Appendix 11-A

Assimilative Capacity Study –
Mixing Zone Modelling for Marine Discharge

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PROJECT NUJIO'QONIK Assimilative Capacity Study - Mixing Zone Modelling for Marine Discharge

August 2023

Prepared for:

world energy GH2

Prepared by:

Stantec Consulting Ltd.

File: 121417575

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Introduction

Project Nujio'qonik (the Project) involves the development, construction, operation and maintenance, and eventual decommissioning and rehabilitation of one of the first Canadian, commercial-scale, "green hydrogen" and ammonia production plants powered by renewable wind energy. Located on the western coast of the island of Newfoundland, Newfoundland and Labrador (NL), the Project will have a maximum production of up to approximately 206,000 t of green hydrogen per year. The hydrogen produced by the Project will be converted into ammonia and the resulting 1.17 Mt of ammonia exported to international markets by ship. The hydrogen / ammonia plant and associated storage and export facilities will be located at the Port of Stephenville (in the Town of Stephenville, NL) on a privately-owned brownfield site and at an adjacent existing marine terminal, both of which are zoned for industrial purposes.

Renewable energy from two approximately 1,000 megawatt (MW) / 1 gigawatt (GW) onshore wind farms on the western coast of Newfoundland will be used to power the hydrogen and ammonia production processes. These wind farms (referred to herein as the "Port au Port area wind farm" and the "Codroy area wind farm") will include up to 328 turbines and collectively produce approximately 2,000 MW / 2 GW of renewable electricity. The Port au Port wind farm will include up to 164 wind turbines, with up to 171 sites that are being studied for the EIS, on the Port au Port Peninsula, NL and adjacently on the Newfoundland "mainland" (i.e., northeast of the isthmus at Port au Port). The Codroy wind farm will also consist of up to 164 wind turbines located on Crown land in the Anguille Mountains of the Codroy Valley, NL. The modelling and assessment work is based on preliminary layouts for both wind farm sites (i.e., 171 potential turbine locations at the Port au Port wind farm and 143 potential turbine locations at Codroy wind farm). Final wind farm layouts will be dependent on results of the wind campaign and more detailed field investigations. Once the layout and number of turbines are finalized, the results of models will be reviewed and updated as required.

The Project is subject to provincial environmental assessment (EA) requirements under the NL *Environmental Protection Act* and associated *EA Regulations* (EA Regulations). This document is the Assimilative Capacity Study - Mixing Zone Modelling for Marine Discharge Study, prepared in support of Project Environmental Impact Statement (EIS).

2.0 Background

World Energy GH2 is proposing to construct and operate a cost-effective green hydrogen/ammonia production and shipping facility with electrical supply via wind power on the west coast of the Island of Newfoundland, in the province of Newfoundland and Labrador (NL). In support of an EIS required under the NLEPA and *EA Regulations*, a study is required to evaluate the assimilative capacity of the marine environment to discharge the reject process water from the hydrogen/ammonia plant.

The hydrogen and ammonia will be produced using electrical power produced by wind energy or supplied by the NL Hydro grid. An electrolyzer plant uses renewable electricity to separate hydrogen from purified water. By applying an electrical current through water, the hydrogen and oxygen molecules split and hydrogen gas is then captured, purified, and compressed for direct use, storage, or distribution. The oxygen may be captured for other uses or safely vented to the atmosphere.

The electrolyzer system will be supplied with demineralized water. The pre-designed demineralization system assumes a potable water stream but is fully customizable for a source of raw water. It is assumed that approximately 36% of the water supplied is eventually lost to purification effluent, cooling, and flushing water and is considered reject process water or effluent. This effluent will contain minerals that are already present in the water source, concentrated to approximately three times the initial concentration. The reject process water is proposed to be discharged through an existing marine outfall at the entrance of the Port of Stephenville (formerly Port Harmon) about 500 m offshore (Figure 1).

The treated effluent will be designed to be discharged to the ocean and will meet the discharge limit under the Schedule A of NLR65/03: *Environmental Control Water and Sewage Regulations* under the *Water Resource Act*. The treated effluent target of TSS <30 mg/L and TDS <1,000 mg/L is adopted as the design basis for concept design. It is important to note that there are other parameters in the NLR65/03 such as the biological oxygen demand, bacteria, and heavy metals, which must be met before discharging the effluent to the harbour. These water quality parameters are not known at this time and are highly dependent on the process. The objective of this assimilative capacity study is to conduct near-field modelling using a three-dimensional (3D) dilution mixing model to determine the mixing zone for parameters of concern in the reject process water (effluent).The modelling assesses whether the concentration of parameters of potential concern at the end of the mixing zone meets Canadian Council of Ministers of the Environment (CCME) Canadian Environmental Quality Guidelines (CEQG), is protective of the environment, and is in compliance with the water quality guidelines for site-specific ambient marine conditions.

3.0 Effluent Characterization

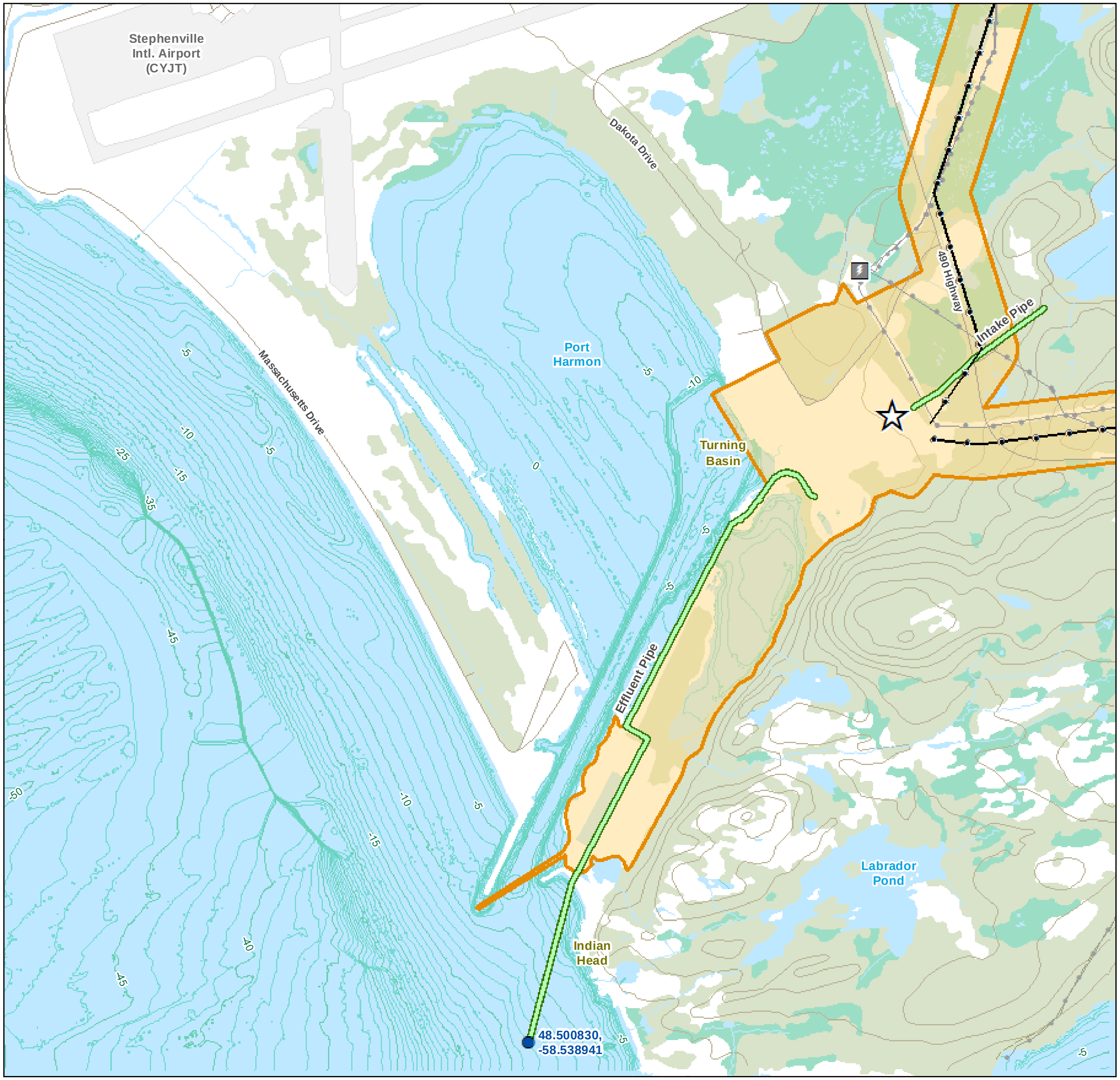
An analysis of the raw water from the source water locations (Noels Pond, Muddy Pond and Gull (Mine) Pond indicates the waters are low in suspended solids (TSS <10 mg/L) and associated turbidity (<5 NTU) with colour ranging from 31.4 to 71.6 TCU. Total Dissolved Solids (TDS) ranged between 44 and 104 mg/L with an average concentration of 70 mg/L. Nitrate concentrations (<0.06 mg/L) and phosphorous concentrations were less than 30 µg/L which is low in comparison to seawater (Bricker et al. 1999). Total metals in the source water were all below the CEQG for the Protection of Aquatic Life – Marine (CCME 1999) (Fracflow 2022 in Stantec 2023). As a result the treatment of source water is not anticipated to result in the exceedance of nutrients or metals above available CEQG guidelines in the effluent.

To achieve preferred performance and meet specifications of the reverse osmosis and deionization units, the assumed process water temperature at discharge is 15 °C (winter) and 25 °C (summer). In addition to temperature being different from ambient marine environment conditions, the effluent will have a lower salinity similar to fresh water because of the low concentration TDS in the reject process effluent. The resulting effluent temperature and salinity are unlikely to meet CEQG in the marine environment at the end of pipe.

TSS discharged at the treated effluent target of 30 mg/L may periodically exceed the CEQGs, though the magnitude of the exceedance is much lower than the magnitude of the temperature and salinity exceedances. TSS will require a dilution ration of 5:1 at the end-of-pipe to meet CEQGs, for the current scenario this is instantaneous. Modelling the mixing zone for temperature and salinity will encompass the TSS mixing zone therefore, conservatively the two parameters of concern identified for the treated effluent are temperature (heated discharge) and salinity.

The Facility's treated effluent is proposed to discharge via an exiting bottom-mounted pipe, extending into the harbor (Figure 3.1). The effluent pipe design is not known, but for the purposes of this assessment, it has been conservatively assumed to be a 0.15 m diameter pipe located on the riser approximately perpendicular to the shoreline and dominant tidal flow. The outfall crib was assumed to be at 1.16 m above seabed. Water depth at the outfall is 12.9 m at the chart datum.

The average effluent flow rate is 0.0936 m^3/s (winter) and 0.0875 m^3/s (summer) as per Table 6 in ARUP (2023).



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Proposed Project Features

- Hydrogen / Ammonia Plant Location
- Outfall Location
- Pipeline
- Transmission Line 230 kV
- Project Area

Other Features

- Electrical Generation, Existing
- Transmission Line, Existing
- Road
- Resource Road / Trail
- Contour (20 m)
- Bathymetry (1 m)
- Watercourse
- Waterbody
- Wetland
- Forested Area

N

0 0.7 Kilometres
(At original document size of 8.5x11)
1:30,000

Notes

1. Coordinate System: NAD 1983 CSRS UTM Zone 21N
2. Data Sources: World Energy GH2, CHS, NRCan CanVec, OpenStreetMap
3. Background: NRCan CanVec

Project Location
Stephenville
NL

Prepared by NW on 2023/07/21
QR by AW on 2023-07-26

Client/Project
World Energy GH2
Project Nujio'qonik

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Figure No.
3.1

General Arrangement of Effluent Pipeline and Marine Outfall

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4.0 Receiving Marine Environment

4.1 Physical and Metocean Characteristics

This section summarizes the data used and the physical, hydrometric, and oceanographic characteristics of the receiving marine environment used to develop the 3D near-field model.

The climate in the vicinity of the outfall is classified as maritime temperate and is heavily influenced by the water in the Gulf of St. Lawrence and continental air masses. Mean air temperatures in the Gulf range from approximately -7°C in February to 18°C in August (Galbraith et al. 2022). Throughout most of the year, the prevailing winds are northwesterly, westerly, or southwesterly. Northwesterly and westerly winds are dominant during colder months, while southwesterly winds are more frequent during warmer months. Hourly wind data available within the study area were obtained from Environment and Climate Change Canada (ECCC) climate stations 8403800 and 8403801 at Stephenville Airport and MSC50 grid M6013677 located 66 km southwest of Stephenville.

A wind rose of hourly wind speed and wind direction at ECCC climate station at Stephenville Airport for the period of 1941 through 2022 is presented in Figure 4.1(a). Wind speed for this period varied between 0 and 35.5 metres per second (m/s) with an average wind speed of 5.3 m/s. A review of the rose plot indicates that the dominant wind directions are from the west and southwest.

A wind rose of hourly wind speed and wind direction at MSC50 grid M6013677 for the period of 1954 through 2018 is presented in Figure 4.1(b). Wind speed for this period varied between 0 and 28.4 m/s with an average wind speed of 7.9 m/s. A review of the rose plot indicates that the dominant wind directions are from the west, northwest, and southwest.

The Canadian Hydrographic Services (CHS) chart data were used to define seabed elevation within the model domain. St. George's Bay is characterized by a central deep basin which is a continuation of the St. George's River Valley and a smaller basin offset to the north. The maximum depth of this St. George River basin is approximately 97 m, while the Stephenville Basin reaches a depth of 57 m. The depth at the outfall is approximately 13 m chart datum.

Ocean currents in the region are influenced by tides, regional meteorological events, freshwater runoff from the St. Lawrence River and transport from the Strait of Belle Isle and the Cabot Strait. Prominent features of the region include coastal currents, gyres, massive eddies in the estuary, and tidal fronts. Currents within the Gulf flow counterclockwise with main currents directed towards the northeast along Western Newfoundland and to the southwest along Quebec's coast in the north (AMEC 2014). Currents are strongest near the surface (0-20 m), except in winter months and along the slopes of the deep Laurentian and Esquiman channels (Galbraith et al. 2022). Currents were established at a conservatively low (i.e., 25^{th} percentile) ambient speed of 0.06 m/s (winter) and 0.02 m/s (summer). These ambient velocities were taken from the MIKE21 model, which was developed and used to predict the fate and transport of ammonia in the Port of Stephenville (Stantec 2023).

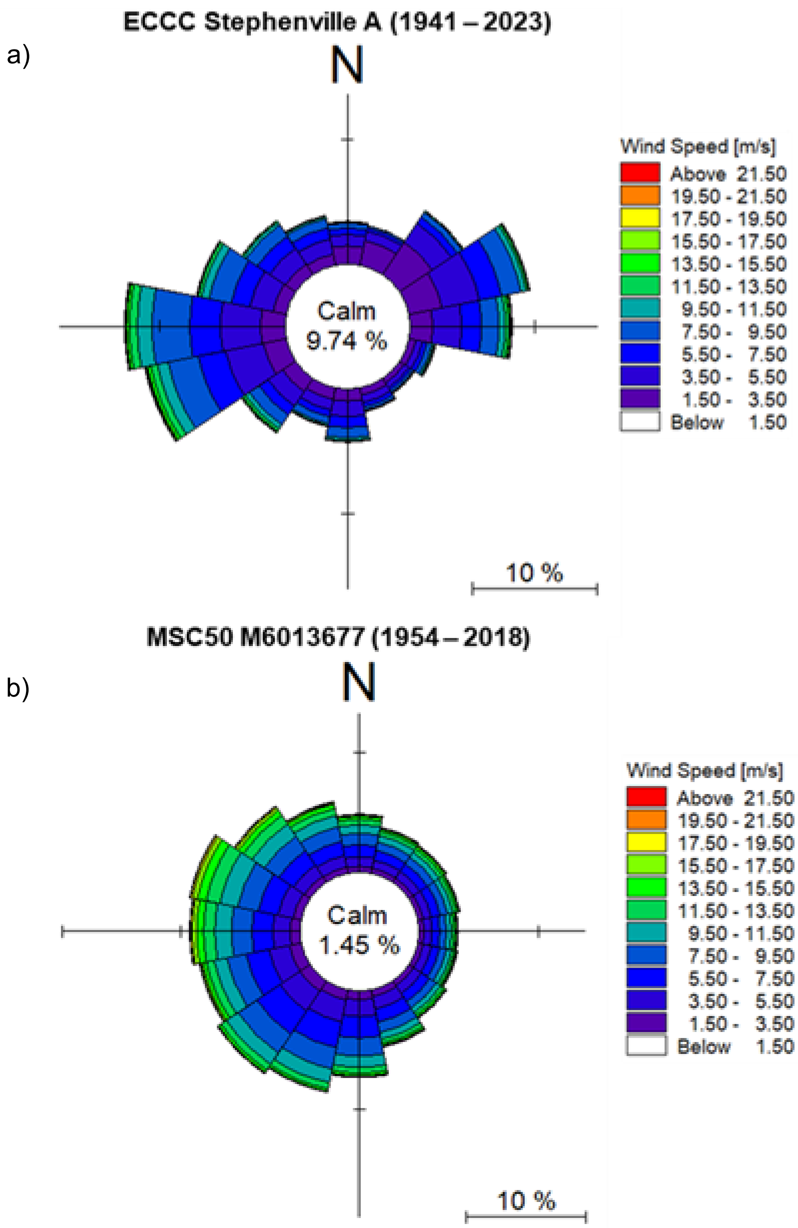

Figure 4.1 Rose Plot of Hourly Wind Speed and Wind Direction (from) at :
a) ECCC Climate Station Stephenville A for the Period of 1941 – 2023 and
b) MSC 50 M6013677 for the Period of 1954 – 2018

4.2 g/L Ambient Seawater Quality

Recorded sea surface water temperature data at Stephenville crossing by the National Oceanic and Atmospheric Administration (NOAA) summarized in Figure 4.2 (seatemperature.org) which indicates a range from -1.8 °C (degrees Celsius) to 17.4 °C for near surface temperature. A review of literature indicates that depth-averaged salinity approximately varied between 30 PSU (practical salinity unit) and 33.7 PSU with an average 31.8 PSU from 0 to 50 m depth near the study area (Cyr et al. 2021).

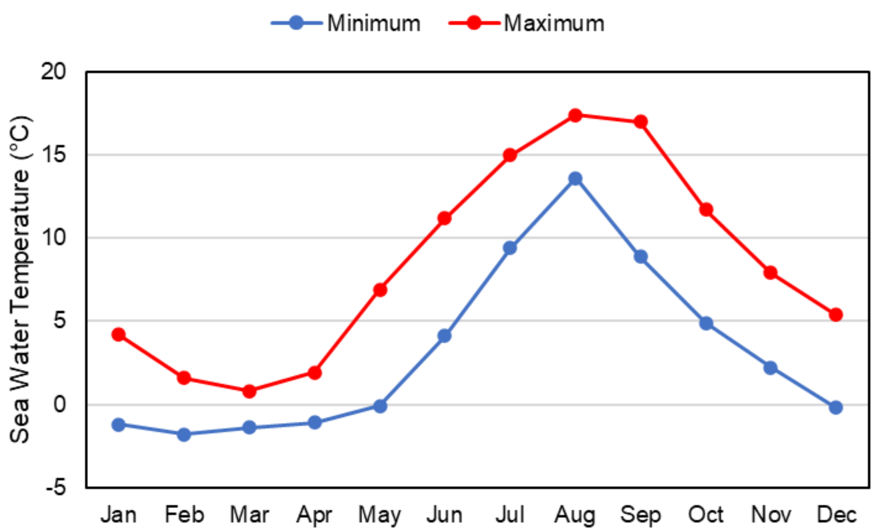

Figure 4.2 Seawater Surface Temperature at Stephenville Crossing

4.3 Receiving Water Quality Objectives

Newfoundland and Labrador is a signatory party to the CCME and has supported the establishment of CCME CEQGs, including those for the protection of marine aquatic life. The CCME marine water quality guidelines for temperature and salinity were used in this study.

The CCME water quality guidelines for the protection of aquatic life for temperature recommend that human activities should not cause changes in the ambient temperature of marine and estuarine waters to exceed ±1°C at any time, location, or depth.

The CCME water quality guidelines for the protection of aquatic life for salinity recommend that human activities should not cause the salinity (expressed as parts per thousand, ppt, or g/kg) of marine and estuarine waters to fluctuate by more than 10% of the natural level expected at that time and depth.

5.0 3D Near-field Modelling

The objective of near-field modelling is to undertake effluent dilution and mixing analysis of the reject water effluent under conservative conditions. Near-field modelling was conducted for the existing outfall location, as shown in Figure 3.1. The scale of the near-field modelling is on the order of several metres to approximately one hundred metres, which allows for a detailed prediction of the effluent plume discharging from the diffuser at the outfall location.

The near-field modelling was performed to determine the concentration of salinity and temperature in the near-field mixing zone. The objective was to confirm that the salinity and temperature at the end of the mixing zone are protective of the environment and in compliance with the water quality guidelines.

The Cornell Mixing Zone Expert System (CORMIX) was used for 3D near-field modelling. CORMIX is a USEPA-supported mixing zone model for environmental impact assessment of regulatory mixing zones resulting from continuous point source discharges. For this assimilative capacity study, CORMIX modelling was undertaken for effluent quality parameters under conservative low current speed conditions for the summer and winter seasons. Winter and summer scenarios were differentiated by ambient and effluent water temperatures and salinity.

5.1 Methods

5.1.1 CORMIX Model

CORMIX (Version 12.0) 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 3D model that can be run in steady-state and tidal ambient conditions.

The CORMIX model was run for winter and summer conditions for water temperature and salinity. The modelling results were compared to the CCME marine water quality guidelines.

5.1.2 Mixing Zone Definition

The modelling of the near-field dilution mixing is aimed to confirm that the ambient seawater quality concentrations or the CCME marine water quality guidelines are met at the edge of the mixing zone. CCME (2003) defines the mixing zone 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”.

5.2 Model Setup and Calibrations

The CORMIX model requires three sets of input parameters to describe: 1) ambient conditions or receiving water body characteristics; 2) effluent discharge characteristics; and 3) diffuser specifications. Receiving water body characteristics were selected based on the characterization of the receiving marine environment presented in Section 3.0. Effluent discharge characteristics are presented in Section 2.0.

5.2.1 Input Parameters

The required model input for the ambient conditions includes ocean water density, temperature, current speed, and average and outfall water depths. These characteristics affect the near-field transport and shape of the resulting plume geometry of the effluent discharge.

The water column at the outfall location was assumed to be non-stratified where the differential in water density between surface and bottom water layers is not substantial. CORMIX was run at a conservatively low (i.e., 25^{th} percentile) ambient speed of 0.06 m/s (winter) and 0.02 m/s (summer). These ambient velocities were taken from the MIKE21 model, which was used to predict the fate and transport of ammonia in the Port of Stephenville (Stantec 2023).

For modelling purposes, the Manning's "n", which represents bottom roughness and is dependent on the bottom substrate, was assumed to be 0.025 in the mixing zone. This value was also taken from the hydrodynamic modeling study of the fate and transport of ammonia (Stantec 2023).

Wind is a relatively insensitive parameter in CORMIX; it can affect circulation, mixing, and plume movement only in very shallow waters. The average wind data for winter and summer was taken from the ECCC's MSC50 wind and wave climate hindcast in Stephenville.

5.2.2 Outfall and Diffuser Configuration

Effluent from the Facility will be discharged via an outfall pipe with a diffuser at the end. The outfall coordinates are 48.500830; -58.538941. The exact configuration of the existing outfall is not known, therefore, conservatively, a single port diffuser design was used. Based on communication with Bailey's Marine Services, the port is assumed to have a 0.15 m diameter opening and be located 1.16 m above the seabed. This port diameter provides sufficient exit (jet) velocity for entrainment, fast initial mixing, and stable plume formation.

The discharge angle theta is the vertical angle of the discharge port relative to the seabed. An angle of 0° indicates that the diffuser jets discharge parallel to the seabed, and 90° indicates an upward vertical discharge. A 90° vertical angle was assumed for this study.

Table 5.1 summarizes the results of the CORMIX model input data for winter and summer scenarios and Figure 5.1 provides a conceptual sketch for the diffuser.

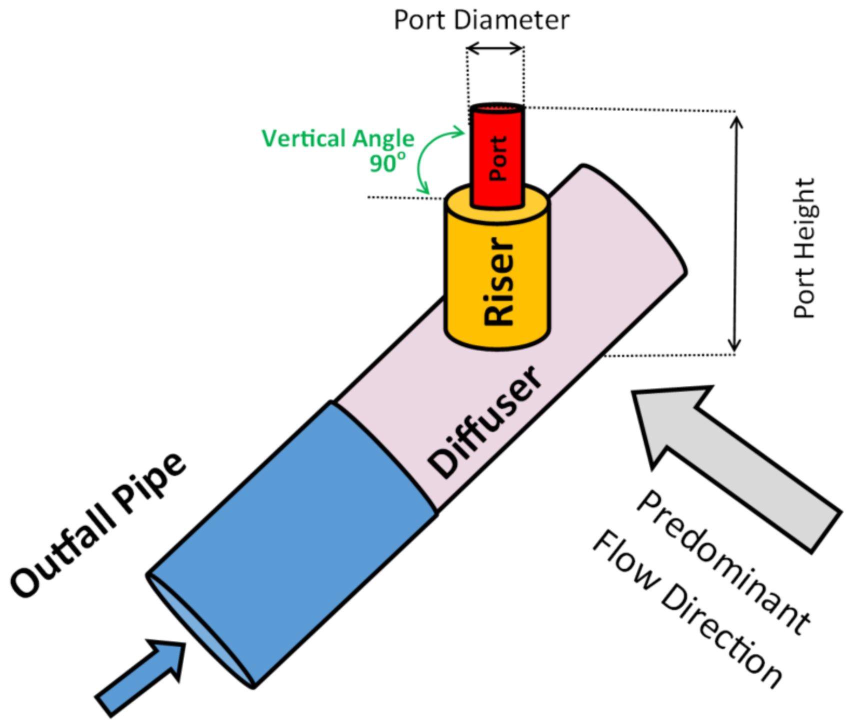

Figure 5.1 Conceptual Sketch of the Diffuser and Configuration for the Marine Outfall

Table 5.1 CORMIX Input Data for Winter and Summer Scenarios

Characteristics	Winter	Summer	Notes
Water Depth at Outfall, m	12.9		Nautical Chart CHS4885 Port Harmon and Approaches
Effluent Flow, m^3/s	0.0936	0.0875	Table 6 in ARUP (2023)
Number of Ports	1		Conservatively assumed based on communication with World Energy GH2
Effluent Temperature, °C	15	25	Typical design temperature range for membrane performance
Effluent Salinity, g/L	0.55		Predicted source water TDS is 70 mg/L (Fracflow 2022)concentrated to 300% during treatment = 210 mg/L + cooling water contributes another 50 mg/L. Conversion to salinity using TDS=C*0.65 and salinity from conductivity data using the PSS-78 practical salinity equation.
Effluent Density, kg/m3	999.18	997.12	Calculated based on temperature and salinity
Ambient Seawater Temperature, °C	0	16.6	Average surface temperature from 2021 and 2022 at Port-aux-Basques (Galbraithe 2022)
Ambient Seawater Salinity, g/L	31.3	30.2	Average surface salinity from 2021 and 2022 at Port-aux-Basques (Galbraithe 2022)
Ambient Water Density, kg/m3	1023.15	1019.75	Calculated based on temperature and salinity
Low Current Speed, 25th Percentile, m/s	0.06	0.02	Stantec (2023)
Average Current Speed, m/s	0.16	0.06	Stantec (2023)
Port Diameter, m	0.15		Assumed based on Communication with World Energy GH2
Vertical Pipe Angle (theta), deg.	90		Conservatively assumed based on communication with World Energy GH2
Horizontal Pipe Angle (sigma), deg.	0		Conservatively assumed based on communication with World Energy GH2
Alignment Angle (gamma), deg.	90		Conservatively assumed based on communication with World Energy GH2
Port Height Above Seabed, m	1.16		Based on communication with World Energy GH2
Manning's n	0.025		Stantec (2023)
Average Wind Speed, m/s	9.0	6.0	Data from MSC50 hindcast in Stephenville
Heat Exchange Coef., W/m^2, °C	42	59	Calculated based on ambient water temperature and wind speed (Adams et al. 1981)

5.3 Near-field Results

Dilution-mixing winter and summer scenarios with conservative ambient and effluent conditions for the Facility were run using a CORMIX model. Based on effluent and ambient conditions, the resulting water temperature in the near-field mixing zone was derived. Temperature results in the mixing zone for winter and summer scenarios are shown in Table 5.2. A schematic representation of effluent plume dispersion for temperature from the marine outfall is provided in Appendix A.

Table 5.2 Temperature Results in the Mixing Zone for Winter and Summer Scenarios

Scenario	Effluent Temp. (°C)	Ambient Temp. (°C)	CCME Guideline [1], (°C)	Temperature at Various Distances from Outfall (°C)						
				1 m	3 m	4 m	5 m	6 m	10 m	50 m
Winter, Low Current	15	0	1.0	0.88	0.78	0.75	0.73	0.70	0.63	0.37
Winter, Average Current	15	0	1.0	1.62	0.68	0.52	0.35	0.31	0.26	0.18
Summer, Low Current	25	16.6	17.6	17.07	17.05	17.04	17.03	17.03	16.99	16.63
Summer, Average Current	25	16.6	17.6	17.12	17.01	17.00	16.99	16.97	16.92	16.83

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

Salinity results in the mixing zone for winter and summer scenarios are shown in Table 5.3. A schematic representation of effluent plume dispersion for salinity from the marine outfall is provided in Appendix B.

Table 5.3 Salinity in the Mixing Zone for Winter and Summer Scenarios

Scenario	Effluent Salinity (g/L)	Ambient Salinity (g/L)	CCME Guideline[1] (g/L)	Salinity at Various Distances from Outfall (g/L)						
				1 m	3 m	4 m	5 m	6 m	10 m	50 m
Winter, Low Current	0.55	31.3	28.2	29.43	29.67	29.75	29.78	29.81	29.93	30.50
Winter, Average Current	0.55	31.3	28.2	27.93	29.89	30.22	30.32	30.34	30.77	30.92
Summer, Low Current	0.55	30.2	27.2	28.53	28.59	28.62	28.65	28.69	28.82	30.08
Summer, Average Current	0.55	30.2	27.2	28.34	28.69	28.74	28.79	28.84	29.03	29.39

Note:
[1] change of 10% from ambient salinity.

Near-field modelling using CORMIX indicates that effluent mixes very quickly with the ambient environment. The primary reasons for quick mixing are the location of the outfall, substantial water depth of the outfall, low effluent flow rate, and high jet velocity.

The mixing zone is less than 1 m for temperature and salinity in most scenarios. The worst-case scenario is winter with an average current speed when the mixing zone for temperature and salinity can extend up to 3 m from the outfall before meeting the respective CCME guidelines. Using the conservative modelling parameters, it can be concluded that no exceedances of marine water quality objectives are observed at the end of the 3 m mixing zone.

Modelling predictions in this assimilative capacity study are based on conservative assumptions such as a single port, low current speed, low tide in the receiving environment (water depth assumed at chart datum), maximum expected temperature and salinity differential between effluent and ambient conditions, and a small mixing zone in the relatively large receiving environment of the entrance of the Port of Stephenville.

6.0 Conclusions

Stantec completed the detailed mixing zone assessment of the reject process water effluent discharge from the Facility.

The CCME marine water quality guidelines for the protection of aquatic life for temperature and salinity were used as water quality objectives in this assimilative capacity study.

The CORMIX (version 12.0) three-dimensional model was used to derive the mixing zone for the Facility effluent. Physical and metocean characteristics of the receiving environment were modelled conservatively based on available information. The outfall configuration was conservatively assumed based on available information.

The mixing zone is less than 1 m for temperature and salinity in most scenarios. The worst-case scenario is winter with an average current speed when the mixing zone for temperature and salinity can extend up to 3 m from the outfall before meeting the respective CCME guidelines. Using the conservative modelling parameters, it can be concluded that no exceedances of marine water quality objectives are observed at the end of the 3 m mixing zone.

7.0 Closure

This report has been prepared for the sole benefit of World Energy GH2. This report may not be used by any other person or entity without the express written consent of Stantec Consulting Ltd. and World Energy GH2.

Any use that a third party makes of this report, or any reliance on decisions made based on it, are the responsibility of such third parties. Stantec Consulting Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made, or actions taken, based on this report.

The information and conclusions contained in this report 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 report should not be construed as legal advice.

The conclusions presented in this report 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 report, we request that we be notified immediately to reassess the conclusions provided herein.

8.0 References

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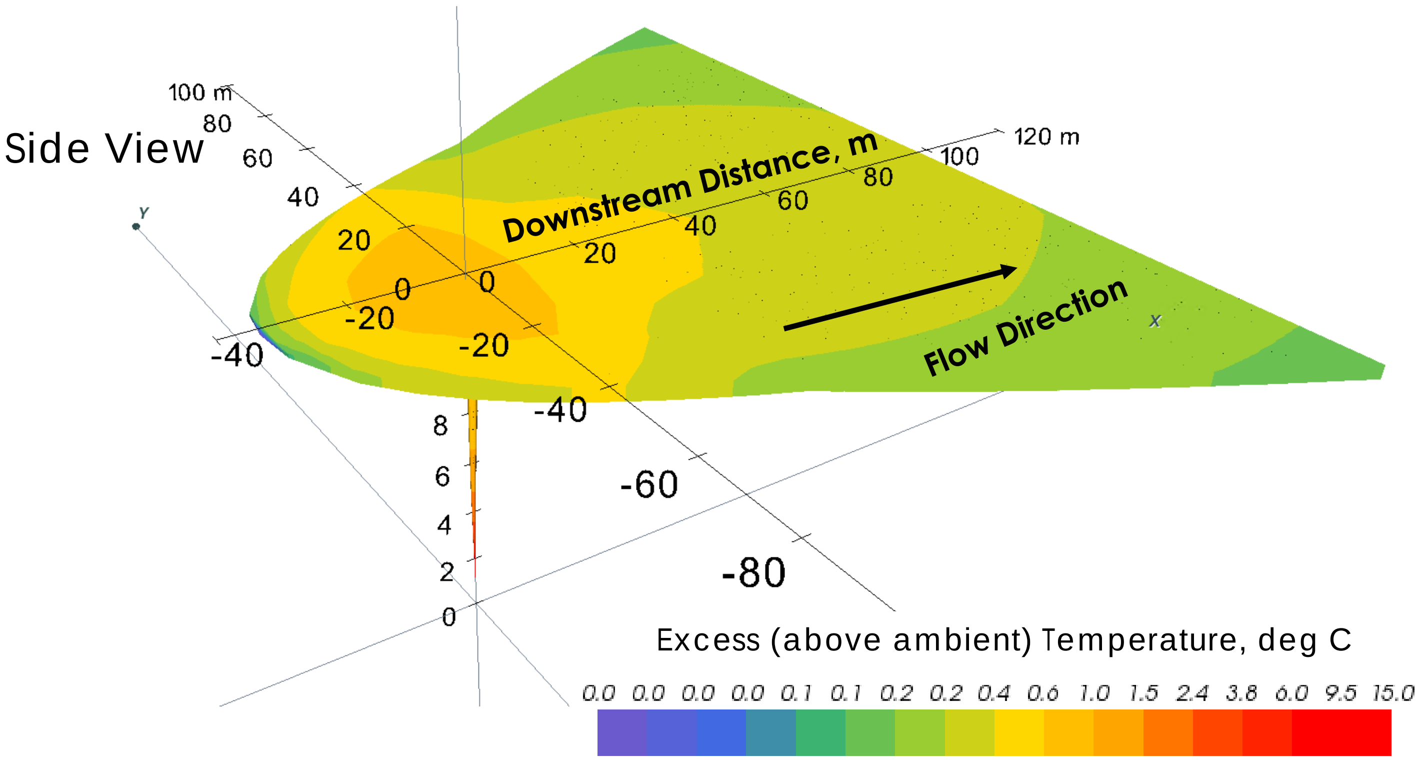
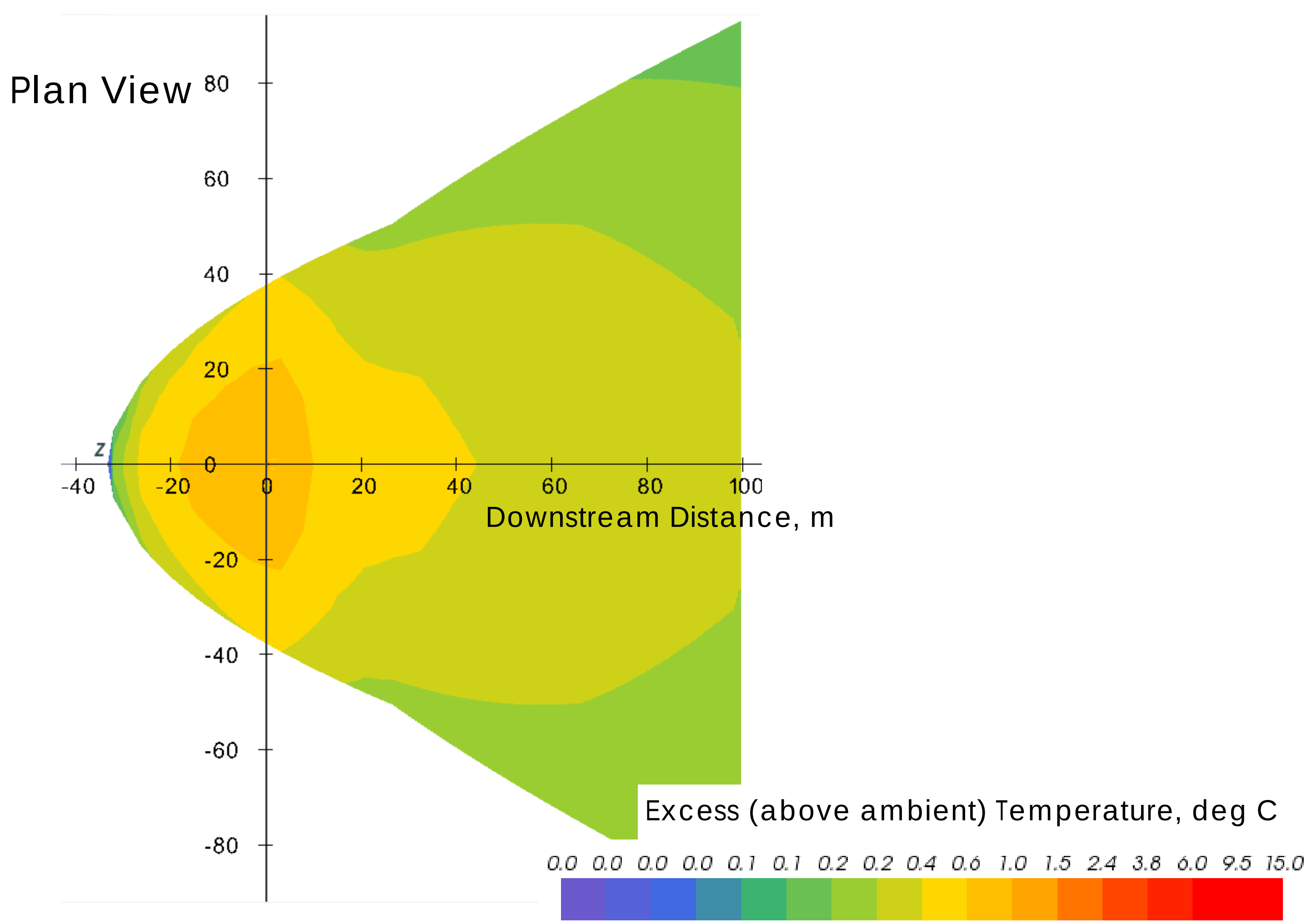
APPENDIX A

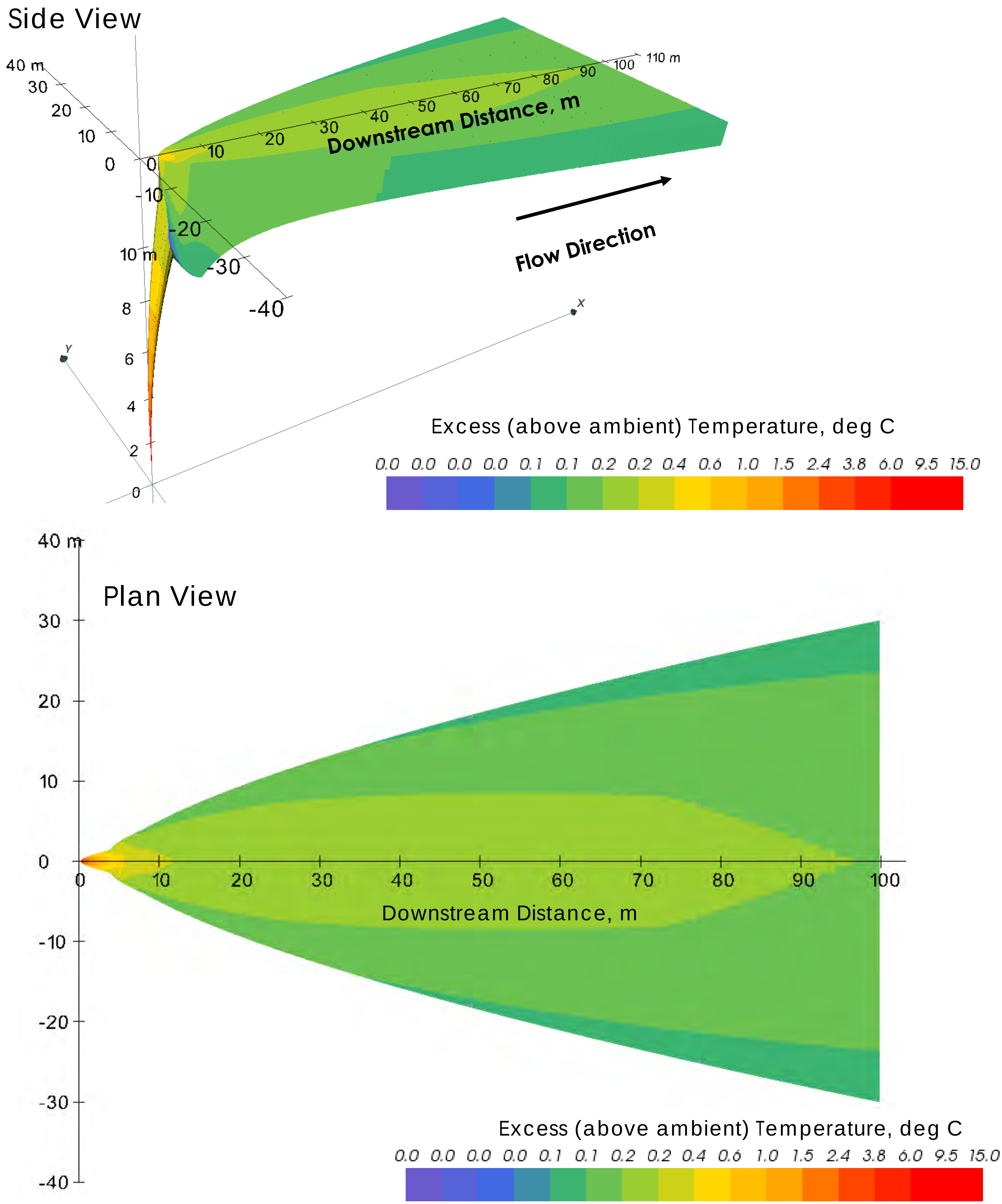
Schematic Representation of Effluent Plume Dispersion for Temperature

Temperature Results—Winter, Low Current Speed



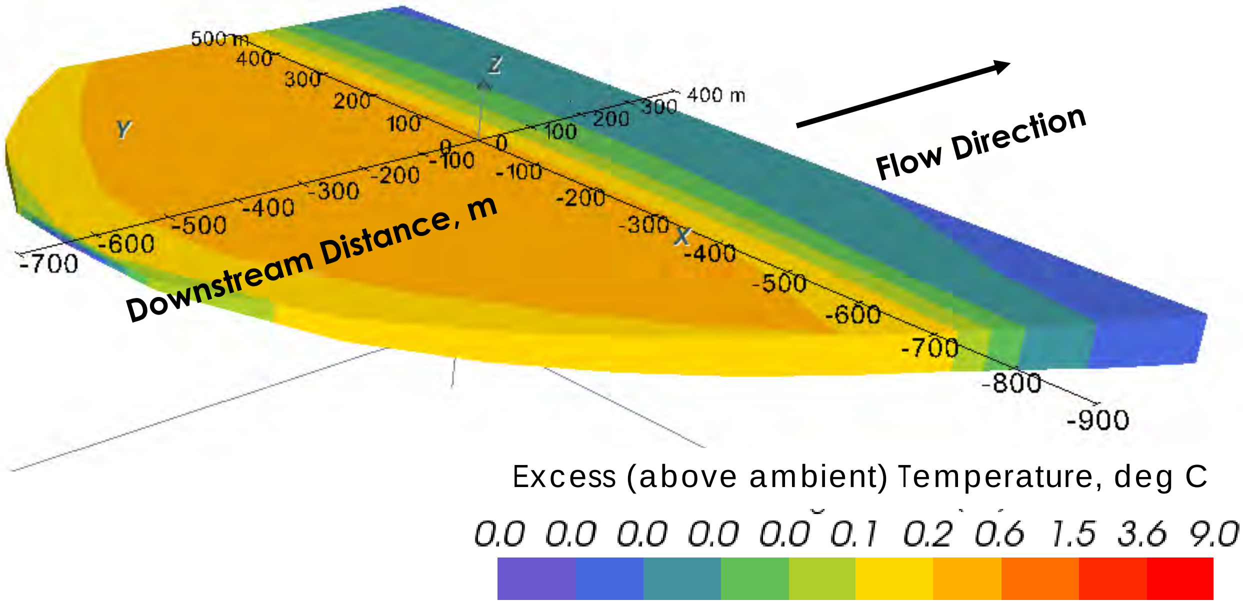


Temperature Results—Winter, Average Current Speed

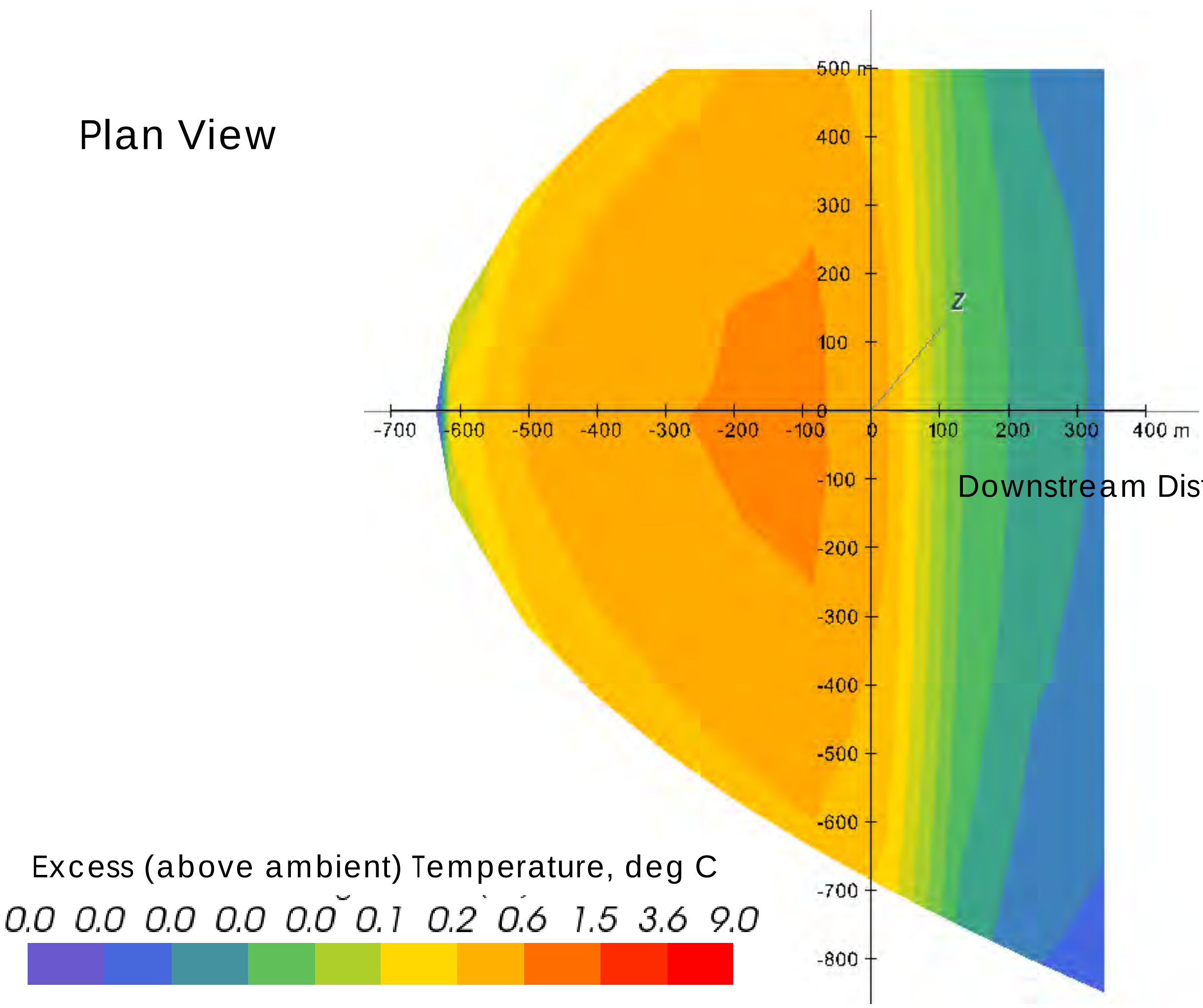


Temperature Results—Summer, Low Current Speed

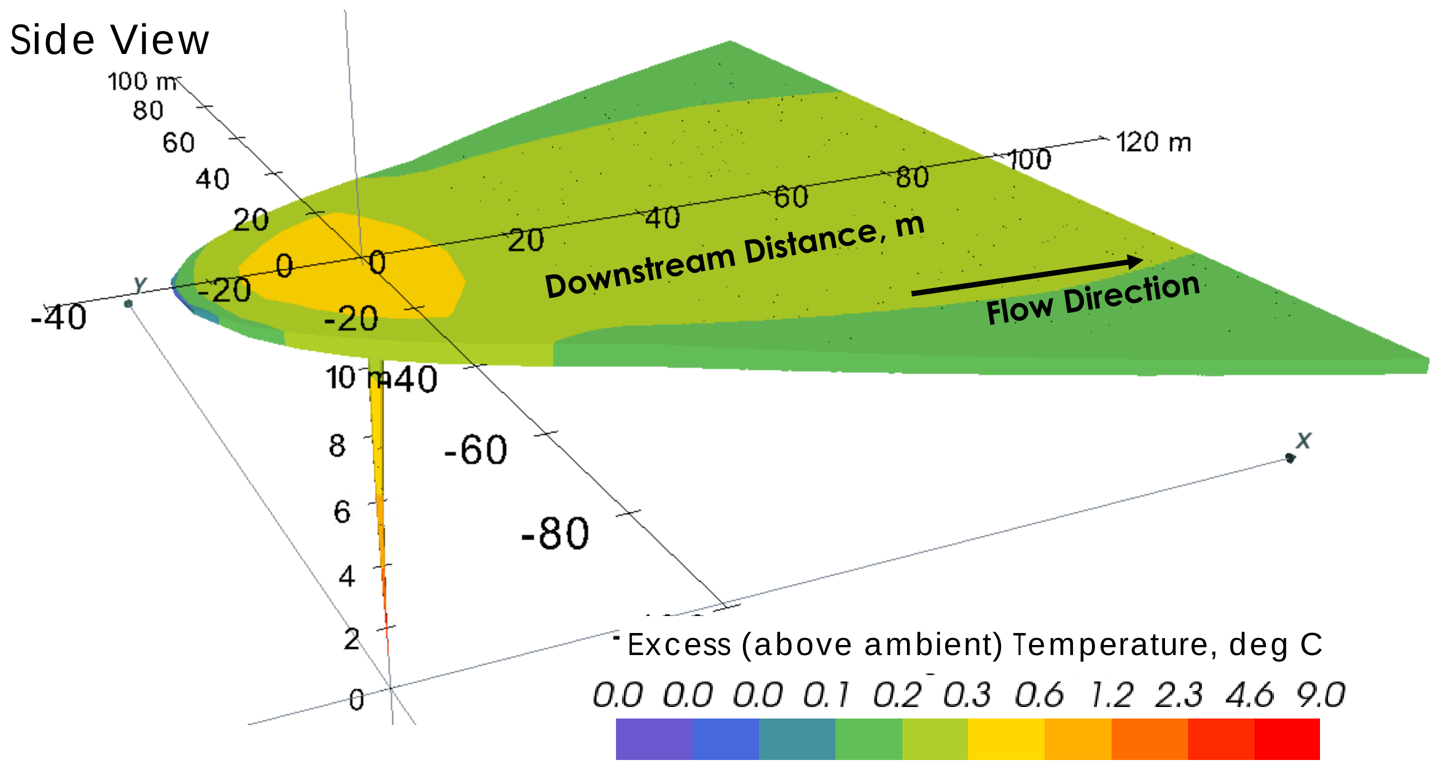
Side View

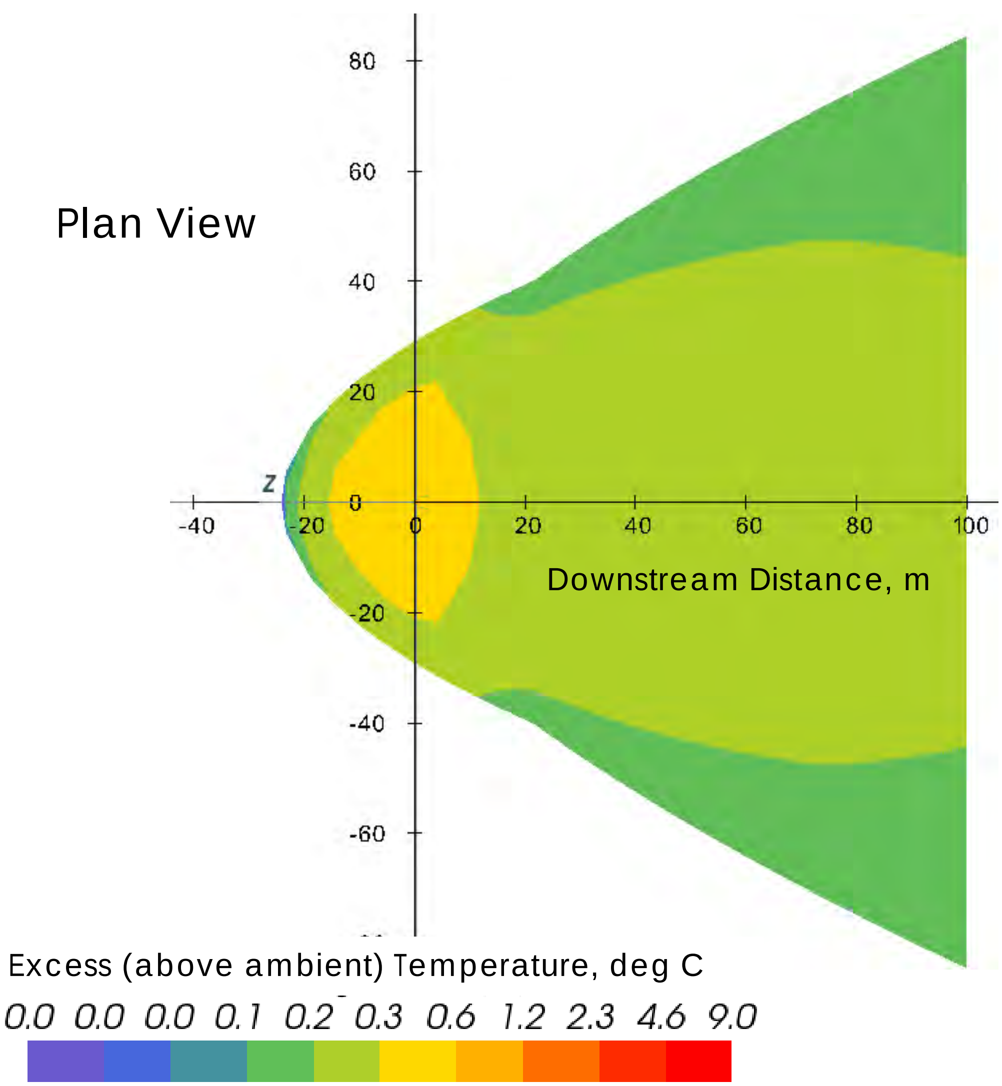


Plan View



Temperature Results—Summer, Average Current Speed

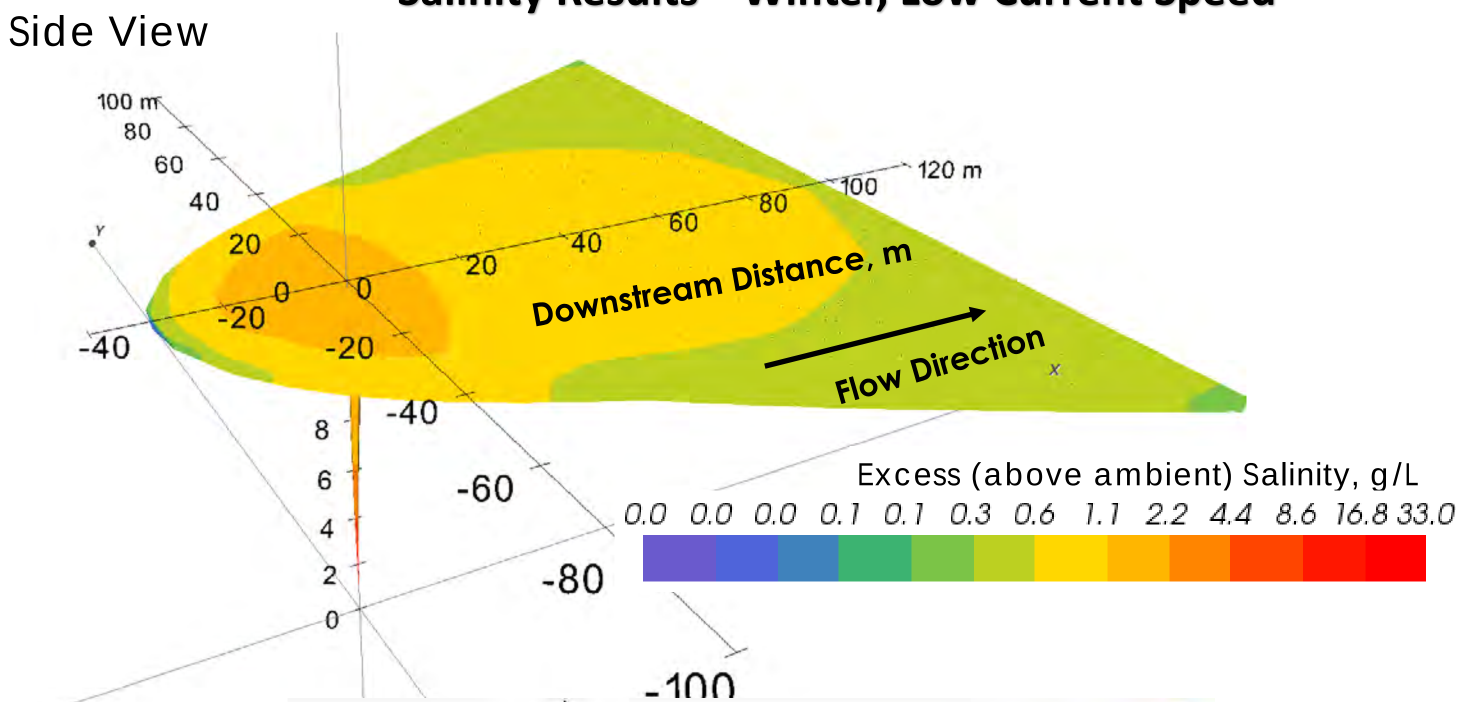


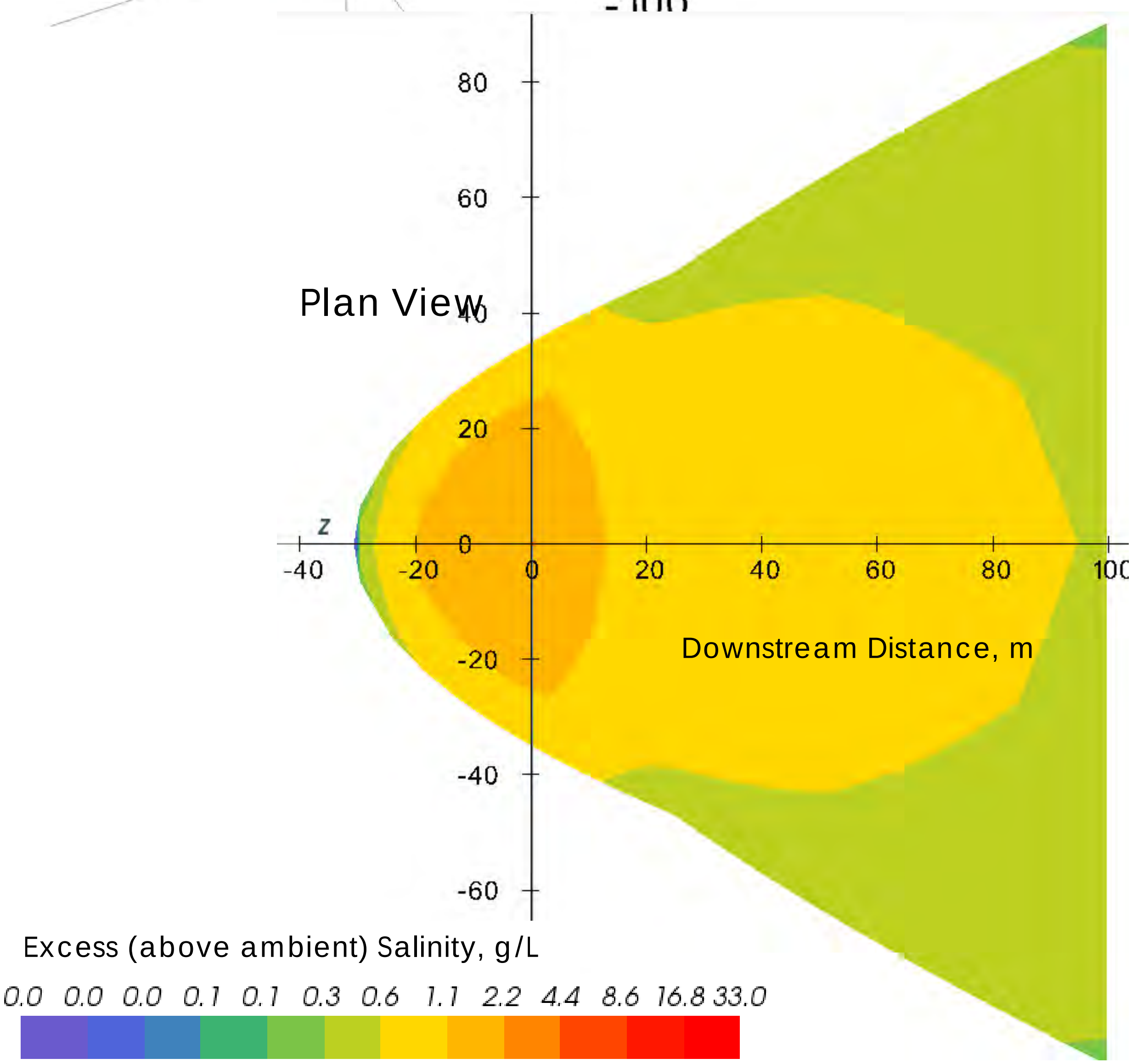


APPENDIX B

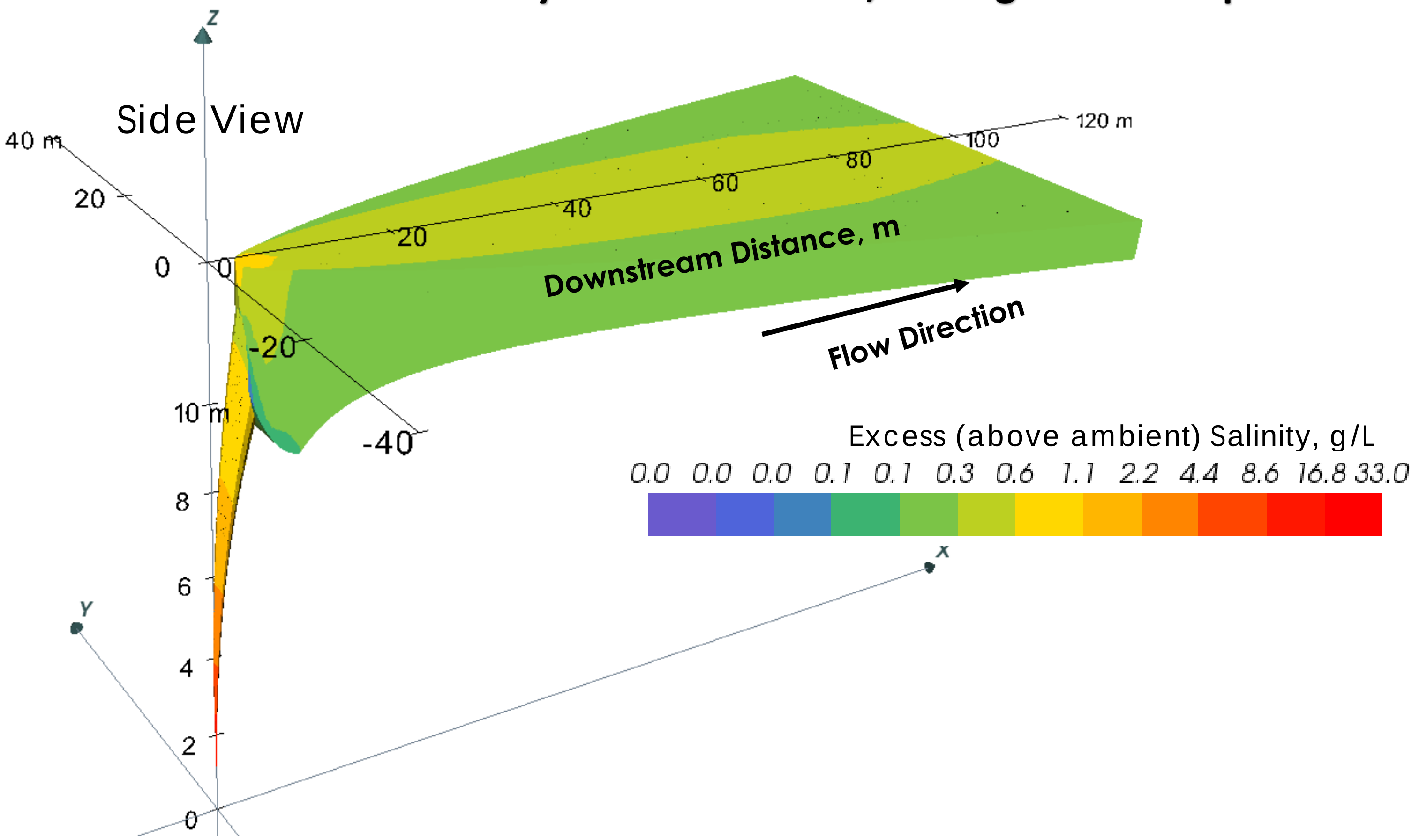
Schematic Representation of Effluent Plume Dispersion for Salinity

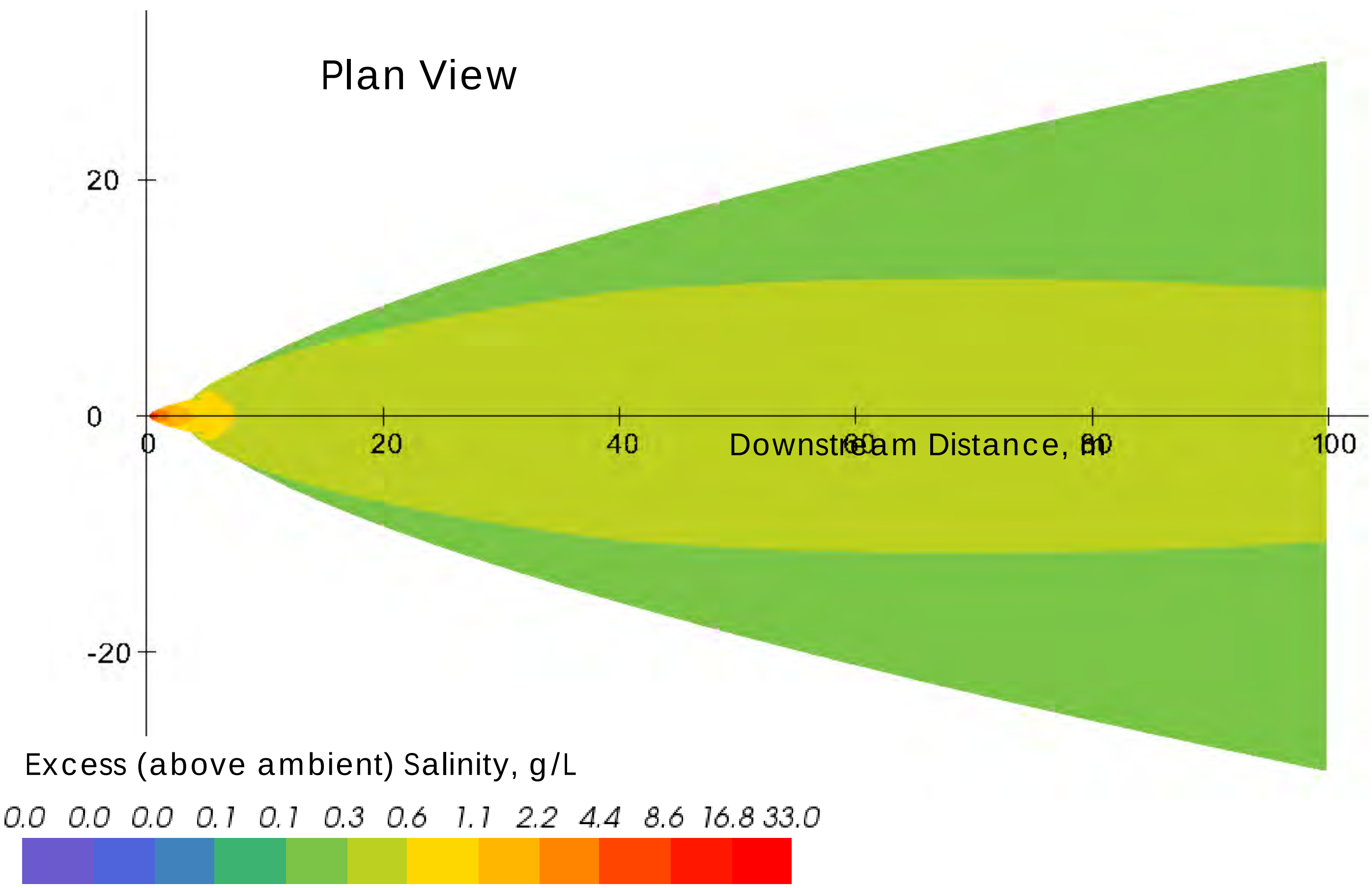
Salinity Results—Winter, Low Current Speed



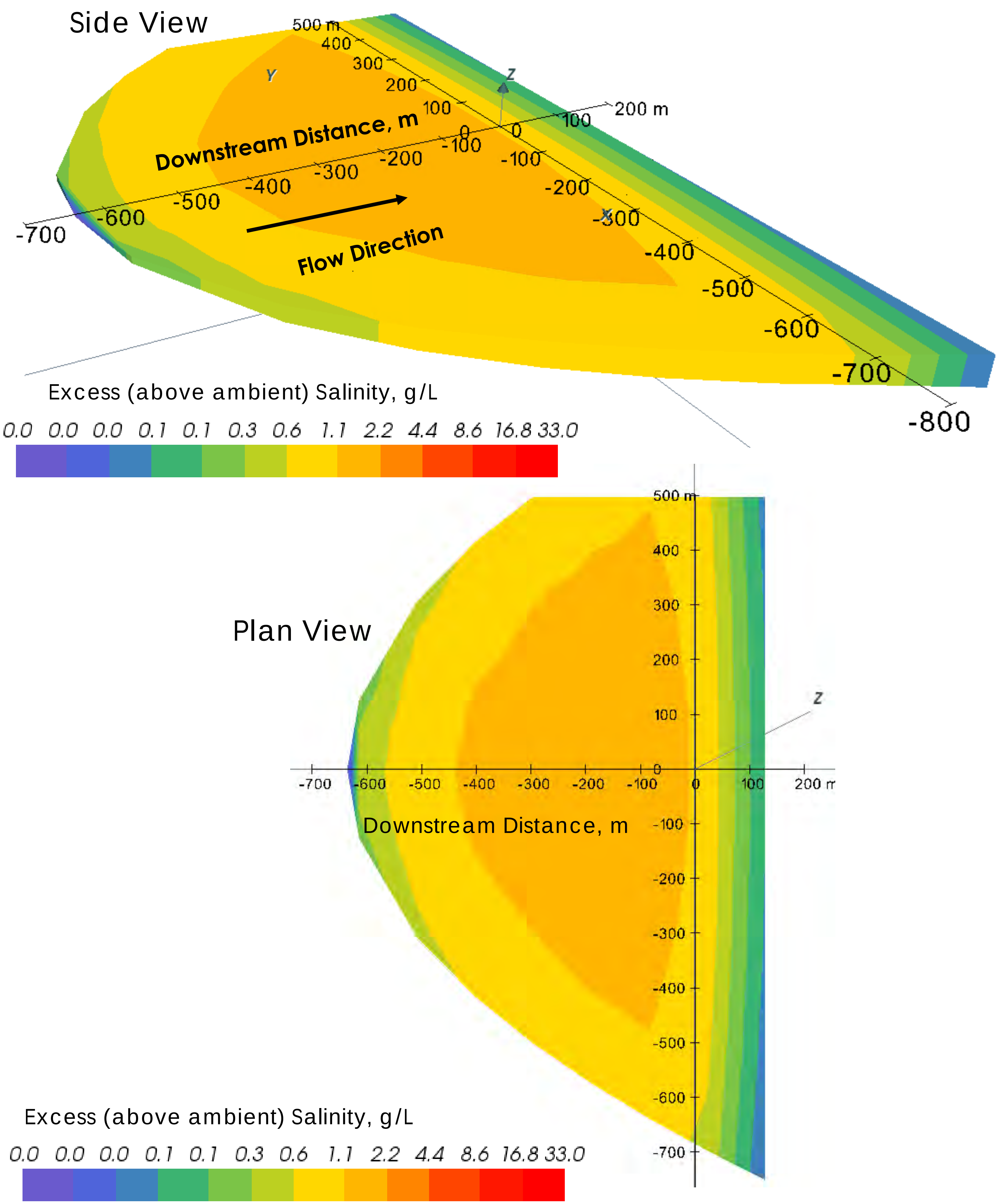


Salinity Results—Winter, Average Current Speed





Salinity Results—Summer, Low Current Speed



Salinity Results—Summer, Average Current Speed