and northwest directions; and
- as ebb currents are relatively stronger than flood currents through the harbour navigation channel towards the offshore, plume intrusion into Caribou Harbour is predicted to be minimum.

In responses to current magnitudes and circulation patterns influenced by the seabed bathymetric and shoreline topographic features, the effluent plume is normally transported to and accumulated in areas with lower circulation velocities and eddies. Figure 37 presents cumulative effects of the simulated effluent concentrations by the end of the one-month simulation period in July. Since the plume is not visible in Figure 37 using the full scale for the arbitrary concentration of 100 mg/L that was used for both the Pictou Harbour RWS (Stantec 2017) and the 2018 Caribou Harbour RWS (Stantec 2018), and due to improved dispersion, a lower concentration scale of 2.5 mg/L is used and shown in Figure 38. Figure 39 presents the achieved dilution ratios by the end of the one-month simulation period in July. The upper scale for the dilution factor in the legend for Figure 39 had to be doubled from 100 used in the previous RWS reports to a dilution factor of 200 in this updated RWS report in order for the effluent plume to be visible, and similar in rationale to lowering the scale for the arbitrary effluent concentration in the figure legends noted above. The results in Figure 38 and Figure 39 indicate:

- little plume intrusion into Caribou Harbour
- no effluent concentration accumulated in the harbour basin and surrounding areas, along the shorelines, and in the entire model domain
- larger plume extent in the southeast than in the northwest
- effluent concentration is mostly less than 1.0 mg/L in the model domain
- the lowest dilution factor achieved is about 80 with a limited plume extent offshore of Caribou Harbour, and the dilution factor in most of the model domain is above 100.

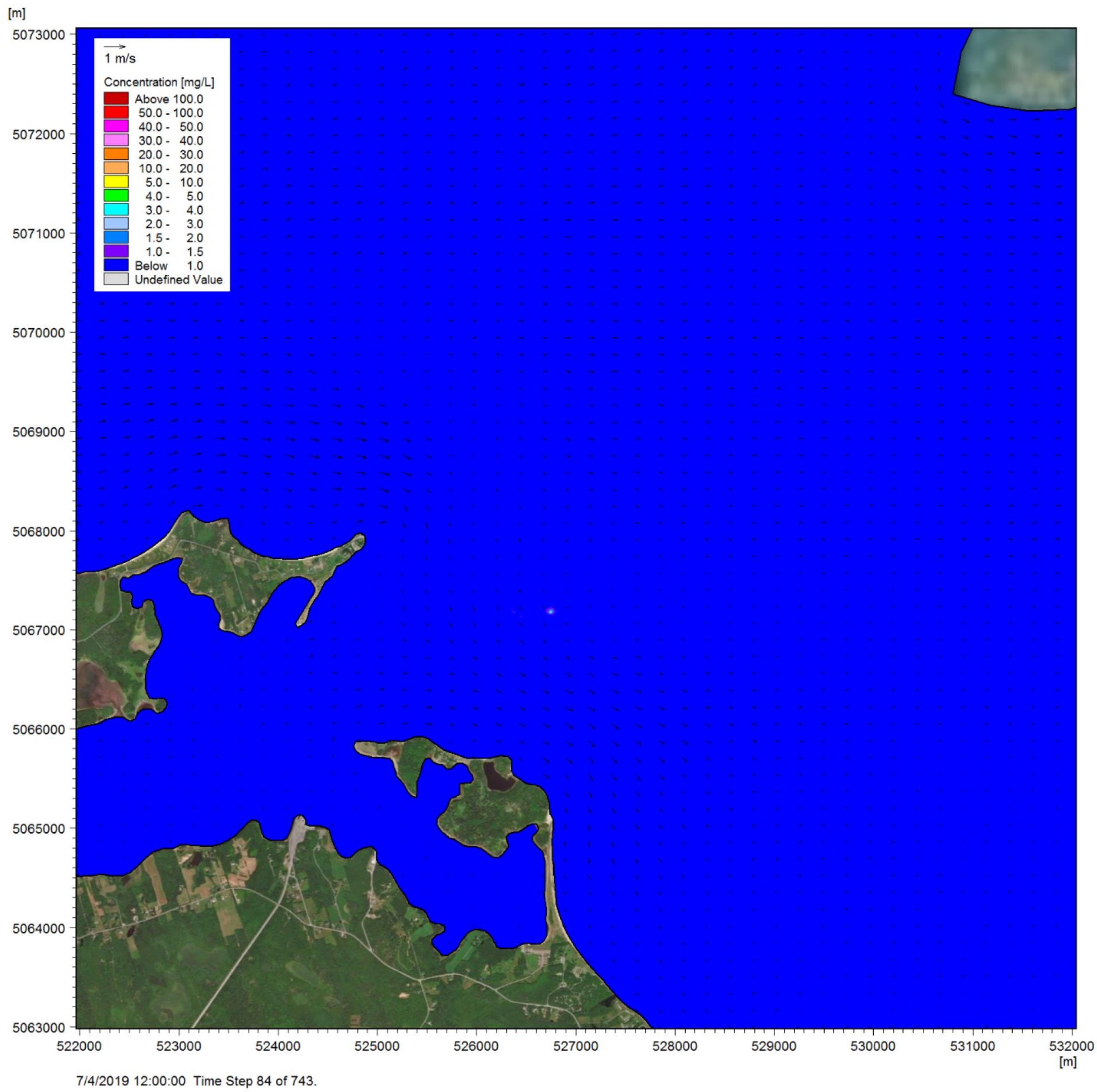


Figure 28 Simulated Effluent Concentrations for Typical Spring Tide – Slack High Tide at 12:00 hr, July 4 (using full scale in the figure legend of arbitrary concentration of 100 mg/L for discharged effluent)

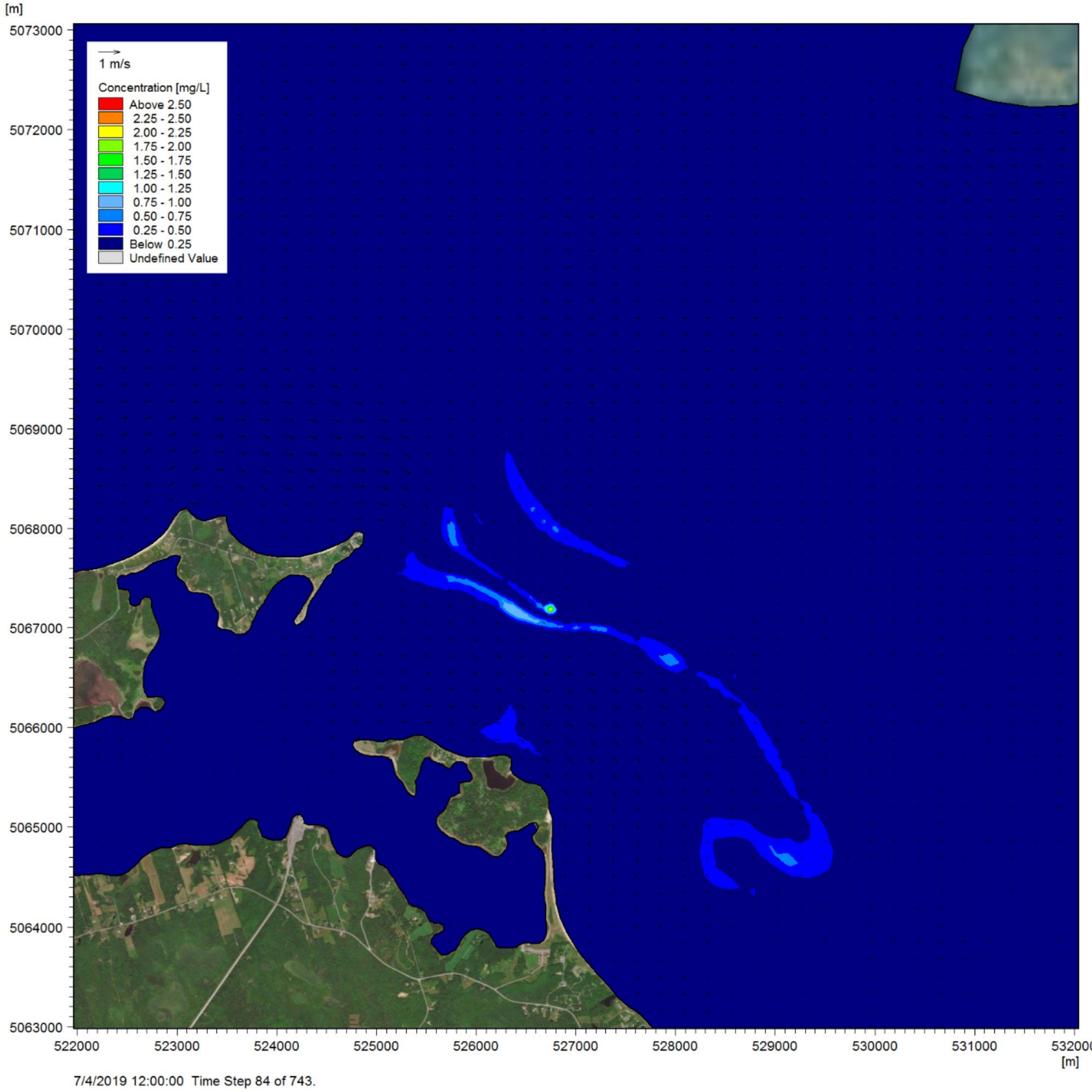


Figure 29 **Simulated Effluent Concentrations for Typical Spring Tide – Slack High Tide at 12:00 hr, July 4 (using lower concentration of 2.5 mg/L for the upper bound in the figure legend)**

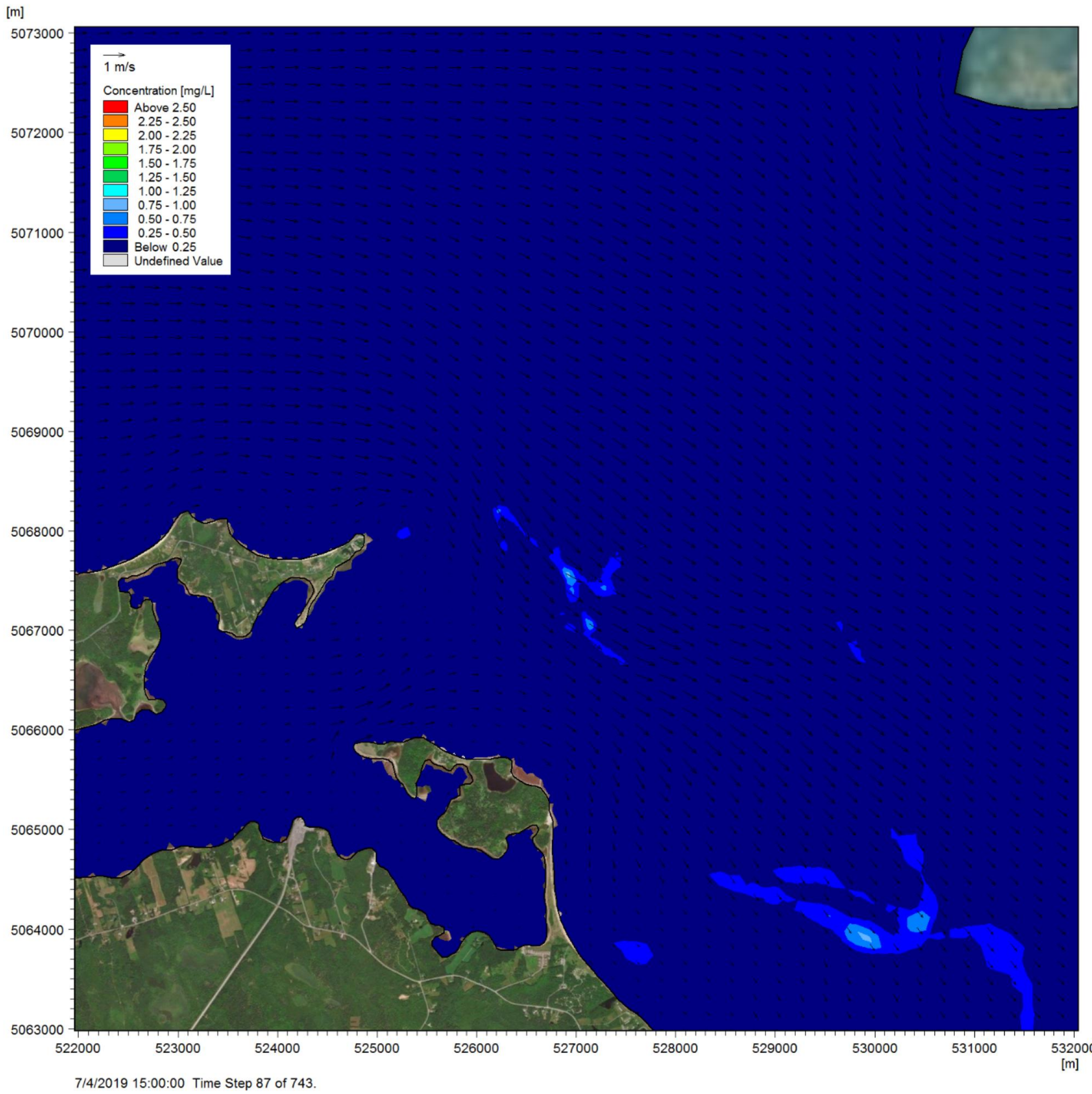


Figure 30 Simulated Effluent Concentrations for Typical Spring Tide – Ebb Tide at 15:00 hr, July 4 (using lower concentration of 2.5 mg/L for the upper bound in the figure legend)

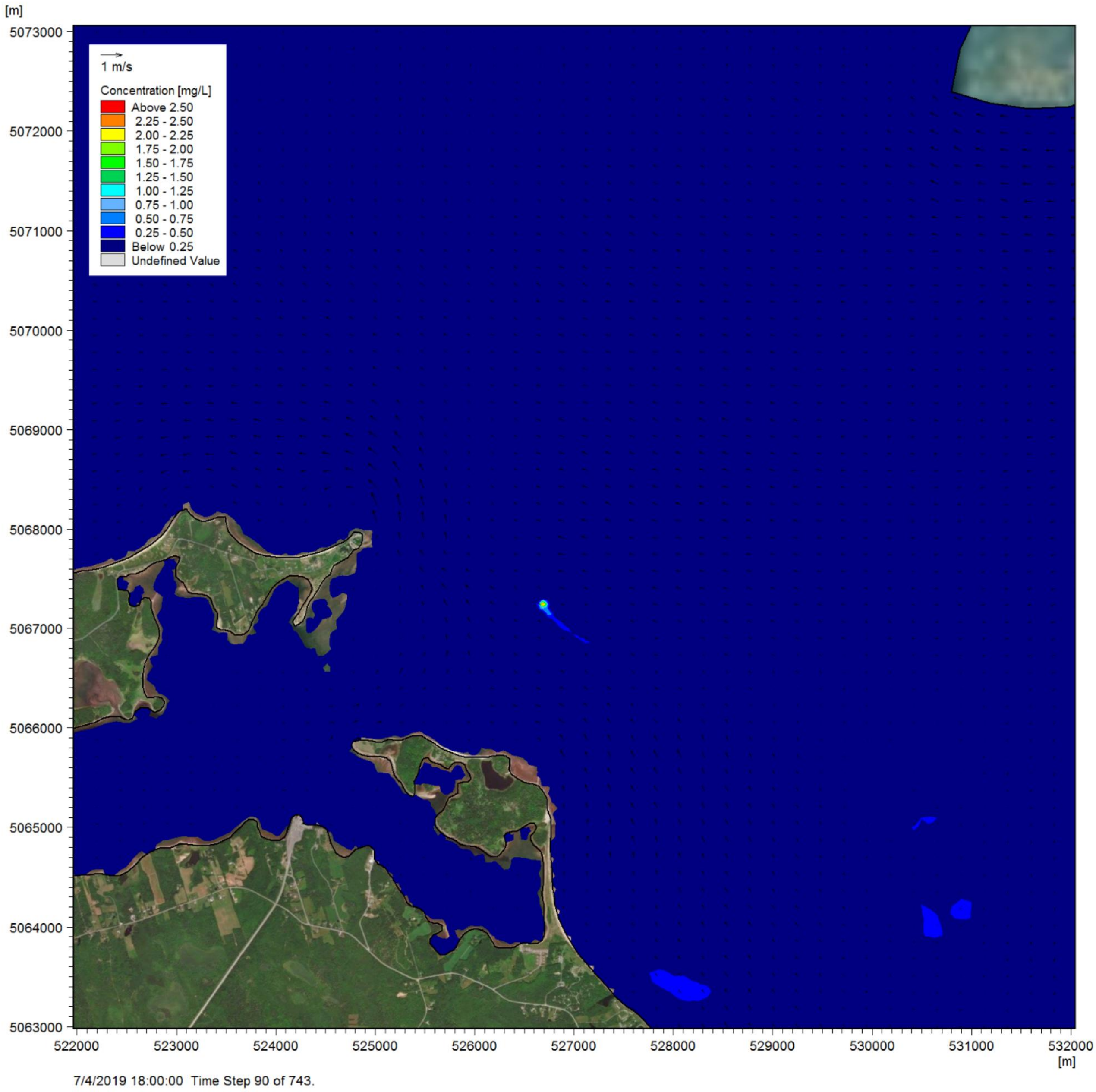


Figure 31 Simulated Effluent Concentrations for Typical Spring Tide – Slack Low Tide at 18:00 hr, July 4 (using lower concentration of 2.5 mg/L for the upper bound in the figure legend)

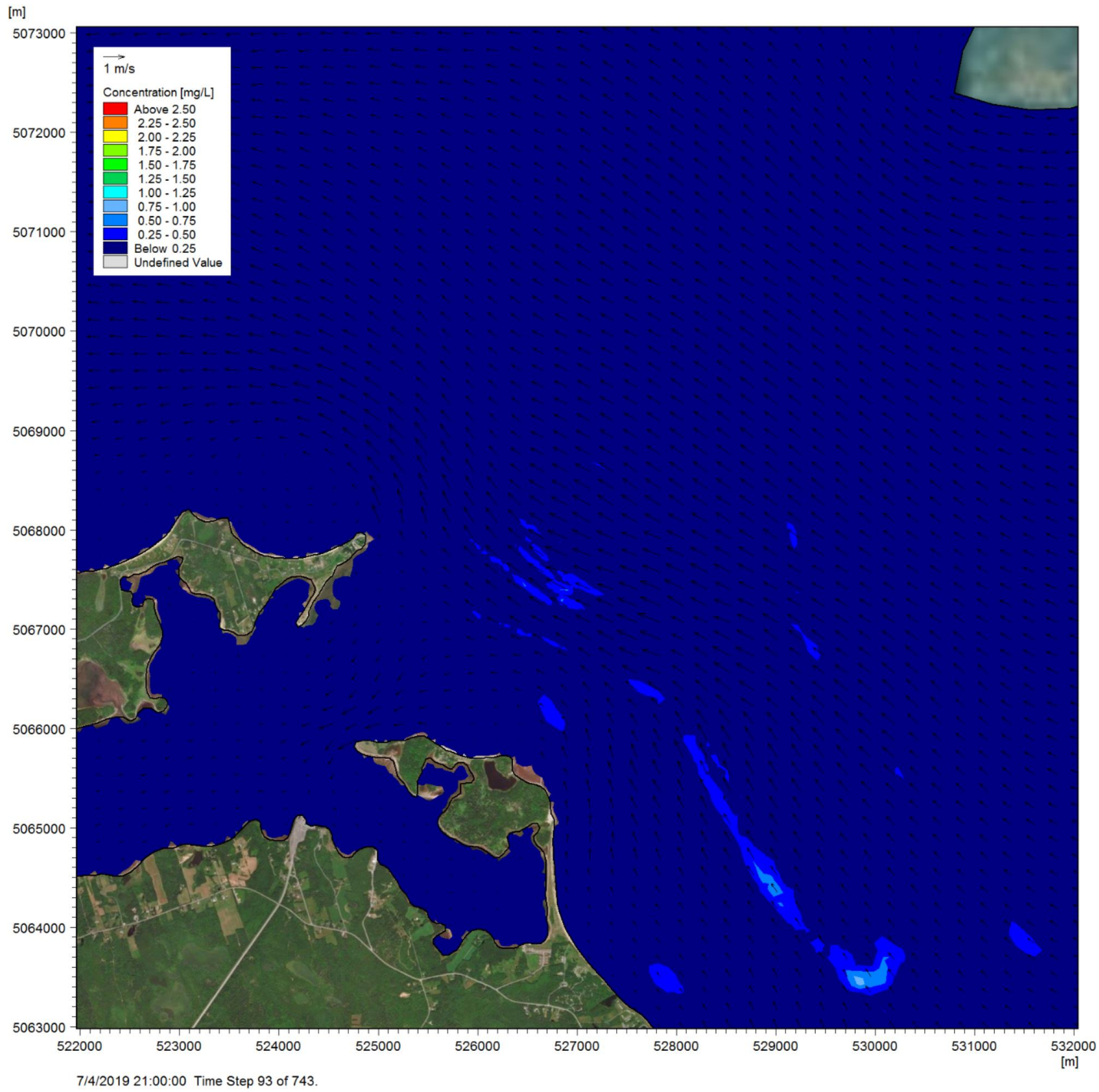


Figure 32 Simulated Effluent Concentrations for Typical Spring Tide – Flood Tide at 21:00 hr, July 4 (using lower concentration of 2.5 mg/L for the upper bound in the figure legend)

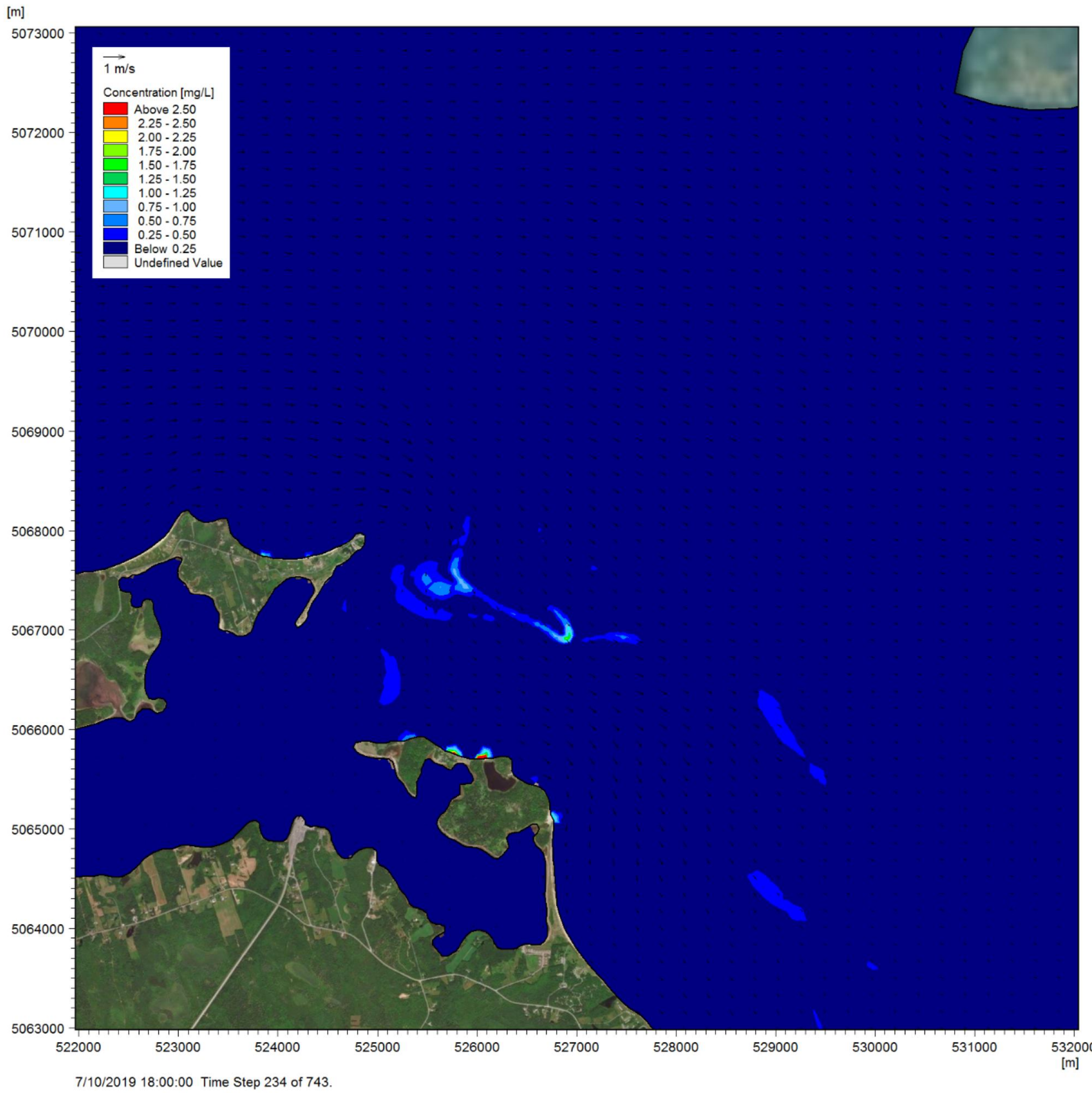


Figure 33 Simulated Effluent Concentrations for Typical Neap Tide – Slack High Tide at 18:00 hr, July 10 (using lower concentration of 2.5 mg/L for the upper bound in the figure legend)

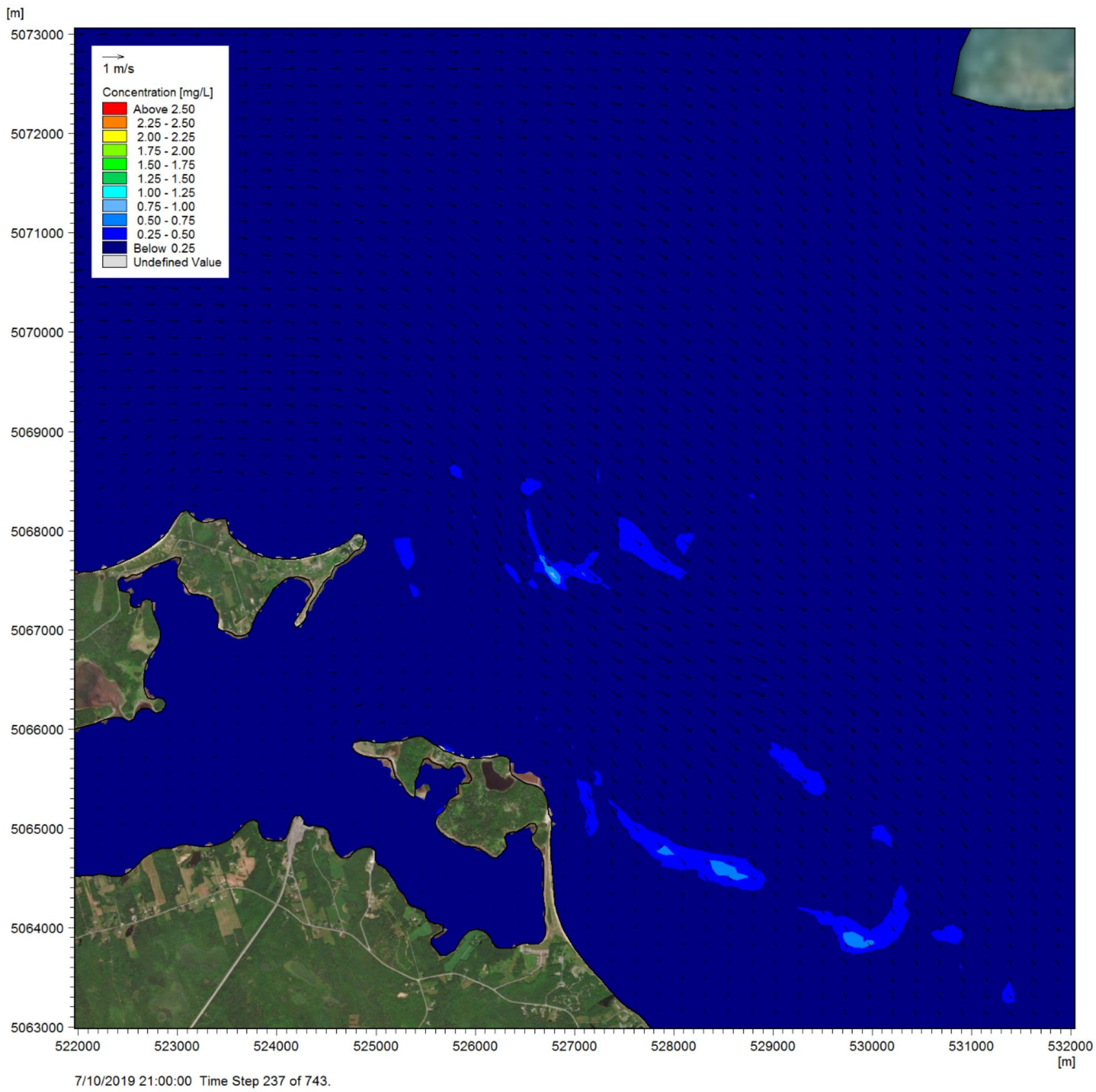


Figure 34 Simulated Effluent Concentrations for Typical Neap Tide – Ebb Tide at 21:00 hr, July 10 (using lower concentration of 2.5 mg/L for the upper bound in the figure legend)

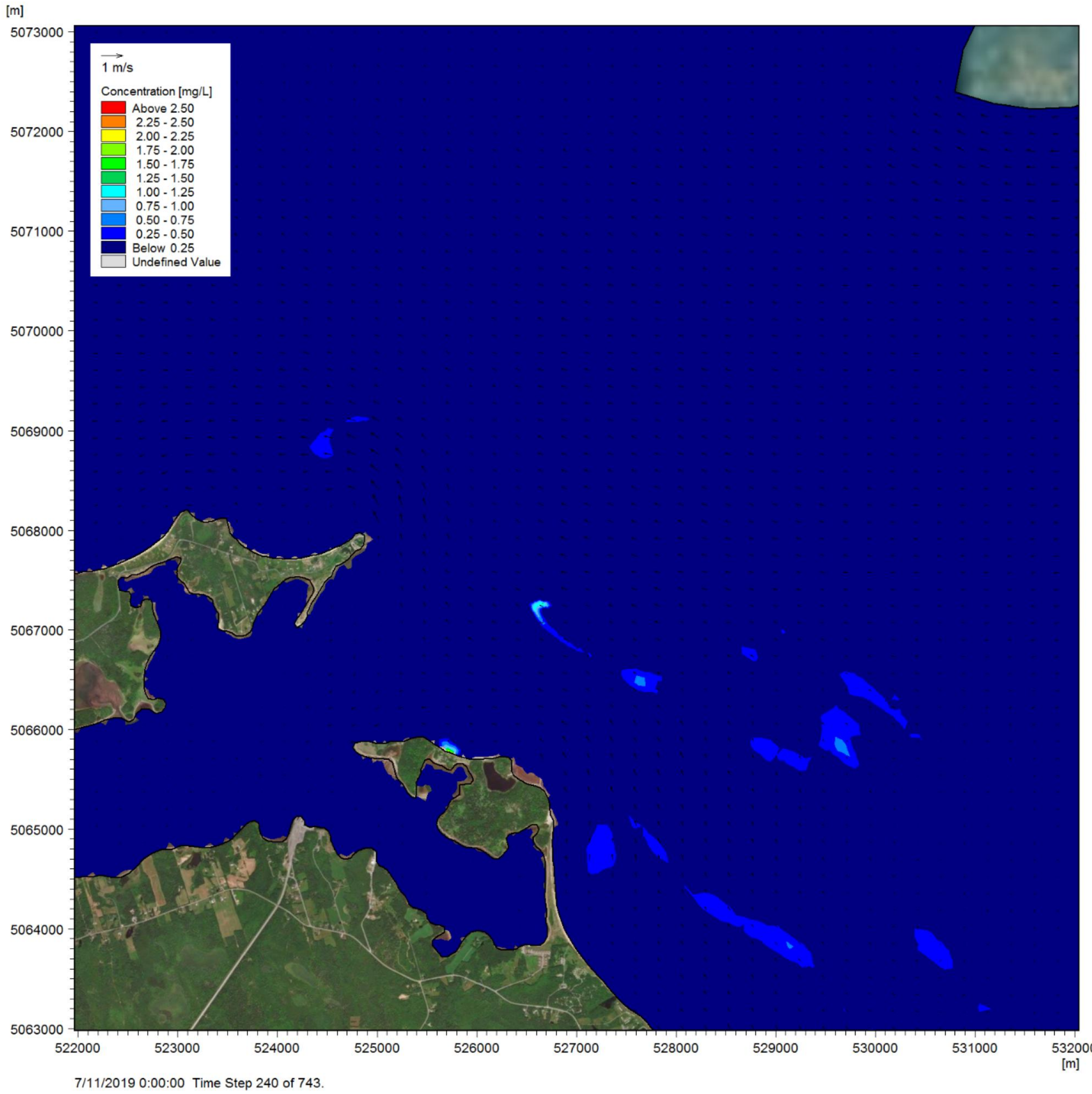


Figure 35 **Simulated Effluent Concentrations for Typical Neap Tide – Slack Low Tide at 00:00 hr, July 11 (using lower concentration of 2.5 mg/L for the upper bound in the figure legend)**

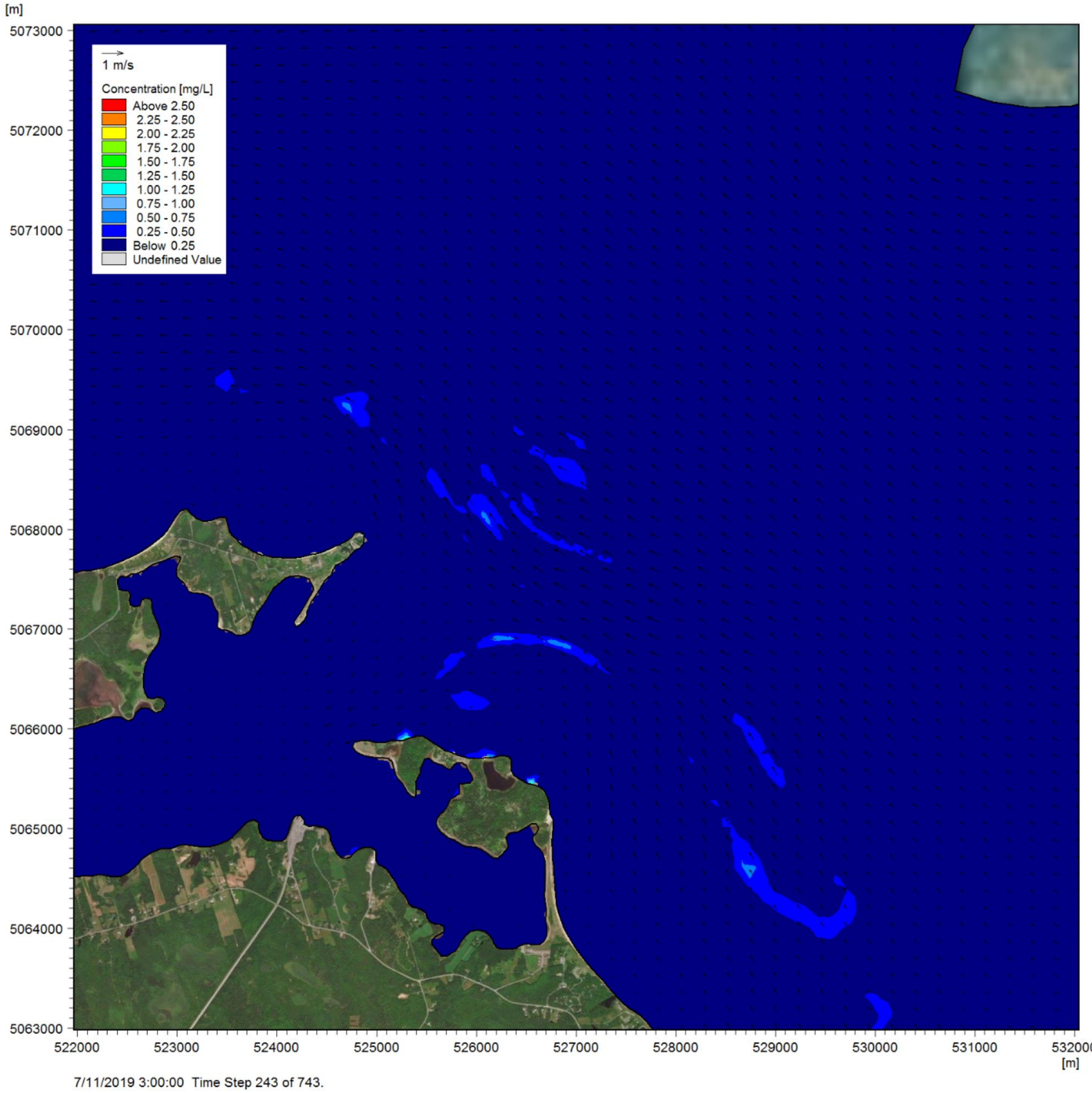


Figure 36 Simulated Effluent Concentrations for Typical Neap Tide – Flood Tide at 03:00 hr, July 11 (using lower concentration of 2.5 mg/L for the upper bound in the figure legend)

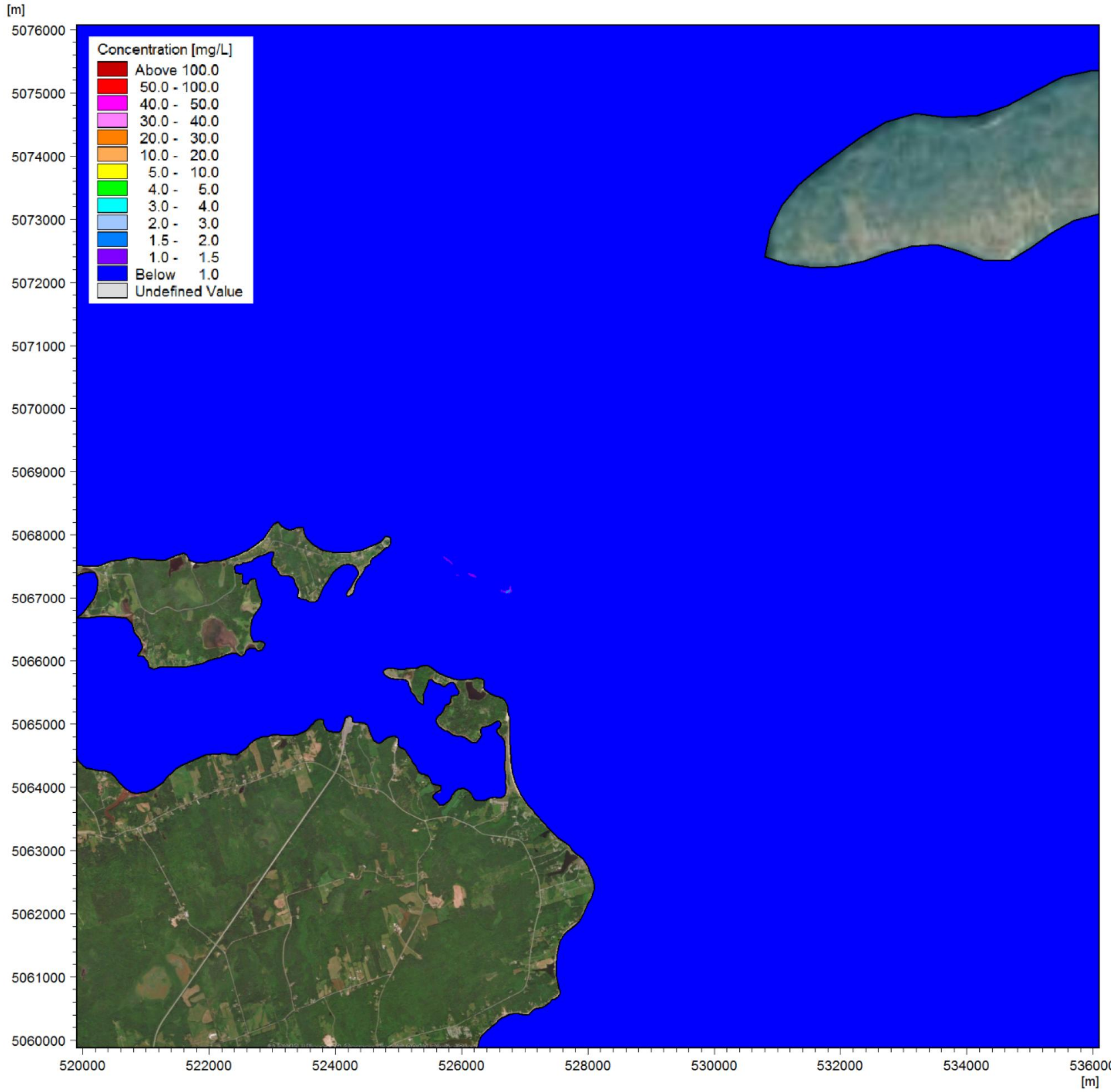


Figure 37 **Simulated Effluent Concentration by End of One-month Simulation Period in July (concentration in effluent arbitrarily set at 100 mg/L and assuming no particle degradation over the simulation period)**

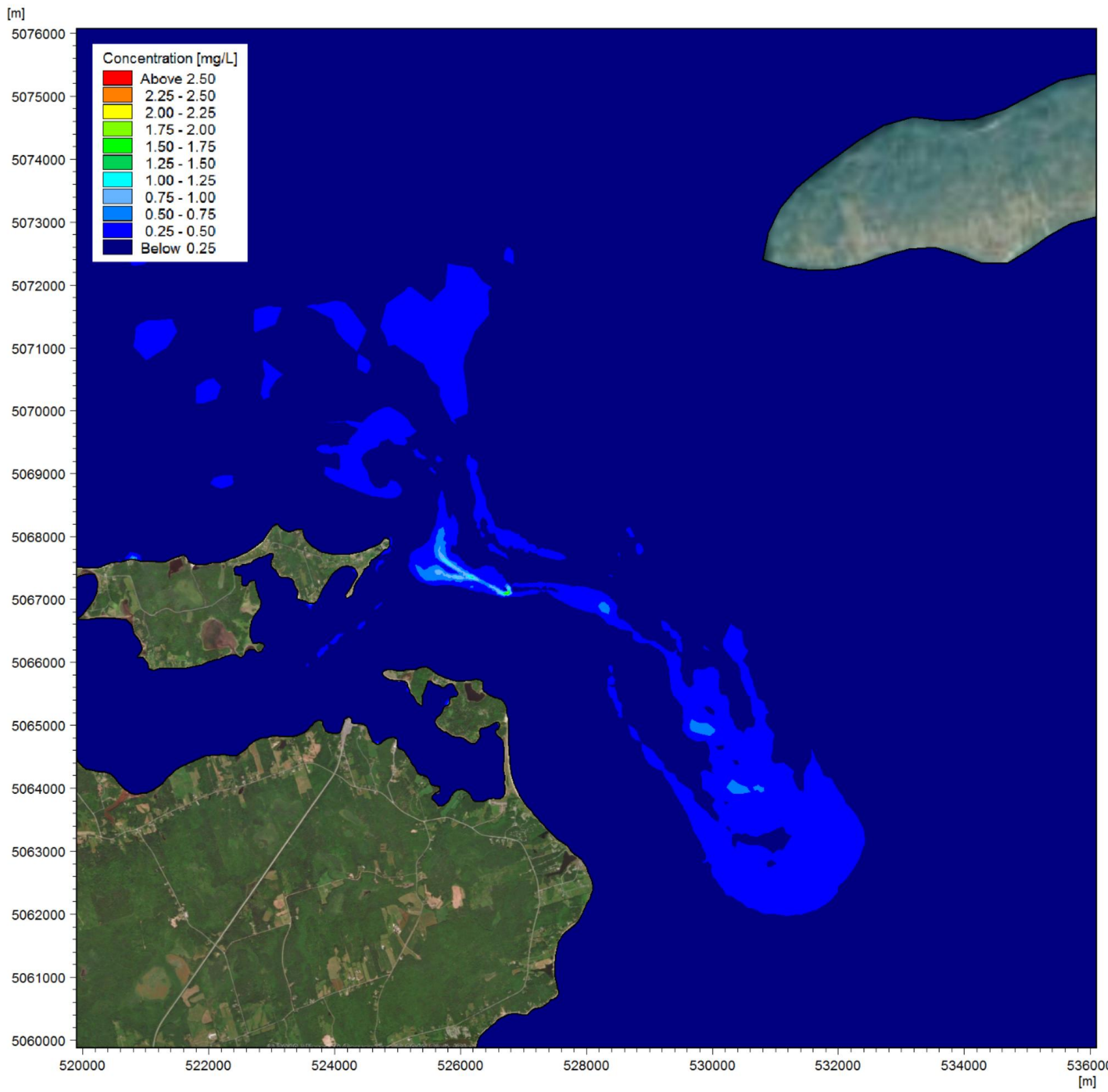


Figure 38 Simulated Effluent Concentration by End of One-month Simulation Period in July (concentration in effluent arbitrarily set at 100 mg/L and assuming no particle degradation over the simulation period; lower concentration of 2.5 mg/L for the upper bound in the figure legend is used)

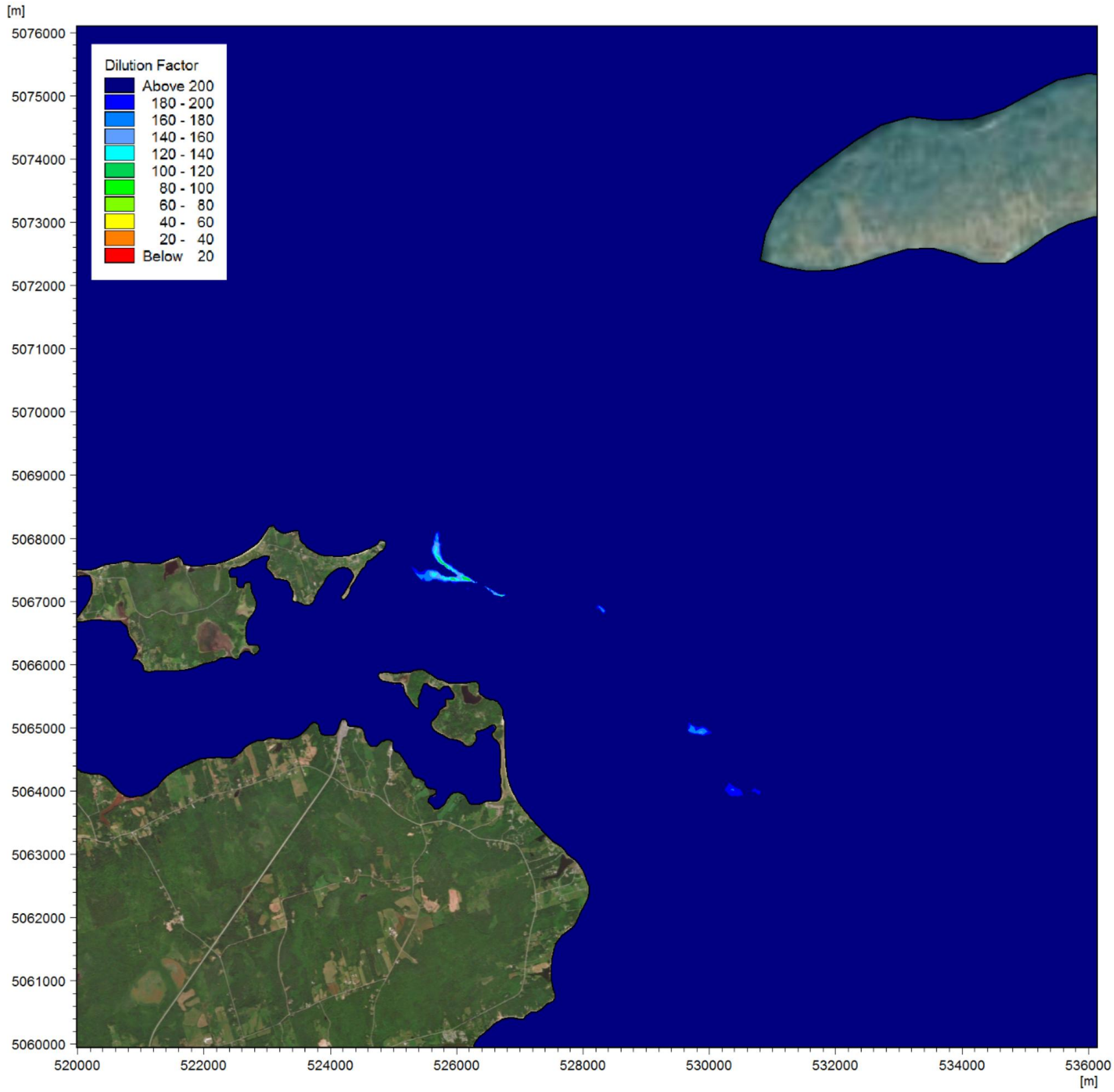


Figure 39 **Spatial Distribution of Simulated Effluent Dilution Factor at the End of One-Month Simulation Period in July (concentration in effluent arbitrarily set at 100 mg/L and assuming no particle degradation over the simulation period)**

To investigate the variation in the arbitrary effluent concentration over time in the surrounding area of the outfall location and to also provide more meaningful comparison to the winter modelling scenario presented in Section 2.3.3, the time series of effluent concentrations at 8 radial locations (in increments of 45 degrees) of 100 m distance from the outfall discharge (Figure 40) are plotted in Figure 41. In general, the locations at 100 m south and west experience higher concentrations most of the time, and concentrations at 100 m north and east locations are lower, with occasional higher values. From the eight radial locations around the outfall and over the whole simulation period, the lowest mean dilution ratio of 441 (Table 12) is achieved at the edge of a 100 m radius.

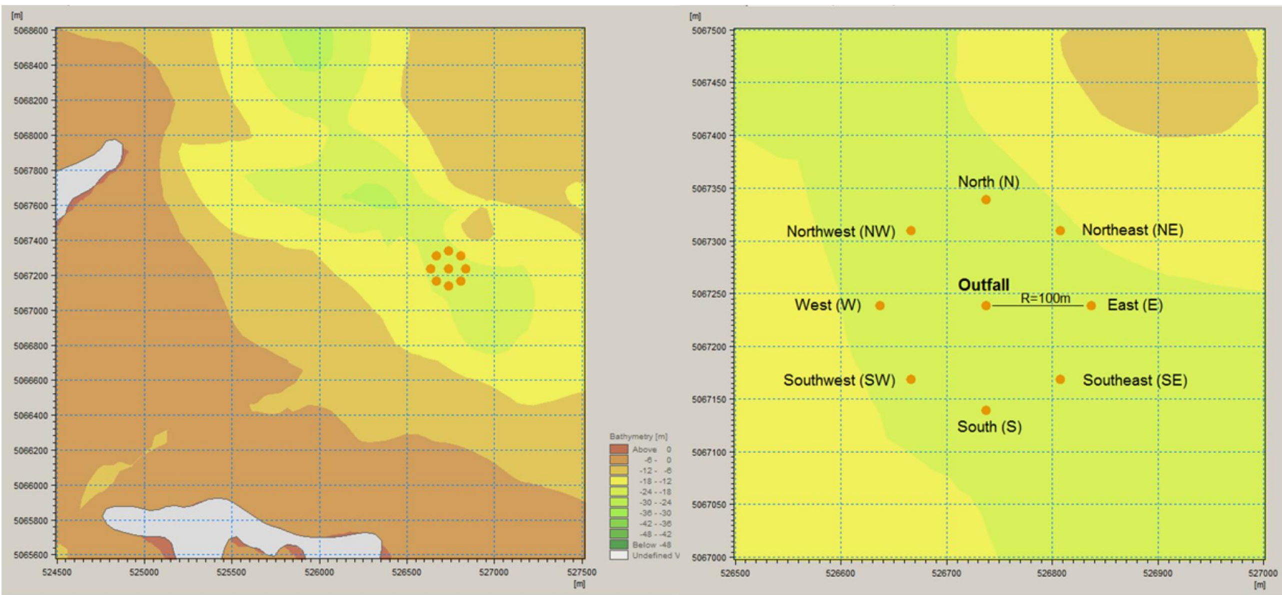


Figure 40 Observation Locations at 100 m Distance from the Outfall Discharge

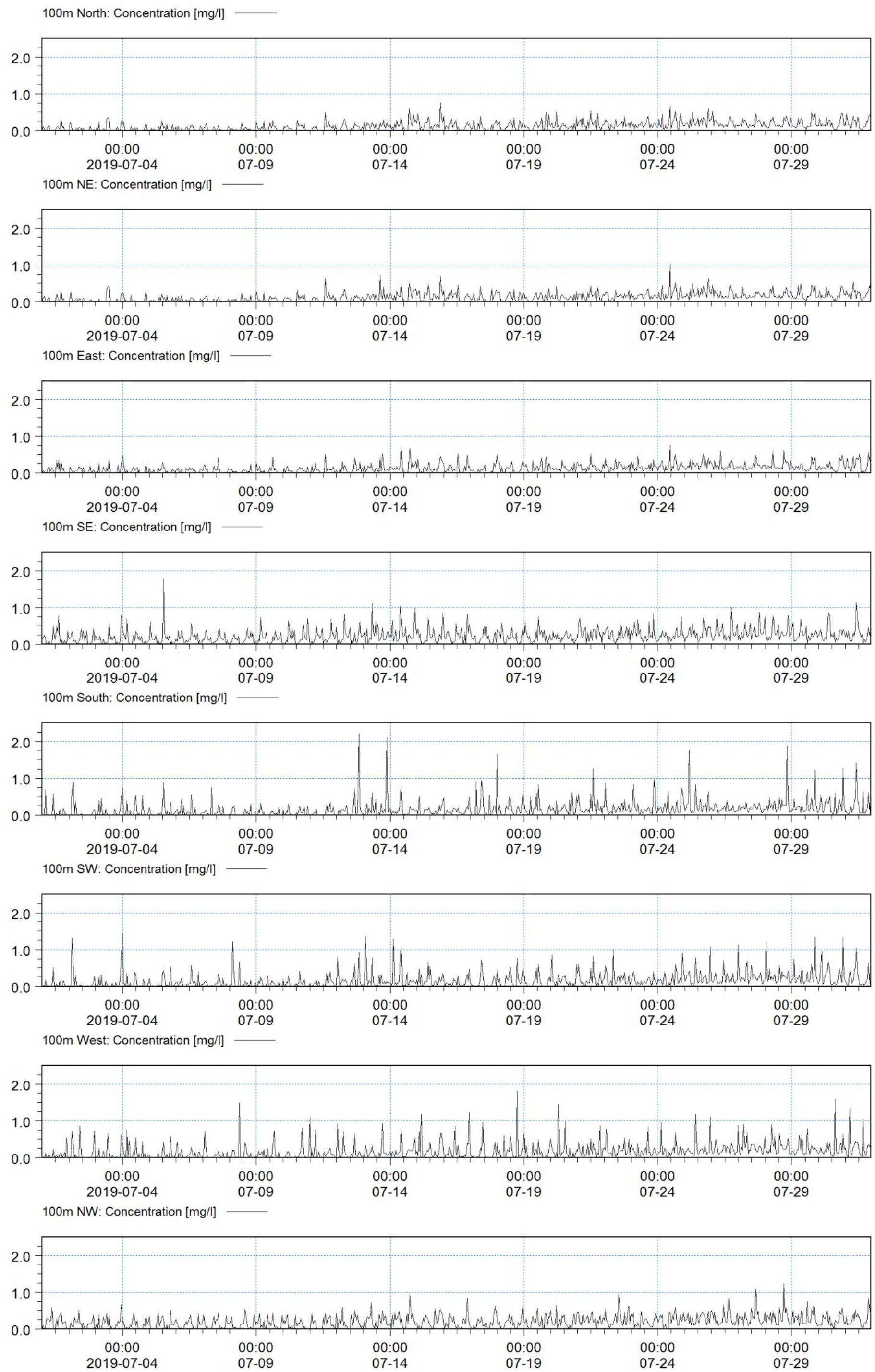


Figure 41 Simulated Effluent Concentrations at 100 m Radius of the Outfall Discharge in July (concentration in effluent arbitrarily set at 100 mg/L)

Table 12 Mean Effluent Concentration and Dilution at 100 m Radius of Outfall Discharge[1] in July

Observation Location	Mean Concentration (mg/L)	Mean Dilution (non-dimensional)
100 m North (N)	0.127	787
100 m Northeast (NE)	0.127	787
100 m East (E)	0.129	775
100 m Southeast (SE)	0.227	441
100 m South (S)	0.164	610
100 m Southwest (SW)	0.162	617
100 m West (W)	0.173	578
100 m Northwest (NW)	0.203	493

NOTE:
1 Effluent concentration at outfall discharge is arbitrarily assumed as 100 mg/L

2.3.3 Winter Scenario

The hydrodynamic dispersion model was conducted to simulate the effluent dispersion characteristics under winter environmental conditions. During the modeling period in February 2019, model domain was assumed covered by an ice sheet with 0.7 m thickness; therefore, the surface forcings of wind, wave, and air heat exchange were not applied. Marine water temperature and salinity were set to constant values of 1.0 ºC and 29.8 ppt respectively. Effluent properties and other boundary conditions applied are summarized in Table 11.

2.3.3.1 Current, Water Temperature and Salinity

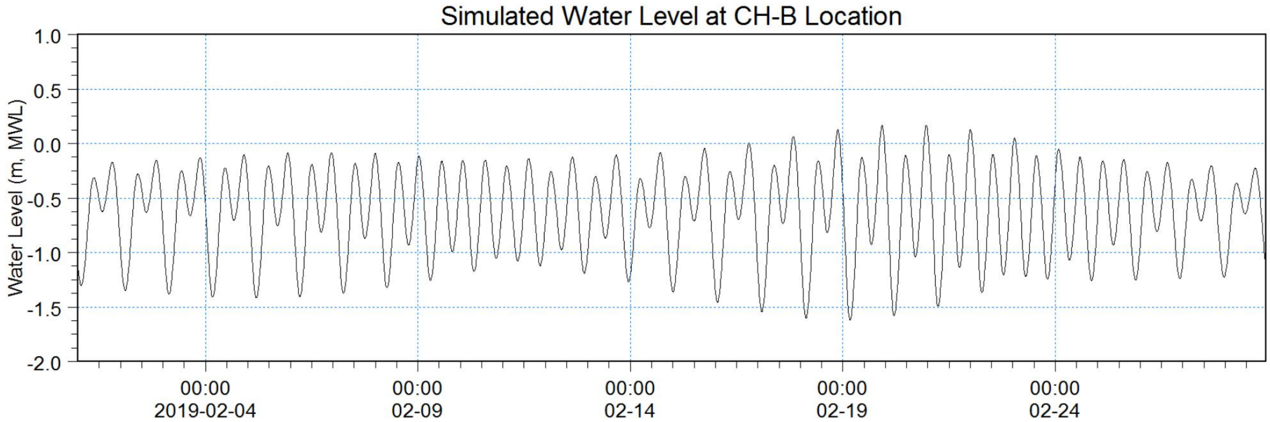
Figure 42 presents the time series of water level (i.e., the surface elevation of water which is underneath the ice cover) and current speed, as well as the direction rose plots of currents in February at the outfall location. Water level changes attributed to tides still occur in winter and where the whole ice cover moves up and down with the tides as observed in Figure 42. This is because tidal level fluctuations are a result of strong gravitational forces that are not constrained by ice cover. Driven primarily by tidal currents, the following is observed.

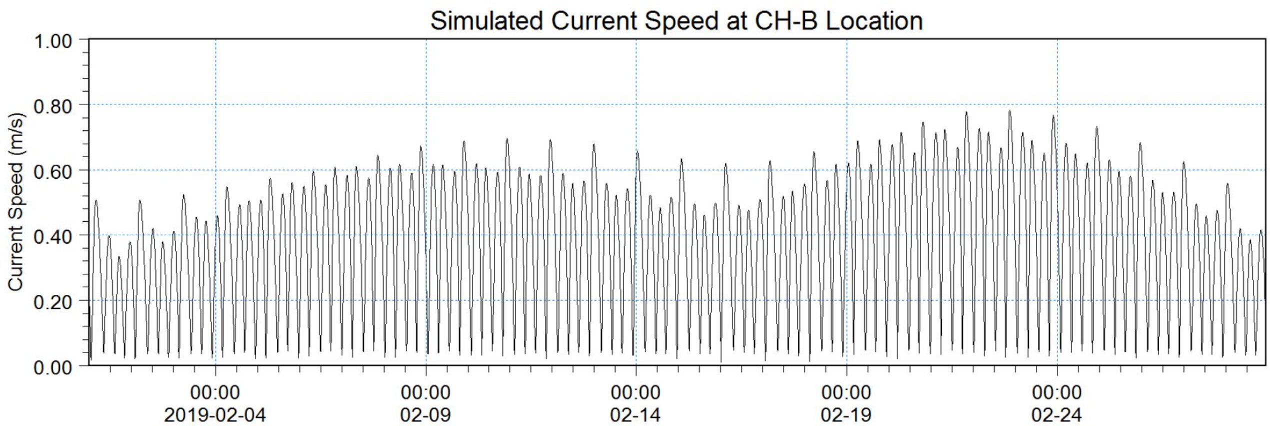
- Water levels vary from -1.62 to 0.17 m (MWL), with a tidal range of 1.79 m which is similar to the tidal range in July (1.82 m). The mean value of water level variation is -0.63 m, which is reduced due to the effect of ice cover compared to the mean water level at 0.00 m during the open-water season in July.
- Current speeds range from 0.01 to 0.78 m/s, with a mean value of 0.38 m/s. The current magnitude is slightly less than that in July. This reduction could be attributed to excluding the effects of wind, wave and the resulting surface current when the water surface is covered by ice. As the receiving water in winter has slightly lower current speeds, this could lead to less current-driven mixing of the effluent plume, and thus potentially lead to lower near-field mixing and dilution. However, with the magnitude of the water currents, the build-up of the effluent plume beneath the ice is not anticipated to occur.

- The circulation pattern shows similar to the summer scenario that currents are typically predominant in the northwest direction for flood currents and in the southeast direction for ebb currents.

Figure 43 presents the simulated time series of water temperature, salinity and density at the outfall location in February, which indicate that:

- without the dynamic effects of air heat exchange on the water surface, the magnitude of water temperature variation overtime is stable, in a range from 1.03 to 1.33 ºC
- the water salinity varies with effluent freshwater and tidal cycles in a range from 29.4 to 29.8 ppt
- corresponding to the variations of water temperature and salinity, the water density varies in a range from 1023.54 to 1023.84 kg/m^3, which is higher than the summer water density. As the receiving water in winter is of higher density, this could lead to more buoyancy-driven mixing of the effluent plume, and thus lead to higher near-field mixing and dilution.





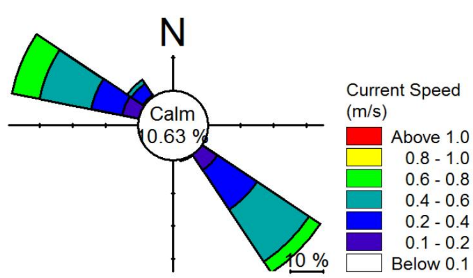


Figure 42 Simulated Water Levels and Currents at the Outfall Location in February 2019

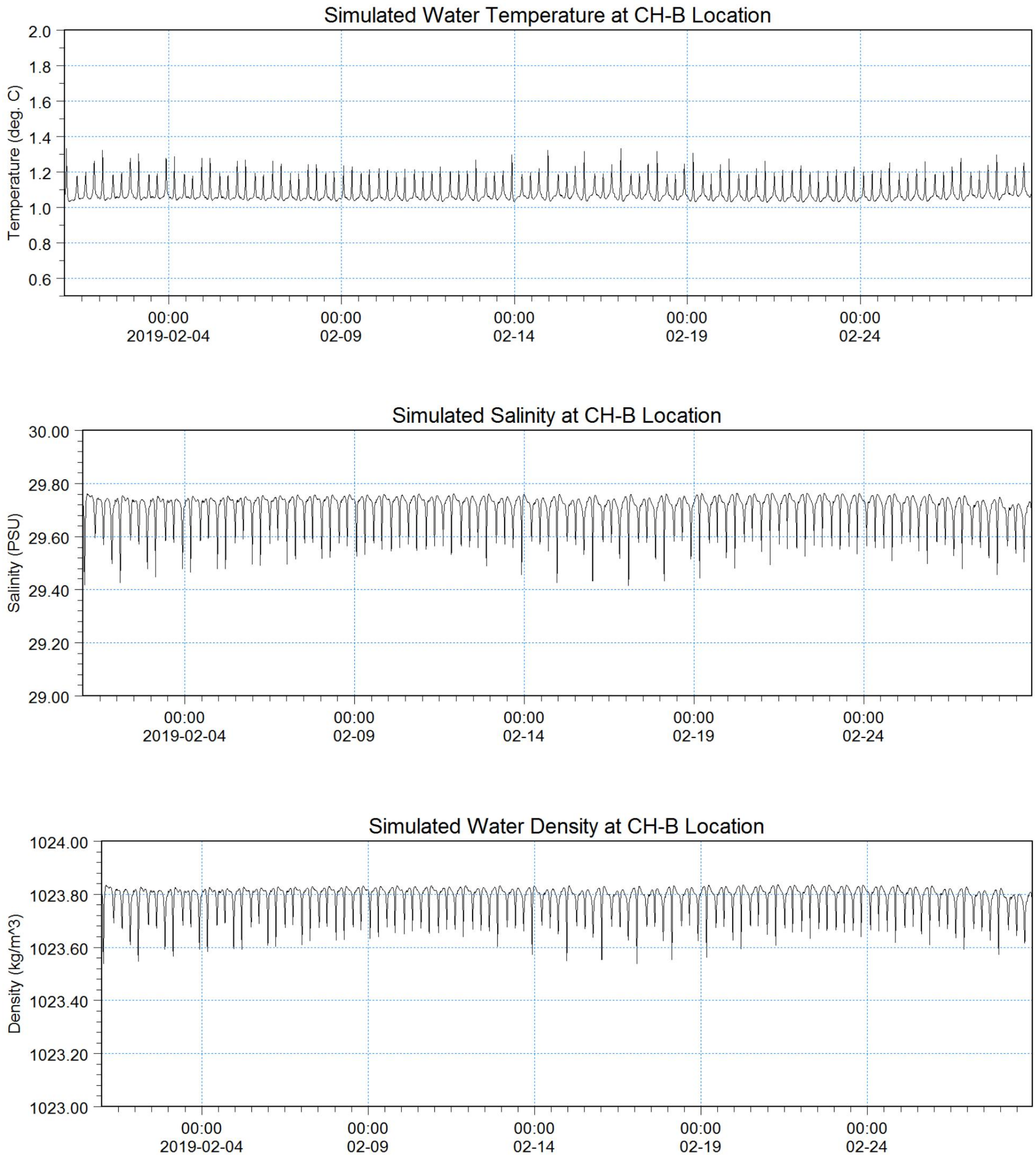


Figure 43 Simulated Water Temperature, Salinity and Density at the Outfall Location in February 2019

2.3.3.2 Effluent Dispersion

Figure 44 presents cumulative effects of the simulated effluent concentrations by the end of the one-month simulation period in February. Since the plume is not visible in Figure 44 using the full scale for the arbitrary concentration of 100 mg/L as was the case for the summer plume, and due to improved dispersion, a lower concentration scale of 2.5 mg/L is used and shown in Figure 45. Figure 46 presents the achieved dilution ratios by the end of the one-month simulation period in February. The upper scale for the dilution factor in the legend for Figure 46 also had to be doubled from 100 to a dilution factor of 200 in this updated RWS report and as for summer conditions in order for the effluent plume to be visible.

The simulated effluent concentrations and achieved dilution ratios by the end of the one-month simulation period in February indicate slightly higher concentrations and lower dilution ratios compared to the summer scenario (Figure 38 and Figure 39), but in the same order of magnitude, i.e., the dilution ratios are mostly higher than 100 in the entire model domain.

Figure 47 provides the time series of effluent concentrations at 8 radial locations (in increments of 45 degrees) of 100 m distance from the outfall discharge (Figure 40). Over the one-month simulation period in February, the lowest mean dilution ratio of 337 (Table 13) is achieved at the edge of 100 m radius, which is slightly lower than that achieved for summer conditions. This mean dilution ratio, however, is relatively indistinguishable at these higher dilution ratios with overall summer dilution ratios, and the resultant arbitrary effluent discharge concentration for winter is generally less than 0.3 mg/L (using an assumed outfall discharge of 100 mg/L concentration for the effluent) and generally less than 0.2 mg/L for summer.

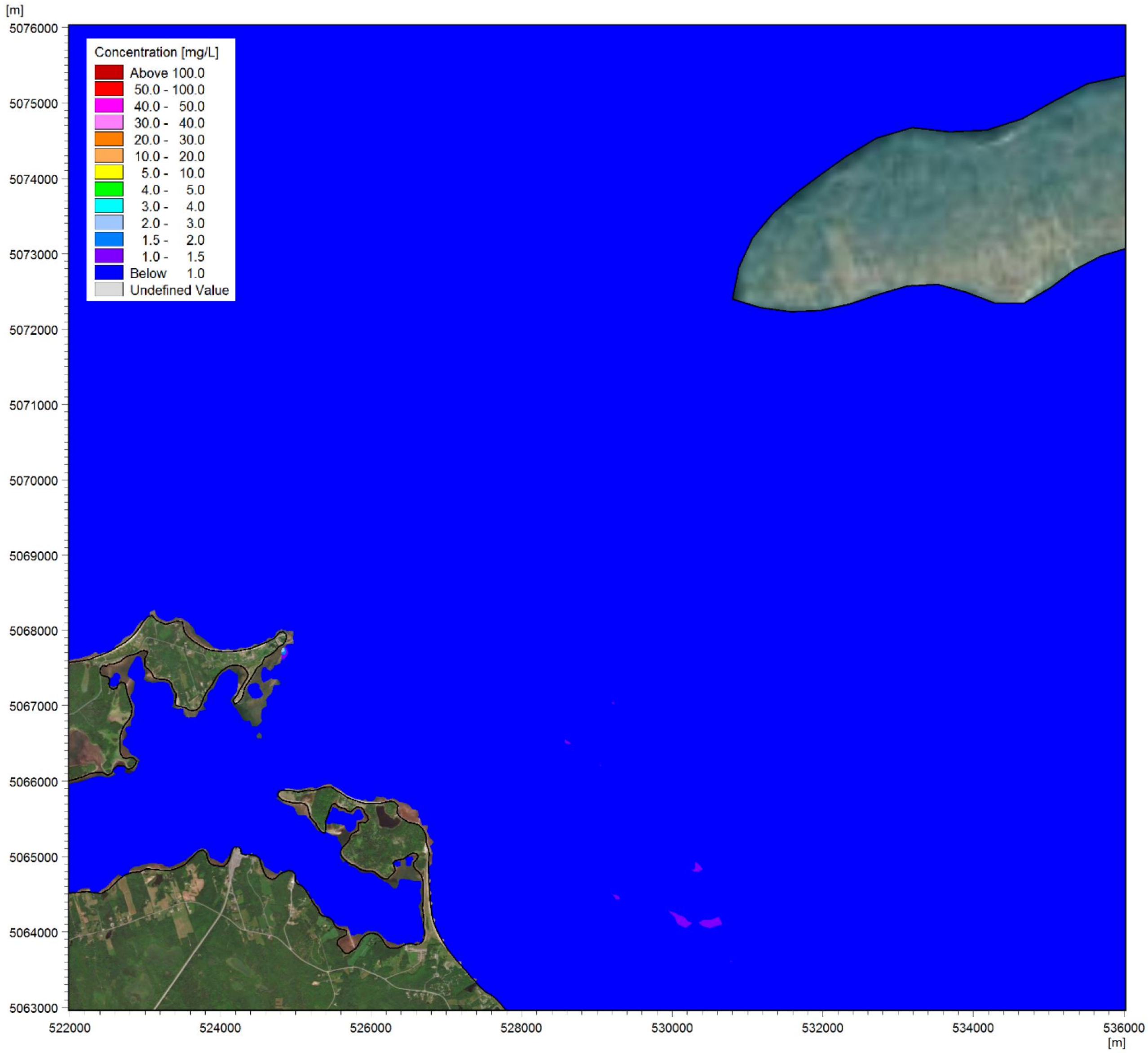


Figure 44 Simulated Effluent Concentration by End of One-month Simulation Period in February (concentration in effluent arbitrarily set at 100 mg/L and assuming no particle degradation over the simulation period)

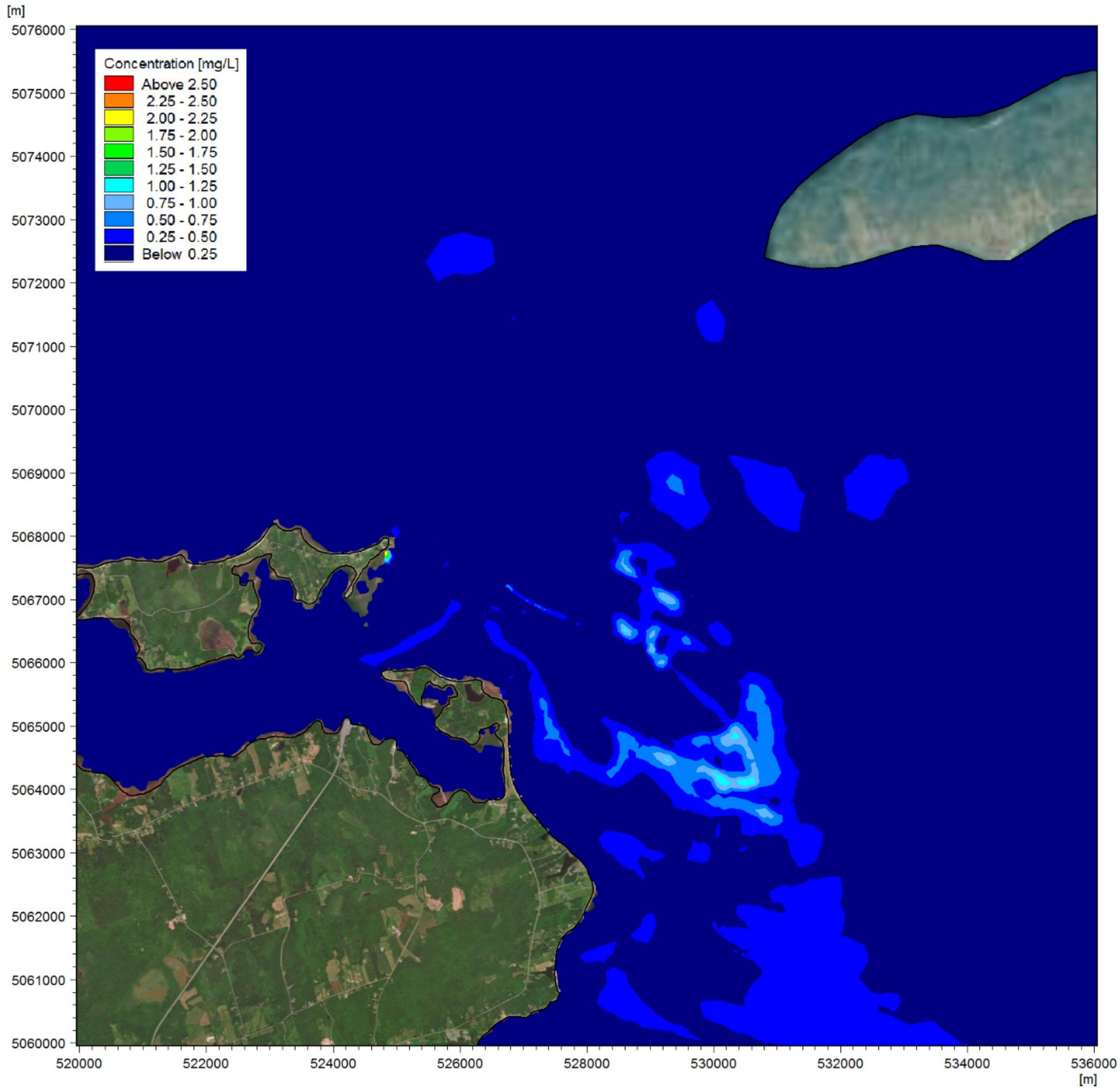


Figure 45 Simulated Effluent Concentration by End of One-month Simulation Period in February (concentration in effluent arbitrarily set at 100 mg/L and assuming no particle degradation over the simulation period; lower concentration of 2.5 mg/L for the upper bound in the figure legend is used)

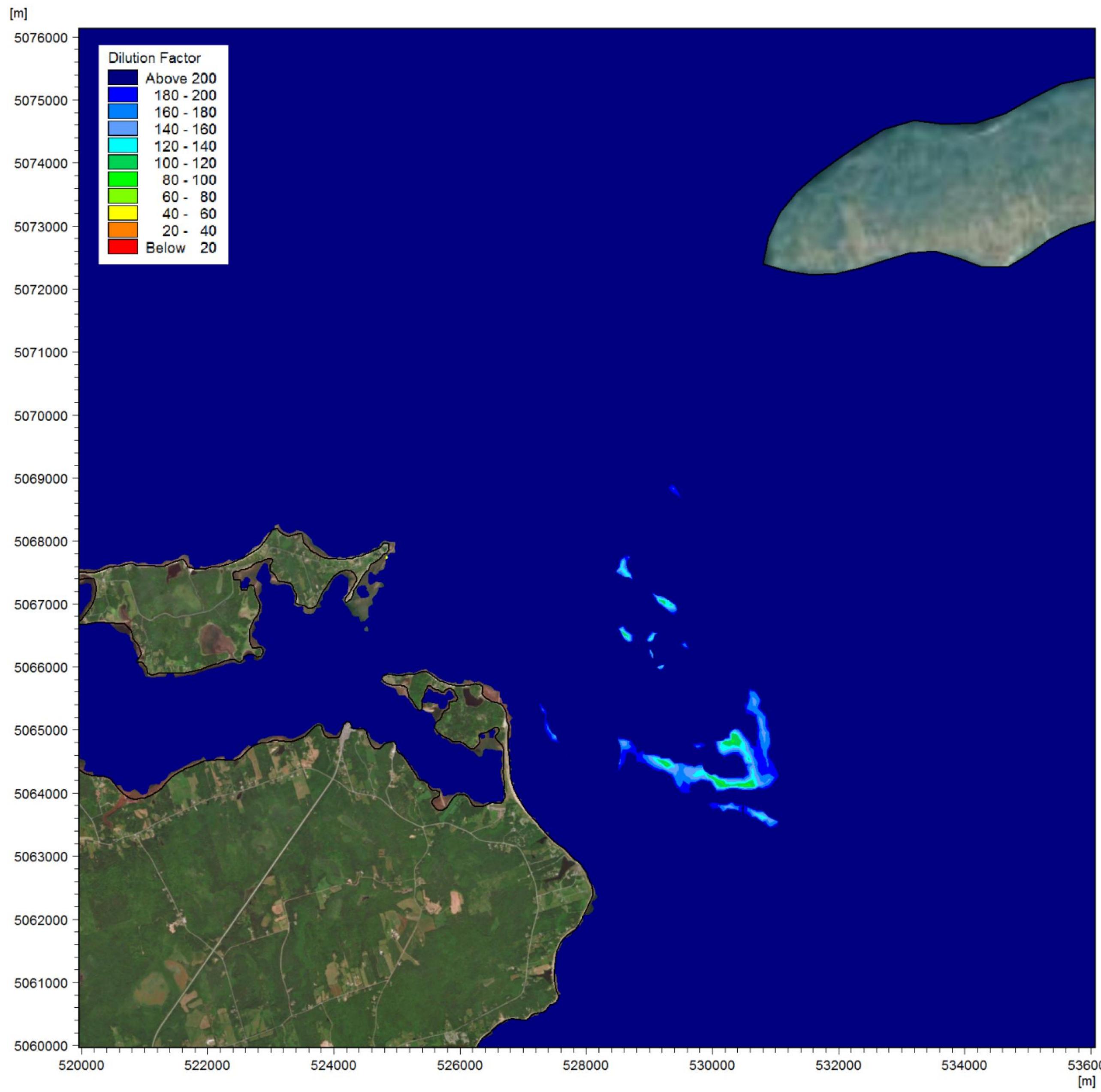


Figure 46 Simulated Dilution Factor Achieved by End of One-month Simulation Period in February (concentration in effluent arbitrarily set at 100 mg/L and assuming no particle degradation over the simulation period)

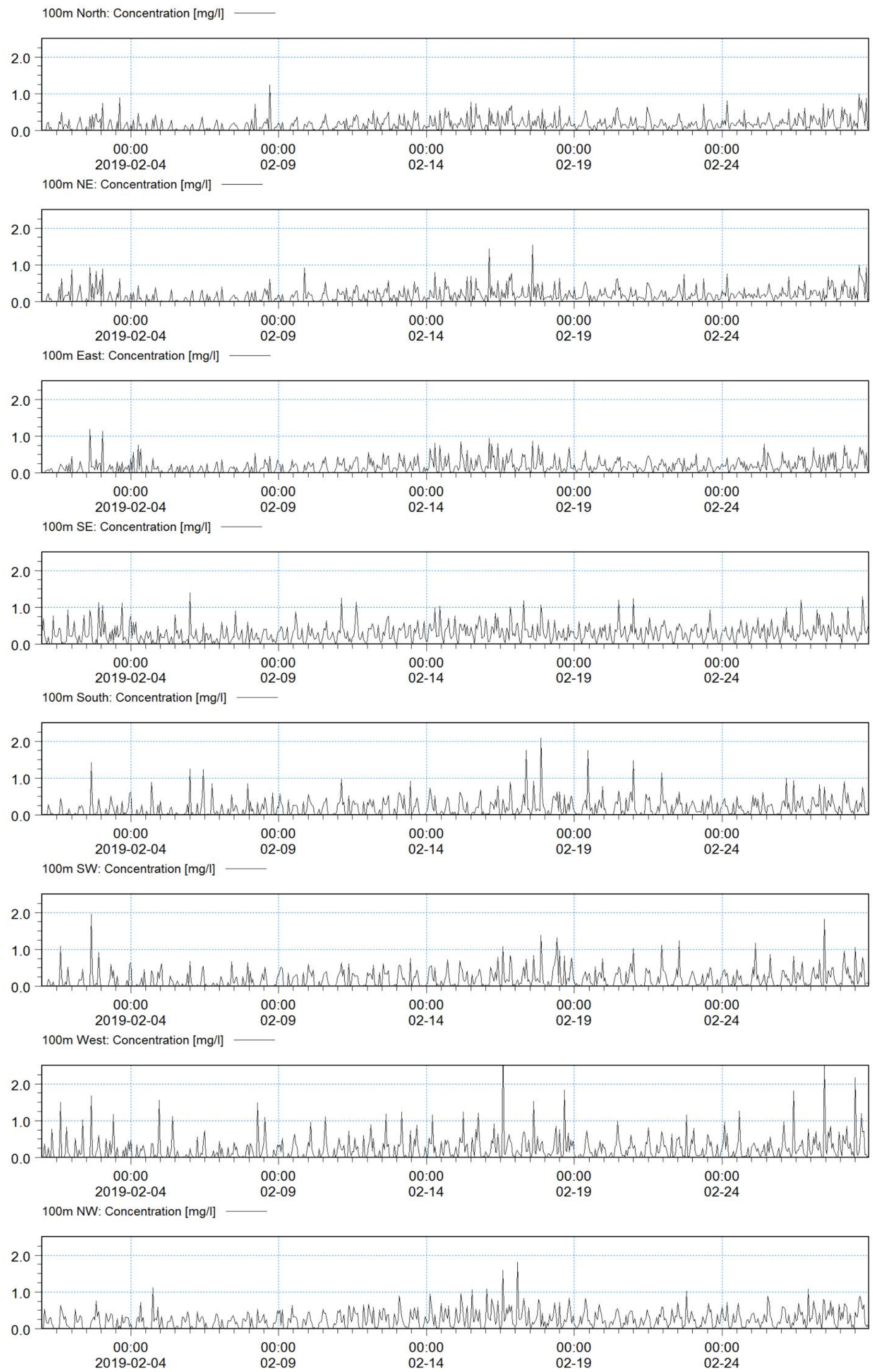


Figure 47 Simulated Effluent Concentrations at 100 m Radius of the Outfall Discharge in February (concentration in effluent arbitrarily set at 100 mg/L)

Table 13 Mean Effluent Concentration and Dilution at 100 m Radius of Outfall Discharge[1] in February

Observation Location	Mean Concentration (mg/L)	Mean Dilution (non-dimensional)
100 m North (N)	0.171	585
100 m Northeast (NE)	0.173	578
100 m East (E)	0.179	559
100 m Southeast (SE)	0.297	337
100 m South (S)	0.191	524
100 m Southwest (SW)	0.188	532
100 m West (W)	0.231	433
100 m Northwest (NW)	0.251	398

NOTE:
1 Effluent concentration at outfall discharge is arbitrarily assumed as 100 mg/L

2.4 CONCLUSION OF FAR-FIELD MODELLING

In this study, the mixing and dispersion of the treated effluent discharged from the NPNS effluent treatment plant into the marine water offshore Caribou Harbour into Northumberland Strait were simulated by a 2D hydrodynamic model for prediction of the far-field effluent dispersion.

The MIKE 21 Coupled Model simulated the effluent dispersion under integrated hydrodynamic and environmental conditions of tidal currents, wind forcing, waves, air heat exchange, density flows, and wastewater discharges to investigate the accumulative characteristics of effluent concentrations and dilution factors in a spatial domain. The hydrodynamic dispersion models were conducted in a time domain over an entire month in July 2019 for the summer conditions and in February 2019 for the winter conditions with ice cover. The effluent discharge was assumed as a single point discharge and no diffuser at the outfall, and the effluent was assumed to have no decay in dispersion which was considered to be a conservative scenario.

The key conclusions based on the effluent dispersion modelling results are summarized as follows:

- Physical oceanographic, hydrometric, and air climate data were collected, reviewed, and analyzed to characterize the physical environments in offshore Caribou Harbour and surrounding areas.
- Field surveys of currents and water temperatures indicated weak vertical stratification in the vicinity of the outfall location, and suggested that a 2D modelling approach was appropriate for this investigation.
- Tide constituents at Skinner and Arisaig were derived based on the Project field water level measurements in 2019 to enable the model to predict the tidal levels in the Northumberland Strait.

- The MIKE 21 spectral wave model was calibrated with 2019 field wave measurements in the vicinity of the outfall location to enable the model to reproduce the local wind-driven waves.
- The MIKE 21 coupled hydrodynamic models of tidal circulation, wave, density flow, and effluent transport were implemented with the objective of simulating the water currents, density flows, and effluent movements that are primarily affected by tidal variation, wind forcing, air temperature, effluent properties, and marine water temperature and salinity. The models were calibrated to the Project 2019 field measurements of water levels, currents, and water temperature. The calibrated model provided confidence in reproduction of the complex hydrodynamic and effluent dispersion processes in the receiving water at the outfall discharge location.
- The hydrodynamic model simulated the dynamic process of circulation currents, water temperature and density, and predicted their variation ranges at the outfall location as follows.

  For the summer conditions:

  - The current speeds ranged from 0.03 to 0.85 m/s, with a mean value of 0.41 m/s. The flood currents are typically predominant in the northwest direction and the ebb currents are predominant in the southeast direction. The strong currents at the outfall site are beneficial for effluent mixing and dispersion driven by currents.
  - The water temperatures ranged from 15.2 to 22.5 ºC. The temperature increase over time is dominated by air heat exchange.
  - The water salinity varied with effluent freshwater and tidal cycles in a small range from 29.5 to 29.8 ppt.
  - As a function of water temperature and salinity, the resulting water density decreased from 1021.90 to 1020.01 kg/m^3.

  For the winter conditions:

  - Current speeds ranged from 0.01 to 0.78 m/s, with a mean value of 0.38 m/s. The current magnitude is slightly less than that for summer conditions.
  - Without the dynamic effects of air heat exchange on the water surface, the magnitude of water temperature variation overtime was in a small range from 1.03 to 1.33 ºC.
  - The water density varied in a small range from 1023.54 to 1023.84 kg/m^3, which is higher than that for summer conditions.
- The hydrodynamic dispersion model simulated the dynamic process of effluent concentrations, and provided the following model results:
  - Driven by circulation currents, the effluent plume from the outfall discharge dispersed primarily southeasterly during ebb tides and northwesterly during flood tides.

- The effluent plumes were well-mixed and dispersed in the receiving water (i.e., entrainment was not observed). By the end of the one-month simulation period, no effluent concentration buildup was found in the harbour basins, along the shorelines and in the entire model domain.
- The dilution factor in most of the model domain was above 100 for both the summer and winter conditions.
- A lowest mean dilution factor of 441 was achieved at the edge of 100 m radius from the outfall location for the summer conditions.
- A lowest mean dilution factor of 337 was achieved at the edge of 100 m radius from the outfall for the winter conditions. The difference between the high summer and winter mean dilution factors does not give rise to appreciable differences between the two seasons for an arbitrary effluent concentration.

- Key assumptions in this modelling study are no decay and no dispersion defined in the Particle Tracking module of MIKE 21; therefore, the modelling results are considered conservative.
- The 2D modelling results provide the hydrodynamic information (water levels and current velocities) required for the CORMIX near-field dispersion modelling presented in Section 3.

3.0 NEAR-FIELD MODELLING

The objective of near-field modelling is to undertake effluent dilution and mixing analysis of the treated effluent from the mill under conservative conditions. Near-field modelling was conducted for a selected 3-port diffuser with configuration and nozzle orientations as proposed in Stantec (2018). The scale of the near-field modelling is on the order of several metres to about two hundred metres, which allows for a detailed prediction of the effluent plume discharging from the diffuser.

The near-field modelling was performed to determine the acceptability of expected daily maximum effluent concentrations for a number of parameters. The acceptability was defined as compliance with applicable federal water quality guidelines at the end of the mixing zone in the receiving environment.

As shown by MIKE 21 2D modelling presented in Section 2.3.3.2, effluent dispersion with winter ice-cover is very similar to dispersion in summer open-water. Both models simulated very high dilution ratios measured at 100 m at 8 radial locations from the outfall. Therefore, CORMIX modelling was undertaken for effluent quality parameters under conservative summer open-water conditions. Open-water conditions exist for a longer period in the year compared to the presence of ice. Temperature, however, was modelled in CORMIX as described further below for both winter and summer conditions because it could be of interest with respect to potential thermal impacts from sudden changes in temperature and thermal shock to marine organisms by the effluent temperature. Also, a thermal differential between effluent and ambient conditions is larger in winter (24°C) than in summer (20.2 °C).

3.1 BACKGROUND

The Cornell Mixing Zone Expert System (CORMIX, Version 11.0) was used to analyze and assess near-field mixing (conditions at and near the initial mixing zone). CORMIX is a software system for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. The major emphasis is on the geometry and dilution characteristics of the initial mixing zone, but the system can also predict the behavior of the discharge plume at larger distances. CORMIX is a three-dimensional (3D) model which can be run in steady-state and tidal ambient conditions.

A mixing zone in this study was defined as per the Canadian Council of Ministers of the Environment (CCME 2003) as “an area contiguous with a point source (effluent) where the effluent mixes with ambient water and where concentrations of some substances may not comply with water quality guidelines or objectives”.

The modelling of the near-field dilution and mixing is aimed to confirm that the ambient water quality concentrations or the established Water Quality Guidelines (WQG) are met at the edge of the mixing zone.

The distance from the outfall pipe to the boundary of the mixing zone applied in this study is limited to 100 m, which is the standard mixing zone distance accepted by CCME (CCME 2009). In addition, the

Atlantic Canada Wastewater Guidelines Manual (EC 2006) indicates that the surface water quality objectives must be achieved at all points beyond a 100-m radius from the effluent outfall. Both above-mentioned documents are applicable for municipal effluent; however, they were used in this study as guidance for the industrial discharge.

3.2 NEAR-FIELD MODELLING CONDITIONS

3.2.1 Ambient Hydrodynamic Conditions

Ambient hydrodynamic conditions are characterized by flows, tides, currents, and wind. Current flows in coastal areas depend strongly on tidal circulation, wind patterns, and nearshore bathymetry. Current velocity magnitude and direction at the CH-B outfall location is the predominant factor defining effluent transport and dispersion.

Hydrodynamic information at the CH-B outfall location was obtained from MIKE 21 2D modelling results as described in Section 2. The proposed outfall is located offshore of Caribou Harbour in Northumberland Strait at a water depth of 20.3 m MWL. Based on bathymetry information in the near-field zone, the average depth for the extent of the mixing zone was conservatively assumed to be 18.9 m.

The depth-averaged maximum and mean current velocities simulated by MIKE 21 at CH-B for July are 0.85 m/s and 0.41 m/s, respectively.

The slack velocities, when the tides are weakest and changing direction, were calculated based on MIKE 21 data as the minimum hourly velocity for 24 hours. Then, the minimum hourly velocities for 30 days were averaged to obtain the slack velocity for a month. The average monthly slack velocity at CH-B is 0.10 m/s and the maximum monthly slack velocity is 0.14 m/s.

Bottom sediments at CH-B are predominantly sandy with approximated particle diameter of 0.5 mm. Bottom roughness in the model is represented by the Manning's "n". For modelling purposes, the Manning's n in the mixing zone was assumed to be 0.022 as directed in USGS (1989).

Winds can affect the circulation, mixing and plume movement at CH-B. The dominant wind direction in the region is from the northwest and west. The mean wind speed for July is 3.79 m/s, which was calculated using hourly data for the Caribou Point (Station ID 8200774).

To provide conservative estimates of water quality in the mixing zone, the decay (or removal) coefficient was not applied in CORMIX for all conservative and non-conservative parameters. The first-order decay option can be used in CORMIX for non-conservative parameters to characterize exponential removal of a contaminant due to sedimentation, bioaccumulation or element transformation, but this option was not applied in this study.

For presentation purposes the initial effluent concentration for an arbitrary parameter prior to discharge for all scenarios was arbitrary assumed to be 100 mg/L. Based on this concentration the dilution factors in the near-field mixing zone were derived. Then, the dilution factors were applied to the studied water quality parameters to derive the concentration of these parameters at distances from the diffuser, and at the end of the 100-m mixing zone, and to derive the proposed effluent limit.

3.2.2 Ambient Water Quality

Water quality data for Northumberland Strait around the CH-B location was collected in May and June 2019 and are presented in Section 4.1 of the Focus Report. These data were used as ambient conditions in CORMIX modelling. A summary of ambient water quality is presented in Table 14.

Table 14 Background Water Quality

Parameter	Unit	Average Value
Adsorbable Organic Halides (AOX)	mg/L	n/a
Total Nitrogen (TN)	mg/L	0.17
Total Phosphorus (TP)	mg/L	0.5
Colour	TCU	4.5
Chemical Oxygen Demand (COD)	mg/L	n/a
Biochemical Oxygen Demand (BOD_5)	mg/L	2.5 [1]
Total Suspended Solids (TSS)	mg/L	2.5
Dissolved Oxygen (DO)	mg/L	9.7
pH	-	7.8
Temperature (summer)	°C	16.8
Temperature (winter)	°C	1
Salinity	g/L	30
Cadmium	µg/L	0.084
Total Dioxins & Furans	pg/L	3.213
Phenanthrene (PAH)	µg/L	0.01
Total Resin Acids	mg/L	0.06
Total Fatty Acids	mg/L	0.07
Total Pulp and Paper Phenols	µg/L	5[1]

[1] Non-detect; a ½ of the reportable detection limit of 5 mg/L was used
n/a – not applicable to marine test

3.2.3 Effluent Characteristics

The wastewater treatment plant is sized to treat a maximum of 85,000 m^3/day or 0.98 m^3/s. The annual average flow rate is 62,000 m^3/day or 0.72 m^3/s (KSH 2016). For the purpose of this study, the maximum effluent flow rate of 0.984 m^3/s was used in CORMIX modelling. An additional scenario for a flow rate of 50,000 m^3/day or 0.579 m^3/s (a 35,000 m^3/day reduction) was also evaluated. Density of the effluent and ambient water was calculated based on temperature and salinity.

The maximum effluent flow rate and maximum effluent limits for modelling were selected to provide conservative results for effluent mixing in the near field to the outfall. Expected daily maximum water quality characteristics of the treated effluent from the mill were provided by KSH (2016) and summarized in Table 15. Scenario A remains unchanged from the effluent quality used in Stantec (2018) except for total dissolved solids (refer to Table 11) and additional parameters that were added to the model in this study.

Effluent quality for Scenarios B and C were provided by NPNS. Effluent quality in both Scenarios B and C are based on the May 2019 draft Pulp and Paper Effluent Regulations (PPER) limits applied to NPNS current Reference Production Rate (RPR) as defined by Environment and Climate Change Canada (ECCC). The draft PPER are mass-based limits. Scenario B applies the regulated limits at 85,000 m^3/day flow, while Scenario C applies the regulated limits at 50,000 m^3/day.

Scenarios A, B and C are discussed in more detail in Section 3.2.5.

Table 15 Daily Maximum Effluent Water Quality

Parameter	Unit	Daily Maximum Effluent Water Quality (2018 Stantec) Scenario A (Average Velocity)	Draft PPER Limits (High Flow and Low Concentration)[1] Scenario B (Slack Velocity)	Draft PPER Limits (Low Flow and High Concentration)[1] Scenario C (Slack Velocity)
Adsorbable Organic Halides (AOX)	mg/L	7.8	7.8	7.8
Total Nitrogen (TN)	mg/L	6.0	15.0	15.0
Total Phosphorus (TP)	mg/L	1.5	1.5	1.5
Colour	TCU	750	750	750
Chemical Oxygen Demand (COD)	mg/L	725	497	845
Biochemical Oxygen Demand (BOD_5)	mg/L	48	29	49
Total Suspended Solids (TSS)	mg/L	48	42	71
Dissolved Oxygen (DO)	mg/L	>1.5	>1.5	>1.5
pH	-	7.7 (range 7.0-8.5)	7.7 (range 7.0-8.5)	7.7 (range 7.0-8.5)
Temperature	°C	25 (winter), 37 (summer)	25 (winter), 35 (summer)	25 (winter), 35 (summer)
Total Dissolved Solids (TDS) or Salinity	g/L	2	2	2
Cadmium	µg/L	1.03	1.03	1.03
Total Dioxins & Furans	pg/L	3.675	3.675	3.675
Phenanthrene (PAH)	µg/L	0.044	0.044	0.044
Total Resin Acids	mg/L	0.57	0.57	0.57
Total Fatty Acids	mg/L	0.335	0.335	0.335
Total P&P Phenols	µg/L	6.13	6.13	6.13

[1] RPR 938.5 Adt/y

3.2.4 Diffuser Configuration

A three-port diffuser is proposed for the outfall design of CH-B as described in Stantec (2018). The ports were assumed to be located 1.0 m above the seabed (i.e., port height). A 0.3 m^2 port opening was used.

The horizontal angle of the diffuser was found to be optimal when it is perpendicular to the predominant flow. Statistical analysis of flow directions at CH-B revealed that 96% of the time flow is either in the southeast or northwest direction (Figures 48 and 49). A current rose (similar to a wind rose) for the depth-average current velocities is shown in Figure 26 for the outfall location.

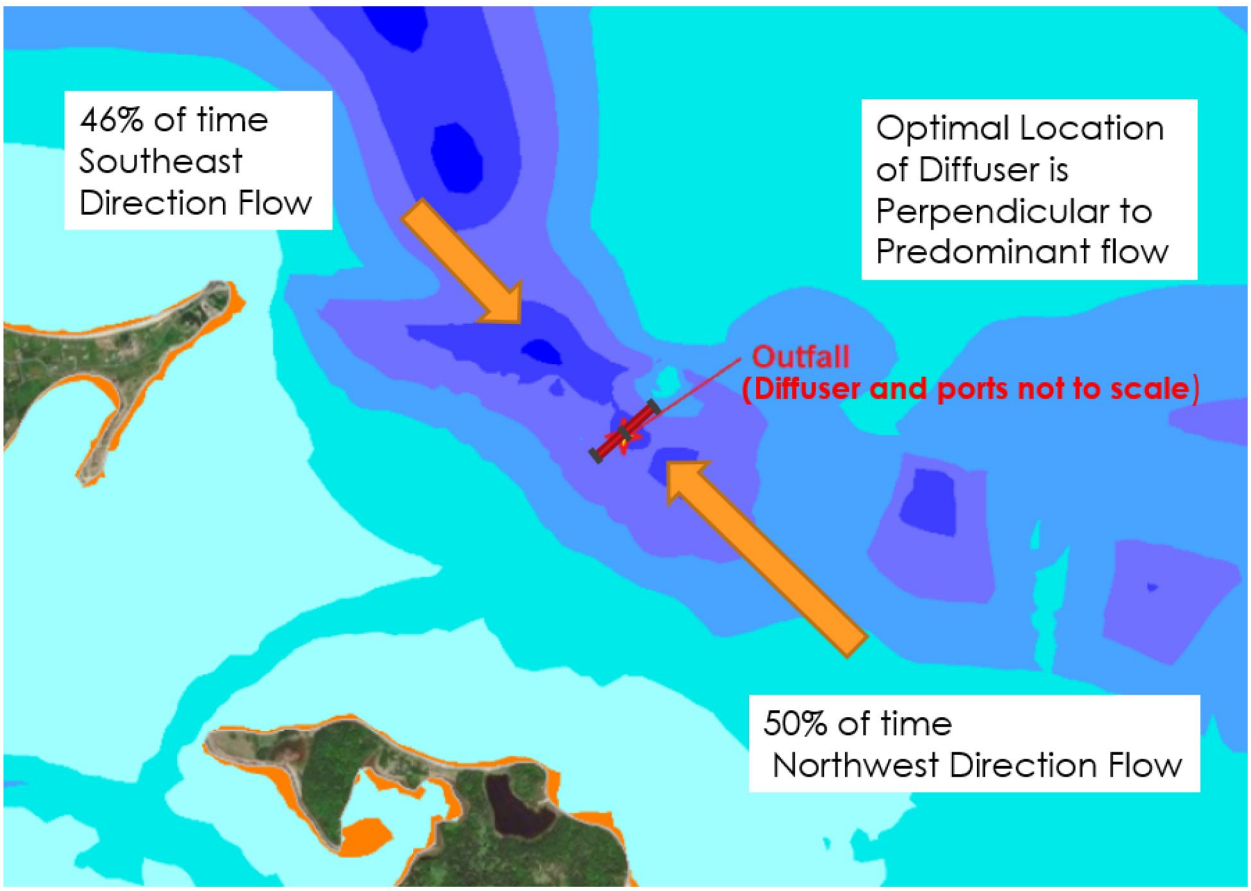


Figure 48 Depth-Averaged Ambient Flow Directions at the CH-B Outfall Location

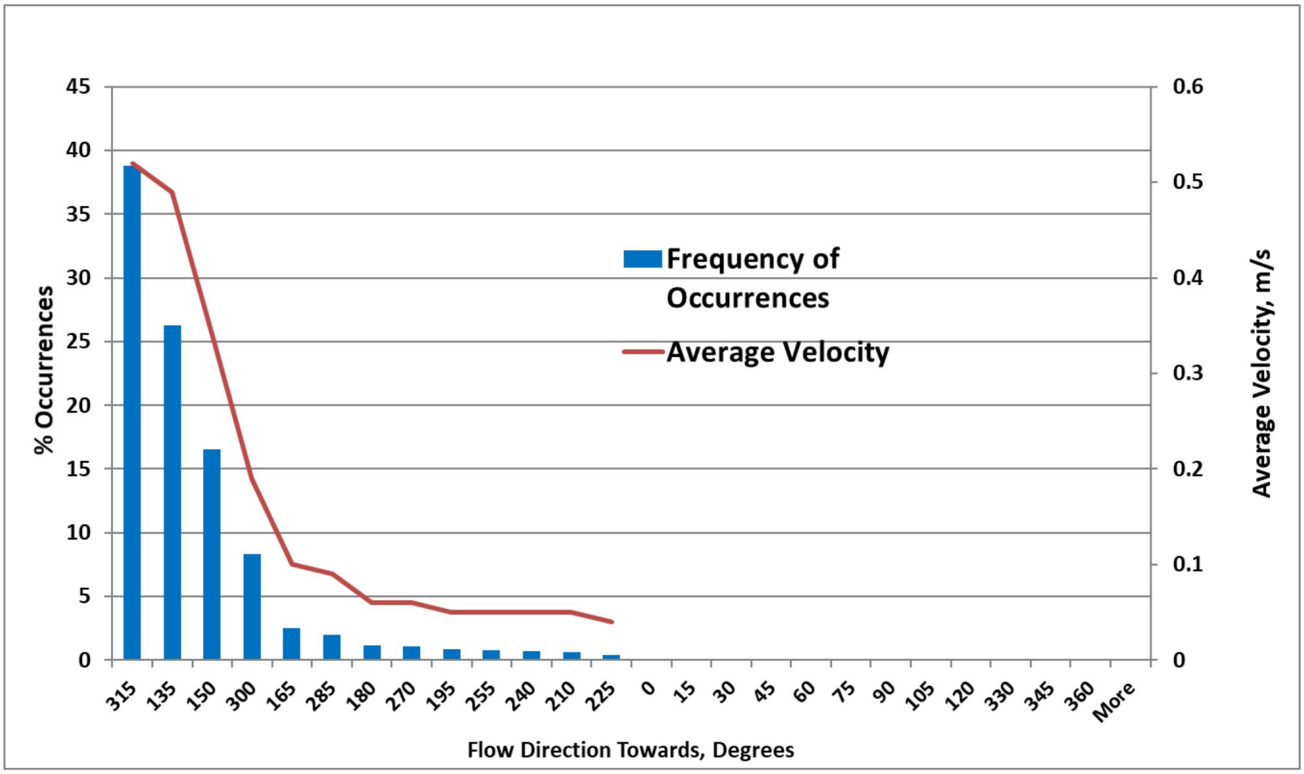


Figure 49 Frequency of Depth-Averaged Ambient Velocities and Flow Directions at the CH-B Outfall Location

Other characteristics of the diffuser are the same as presented and discussed in Stantec (2018). Schematic representation of the three-port diffuser used in the CORMIX model is shown in Figure 50.

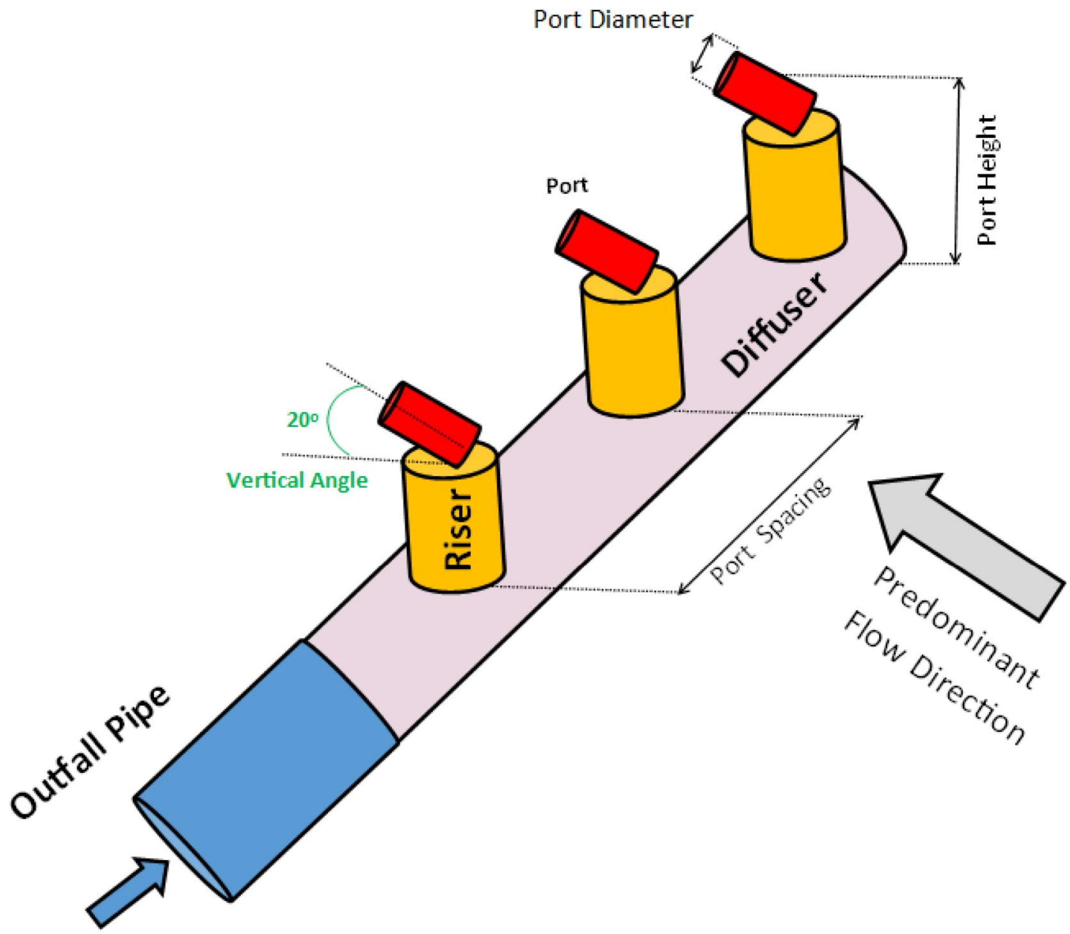


Figure 50 Schematic Representation of Three-Port Diffuser

Table 16 summarizes the CORMIX model input data for CH-B for a three-port diffuser. Ice cover for winter conditions was modelled in CORMIX for temperature to assess potential thermal impacts and where the wind speed was set to zero and the water depth was reduced to account for the ice thickness.

Table 16 CORMIX Input Data

Characteristic	Value
Port Opening, m^2	0.3
Number of Ports	3
Port Spacing, m	25
Vertical Pipe Angle (theta)[1], degree	20
Horizontal Pipe Angle (sigma)[2], degree	0
Alignment Angle (gamma)[3], degree	90
Relative Orientation Angle (beta)[4], degree	90
Port Height Above Seabed, m	1.0
Wastewater Flow Rate, m^3/s	0.984 (Scenario A, B), 0.579 (Scenario C)
Water Depth at Outfall, m	20.3
Average Depth in Mixing Zone, m	18.9
Ambient Velocity at Tidal Conditions, m/s	Max=0.85, Average=0.41
Slack Ambient Velocity, m/s	Max=0.14, Average=0.10
Manning's n	0.022
Ambient Water Density, kg/m^3	1021.76
Ambient Salinity, g/L	30
Ambient Summer Temperature, °C	16.8
Ambient Winter Temperature, °C	1
Effluent Density, kg/m^3	993.36 (Scenario A), 955.55 (Scenario B and C)
Effluent Salinity, g/L	2
Effluent Summer Temperature, °C	37 (Scenario A), 35 (Scenario B and C)
Effluent Winter Temperature, °C	25
Average Wind Speed in July, m/s	3.79

Notes:
[1] Vertical Pipe Angle (Theta) – angle between port centerline and a horizontal plain
[2] Horizontal Angle (Sigma) – angle measured counterclockwise from ambient current direction to the plane projection of the port center line. Angle is 0° when the port points downstream in the ambient flow direction
[3] Alignment Angle (Gamma) – angle measured counterclockwise from the ambient flow direction to the diffuser axis.
[4] Relative Orientation Angle (Betta) – angle measured counterclockwise or clockwise from the average plan projection of the port centerline to the nearest diffuser axis.

3.2.5 Modelling Scenarios

Three modelling scenarios, representative of summer open-water conditions, were modelled for the CH-B outfall location using CORMIX.

Scenario A – Maximum Effluent Quality. This scenario utilizes the average current velocities for July 2019 and effluent flow rate of 85,000 m^3/day or 0.984 m^3/s. Effluent summer temperature was assumed (37°C), similar to the 2018 RWS report (Stantec 2018).

Scenario B – Draft PPER Limits. This scenario utilizes the slack velocity for July 2019 and effluent flow rate of 85,000 m^3/day or 0.984 m^3/s. Effluent summer temperature was assumed to be 35 °C.

Scenario C – Draft PPER Limits. This scenario utilizes the slack velocity for July 2019 and effluent flow rate of 50,000 m^3/day or 0.579 m^3/s. Effluent summer temperature was assumed to be 35 °C.

3.3 NEAR-FIELD MODELLING RESULTS

The results for Scenario A are presented in Figure 51. The plume reaches the surface at about 25 m from the diffuser. Initial discharge velocity is 4.6 m/s, which provides entrainment of ambient water for mixing, fast initial mixing, and a stable plume formation. The dilution ratio is 252 times at 10 m from the ports and 427 times at the end of the mixing zone (i.e., at 100 m). Figure 51 presents the plan and side views of the effluent plume for Scenario A, as well as the dilution isolines for the three-port diffuser.

Scenario B is the most conservative scenario as it utilizes slack ambient velocities and maximum effluent flow rate. The results for Scenario B are presented in Figure 52. Effluent flow rate and diffuser characteristics are the same as for Scenario A, therefore, the initial discharge velocity is the same as for Scenario A. The dilution ratio is 51 times at 5 m from the ports and 146 times at the end of the mixing zone (i.e., at 100 m). Figure 52 presents the plan and side views of the effluent plume for Scenario B, as well as the dilution isolines for the three-port diffuser.

The results for Scenario C are presented in Figure 53. The plume reaches the surface also at about 25 m from the diffuser. Initial discharge velocity is 2.7 m/s and lower than for Scenarios A and B because of the lower effluent flow rate of 50,000 m^3/day. The dilution ratio is 78 times at 5 m from the ports and 219 times at the end of the mixing zone (i.e., at 100 m). Figure 53 presents the plan and side views of the effluent plume for Scenario C, as well as the dilution isolines for the three-port diffuser.

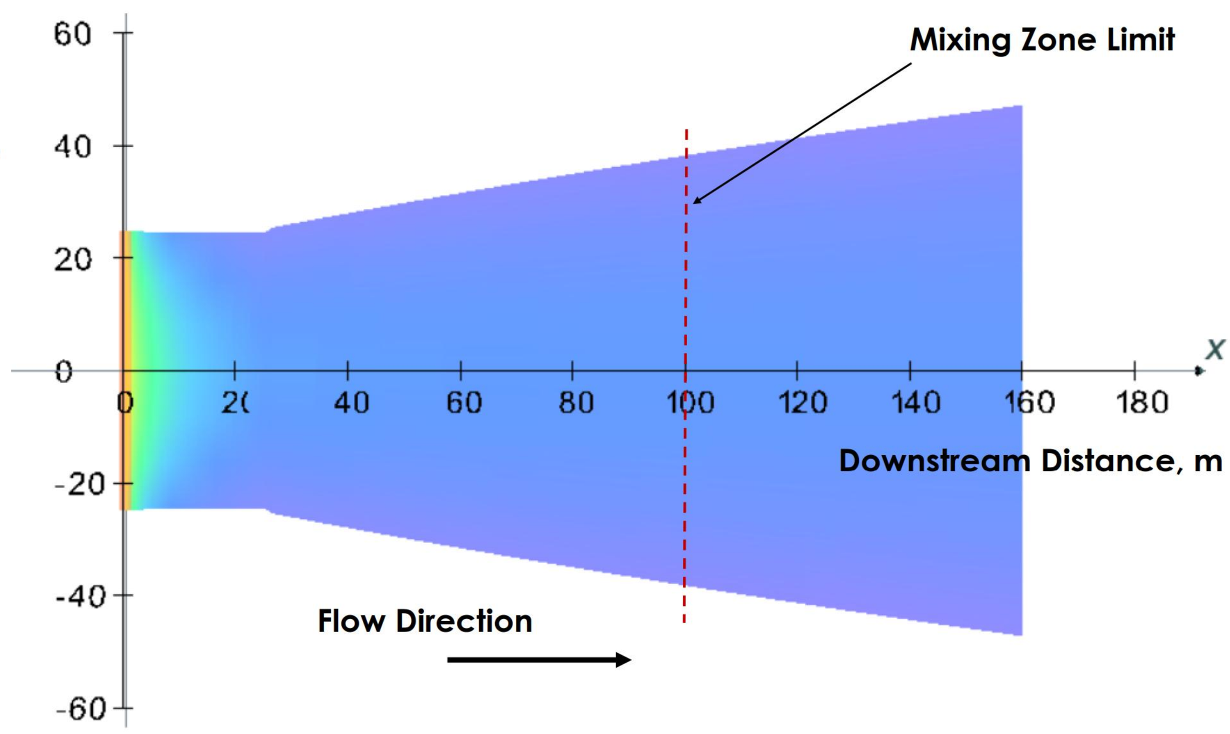
The summary of results for the effluent dilution ratios for the scenarios is presented in Table 17.

Table 17 Effluent Dilution Ratios for the CH-B Outfall Location with a Three-Port Diffuser

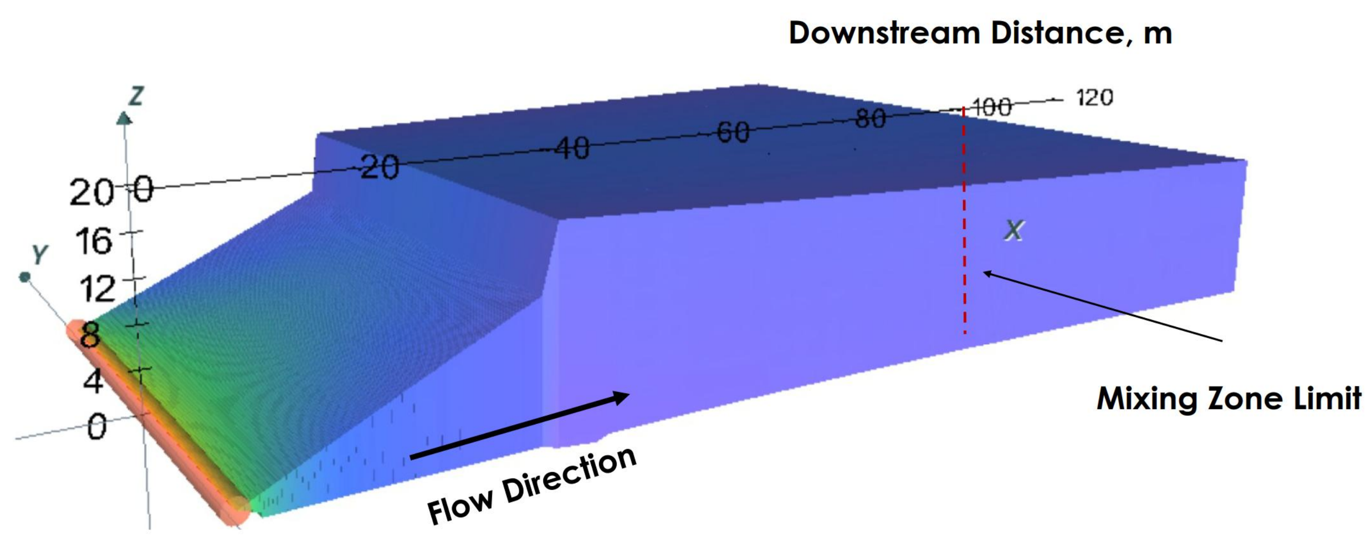
Scenario	Distance from Diffuser and Dilution Ratio						
	2 m	5 m	10 m	20 m	50 m	100 m	200 m
Scenario A	113.5	178.6	251.6	353.8	407.5	427.2	454.3
Scenario B	33.0	51.4	71.8	100.1	129.9	145.7	164.1
Scenario C	50.1	78.3	109.6	152.8	195.6	219.0	247.9

Figure 51 Scenario A (Effluent Flow 0.984 m^3/s and Average Ambient Velocities)

Plan View



Side View



Dilution Isolines

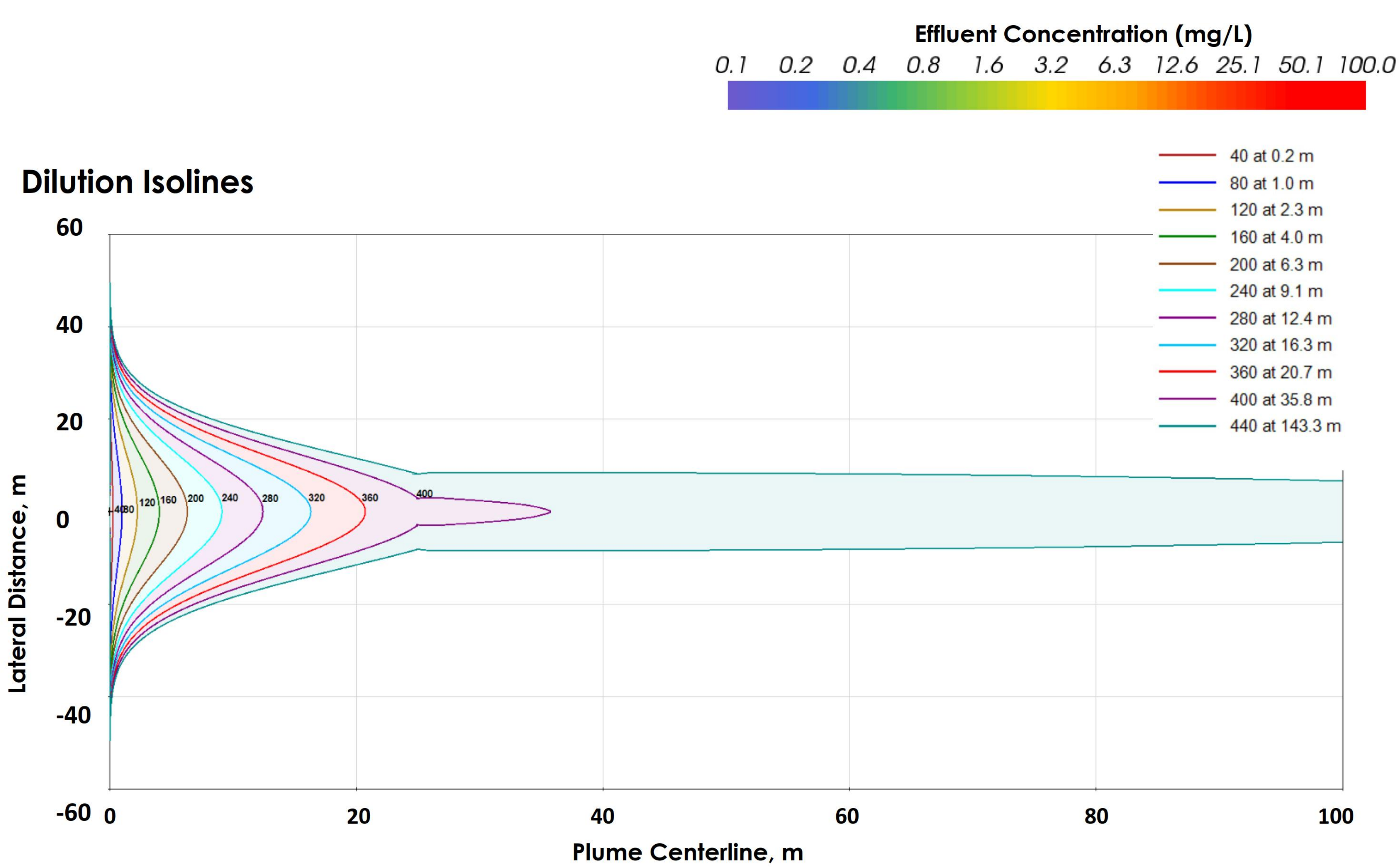
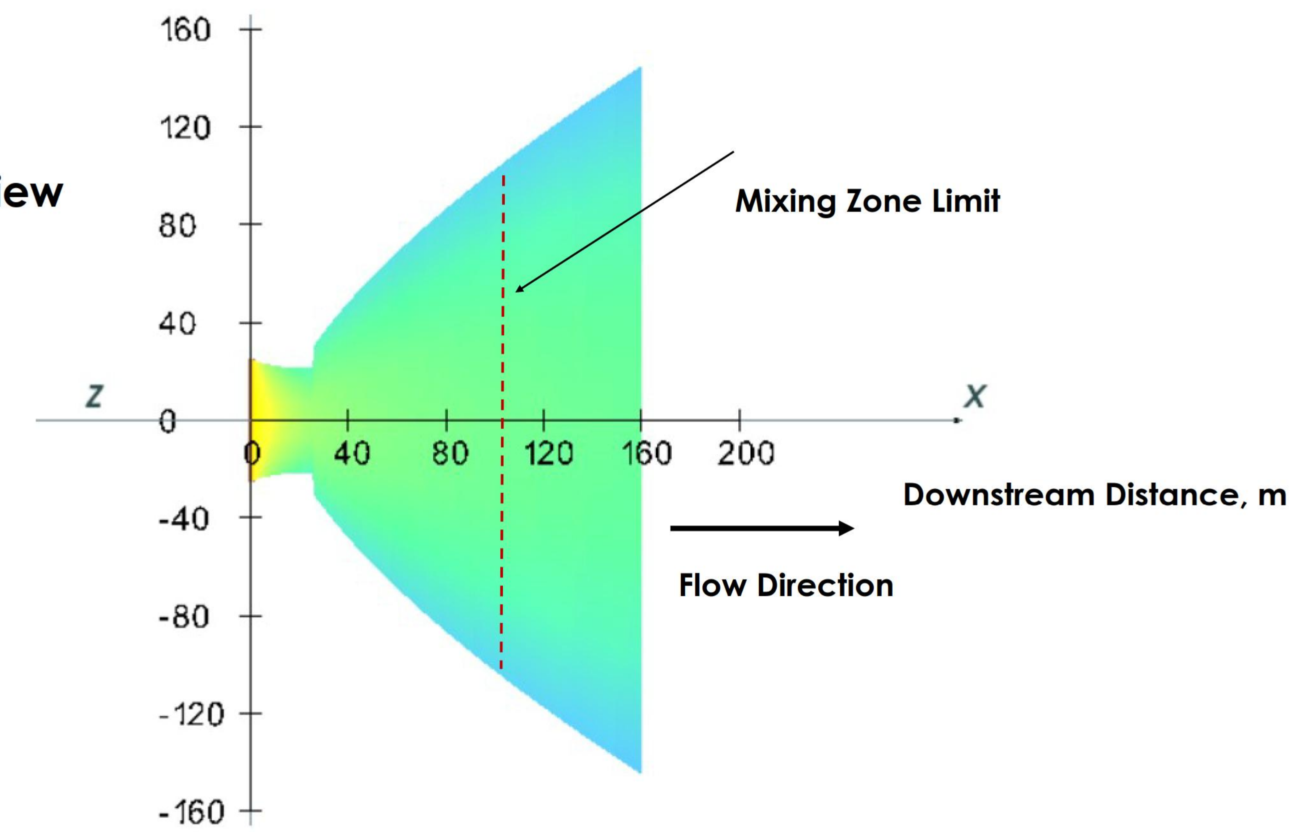
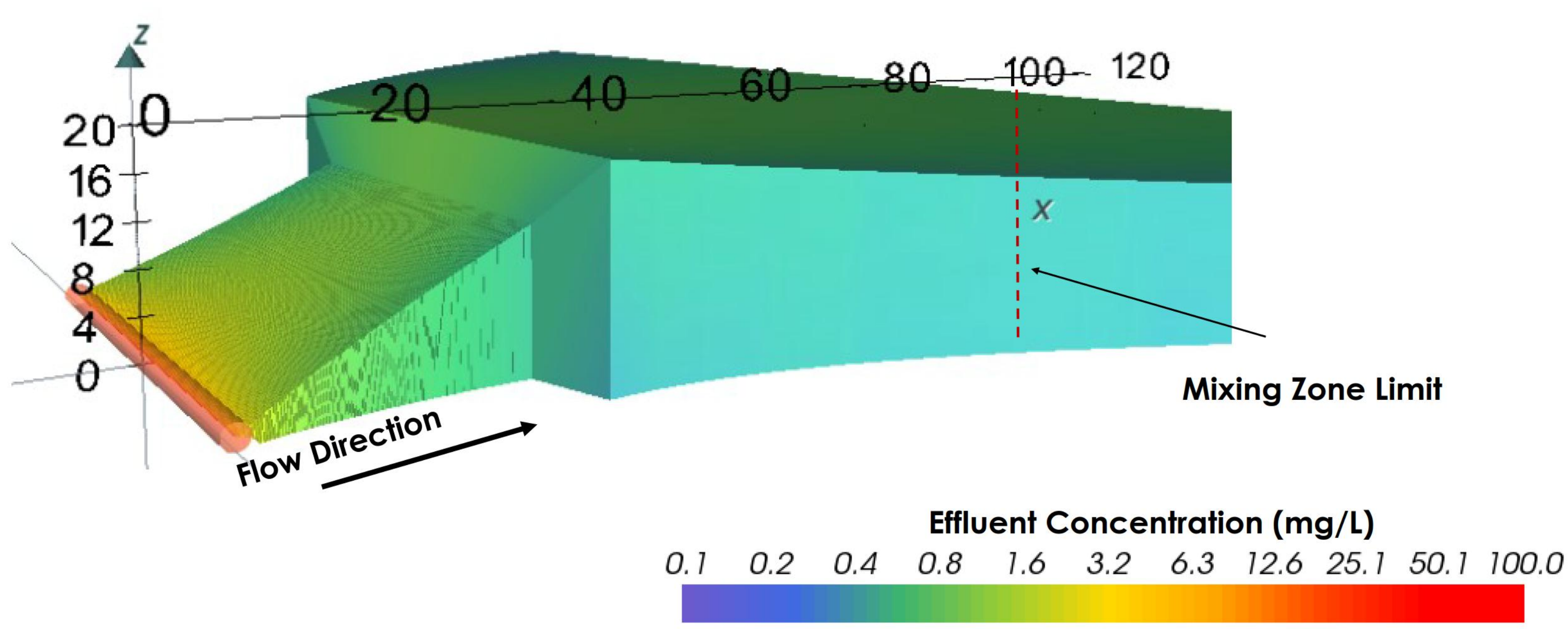


Figure 52 Scenario B (Effluent Flow 0.984 m³/s and Slack Velocities)

Plan View



Side View



Dilution Isolines

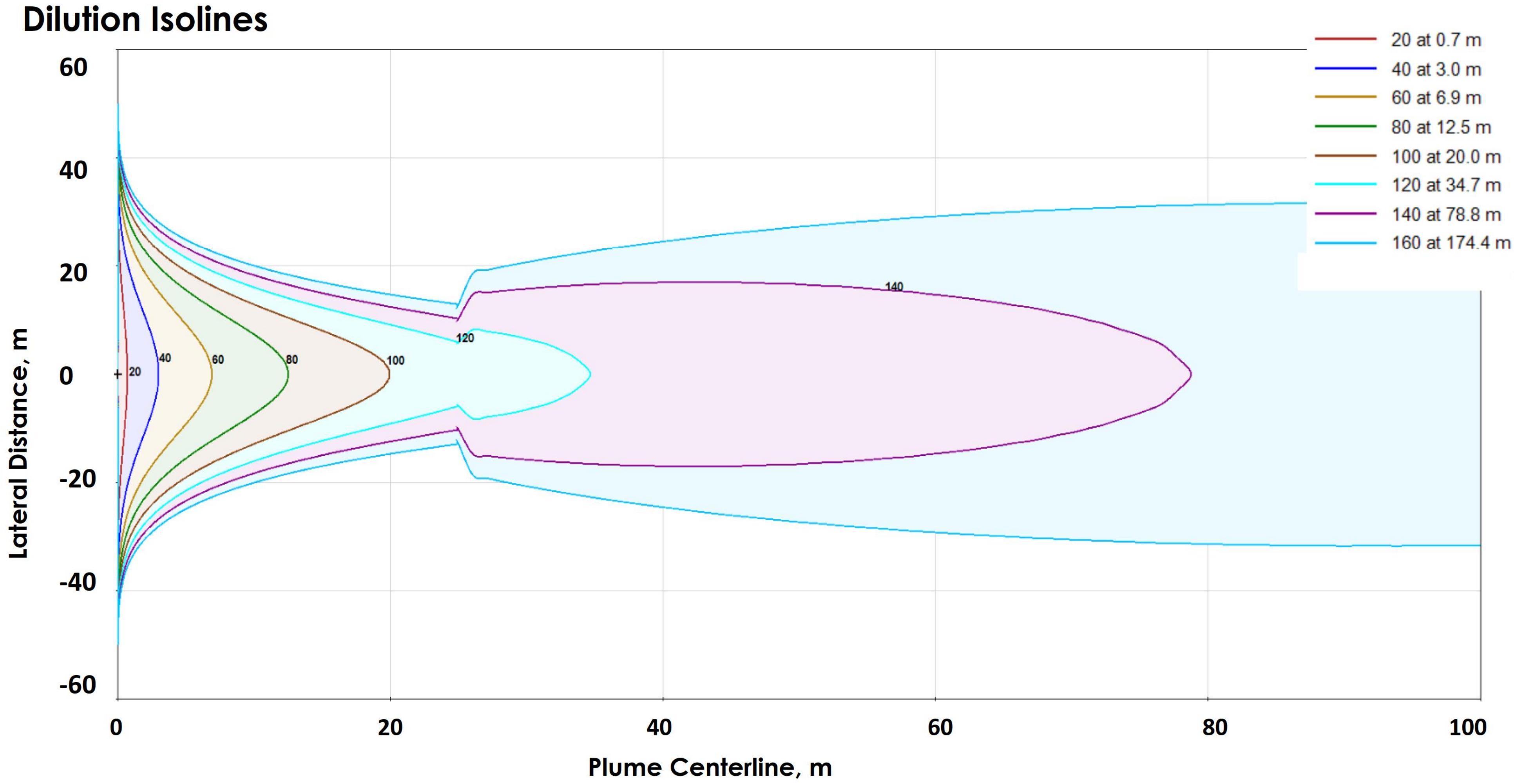
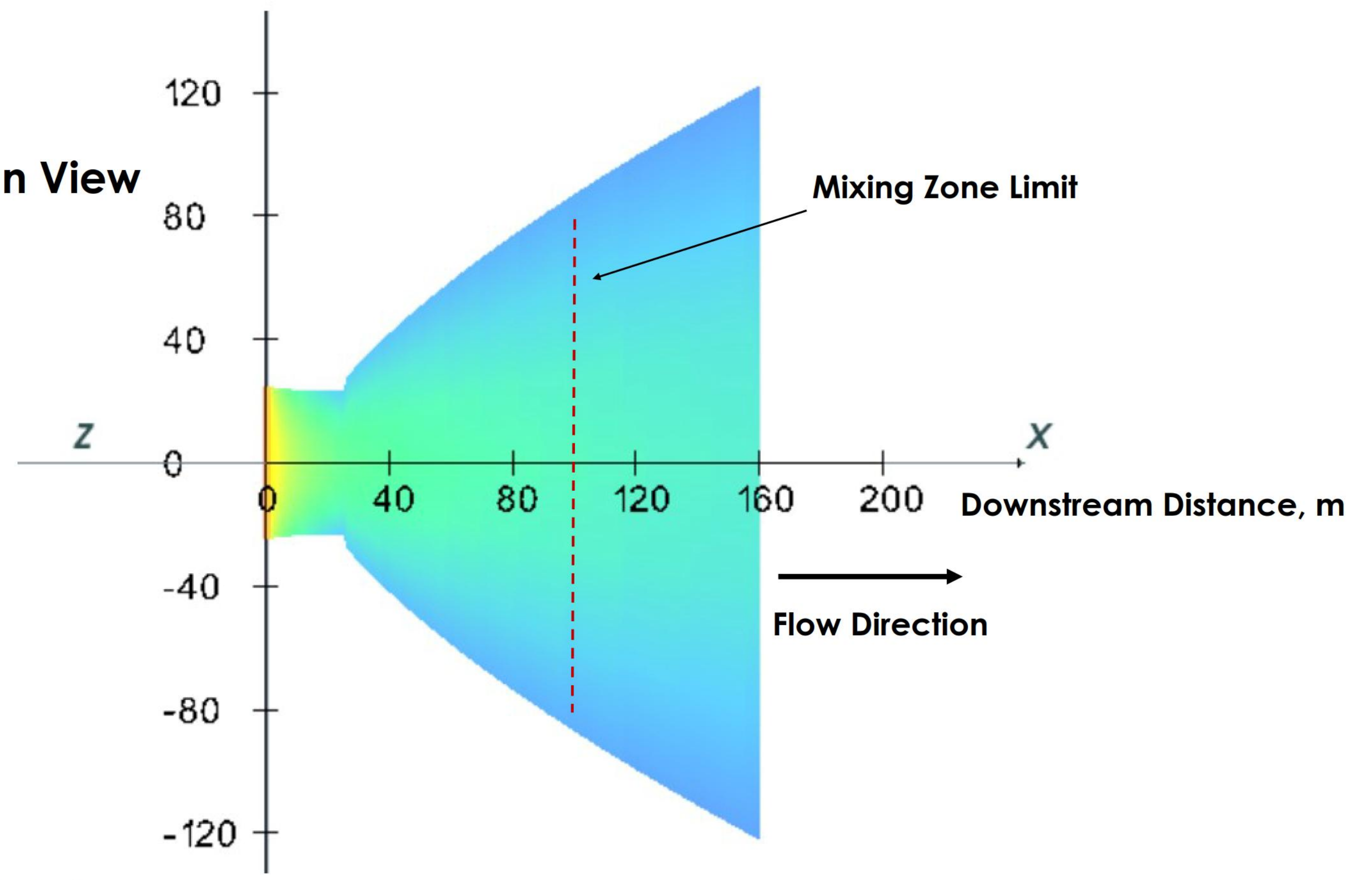
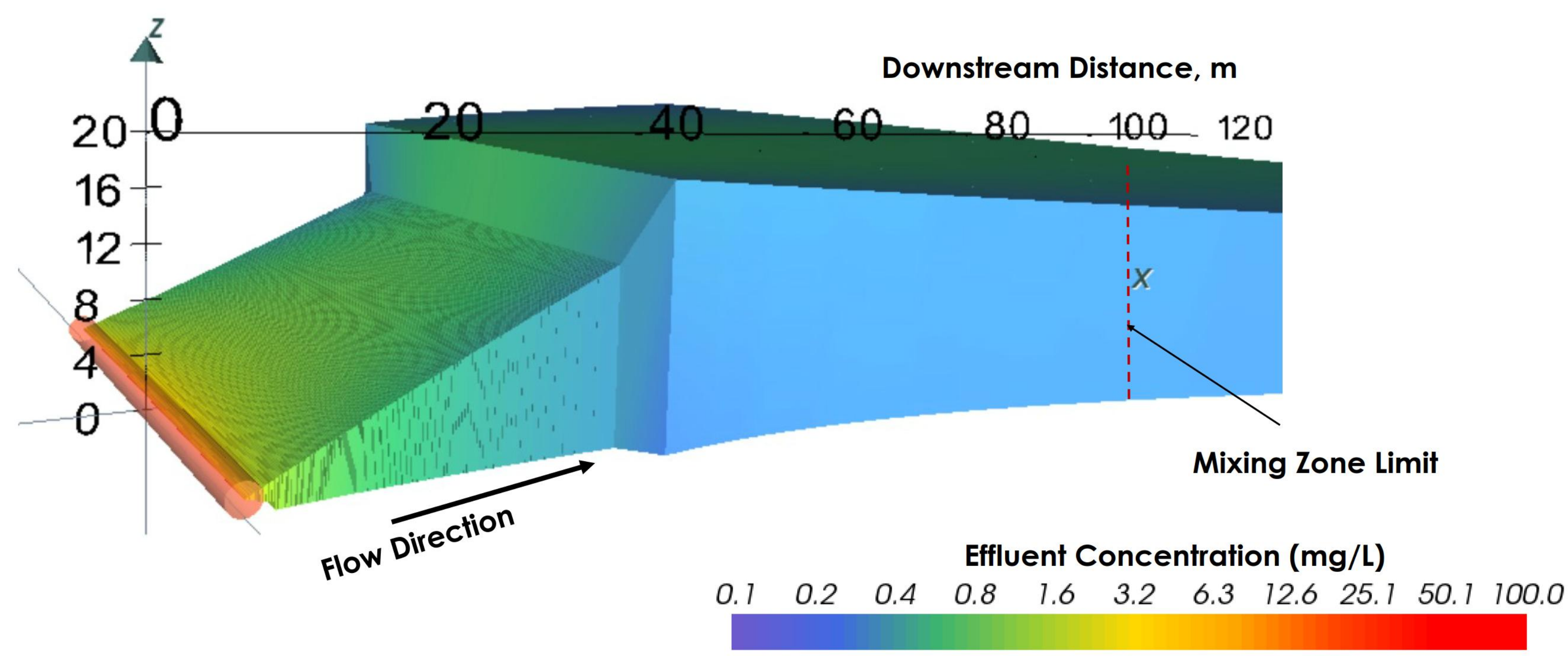


Figure 53 Scenario C (Effluent Flow 0.579 m³/s and Slack Velocities)

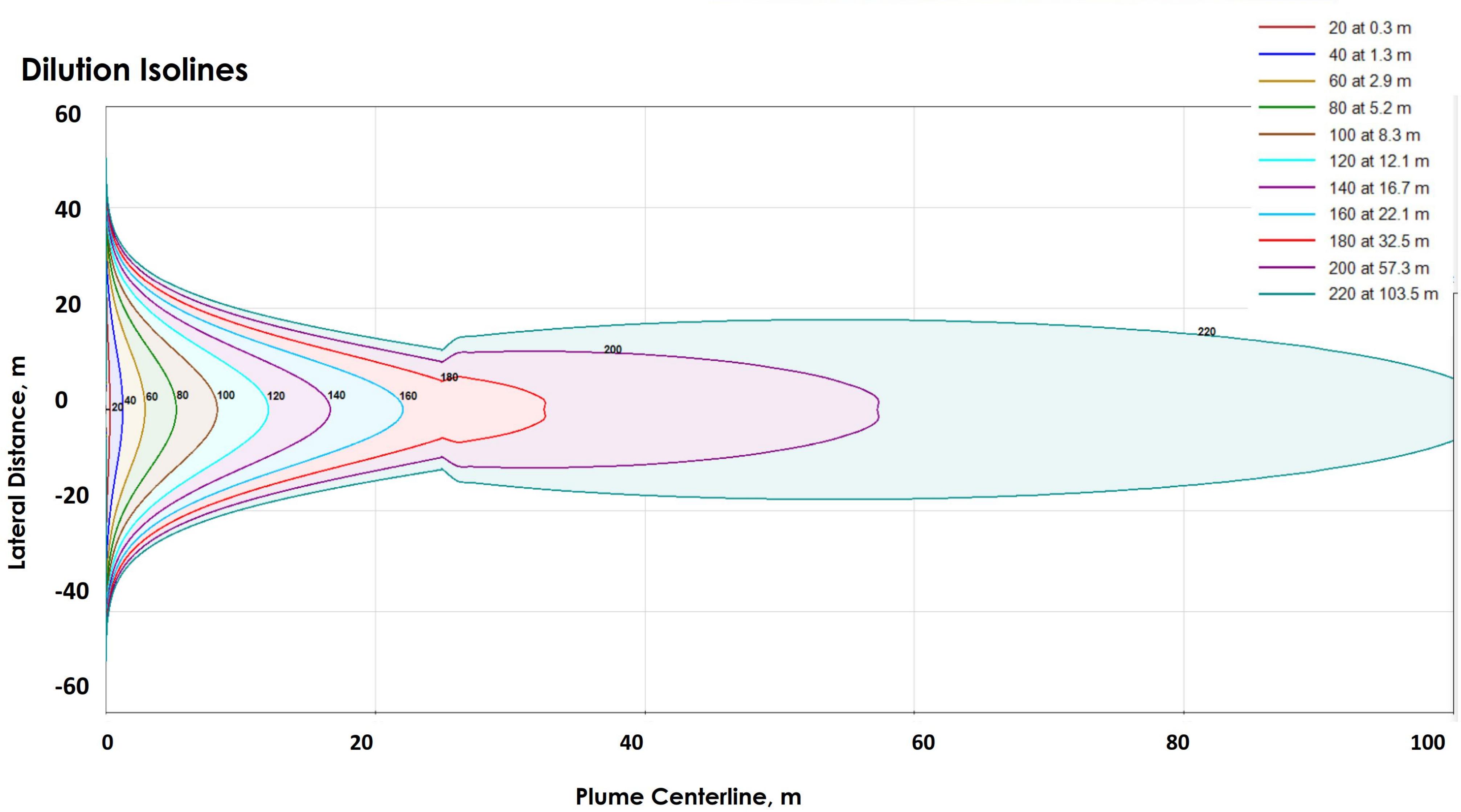
Plan View



Side View



Dilution Isolines



Water quality parameters of concern in the mill treated effluent are adsorbable organic halides (AOX), total nitrogen (TN), total phosphorus (TP), colour, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), dissolved oxygen (DO), pH, water temperature, salinity, cadmium, total dioxins, phenanthrene, total resin acids, total fatty acids and total Pulp and Paper (P&P) phenols. Water quality at the end of the 100-m mixing zone for Scenarios A, B and C is presented in Tables 18, 19 and 20 respectively.

AOX Data for AOX in CH-B are not available as there is currently no valid analytical method for the measurement in sea water; however, it is expected that the AOX ambient concentrations are negligible as there are no natural sources of AOX in ocean water. Proposed daily maximum AOX concentration in the effluent is 7.8 mg/L, which is substantially less than the World Bank guideline of 40 mg/L as the maximum limit for pulp mill effluents discharging into surface waters and slightly less than the 8 mg/L limit target objective for retrofit mills (World Bank 1998). For the NPNS mill effluent discharged at CH-B, and conservatively assuming no decay, sedimentation or any other form of transformation of organic halides in the receiving environment, the resulting AOX concentration at the edge of the 100-m mixing zone is 0.02 mg/L for Scenario A, 0.05 mg/L for Scenario B, and 0.04 mg/L for Scenario C.

TN Proposed daily maximum TN concentration in the effluent is 6.0 mg/L for Scenario A and 15 mg/L for Scenarios B and C. At these concentrations, TN is below the CCME marine guideline limit for the nitrate ion, which is a component and nitrogen form that contributes to the concentration of TN. Average background concentration of TN is 0.17 mg/L. A 1:35 (effluent: receiving environment) dilution ratio is required in Scenario A to reduce the effluent concentration of TN to approximately background levels. A 1:88 (effluent: receiving environment) dilution ratio is required for Scenarios B and C to reduce the effluent concentration of TN to approximately background levels This dilution ratio is achieved in the immediate vicinity (< 2 m) of the diffuser for Scenario A, within 20 m for Scenario B and within 10 m of the diffuser for Scenario C.

TP Proposed daily maximum TP concentration in the effluent is 1.5 mg/L. Average background concentration is 0.5 mg/L. A 1:3 (effluent: receiving environment) dilution ratio is required to reduce the effluent concentration to approximately background levels. This dilution ratio is achieved in the immediate vicinity (< 2 m) of the diffuser for all three Scenarios.

Colour Proposed daily maximum colour concentration in the effluent is 750 true colour units (TCU). Average background concentration is 4.5 TCU. A colour of 15 TCU can be detected in a glass of water by most people and it is the aesthetic objective of the Canadian drinking water guidelines (Health Canada, 1995). A 1:50 (effluent: receiving environment) dilution ratio is adequate to reduce the effluent concentration of 750 TCU to 15 TCU. This dilution ratio is achieved within 5 m from the diffuser for all three scenarios.In all three scenarios the plume reaches the surface at about 20 m, meaning that the plume will not be visible at the water surface.

BOD_5 Proposed daily maximum BOD_5 concentration in the effluent is 48 mg/L. There are no CCME or provincial guidelines for BOD. BOD was not detected in the marine water at CH-B using a detection limit of 5 mg/L. Background BOD was assumed at half of the reportable detection limit of 5 mg/L. Conservatively assuming no decay, sedimentation or any other form of transformation of organic matter, the resulting BOD_5 concentration at the edge of the 100-m mixing zone will be at approximately background levels for all three scenarios. McNeeley et al. (1979) consider waters with BOD_5 less than 4 mg/L to be reasonably clean.

COD Proposed daily maximum COD concentration in the effluent is 725 mg/L for Scenario A, 497 mg/L for Scenario B and 845 mg/L for Scenario C. Data for COD for the ambient waters at CH-B are not available due to analytical interference with the chloride and bromine in sea water; however, it is expected that the COD ambient concentrations are negligible in ocean water. Conservatively assuming no decay, sedimentation or any other form of transformation of organic matter, the resulting COD concentration at the edge of the 100-m mixing zone will be 1.7 mg/L for Scenario A, 3.4 mg/L for Scenario B and 3.9 mg/L for Scenario C. Natural waters with concentrations of COD less than 20 mg/L are generally considered unpolluted (UNESCO 1996).

TSS Proposed daily maximum TSS concentration in the effluent is 48 mg/L for Scenario A, 42 mg/L for Scenario B and 71 mg/L for Scenario C. The water quality limit for a TSS concentration of 7.5 mg/L (background 2.5 mg/L plus CCME threshold of 5 mg/L) is achieved in the immediate vicinity (< 2 m) of the diffuser for all three Scenarios.

DO Proposed daily maximum DO concentration in the effluent is > 1.5 mg/L. It is expected that due to the high jet velocity (2.7 to 4.6 m/s), dynamic ambient hydrodynamic conditions (agitation of water attributed to wind, tides, and waves) and substantial mass of ambient water (water depth is 20 m), the DO levels in the effluent will improve to the background concentration of 9.7 mg/L within the immediate vicinity of the diffuser (< 2m) for all three Scenarios.

pH Proposed daily maximum pH in the effluent is in a range of 7 to 8.5. Background pH at CH-B is 7.8. Due to substantial initial mixing after the effluent is discharged from the diffuser, the effluent pH is expected to reach ambient pH in the immediate vicinity of the diffuser (< 2 m) for all three Scenarios.

Water Temperature Ambient average summer temperature is 16.8°C and average winter temperature is 1 °C. Maximum effluent temperature is 35°C (Scenario B and C) and 37°C (Scenario A) in summer and 25°C in winter. Potential thermal impacts of the treated effluent on the thermal regime of the receiving environment at the CH-B discharge location were modelled using CORMIX. The results for all three Scenarios demonstrate that during the worst-case winter conditions, when effluent temperature is 25°C and ambient water temperature is about 1°C, the CCME guideline limits (i.e., 1°C differential) are met within approximately 2 m of the diffuser. CORMIX shows that the heated effluent quickly mixes with ambient water and the effluent temperature exponentially drops within several metres from the diffuser. After 2 m, the temperature drop decreases substantially and at 100 m the effluent plume temperature is less than 0.1 °C above background. During summer conditions the temperature differential between effluent and ambient conditions is less than in winter conditions. The results for all three scenarios demonstrate that for summer conditions, when the effluent temperature is 37°C and the ambient water temperature is 16.8 °C, the CCME temperature guideline limit (i.e., 1°C differential) is met within approximately 2 m of the diffuser. After 2 m, the temperature drop decreases substantially and at 100 m the effluent plume temperature is less than 0.1 °C above background.

Salinity Average salinity at CB-H is 30 g/L. Salinity, or its freshwater equivalent TDS, of the treated effluent is 2 g/L. A dilution ratio of 1:15 (effluent: receiving environment) is required for the ambient water to assimilate effluent and to reach the background levels of salinity. This dilution ratio is achieved in the immediate vicinity (< 2 m) of the diffuser. Due to the differential in salinity between the effluent and ambient conditions, density of the effluent is lower, and it is quickly mixed with the ambient water, which is already accommodated into the CORMIX model (Table 16).

Cadmium Ambient cadmium concentration is 0.084 µg/L and CCME marine guideline for long-term concentration is 0.12 ug/L. Proposed daily maximum cadmium concentration in the effluent is 1.03 µg/L. A 1:12 (effluent: receiving environment) dilution ratio is required to reduce the effluent concentration to approximately background levels. This dilution ratio is achieved in the immediate vicinity (< 2 m) of the diffuser for all three Scenarios.

Total Dioxins & Furans, PAH, Total Resin Acids, Total Fatty Acids, Total Pulp and Paper Phenols
These parameters do not have regulatory CCME limits for marine environment. Based on their effluent and background concentrations, a maximum of 1:10 (effluent: receiving environment) dilution ratio is required to reduce their effluent concentration to approximately background levels. This dilution ratio is achieved in the immediate vicinity (< 2 m) of the diffuser for these parameters for all three Scenarios.

Water quality at the end of the mixing zone for Scenario A is summarized in Table 18, Scenario B is summarized in Table 19 and Scenario C is summarized in Table 20.

Table 18 Water Quality at the End of the Mixing Zone in Scenario A

Parameter	Unit	Effluent Daily Maximum Limit	CCME, Marine Guideline	Ambient Conditions	Concentration at 100 m from Diffuser based on Dilution Ratios	Distance (m) from Diffuser Ambient Condition is Reached based on Dilution Ratios
Adsorbable Organic Halides (AOX)	mg/L	7.8	n/a	n/a	0.02	n/a
Total Nitrogen (TN)	mg/L	6.0	45[1]	0.17	0.17	< 2 m
Total Phosphorus (TP)	mg/L	1.5	n/a	0.5	0.5	< 2 m
Colour	TCU	750	n/a	4.5	4.5	< 5 m
Chemical Oxygen Demand (COD)	mg/L	725	n/a	n/a	1.7	n/a
Biochemical Oxygen Demand (BOD_5)	mg/L	48	n/a	2.5	2.5	< 2 m
Total Suspended Solids (TSS)	mg/L	48	Narrative [2]	2.5	2.5	< 2 m
Dissolved Oxygen	mg/L	> 1.5	>8	9.7	9.7	< 2 m

Table 18 Water Quality at the End of the Mixing Zone in Scenario A

Parameter	Unit	Effluent Daily Maximum Limit	CCME, Marine Guideline	Ambient Conditions	Concentration at 100 m from Diffuser based on Dilution Ratios	Distance (m) from Diffuser Ambient Condition is Reached based on Dilution Ratios
pH	-	7.0 - 8.5	7.0 - 8.7	7.8	7.8	< 2 m
Temperature (summer)	°C	37	Narrative [3]	16.8	16.8	< 2 m
Temperature (winter)	°C	25	Narrative [3]	1	1.0	< 2 m
Salinity	g/L	2	Narrative [4]	30	30.0	< 2 m
Cadmium	µg/l	1.03	0.12 [5]	0.084	0.084	< 2 m
Total Dioxins & Furans	pg/l	3.675	n/a	3.213	3.213	< 2 m
Phenanthrene (PAH)	µg/l	0.044	n/a	0.01	0.01	< 2 m
Total Resin Acids	mg/l	0.57	n/a	0.06	0.06	< 2 m
Total Fatty Acids	mg/l	0.335	n/a	0.07	0.07	< 2 m
Total P&P Phenols	µg/l	6.13	n/a	5	5	< 2 m

n/a – not available
[1] - CCME marine limit for NO_3^- as N
[2] - Maximum average increase of 5 mg/L from background levels for longer-term exposures (e.g., inputs lasting between 24 h and 30 d)
[3] - Human activities should not cause changes in ambient temperature of marine and estuarine water to exceed ±1°C at any time, location, or depth
[4] - Human activities should not cause the salinity (parts per thousand [‰], expressed here in g/L) of marine and estuarine waters to fluctuate by more than 10% of the natural level expected at that time and depth
[5] - Long-term concentration

Table 19 Water Quality at the End of the Mixing Zone in Scenario B

Parameter	Unit	Effluent Daily Maximum Limit	CCME, Marine Guideline	Ambient Conditions	Concentration at 100 m from Diffuser based on Dilution Ratios	Distance (m) from Diffuser Ambient Condition is Reached based on Dilution Ratios
Adsorbable Organic Halides (AOX)	mg/L	7.8	n/a	n/a	0.05	n/a
Total Nitrogen (TN)	mg/L	15.0	45[1]	0.17	0.17	<20 m
Total Phosphorus (TP)	mg/L	1.5	n/a	0.5	0.5	< 2 m

Table 19 Water Quality at the End of the Mixing Zone in Scenario B

Parameter	Unit	Effluent Daily Maximum Limit	CCME, Marine Guideline	Ambient Conditions	Concentration at 100 m from Diffuser based on Dilution Ratios	Distance (m) from Diffuser Ambient Condition is Reached based on Dilution Ratios
Colour	TCU	750	n/a	4.5	5.1	< 200 m
Chemical Oxygen Demand (COD)	mg/L	497	n/a	n/a	3.4	n/a
Biochemical Oxygen Demand (BOD_5)	mg/L	29	n/a	2.5	2.5	< 2 m
Total Suspended Solids (TSS)	mg/L	42	Narrative [2]	2.5	2.5	< 2 m
Dissolved Oxygen	mg/L	> 1.5	>8	9.7	9.7	< 2 m
pH	-	7.0 - 8.5	7.0 - 8.7	7.8	7.8	< 2 m
Temperature (summer)	°C	35	Narrative [3]	16.8	16.8	< 2 m
Temperature (winter)	°C	25	Narrative [3]	1	1.0	< 2 m
Salinity	g/L	2	Narrative [4]	30	30.0	< 2 m
Cadmium	µg/l	1.03	0.12 [5]	0.084	0.084	< 2 m
Total Dioxins & Furans	pg/l	3.675	n/a	3.213	3.213	< 2 m
Phenanthrene (PAH)	µg/l	0.044	n/a	0.01	0.01	< 2 m
Total Resin Acids	mg/l	0.57	n/a	0.06	0.06	< 2 m
Total Fatty Acids	mg/l	0.335	n/a	0.07	0.07	< 2 m
Total P&P Phenols	µg/l	6.13	n/a	5	5	< 2 m

n/a – not available
[1] - CCME marine limit for NO_3^- as N
[2] - Maximum average increase of 5 mg/L from background levels for longer-term exposures (e.g., inputs lasting between 24 h and 30 d)
[3] - Human activities should not cause changes in ambient temperature of marine and estuarine water to exceed ±1°C at any time, location, or depth
[4] - Human activities should not cause the salinity (parts per thousand [‰], expressed here in g/L) of marine and estuarine waters to fluctuate by more than 10% of the natural level expected at that time and depth
[5] - Long-term concentration

Table 20 Water Quality at the End of the Mixing Zone in Scenario C

Parameter	Unit	Effluent Daily Maximum Limit	CCME, Marine Guideline	Ambient Conditions	Concentration at 100 m from Diffuser based on Dilution Ratios	Distance (m) from Diffuser Ambient Condition is Reached based on Dilution Ratios
Adsorbable Organic Halides (AOX)	mg/L	7.8	n/a	n/a	0.04	n/a
Total Nitrogen (TN)	mg/L	15.0	45[1]	0.17	0.17	<10 m
Total Phosphorus (TP)	mg/L	1.5	n/a	0.5	0.5	< 2 m
Colour	TCU	750	n/a	4.5	4.5	< 50 m
Chemical Oxygen Demand (COD)	mg/L	845	n/a	n/a	3.9	n/a
Biochemical Oxygen Demand (BOD_5)	mg/L	49	n/a	2.5	2.5	< 2 m
Total Suspended Solids (TSS)	mg/L	71	Narrative [2]	2.5	2.5	< 2 m
Dissolved Oxygen	mg/L	> 1.5	>8	9.7	9.7	< 2 m
pH	-	7.0 - 8.5	7.0 - 8.7	7.8	7.8	< 2 m
Temperature (summer)	°C	35	Narrative [3]	16.8	16.8	< 2 m
Temperature (winter)	°C	25	Narrative [3]	1	1.0	< 2 m
Salinity	g/L	2	Narrative [4]	30	30.0	< 2 m
Cadmium	µg/l	1.03	0.12 [5]	0.084	0.084	< 2 m
Total Dioxins & Furans	pg/l	3.675	n/a	3.213	3.213	< 2 m
Phenanthrene (PAH)	µg/l	0.044	n/a	0.01	0.01	< 2 m
Total Resin Acids	mg/l	0.57	n/a	0.06	0.06	< 2 m
Total Fatty Acids	mg/l	0.335	n/a	0.07	0.07	< 2 m
Total P&P Phenols	µg/l	6.13	n/a	5	5	< 2 m

n/a – not available
[1] - CCME marine limit for NO_3^- as N
[2] - Maximum average increase of 5 mg/L from background levels for longer-term exposures (e.g., inputs lasting between 24 h and 30 d)
[3] - Human activities should not cause changes in ambient temperature of marine and estuarine water to exceed ±1°C at any time, location, or depth
[4] - Human activities should not cause the salinity (parts per thousand [‰], expressed here in g/L) of marine and estuarine waters to fluctuate by more than 10% of the natural level expected at that time and depth
[5] - Long-term concentration

Assimilative Capacity

Using CORMIX the maximum effluent concentration which can be assimilated by the receiving environment to meet the CCME limits was back-calculated. The results for Scenarios A, B and C for parameters with CCME limits are discussed below.

Scenario A – Maximum Effluent Quality Total nitrogen in the effluent can be as high as 19,152 mg/L in order to comply with the CCME limit of 45 mg/L at the 100 m mixing zone with an ambient concentration of 0.17 mg/L. TSS can reach 2,139 mg/L in the effluent to comply with the CCME limit of 7.5 mg/L (2.5 mg/L in the background water plus an increase of 5 mg/L). Cadmium can be 15.5 mg/L in the effluent to comply with the CCME limit of 0.12 mg/L for the marine environment at the 100 m mixing zone and for an ambient cadmium concentration of 0.084 mg/L. Temperature modelling of heated effluent for winter and summer conditions indicated that effluent can be as high as 50 °C to comply with the CCME limit at the end of the mixing zone (i.e., to not exceed ±1°C from background water). A 50 °C limit is the maximum temperature CORMIX can use and model for a heated discharge. The CCME marine limit for pH is 7-8.7; the effluent is already in compliance with the limit. Salinity and DO have the effluent limits below the ambient concentrations and back-calculation is not practical as it returns unreasonable, close to zero concentrations for salinity and DO in the effluent.

Scenario B – Draft PPER Limits Total nitrogen in the effluent can be as high as 6,532 mg/L in order to comply with the CCME limit of 45 mg/L at the 100 m mixing zone with an ambient concentration of 0.17 mg/L. TSS can reach 731 mg/L in the effluent to comply with the CCME limit of 7.5 mg/L (2.5 mg/L in the background water plus an increase of 5 mg/L). Cadmium can be 5.3 mg/L in the effluent to comply with the CCME limit of 0.12 mg/L for the marine environment at the 100 m mixing and for an ambient cadmium concentration of 0.084 mg/L. Results for temperature, pH, salinity and DO are the same as for Scenario A.

Scenario C – Draft PPER Limits Total nitrogen in the effluent can be as high as 9,818 mg/L in order to comply with the CCME limit of 45 mg/L at the 100 m mixing zone with an ambient concentration of 0.17 mg/L. TSS can reach 1,098 mg/L in the effluent to comply with the CCME limit of 7.5 mg/L (2.5 mg/L in the background water plus an increase of 5 mg/L). Cadmium can be 8.0 mg/L in the effluent to comply with the CCME limit of 0.12 mg/L for the marine environment at the 100 m mixing and for an ambient cadmium concentration of 0.084 mg/L. Results for temperature, pH, salinity and DO are the same as for Scenario A.

3.4 CONCLUSION OF NEAR-FIELD MODELLING

The CORMIX model was used for the 3D near-field hydrodynamic modelling of the CH-B outfall location. The mixing zone was defined as the 100-m distance from the outfall pipe.

Three modelling scenarios, representative of summer open-water conditions, were modelled. Scenarios differ by ambient current velocity, maximum effluent flow rate, and some effluent parameters.

Scenario A utilizes average current velocities for July 2019, maximum expected effluent quality and effluent flow rate of 85,000 m^3/day or 0.984 m^3/s. The dilution ratio is 252 times at 10 m from the ports and 427 times at the end of the mixing zone (i.e., at 100 m). Figure 51 presents the plan and side views of the effluent plume for Scenario A, as well as the dilution isolines for the one-port diffuser.

Scenario B is the most conservative scenario as it utilizes slack velocity for July 2019, PPER draft limits and effluent flow rate of 85,000 m^3/day or 0.984 m^3/s. The dilution ratio is 51 times at 5 m from the ports and 146 times at the end of the mixing zone (i.e., at 100 m). Figure 52 presents the plan and side views of the effluent plume for Scenario B, as well as the dilution isolines for the three-port diffuser.

Scenario C utilizes slack velocity for July 2019, PPER draft limits and reduced effluent flow rate of 50,000 m^3/day or 0.579 m^3/s. The dilution ratio is 78 times at 5 m from the ports and 219 times at the end of the mixing zone (i.e., at 100 m). Figure 53 presents the plan and side views of the effluent plume for Scenario C, as well as the dilution isolines for the three-port diffuser.

The summary of results for the effluent dilution ratios for the scenarios is presented in Table 17.

The results of the near-field modelling and water quality at the end of the 100-m mixing zone for Scenarios A, B and C are shown in Tables 18, 19 and 20 respectively. The proposed effluent discharge quality for AOX, TN, TP, colour, BOD, COD, TSS, water temperature, DO, pH, salinity, cadmium, total dioxins, phenanthrene, total resin acids, total fatty acids and total pulp and paper phenols are anticipated to meet compliance at the end of the mixing zone for applicable federal water quality guidelines and/or background conditions.

Using CORMIX the maximum effluent concentration which can be assimilated by the receiving environment to meet the CCME limits at the 100 mixing zone was back-calculated. The results for Scenarios A, B and C for parameters with CCME limits indicate that the receiving environment has substantial assimilative capacity. Thus, total nitrogen in the effluent can reach 6,532 mg/L to 19,152 mg/L (depending on the Scenario) to comply with the CCME limit. TSS can reach 731 mg/L to 2,139 mg/L and cadmium can reach 5.3 mg/L to 15.5 mg/L in the effluent to comply with the CCME limits. Other parameters (temperature, pH, salinity and DO) also showed a similar pattern of compliance with the CCME limits at the end of the mixing zone.

4.0 REFERENCES

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