Near-Field Modelling Study of Effluent Dispersion

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1.0 Introduction

This study employs three-dimensional near-field modeling to assess dilution patterns from a preliminary marine outfall discharge location, focusing on near-field mixing dynamics within and adjacent to the initial mixing zone. Simulations were conducted under typical summer and winter ambient conditions using the CORMIX model to evaluate temperature and salinity changes due to effluent dispersion. The primary objective was to determine compliance with the Canadian Council of Ministers of the Environment (CCME) Canadian Environmental Quality Guidelines (CEQG) at the mixing zone boundary.

The report delineates effluent characterization alongside ambient seawater conditions pertinent to the effluent discharge in Section 2. Subsequently, Section 3 expounds upon the model's configuration specifics and presents the resultant modeling outcomes. Finally, Section 4 encapsulates the study's findings and draws pertinent conclusions.

2.0 Effluent and Ambient Characterizations

The marine outfall (47.799625°N, 54.002390°W) used in this study, is an existing outfall used for Braya's current productions. It is situated approximately 100 m northwest of Duck Pond, between the beach and the final holding basin. The structure consists of a 32" × 22" concrete channel that conveys effluent from the holding basin to the sea (Figure 2.1).

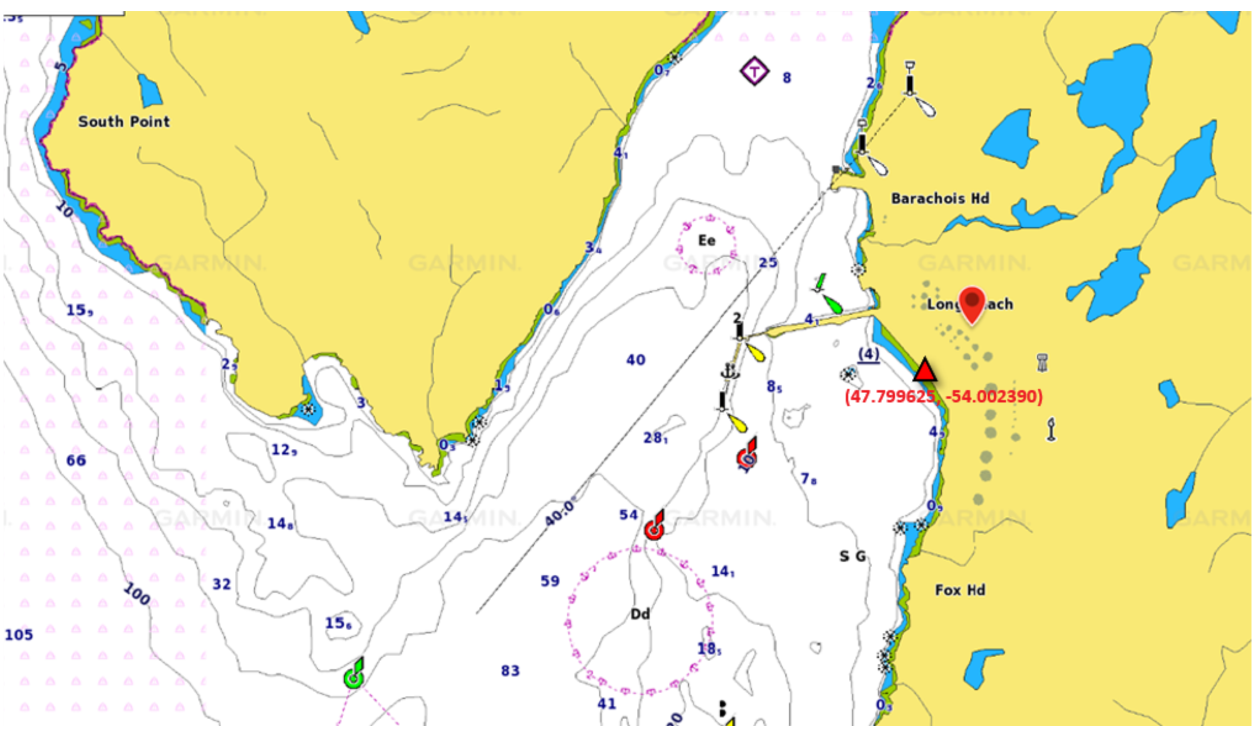

Figure 2.1: Location of the Outfall to Sea and nearby bathymetry.

The marine outfall discharges combined effluents from Braya and North Atlantic Refining Corp.'s (North Atlantic) Wind to Hydrogen Project. Based on Braya's production capacity (18,000 barrels/day) and typical refinery wastewater ratios (0.4-1.6 × crude volume; Jafarinejad & Jiang, 2019), Braya's estimated discharge rate is 0.0529 m^3/s. With North Atlantic's maximum documented discharge rate of 0.0140 m^3/s (Hatch Pre-FEED/FEL-2 report), the total combined discharge is 0.0669 m^3/s (5,780,160 L/day).

The effluent from Braya undergoes cooling in a settling pond, equilibrating to ambient air temperature before release. Climate records for Come By Chance show seasonal temperature variations, with average minimum air temperatures of -3.5°C occurring from October through March and 15.33°C from April through September. In accordance with Newfoundland and Labrador's (NL's) regulatory limit of 32°C for discharge temperature, we established three modeling scenarios: a winter condition using 0.01°C effluent temperature, a summer condition at 15.33°C, and an extreme summer scenario evaluating the maximum permitted discharge temperature of 32.00°C.

The effluent salinity is modeled using North Atlantic's discharge characteristics as representative of both effluents discharged in the current outfall. Based on client-provided data showing 0.0285 ppt salinity for North Atlantic, the approximated combined discharge salinity is 28.5 PSU (Practical Salinity Units). This assumption reflects similar expected discharge properties between Braya and North Atlantic facilities. The changes in ambient water salinity were evaluated by modeling the minimum and maximum allowable amount in the area, 25.48 and 34.21 PSU, respectively. In total, six scenarios are modeled, as shown in Table 2.1.

Table 2.1: Effluent Discharge Rate and Characterizations

Scenario	Season	Discharge Rate (L/day)	Temperature (°C)	Salinity (PSU)
1	Summer	5,780,160	15.33	25.48
2				34.21
3			32.00	25.48
4				34.21
5	Winter		0.01	25.48
6				34.21

Analysis of CTD observations from MS1-MS3 revealed consistent temperature and salinity profiles at the three locations on July 12, September 28, and December 4-5, 2024 surveys, respectively with the exception of MS1 showing freshwater influence (≈2m surface layer) in July and December profiles. No significant thermocline was observed in vertical profiles or in the July to December 2024 time series data. The July profile exhibited warmer, fresher surface water compared to deeper layers, while December showed uniform conditions throughout the water column. Temperature records indicated seasonal extremes, ranging from >20°C (August to September 2024) to 2°C (November 2024).

For modeling purposes, the following representative conditions were adopted. For summer conditions, typical values of 20°C temperature and 30 PSU salinity in the upper layer were used, with 12.5°C and 30.7 PSU at the bottom. For winter conditions, uniform values of 2°C temperature and 30.5 PSU salinity throughout the water column were used.

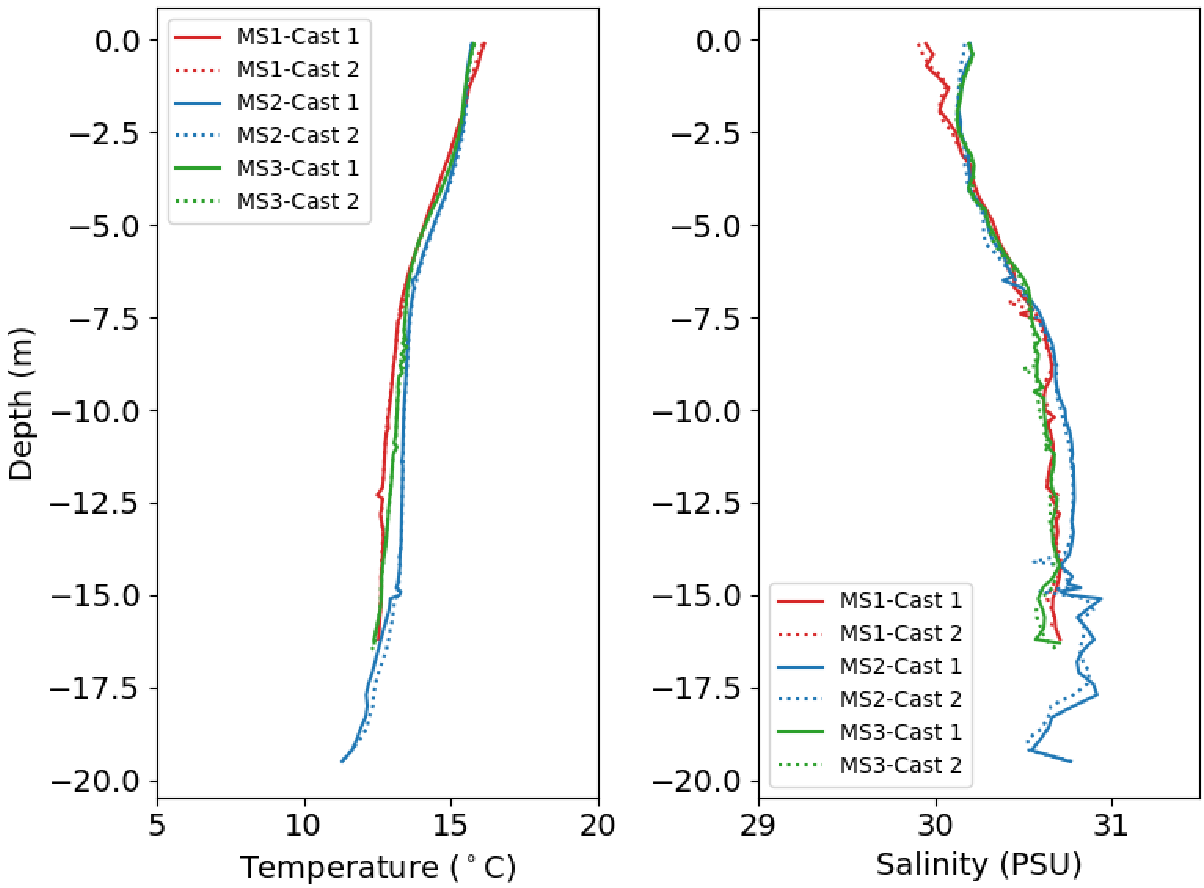

Figure 2.2: CTD Vertical Profiles of Temperature and Salinity at MS1 to MS3 on July 12, 2024

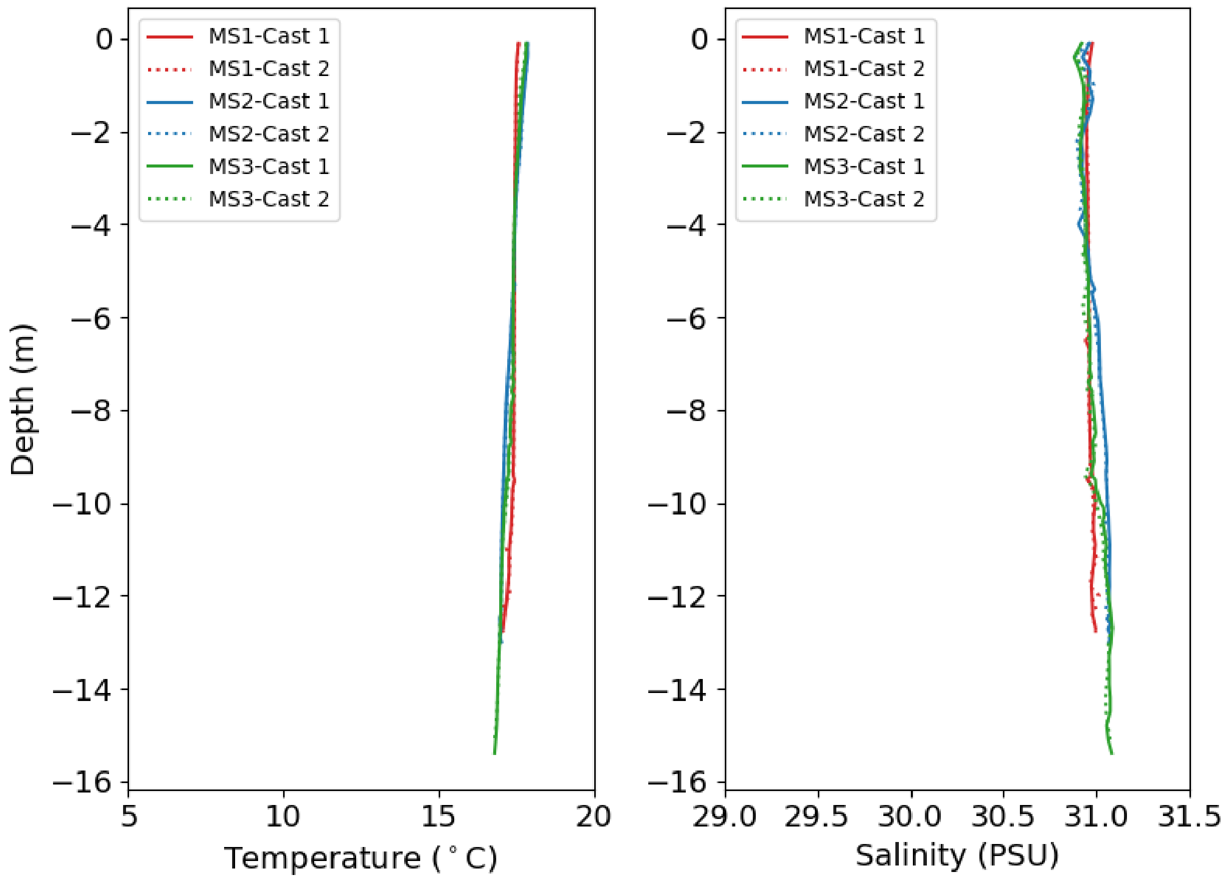

Figure 2.3: CTD Vertical Profiles of Temperature and Salinity at MS1 to MS3 on September 28, 2024

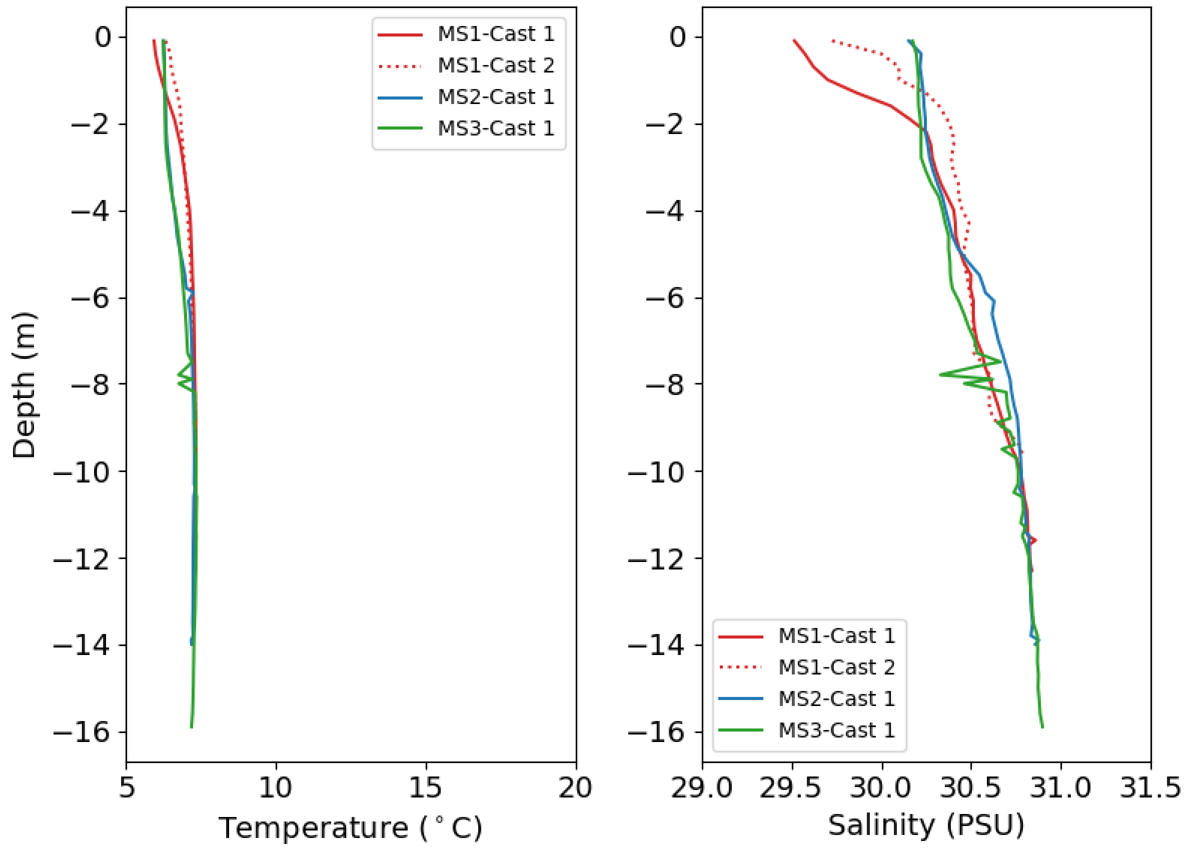

Figure 2.4: CTD Vertical Profiles of Temperature and Salinity at MS1 to MS3 on December 4 to 5, 2024

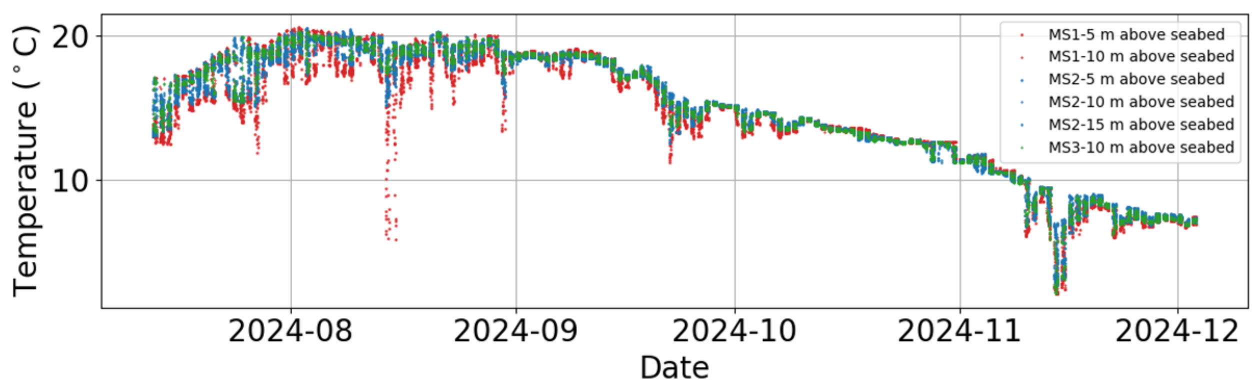

Figure 2.5: Time Series of Temperature at Different Depths at MS1 to MS3 from Tidbit Observations

In the absence of recent current data for Placentia Bay, historical observations from Schillinger et al. (2000) to estimate near-field currents were utilized. While mooring M7 was geographically closest to the discharge site, it only recorded currents below 100 m depth. Therefore mooring M6 data were selected, which showed mean current magnitudes of 14.36 cm/s at 20 m depth and 3.39 cm/s at 45 m depth, as more representative of discharge-area conditions.

In shallow coastal environments, currents typically align with bathymetric contours, following depth isolines. Given the outfall's location along a topographic slope extending from shore, the discharged effluent will likely be influenced by tidal currents flowing parallel to these shoreline-parallel contours. This configuration suggests that effluent dispersion will be most effective when the discharge direction is oriented perpendicular to the shoreline, as the ambient current regime would then promote optimal transport away from the release point.

This study models surface discharge via the outfall system (OFS) and beach by adopting a conservative 5 cm/s surface current to minimize ambient current effects on dispersion. Tidal reversal timescales (order of hours) substantially exceed the effluent's regulatory mixing period (order of minutes). Consequently, current direction reversals were excluded from simulations as their temporal influence falls beyond the critical dispersion phase.

Furthermore, as outlined in the CORMIX User Manual (2021), wind is deemed inconsequential for near-field mixing, exerting critical influence solely on plume behavior in the far field. Therefore, wind effects were disregarded in this study.

Table 2.2 summarizes the representative ambient seawater conditions adopted for near-field modeling, including both summer and winter scenarios.

Table 2.2: Ambient Seawater Conditions

Season	**Temperature (°C)**		**Salinity (PSU)**		**Current (m/s)**
	Top Layer	**Bottom Layer**	**Top Layer**	**Bottom Layer**	
Summer	20.0	12.5	30.0	30.7	0.05
Winter	2.0		30.5		0.05

3.0 3D-Near Field Modelling

The objective of the near-field dilution mixing modeling is to verify compliance with the ambient seawater quality concentrations, particularly those outlined in the CCME CEQG, at the periphery of the mixing zone. As defined by CCME (2003), the mixing zone denotes an area contiguous with a point source (i.e., effluent discharge), where the effluent blends with ambient water, potentially leading to concentrations of certain substances that may not align with Water Quality Guidelines (WQG).

NL, as a signatory to the CCME, has endorsed the establishment of CCME CEQGs, including those aimed at safeguarding marine aquatic life. In this study, CCME’s WQG pertaining to temperature and salinity in the marine environment were employed.

CCME's WQG for the protection of aquatic life regarding temperature advocates for the prevention of human activities inducing changes in the ambient temperature of marine and estuarine waters beyond ±1°C at any given time, location, or depth.

Similarly, CCME's WQG for the protection of aquatic life regarding salinity advocate for human activities to avoid causing fluctuations in the salinity (expressed as parts per thousand, ppt, or g/kg) of marine and estuarine waters exceeding 10% of the natural level anticipated at that specific time and depth.

3.1 CORMIX Model

CORMIX was employed to conduct an in-depth analysis and evaluation of near-field mixing, focusing on conditions within and proximate to the initial mixing zone. CORMIX stands as a sophisticated software system designed for the comprehensive analysis, prediction, and design of discharges of aqueous toxic or conventional pollutants into various water bodies. Its primary emphasis lies in assessing the geometry and dilution characteristics of the initial mixing zone, although the system is also capable of forecasting the behavior of the discharge plume at greater distances. CORMIX operates as a three-dimensional (3D) model that can be executed under steady-state, unsteady-state, and tidal ambient conditions, thus offering a versatile tool for modeling diverse scenarios of pollutant dispersion.

3.2 Discharge Configuration

The CORMIX model necessitates three distinct sets of input parameters for comprehensive characterization:

i. Effluent Discharge Characteristics:

- Pertains to the specific attributes of the effluent discharge.
- Detailed in Section 2 and tabulated in Table 2.1.

ii. Ambient Conditions or Receiving Water Body Characteristics:

- Describes the ambient conditions prevailing within the receiving water body.
- Presented in Section 2, encompassing parameters delineated in Table 2.2.

iii Outfall and Diffuser Specifications:

- Specifies the outfall structure and any associated diffuser configuration.
- The outfall features a 32" by 22” channel.
- The outfall is oriented perpendicular to the shoreline, facilitating horizontal effluent discharge (parallel to the seabed) through the beach and into the receiving waters at the surface.
- No diffuser is incorporated into the study.

Model simulations encompassed four sets of ambient conditions:

- Representative summer ambient conditions without current.
- Representative summer ambient conditions with current.
- Representative winter ambient conditions without current.
- Representative winter ambient conditions with current.

The modeling also evaluates high-temperature effluent discharge at the maximum permitted 32°C under summer conditions, simulating both quiescent (no current) and advective (5 cm/s current) scenarios.

3.3 Near Field Results

The CORMIX model was employed to conduct dilution-mixing simulations for both summer and winter scenarios, utilizing conservative ambient and effluent conditions. By considering the specified effluent and ambient parameters, the resultant water temperature within the near-field mixing zone was determined.

The temperature outcomes for all six scenarios are tabulated in Table 3.1. The salinity results within the mixing zone for all scenarios are presented in Table 3.2. The tables provide a comprehensive overview of the temperature and salinity characteristics prevailing within the near-field mixing zone under varying conditions.

Table 3.1: Temperature Results in the Mixing Zone for Summer and Winter Scenarios

Scenario	Current (cm/s)	Effluent Temperature (°C)	Ambient Temperature (°C)	CCME WQG[1] (°C)	Temperature at Various Distance from Outfall (°C)				
					1 m	3 m	5 m	7 m	9 m
1	0	15.33	20	[19, 21]	16.7	18.0	18.6	18.9	19.1
	5				18.1	19.2	19.5	19.6	19.7
2	0				16.7	18.0	18.6	18.9	19.1
	5				18.1	19.2	19.5	19.6	19.7
3	0	32.00			28.4	25.1	23.7	22.9	22.4
	5				25.0	21.9	21.2	21.0	20.8
4	0				28.4	25.1	23.7	22.9	22.4
	5				25.0	21.9	21.2	21.0	20.8
5	0	0.01	2	[1, 3]	0.6	1.2	1.4	1.5	1.6
	5				1.2	1.7	1.8	1.8	1.9
6	0				0.6	1.2	1.4	1.5	1.6
	5				1.2	1.7	1.8	1.8	1.9

Note: [1] change of 1 °C from ambient temperature.

Table 3.2: Salinity Results in the Mixing Zone for Summer and Winter Scenarios

<table>
<tr><th rowspan="2">Scenario</th><th rowspan="2">Current (cm/s)</th><th rowspan="2">Effluent Salinity (PSU)</th><th rowspan="2">Ambient Salinity (PSU)</th><th rowspan="2">CCME WQG [1] (PSU)</th><th colspan="5">Salinity at Various Distance from Outfall (PSU)</th></tr>
<tr><th>1 m</th><th>3 m</th><th>5 m</th><th>7 m</th><th>9 m</th></tr>
<tr><td rowspan="2">1</td><td>0</td><td rowspan="2">25.48</td><td rowspan="8">30.0</td><td rowspan="8">[27.0, 33.0]</td><td>26.8</td><td>28.1</td><td>28.6</td><td>28.9</td><td>29.1</td></tr>
<tr><td>5</td><td>28.1</td><td>29.3</td><td>29.5</td><td>29.6</td><td>29.7</td></tr>
<tr><td rowspan="2">2</td><td>0</td><td rowspan="2">34.21</td><td>32.9</td><td>31.8</td><td>31.3</td><td>31.0</td><td>30.8</td></tr>
<tr><td>5</td><td>31.8</td><td>30.7</td><td>30.4</td><td>30.3</td><td>30.3</td></tr>
<tr><td rowspan="2">3</td><td>0</td><td rowspan="2">25.48</td><td>26.8</td><td>28.1</td><td>28.6</td><td>28.9</td><td>29.1</td></tr>
<tr><td>5</td><td>28.1</td><td>29.3</td><td>29.5</td><td>29.6</td><td>29.7</td></tr>
<tr><td rowspan="2">4</td><td>0</td><td rowspan="2">34.21</td><td>32.9</td><td>31.8</td><td>31.3</td><td>31.0</td><td>30.8</td></tr>
<tr><td>5</td><td>31.8</td><td>30.7</td><td>30.4</td><td>30.3</td><td>30.3</td></tr>
<tr><td rowspan="2">5</td><td>0</td><td rowspan="2">25.48</td><td rowspan="4">30.5</td><td rowspan="4">[27.5, 33.6]</td><td>27.0</td><td>28.4</td><td>29.0</td><td>29.3</td><td>29.5</td></tr>
<tr><td>5</td><td>28.4</td><td>29.7</td><td>30.0</td><td>30.1</td><td>30.2</td></tr>
<tr><td rowspan="2">6</td><td>0</td><td rowspan="2">34.21</td><td>33.1</td><td>32.1</td><td>31.6</td><td>31.4</td><td>31.2</td></tr>
<tr><td>5</td><td>32.0</td><td>31.1</td><td>30.9</td><td>30.8</td><td>30.7</td></tr>
<tr><td colspan="10">Note: [1] change of 10% from ambient salinity.</td></tr>
</table>

Figure 3.1 illustrates the plume boundary and centerline from the marine outfall under quiescent conditions for both seasons. The plume geometry remained consistent between seasons due to identical discharge velocities and absence of currents. However, seasonal differences were observed in the mixed temperature and salinity fields. Figure 3.2 shows the current-influenced plume for both seasons. In both seasons, ambient currents enhanced mixing, enabling faster compliance with regulatory standards closer to the source. Both figures include mean dilution versus distance plots, characterizing effluent dispersion.

As a surface discharge, the effluent diffuses downward during release. The high-temperature summer case (32°C effluent, 20°C ambient) exhibits similar plume geometry to the standard summer scenario (Figures 3.1 and 3.2). However, the greater temperature differential significantly extends the distance required to meet regulatory dilution thresholds as detailed below.

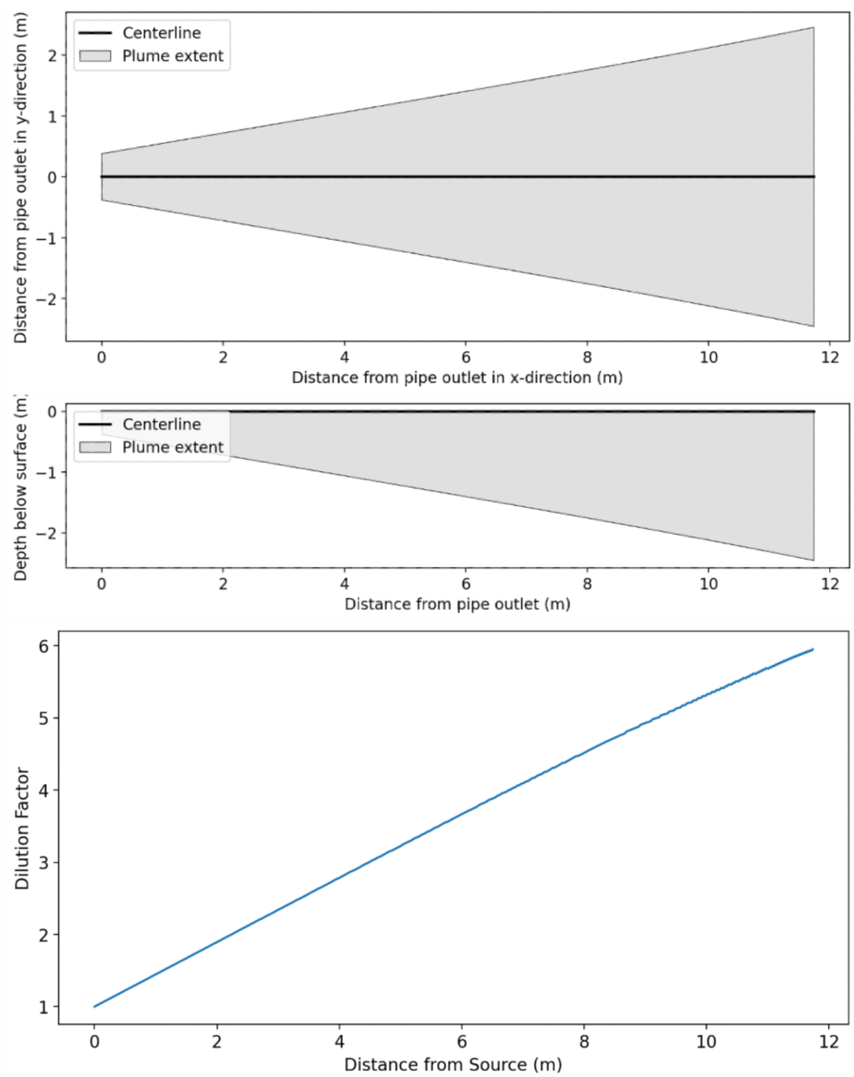

Figure 3.1: Schematic representation of plume boundary and centerline in the x-y plane (upper panel) and x-z plane (middle) for both the summer and winter scenarios without current. The lower panel shows dilution factor as a function of distance from the source. Coordinate system: x-coordinate perpendicular to shoreline, y-coordinate parallel to shoreline, and z-coordinate positive upward.

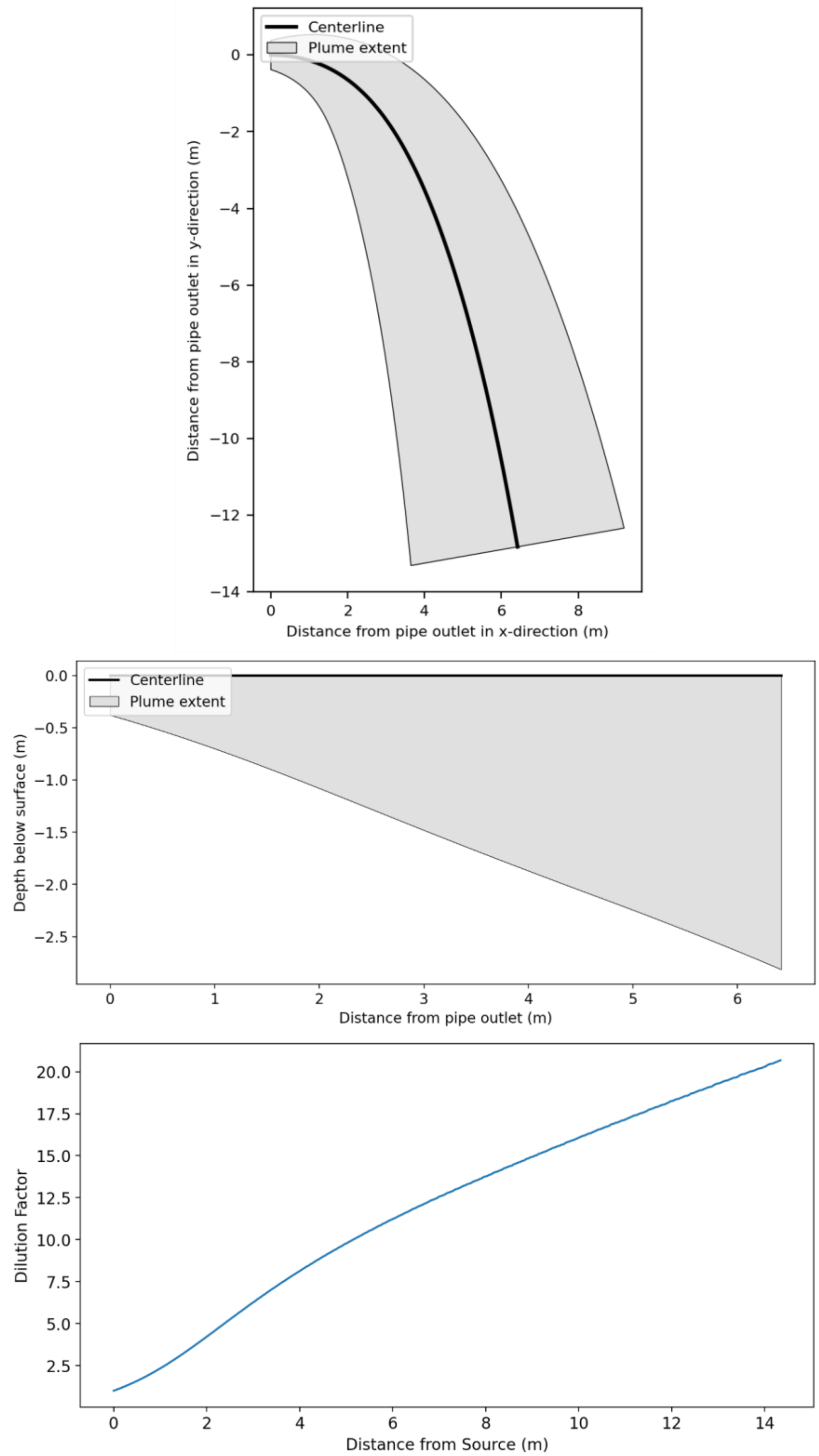

Figure 3.2: Schematic representation of plume boundary and centerline in the x-y plane (upper left panel) and x-z plane (upper right panel) for both the summer and winter scenarios with current. The lower panel shows dilution factor as a function of distance from the source. Coordinate system: x-coordinate perpendicular to shoreline, y-coordinate parallel to shoreline, and z-coordinate positive upward.

The key findings from the simulations are summarized as follows:

i. Summer Scenario without Current (Scenarios 1 & 2 without Current):

- For both Scenarios 1 and 2, temperature decreased to below 1°C within 159 seconds at a distance of 8.23 m from the source.
- For Scenarios 1 and 2, salinity decreased to below 10% of ambient levels (3.00 PSU) within 10 and 8 seconds, at distances of 1.17 m and 0.97 m from the source, respectively.

ii. Summer Scenario with Current (Scenarios 1 & 2 with Current):

- For both Scenarios 1 and 2, temperature decreased to below 1°C within 29 seconds at a distance of 2.24 m from the source.
- For Scenarios 1 and 2, salinity decreased to below 10% of ambient levels (3.00 PSU) within 4 and 3 seconds, at distances of 0.49 m and 0.38 m from the source, respectively.

iii. Winter Scenario without Current (Scenarios 5 & 6 without Current):

- For both Scenarios 5 and 6, temperature decreased to below 1°C within 23 seconds at a distance of 2.25 m from the source.
- For Scenarios 5 and 6, salinity decreased to below 10% of ambient levels (3.05 PSU) within 13 and 4 seconds, at distances of 1.45 m and 0.53 m from the source, respectively.

iv. Winter Scenario with Current (Scenarios 5 & 6 with Current):

- For both Scenarios 5 and 6, temperature decreased to below 1°C within 7 seconds at a distance of 0.79 m from the source.
- For Scenarios 5 and 6, salinity decreased to below 10% of ambient levels (3.05 PSU) within 5 and 2 seconds, at distances of 0.60 m and 0.27 m from the source, respectively.

v. High-Temperature Effluent Under Summer Scenario without Current (Scenarios 3 & 4 without Current):

- For both Scenarios 3 and 4, temperature decreased to below 1°C within 3319 seconds at a distance of 33.73 m from the source.
- For Scenarios 3 and 4, salinity decreased to below 10% of ambient levels (3.00 PSU) within 10 and 8 seconds, at distances of 1.17 m and 0.97 m from the source, respectively.

vi. High-Temperature Effluent Under Summer Scenario with Current (Scenarios 3 & 4 with Current):

- For both Scenarios 3 and 4, temperature decreased to below 1°C within 128 seconds at a distance of 6.64 m from the source.
- For Scenarios 3 and 4, salinity decreased to below 10% of ambient levels (3.00 PSU) within 4 and 3 seconds, at distances of 0.49 m and 0.38 m from the source, respectively.

4.0 Conclusions

In this study, modelling of near field mixing and dispersion of effluent discharge from a marine outfall near Placentia Bay was conducted with the CORMIX model. The model was run for winter and summer ambient conditions for water temperature and salinity. The modelling results were compared to the CCME's WQG for the marine environment.

The main conclusions are as follows:

- The CCME's WQG for temperature was met at a short distance from the discharge source for all scenarios except the high-temperature effluent discharge under summer ambient conditions, where compliance was achieved at 33.73 m. Among other cases, the summer scenarios without current required the longest distance to meet the guideline (8.23 m from the source).
- The CCME's WQG for salinity was satisfied within 1.50 m of the discharge source for all scenarios. The winter scenario (25.48 PSU effluent salinity) without current required the greatest distance (1.45 m) to achieve compliance.
- The presence of a conservative 5 cm/s current significantly reduced the required compliance distance in all scenarios.
- The thermocline did not affect mixing and dispersion since the discharge occurred at the surface, well above this boundary. However, a bottom discharge (below the thermocline) would also meet CCME's WQG guidelines, as the buoyant effluent plume would rise through the thermocline to the surface.

5.0 References

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