Near-Field Modelling Study of Effluent Dispersion

Submitted to

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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 Visual Plumes 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 is located approximately 60 meters offshore into the receiving coastal waters (Option 2 in Figure 2.1). The outfall discharges effluent through a 3-inch diameter pipe positioned on the seabed at a depth of approximately 7.14 meters below the water surface, with a maximum flow rate of 50.3 m^3/h (equivalent to 1,207,200 L/day). No settling pond is present prior to discharge into the marine environment.

Based on the previous Hatch Pre-FEED/FEL-2 report and the maximum allowable effluent temperature outlined in Newfoundland and Labrador’s (NL’s) regulations, the effluent discharge temperatures used in the modeling range from a minimum of 0.3 °C to a maximum of 32 °C. Salinity values are derived from client-provided data indicating an effluent salinity of 0.0285 ppt for North Atlantic; this corresponds to an estimated combined discharge salinity of 28.5 PSU (Practical Salinity Units).

The potential impacts on ambient water temperature and salinity were evaluated by modeling the effluent at the specified temperature and salinity values, as summarized in Table 2.1.

Table 2.1: Effluent Discharge Rate and Characterizations

Scenario	Season	Discharge Rate (L/day)	Temperature (°C)	Salinity (PSU)
1	Summer	1,207,200	0.3	28.5
2			32.0	
3	Winter		0.3	
4			32.0	

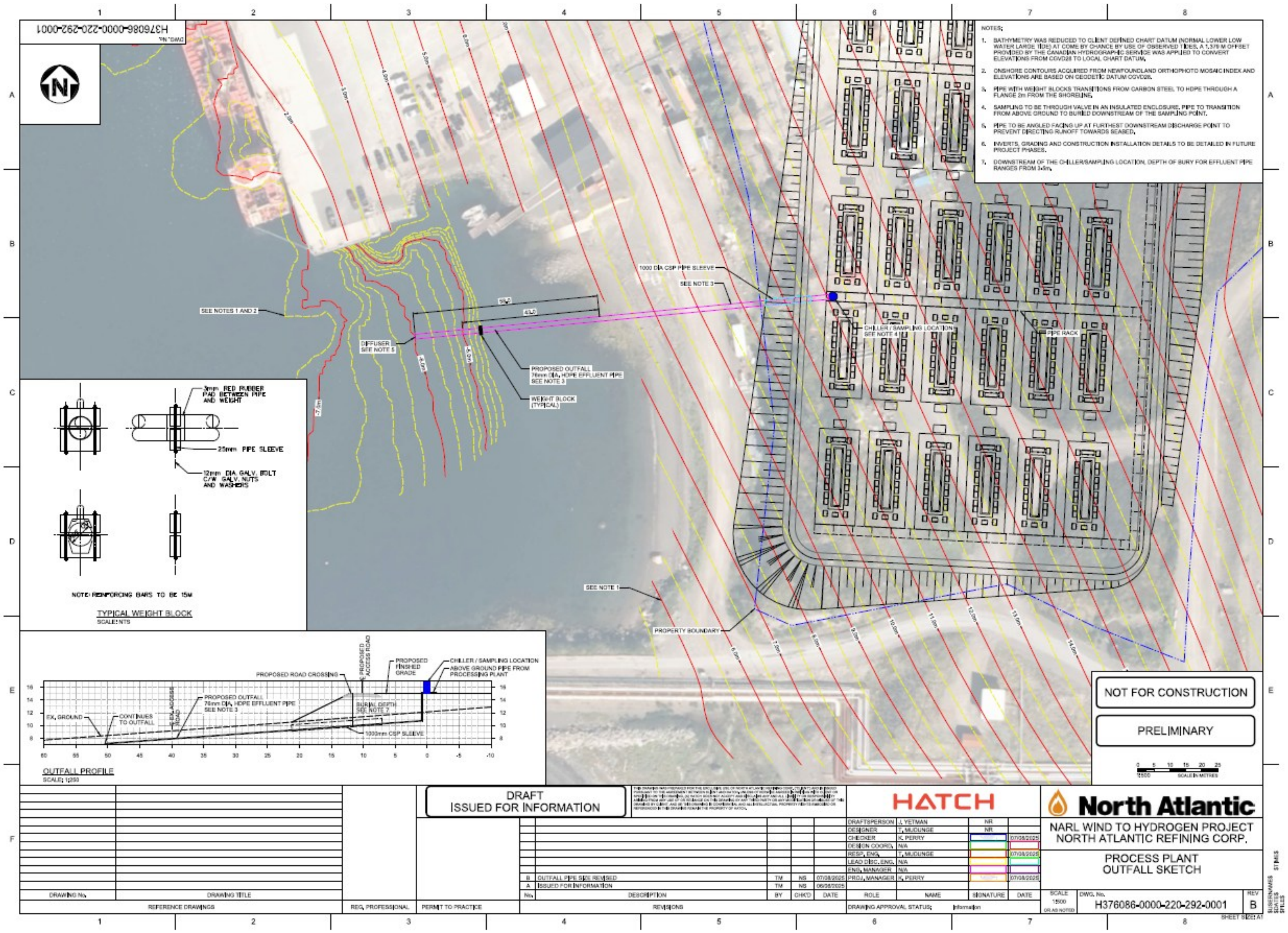

Figure 2.1: Location of the proposed outfall (option 2) and nearby bathymetry

Analysis of CTD observations from MS1 to MS3 in Placentia Bay revealed consistent temperature and salinity profiles at the three locations on July 12, September 28, and December 4 to 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. The CTC profiles are shown in Figures 2.2 through 2.4. Figure 2.5 shows time series of temperature records, which indicated seasonal extremes, ranging from >20 °C (August to September 2024) to 2 °C (November 2024).

For modeling purposes, the following representative ambient conditions were adopted. Under summer conditions, a uniform water column temperature of 20 °C and salinity of 30 PSU were applied over the full depth of approximately 7.14 meters, corresponding to the location of the outfall port at the seabed. For winter conditions, the water column was similarly assumed to be vertically uniform, with a temperature of 2 °C and a salinity of 30.5 PSU.

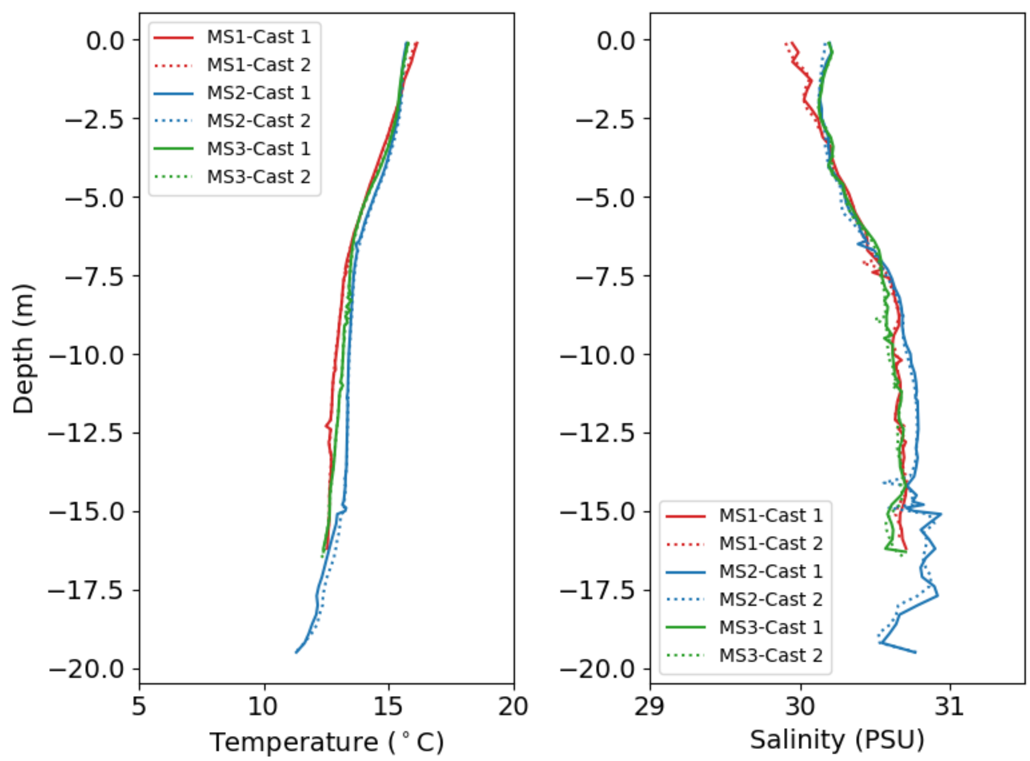

Figure 2.2: CTD Vertical Profiles of Temperature and Salinity at MS1 to MS3 on July 12, 2024

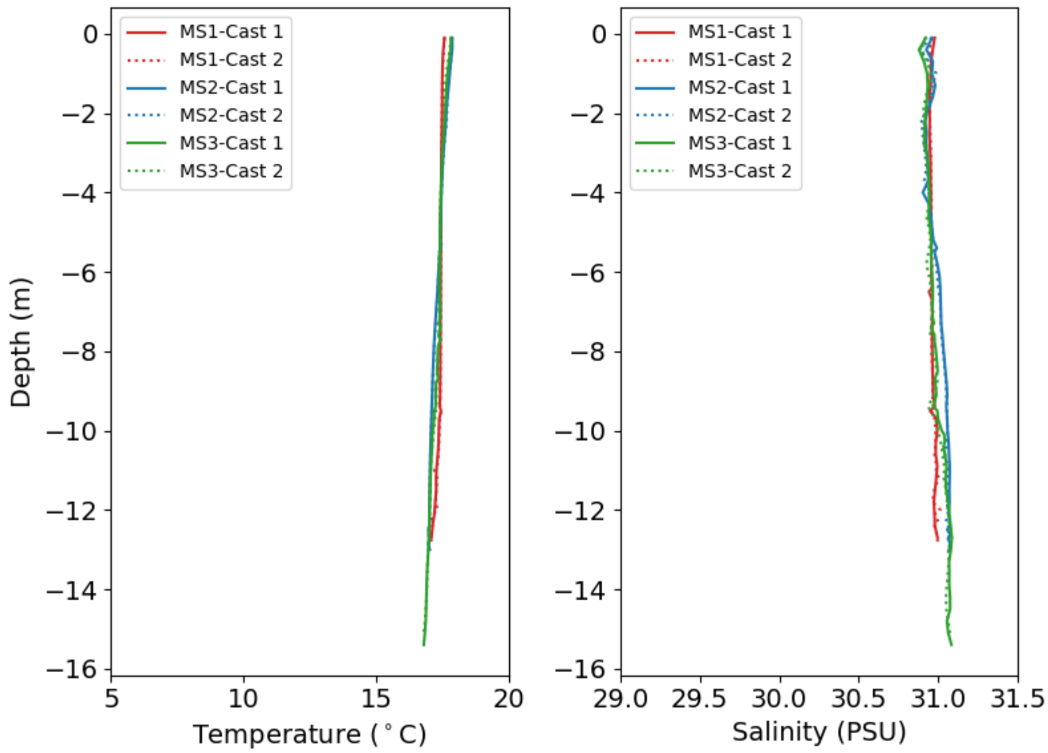

Figure 2.3: CTD Vertical Profiles of Temperature and Salinity at MS1 to MS3 on September 28, 2024

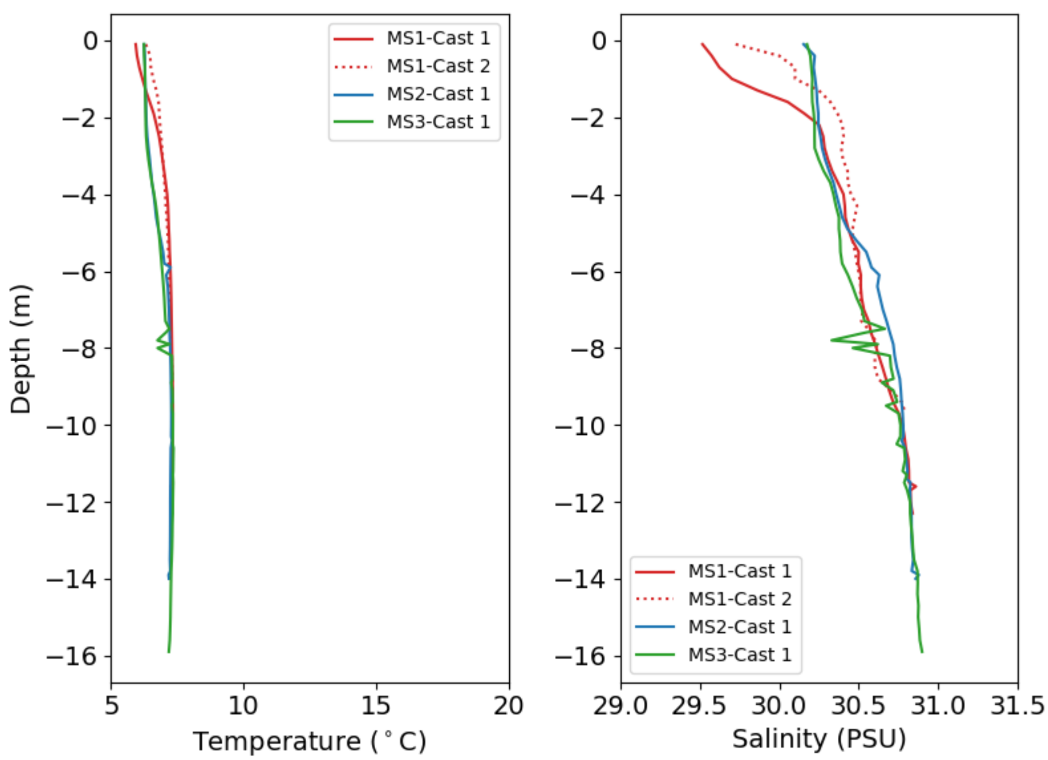

Figure 2.4: CTD Vertical Profiles of Temperature and Salinity at MS1 to MS3 on December 4 to 5, 2024

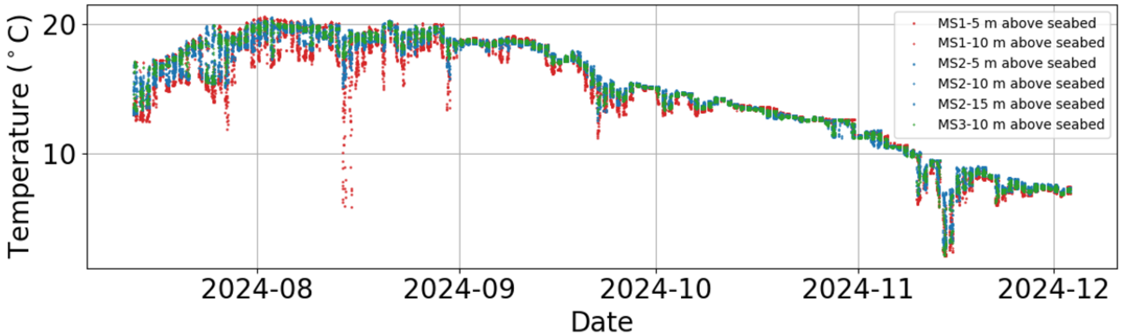

Figure 2.5: Time Series of Temperature at Different Depths at MS1 to MS3 from Tidbit Observations

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 was 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 study models bottom discharge via the outfall pipe 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.

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)
Summer	20.0	30.0	0.05
Winter	2.0	30.5	

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) or objectives.

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 pertaining to temperature and salinity in the marine environment were employed.

CCME's WQG for the protection of aquatic life regarding temperature advocate 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 Visual Plumes Model

Visual Plumes is a plume modeling system developed by the U.S. Environmental Protection Agency (EPA) for simulating the behavior of discharges into water bodies, such as wastewater and thermal effluents. The model is specifically designed to characterize the initial (near-field) mixing zone, where momentum and buoyancy-driven processes dominate. Visual Plumes supports a range of discharge configurations, including single-port, multiport, surface, and submerged outfalls. It can account for variable ambient conditions, including temperature, salinity, current velocity, and water column stratification.

3.2 Discharge Configuration

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

i. Diffuser Specifications:

- A single discharge port is used.
- The port is located at a depth of 7.139 meters below the water surface.
- The port is elevated 0.1 meters above the seabed.
- The port diameter is specified as 3 inches (76.2 mm).
- The port orientation is set with a vertical angle of 90° and a horizontal angle of 0°, indicating that the effluent is discharged vertically upward.

ii. Effluent Discharge Characteristics:

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

iii. 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.

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 Visual Plumes 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 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	2 m	3 m	4 m	5 m
1	0	0.3	20.0	[19.0, 21.0]	16.9	18.3	18.8	19.1	19.3
	5				16.9	18.4	19.0	19.3	19.6
2	0	32.0	20.0		21.9	21.0	20.7	20.5	20.4
	5				21.9	21.0	20.6	20.4	20.3
3	0	0.3	2.0	[1.0, 3.0]	1.7	1.9	1.9	1.9	1.9
	5				1.7	1.9	1.9	1.9	2.0
4	0	32.0	2.0		6.8	4.6	3.7	3.3	3.0
	5				6.8	4.5	3.5	3.1	2.7
Note: [1] change of 1 °C from ambient temperature.									

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

Scenario	Current (cm/s)	Effluent Salinity (PSU)	Ambient Salinity (PSU)	CCME WQG [1] (PSU)	Salinity at Various Distance from Outfall (PSU)				
					1 m	2 m	3 m	4 m	5 m
1	0	28.5	30.0	[27.0, 33.0]	29.8	29.9	29.9	30.0	30.0
	5				29.8	29.9	30.0	30.0	30.0
2	0				29.8	29.9	29.9	30.0	30.0
	5				29.8	29.9	30.0	30.0	30.0
3	0		30.5	[27.5, 33.6]	30.2	30.4	30.4	30.4	30.5
	5				30.2	30.4	30.4	30.5	30.5
4	0				30.2	30.4	30.4	30.5	30.5
	5				30.2	30.4	30.4	30.5	30.5
Note: [1] change of 10% from ambient salinity.									

Figure 3.1 presents the simulated plume under quiescent summer conditions for an effluent temperature of 0.3 °C, along with the corresponding dilution factor as a function of distance from the discharge point. Figure 3.2 shows the results for an effluent temperature of 32.0 °C. The lower effluent temperature in Figure 3.1 results in a negatively buoyant discharge (i.e., effluent is denser than the ambient water), whereas the higher temperature in Figure 3.2 leads to a positively buoyant discharge (i.e., effluent is less dense than the ambient water). In the latter case, buoyancy enhances near-field mixing by generating vertical motion and entraining ambient water, thereby increasing dilution. This difference in buoyancy leads to observable variations in plume geometry between the two scenarios.

Figures 3.3 and 3.4 illustrate the plume geometry and dilution profiles for the two effluent temperature cases (0.3 °C and 32.0 °C, respectively), under the influence of an ambient current of 5 cm/s. While the difference in effluent buoyancy leads to slight variations in plume geometry, both scenarios exhibit a horizontally slanted plume trajectory due to advection by the ambient current, which flows in the downstream (negative *x*-axis) direction, parallel to the shoreline.

Figures 3.5 through 3.8 present the plume geometry and dilution profiles under winter ambient conditions for effluent temperatures of 0.3 °C and 32.0 °C. Both scenarios represent positively buoyant discharges, with the latter (32.0 °C) exhibiting higher buoyancy due to the greater temperature difference relative to the ambient water. Figures 3.7 and 3.8 correspond to the same effluent cases but include the influence of a 5 cm/s ambient current.

In all cases, compliance with temperature-based regulatory thresholds is achieved shortly after discharge, while salinity criteria are met almost immediately at the source due to the relatively small difference between the effluent salinity (28.5 PSU) and ambient salinity (30.0 PSU in summer and 30.5 PSU in winter). As observed in previous scenarios, the presence of an ambient current enhances near-field mixing and dilution, enabling more rapid attainment of water quality standards within a shorter distance from the outfall.

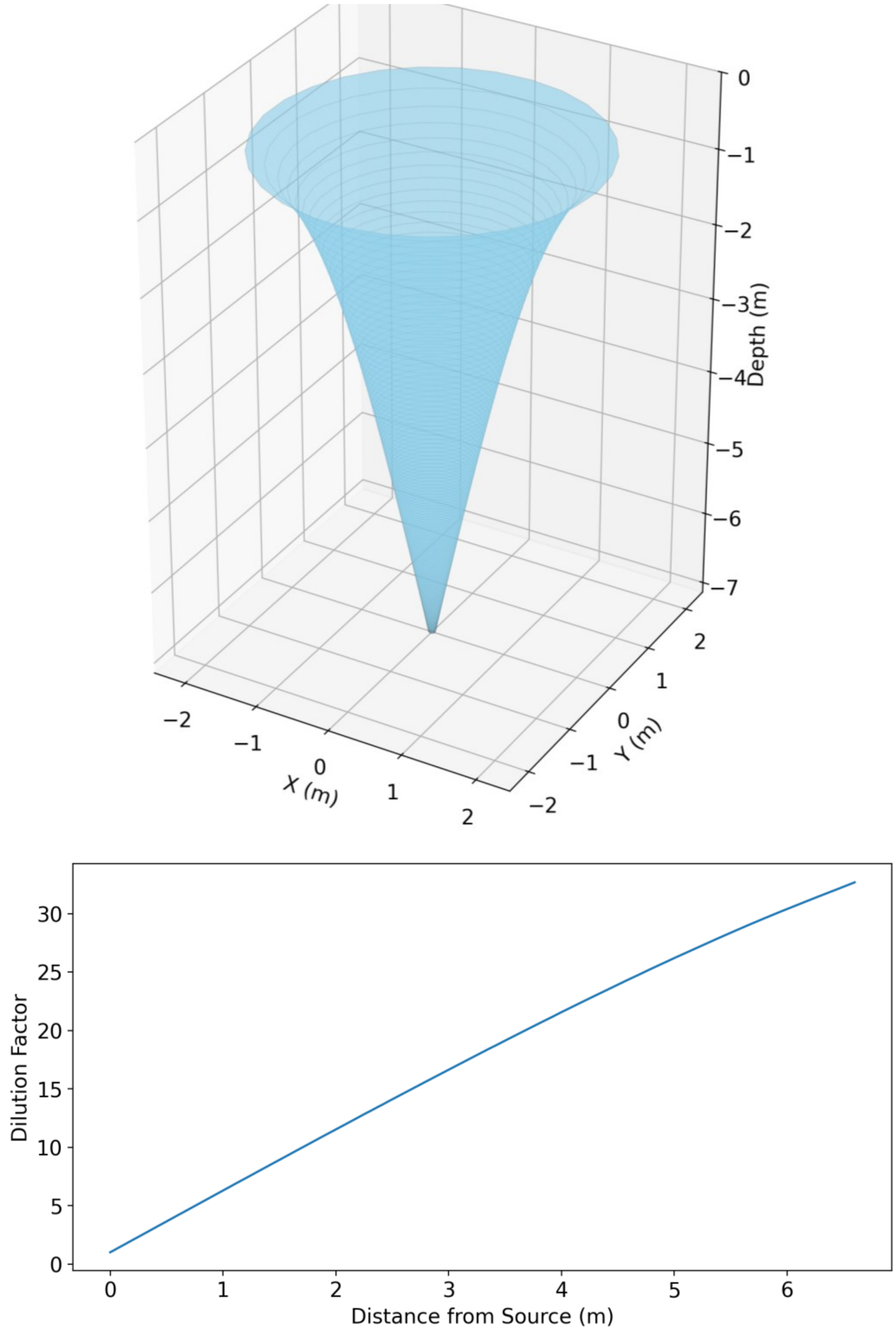

Figure 3.1: Schematic representation of the plume under summer conditions with an effluent temperature of 0.3 °C and no ambient current (upper panel). The lower panel shows the dilution factor as a function of distance from the discharge point. Coordinate system: *x*-axis is parallel to the shoreline, *y*-axis is perpendicular to the shoreline, and *z*-axis is positive upward.

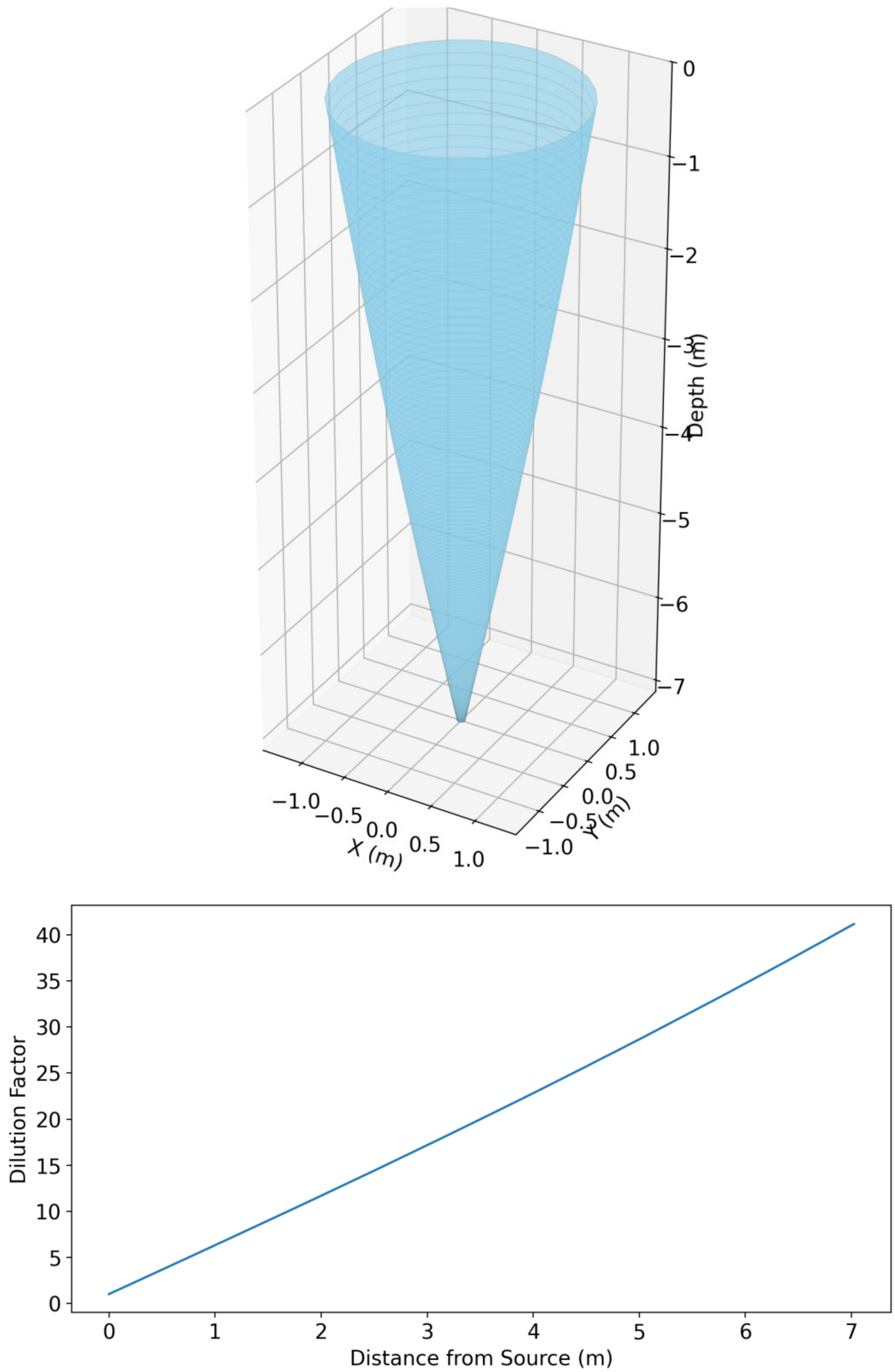

Figure 3.2: Schematic representation of the plume under summer conditions with an effluent temperature of 32.0 °C and no ambient current (upper panel). The lower panel shows the dilution factor as a function of distance from the discharge point. Coordinate system: *x*-axis is parallel to the shoreline, *y*-axis is perpendicular to the shoreline, and *z*-axis is positive upward.

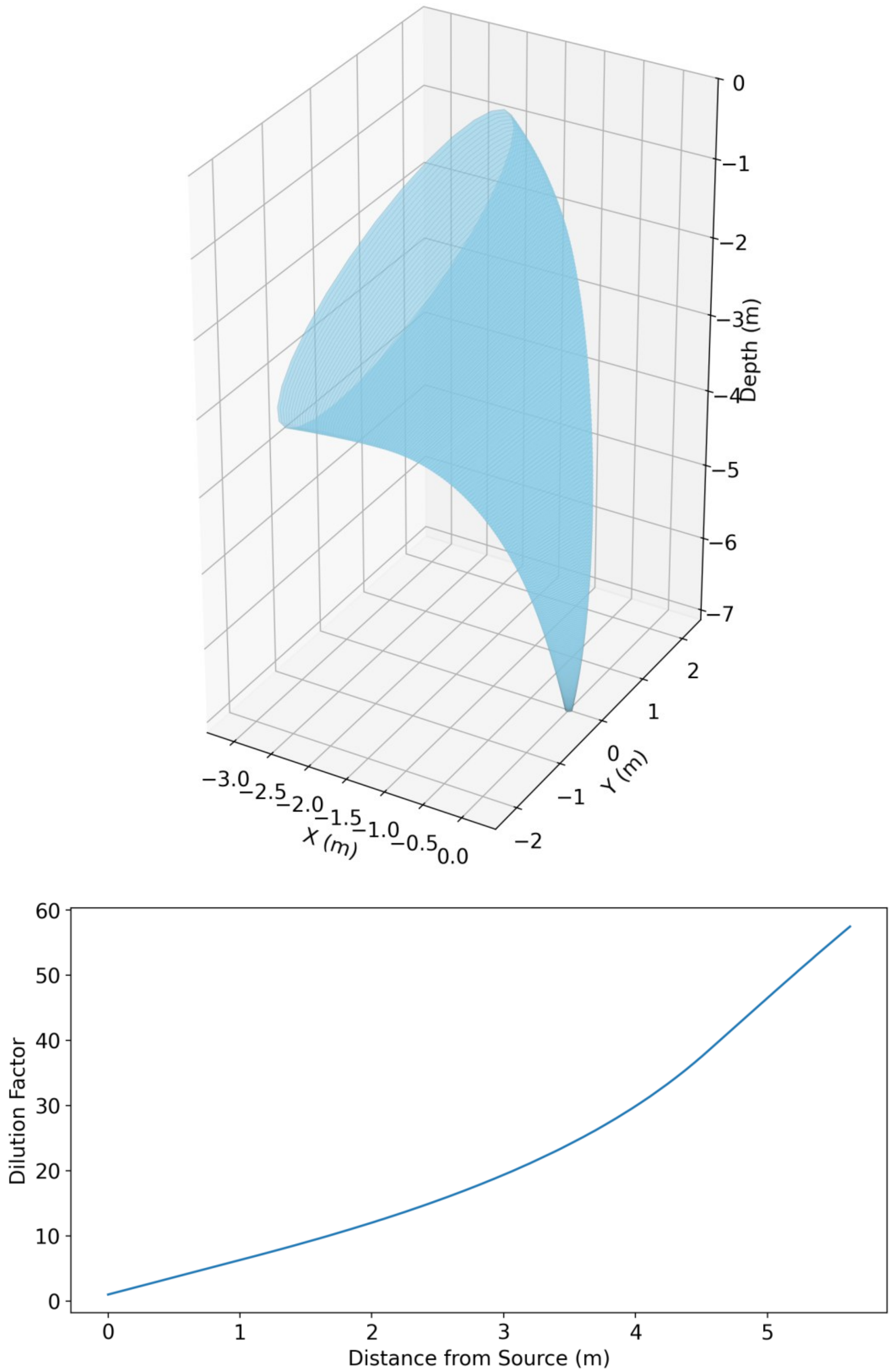

Figure 3.3: Schematic representation of the plume under summer conditions with an effluent temperature of 0.3 °C and an ambient current of 5 cm/s (upper panel). The lower panel shows the dilution factor as a function of distance from the discharge point. Coordinate system: *x*-axis is parallel to the shoreline, *y*-axis is perpendicular to the shoreline, and *z*-axis is positive upward.

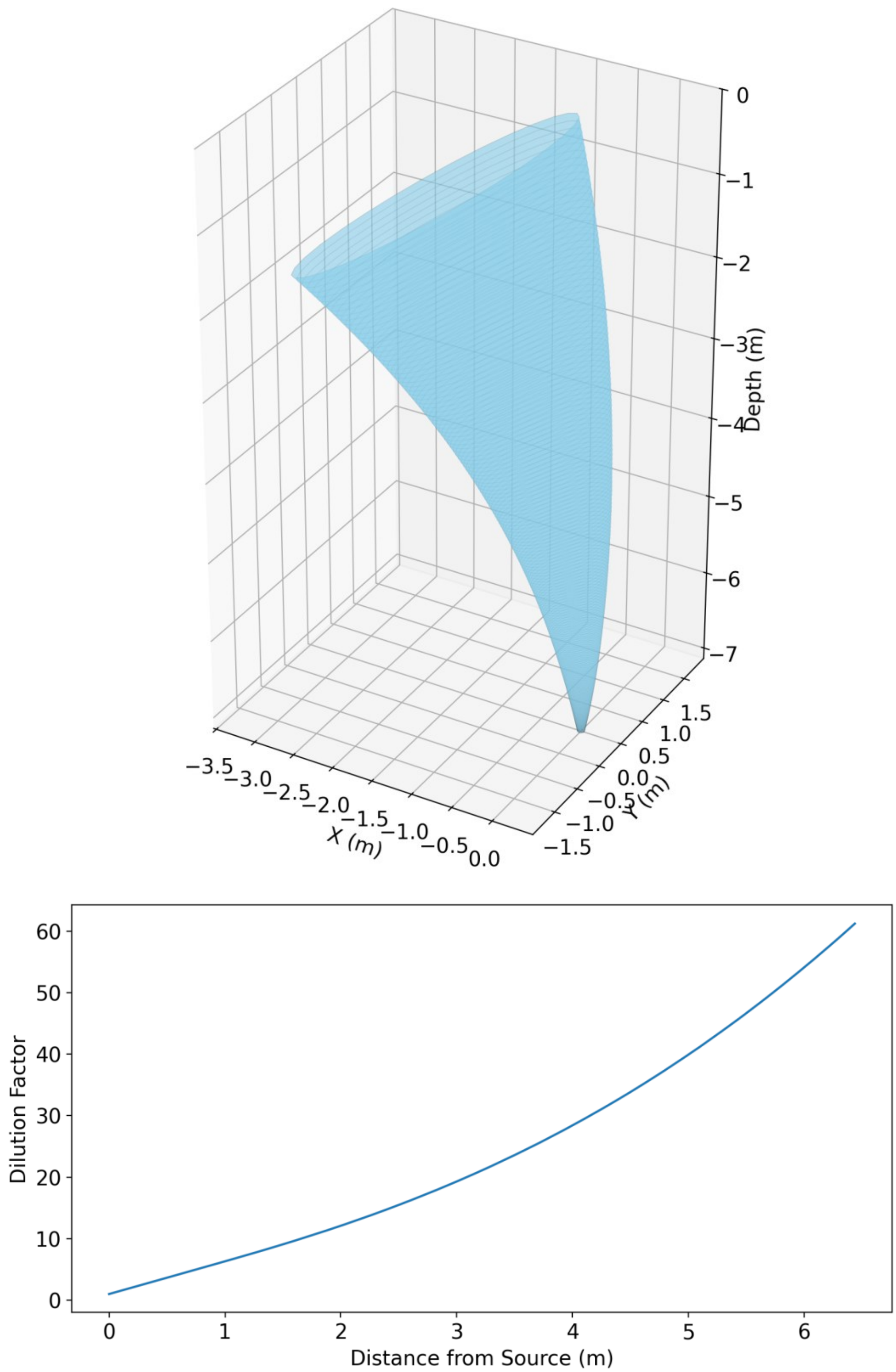

Figure 3.4: Schematic representation of the plume under summer conditions with an effluent temperature of 32.0 °C and an ambient current of 5 cm/s (upper panel). The lower panel shows the dilution factor as a function of distance from the discharge point. Coordinate system: *x*-axis is parallel to the shoreline, *y*-axis is perpendicular to the shoreline, and *z*-axis is positive upward.

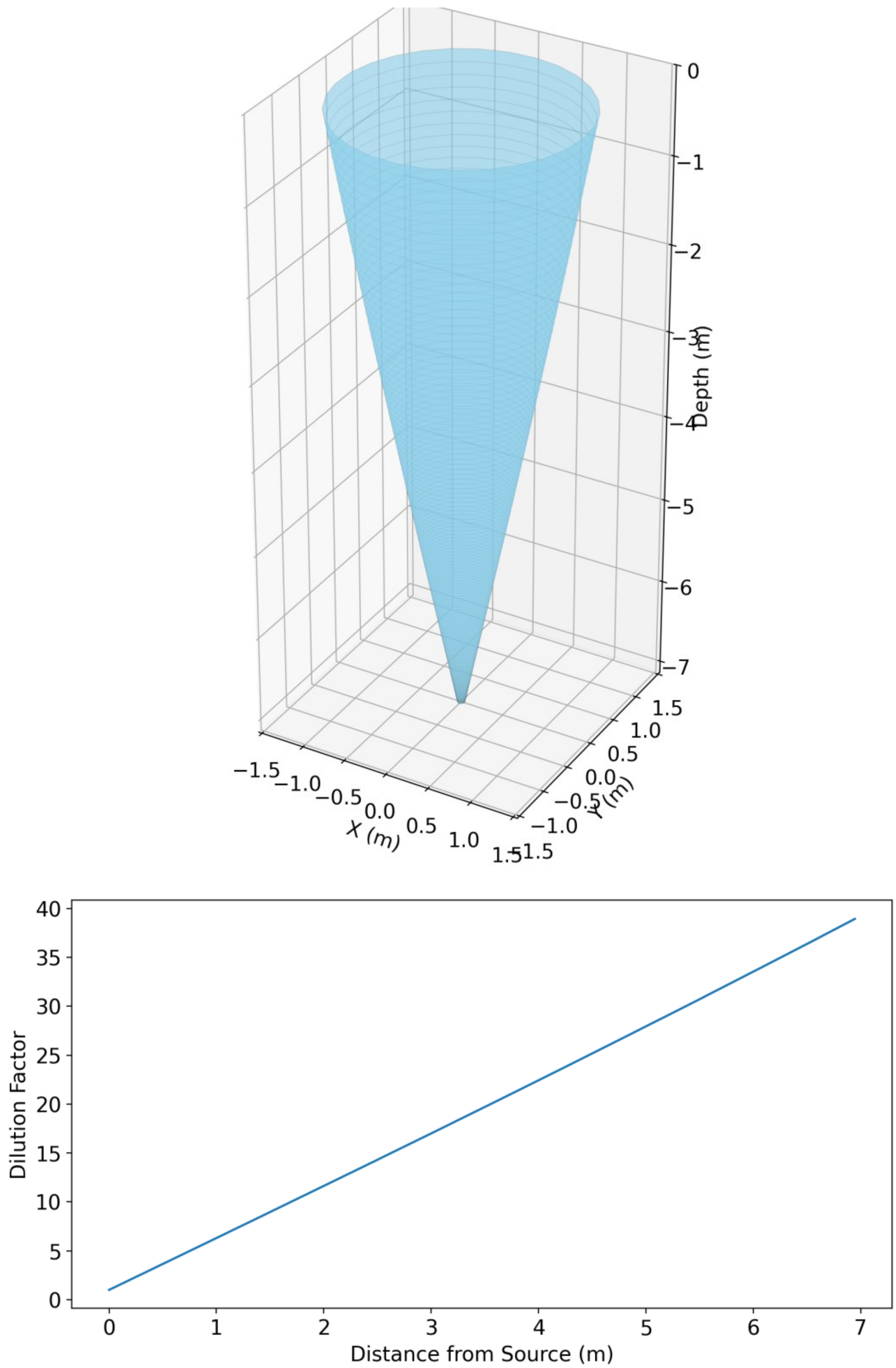

Figure 3.5: Schematic representation of the plume under winter conditions with an effluent temperature of 0.3 °C and no ambient current (upper panel). The lower panel shows the dilution factor as a function of distance from the discharge point. Coordinate system: *x*-axis is parallel to the shoreline, *y*-axis is perpendicular to the shoreline, and *z*-axis is positive upward.

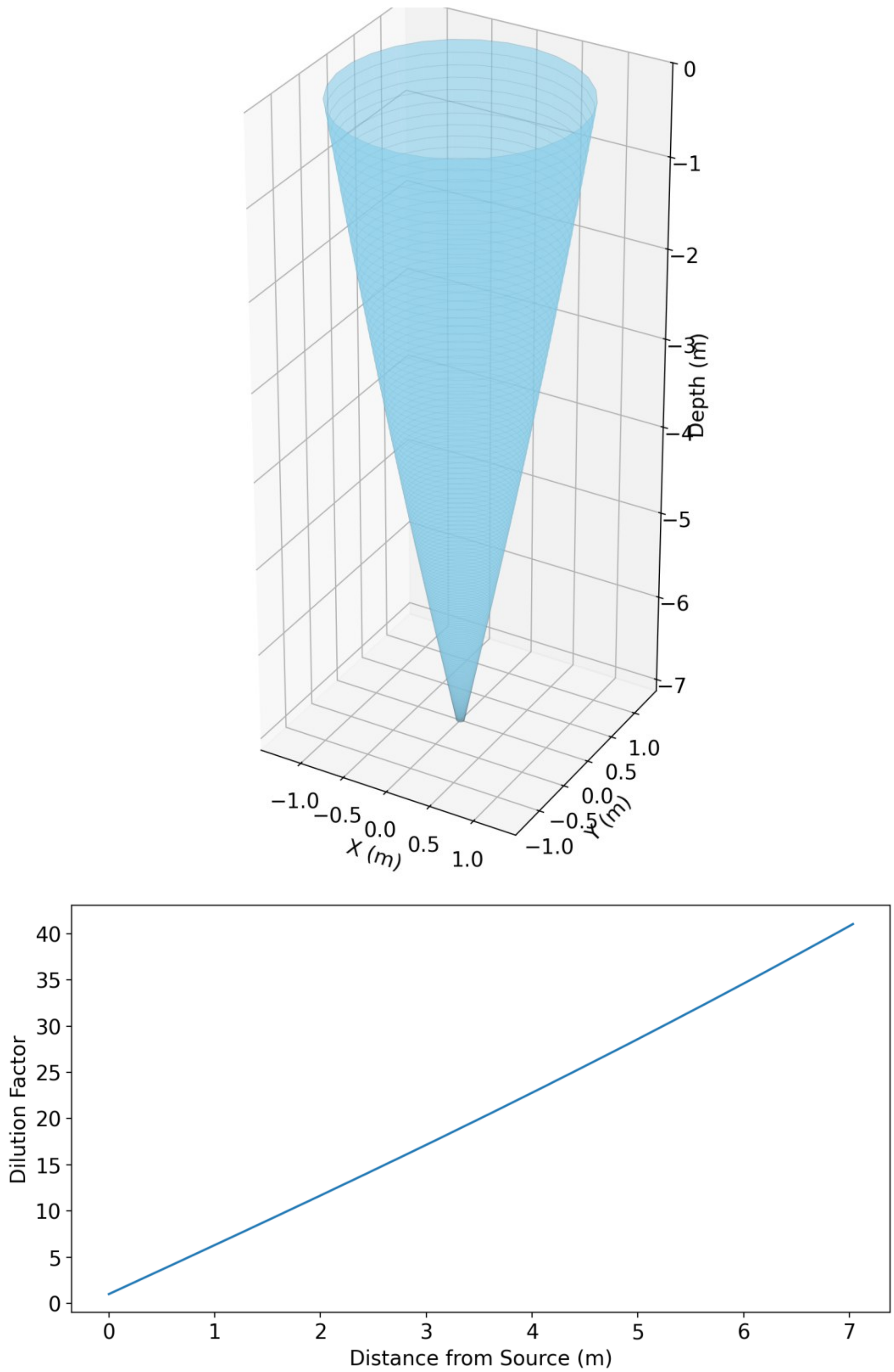

Figure 3.6: Schematic representation of the plume under winter conditions with an effluent temperature of 32.0 °C and no ambient current (upper panel). The lower panel shows the dilution factor as a function of distance from the discharge point. Coordinate system: *x*-axis is parallel to the shoreline, *y*-axis is perpendicular to the shoreline, and *z*-axis is positive upward.

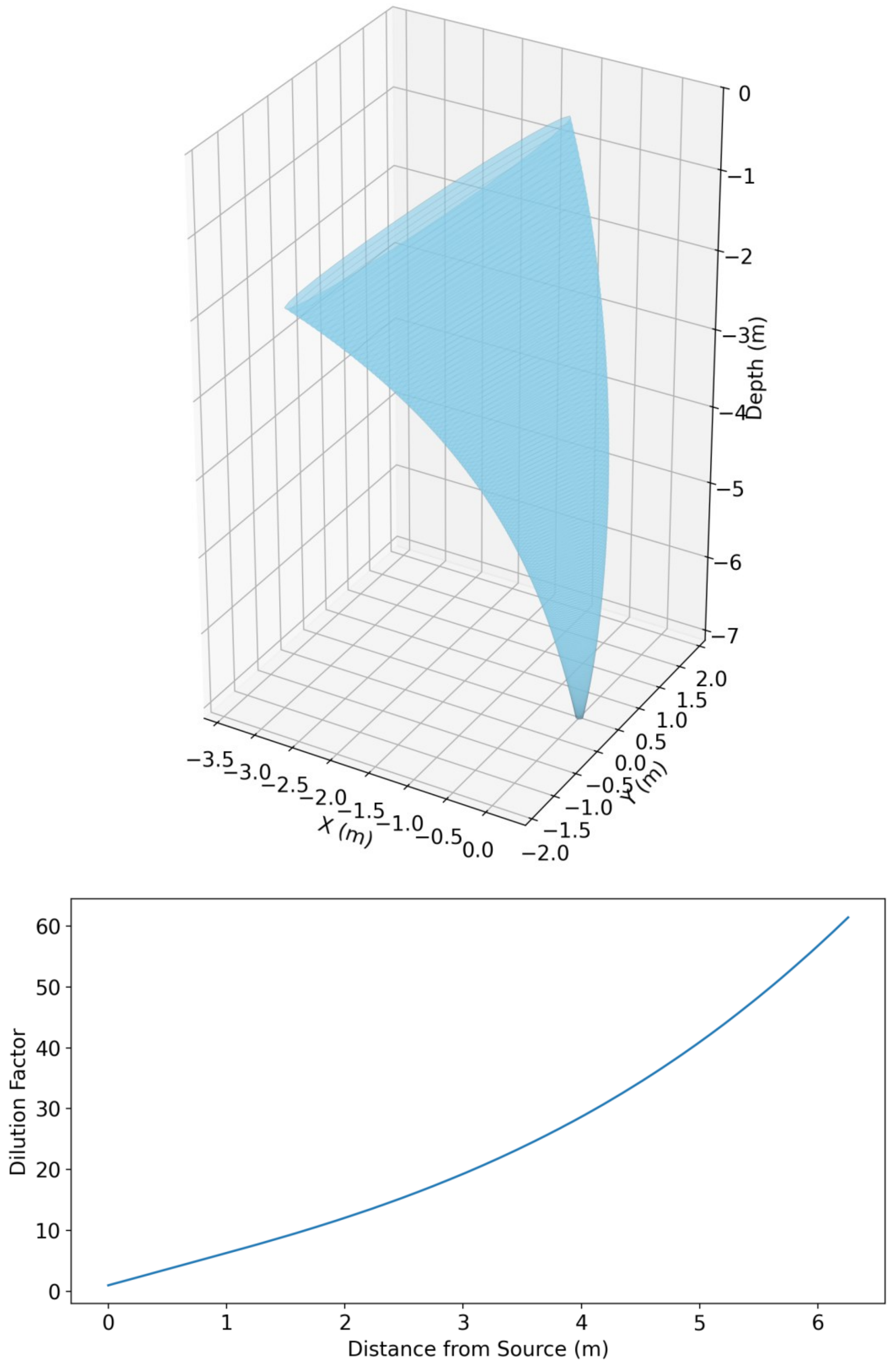

Figure 3.7: Schematic representation of the plume under winter conditions with an effluent temperature of 0.3 °C and an ambient current of 5 cm/s (upper panel). The lower panel shows the dilution factor as a function of distance from the discharge point. Coordinate system: *x*-axis is parallel to the shoreline, *y*-axis is perpendicular to the shoreline, and *z*-axis is positive upward.

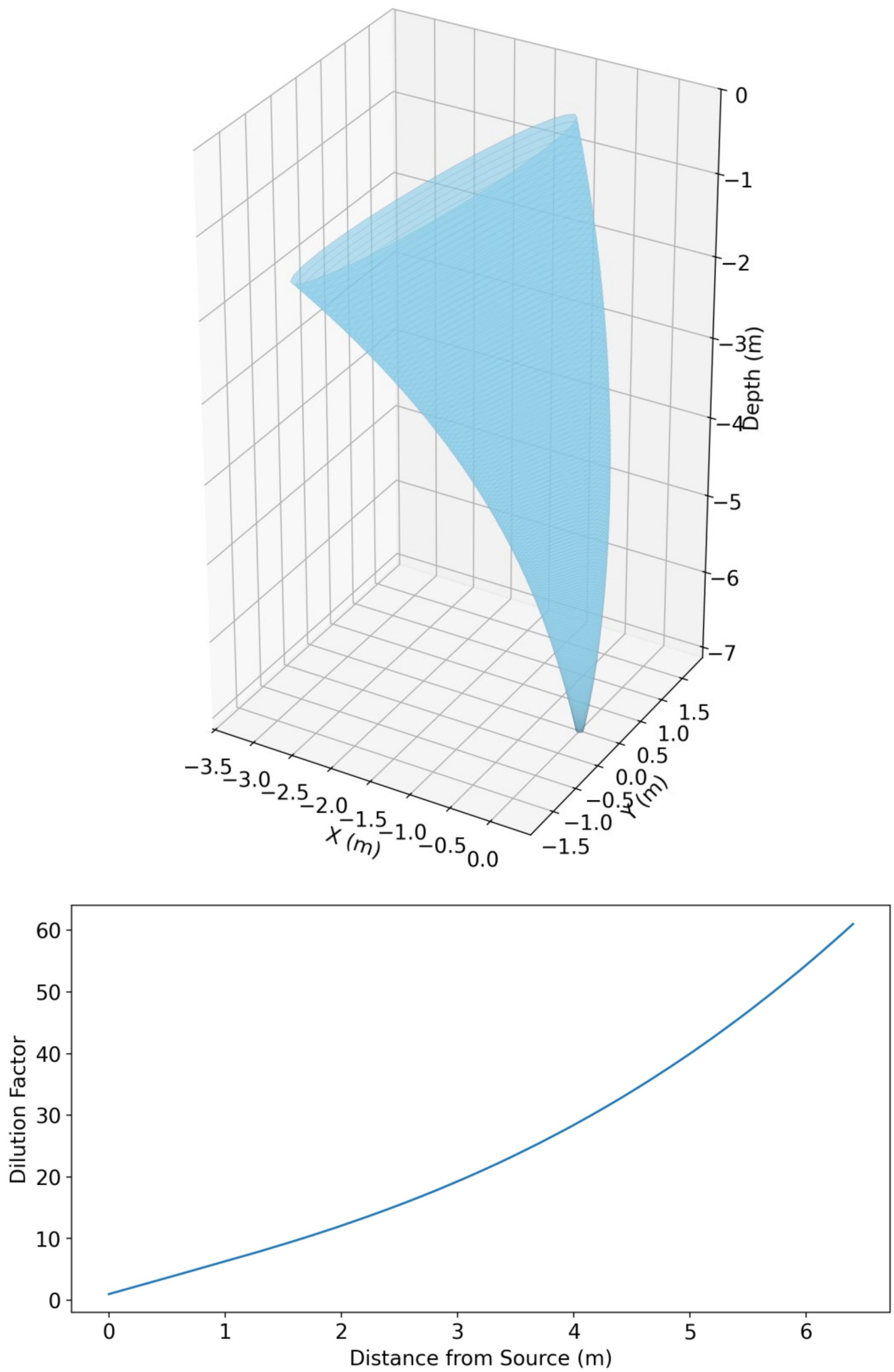

Figure 3.8: Schematic representation of the plume under winter conditions with an effluent temperature of 32.0 °C and an ambient current of 5 cm/s (upper panel). The lower panel shows the dilution factor as a function of distance from the discharge point. Coordinate system: *x*-axis is parallel to the shoreline, *y*-axis is perpendicular to the shoreline, and *z*-axis is positive upward.

The key findings from the simulations are summarized as follows:

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

- In Scenario 1 with an effluent temperature of 0.3 °C, the change in temperature decreased to below 1 °C within 14 seconds at a distance of 3.66 m from the discharge point.
- In Scenario 2 with an effluent temperature of 32.0 °C, the change in temperature dropped below 1 °C within 4 seconds at a distance of 2.07 m from the source.
- For both Scenarios 1 and 2, the change in salinity decreased to less than 10% of the ambient level (i.e., ≤ 3.00 PSU) almost immediately at the point of discharge.

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

- In Scenario 1 with an effluent temperature of 0.3 °C, the change in temperature decreased to below 1 °C within 10 seconds at a distance of 3.06 m from the discharge point.
- In Scenario 2 with an effluent temperature of 32.0 °C, the change in temperature dropped below 1 °C within 4 seconds at a distance of 2.00 m from the source.
- For both Scenarios 1 and 2, the change in salinity decreased to less than 10% of the ambient level (i.e., ≤ 3.00 PSU) almost immediately at the point of discharge.

iii. Winter Scenario without Current (Scenarios 3 & 4 without Current):

- In Scenario 3 with an effluent temperature of 0.3 °C, the change in temperature decreased to below 1 °C within 0.1 seconds at a distance of 0.13 m from the discharge point.
- In Scenario 4 with an effluent temperature of 32.0 °C, the change in temperature dropped below 1 °C within 23 seconds at a distance of 5.22 m from the source.
- For both Scenarios 3 and 4, the change in salinity decreased to less than 10% of the ambient level (i.e., ≤ 3.05 PSU) almost immediately at the point of discharge

iv. Winter Scenario with Current (Scenarios 3 & 4 with Current):

- In Scenario 3 with an effluent temperature of 0.3 °C, the change in temperature decreased to below 1 °C within 0.1 seconds at a distance of 0.13 m from the discharge point.
- In Scenario 4 with an effluent temperature of 32.0 °C, the change in temperature dropped below 1 °C within 16 seconds at a distance of 4.12 m from the source.
- For both Scenarios 3 and 4, the change in salinity decreased to less than 10% of the ambient level (i.e., ≤ 3.05 PSU) almost immediately at the point of discharge.

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 Visual Plumes 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' WQG for temperature was met at a short distance from the discharge source for all scenarios. Among all scenarios, the winter case with a 32 °C effluent and no ambient current required the longest distance to achieve compliance with the temperature guideline, at 5.22 m from the discharge point.

- The CCME' WQG for salinity was effectively met at the point of discharge in all scenarios, owing to the small difference between the effluent salinity (28.5 PSU) and the ambient salinity (30.0 PSU in summer and 30.5 PSU in winter).
- The presence of a conservative 5 cm/s current significantly reduced the required compliance distance in all scenarios.
- It is recommended that the riser height, the elevation of the discharge port above the seabed, be less than 1.92 m, based on the worst-case scenario (winter conditions with a 32 °C effluent and no ambient current), which requires a distance of 5.22 m from the source to meet temperature regulations. This recommendation also accounts for the total water depth of approximately 7.14 m at the discharge location.

5.0 References

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