TECHNICAL MEMORANDUM

DATE 14 June 2019

Reference No. 1663724-127-TM-Rev0

TO Lou Kamermans
Baffinland Iron Mines Corporation

FROM David Hurley, Phil Osborne

BALLAST WATER DISPERSION SENSITIVITY SIMULATIONS

1.0 INTRODUCTION

In 2018, Golder was retained by Baffinland to conduct ballast water dispersion modelling for Eclipse Sound and Milne Inlet (Golder, 2018) in support of Baffinland's Phase 2 Proposal. Results of this ballast water dispersion modelling were presented in Technical Support Document (TSD) No. 18 in Baffinland's Addendum to the Final Environmental Impact Statement (FEIS for the Phase 2 Proposal. During their technical review of this document, Qikiqtani Inuit Association (QIA) noted that a sensitivity analysis of ballast water dispersion to varying ballast water salinity and temperature (i.e. density) had thus far not been completed. Golder was subsequently retained by Baffinland in 2019 to address the sensitivity of ballast water dispersion to variations in ballast water salinity and temperature. This technical memorandum has been prepared in response to QIA's Technical Comment No. 44 and associated commitment made by Baffinland during the Technical Review Meeting held April 9-11, 2019 in Iqaluit, NU, as as outlined in Table 1.

Table 1: QIA Technical Comment No. 44 and Baffinland Commitments

Technical Comment #	Technical Comment / Recommendation	Baffinland Response to Technical Comment	Baffinland Commitment Following Technical Meeting
QIA 44	QIA recommends that the Proponent monitor the physical and chemical properties of incoming ballast water, treated and untreated, to inform risk assessment and adaptive management. QIA recommends that the Proponent gather seasonal CTD profiles and other oceanographical data needed to calibrate and verify the hydrodynamic model. QIA recommends the Proponent update and rerun the ballast water dispersal model to assess the physical and chemical effects on the marine environment (including any downslope currents and pooling) of exchange, treatment, or both together to inform mitigation and monitoring.	The comment is acknowledged. Baffinland will continue to work with the NIRB and the MEWG regarding updates to the Marine Environmental Effects Monitoring Program.	Baffinland will provide a technical memo on the sensitivity analysis of the ballast water modelling by June 15

This technical memorandum examines the dispersion of ballast water discharged from vessels at anchorage with the existing ore dock configuration during the period August 01 to August 31, 2018. The primary objective of the memorandum is to present results from a series of simulations with variable ballast water salinity and temperature. Six ballast water simulations were conducted with ballast water salinity and temperature ranging between 30 and 36 PSU and 2 and 13 degrees Celsius. The combinations of salinity and temperature of the ballast water were chosen to be representative of the anticipated range in salinity and temperature of the onboard ballast water and hence the potential range of ballast water density that could occur in Milne Inlet (see Section 3.3). Simulations of the observed onboard ballast water salinity and temperature during the 2018 shipping season are currently in progress and will be reported at a later date.

In Section 2.0 the memorandum presents a brief overview of the study area. Section 3.0 presents a summary of the hydrodynamic model development, including prescription of the model boundary and initial conditions, 2018 ballast water discharge timing and quantities, and selection of ballast water discharge scenarios in terms of salinity and temperature. Section 4.0 summarizes the results of the ballast water dispersion sensitivity analysis.

2.0 STUDY AREA

Milne Inlet is located along the Northwest coast of Baffin Island in the Qikiqtani Region of Nunavut. The inlet is connected to Baffin Bay at its northern terminus through Eclipse Sound and Navy Board Inlet which are separated by Bylot Island (Figure 2.1). The northern section of Milne Inlet, extending from Ragged Island to Bruce Head, is approximately 50 km long, up to 800 m deep, and tapers from approximately 15 km in width at Ragged Island to less than 8 km in width at Bruce Head. The southern section of Milne Inlet, extending from Bruce Head to the head of Milne Inlet, is approximately 25 km long, up to 400 m deep, and tapers in width from approximately 8 to 14 km near Koluktoo Bay to less than 3 km at the southern terminus.

The southern and northern sections of Milne Inlet have a predominant north-south orientation, except between Bruce Head and Stephens Island where there is a northwest-southeast orientation. At Bruce Head there is a sill (an area of decreased depth) between Bruce Head and Poirier Island. Just north of Bruce Head is Stephens Island, both Stephens Island and Poirier Island act to bifurcate the channel and subsequently create some of the narrowest sections of Milne Inlet, some sections reaching less than 3 km in width. Sills are also present at the north end of Stephens Island and at Ragged Island. Along all sections of the Milne Inlet the topography is characterized by mountainous terrain and steep cliffs vegetated with tundra.

At the head of Milne Inlet is Milne Port which supports Baffinland's iron ore exports via the Northern Shipping Route (from Milne Inlet to Baffin Bay) during the open-water season. The water depth near Milne Port varies from less than 10 m to more than 100 m and is characterized by a steep nearshore shelf that drops off into a gradual sloping bed extending northward away from the port. Near Milne Port, there are two sources of freshwater discharge, Phillips Creek to the west and Robertson River to the east of the port.

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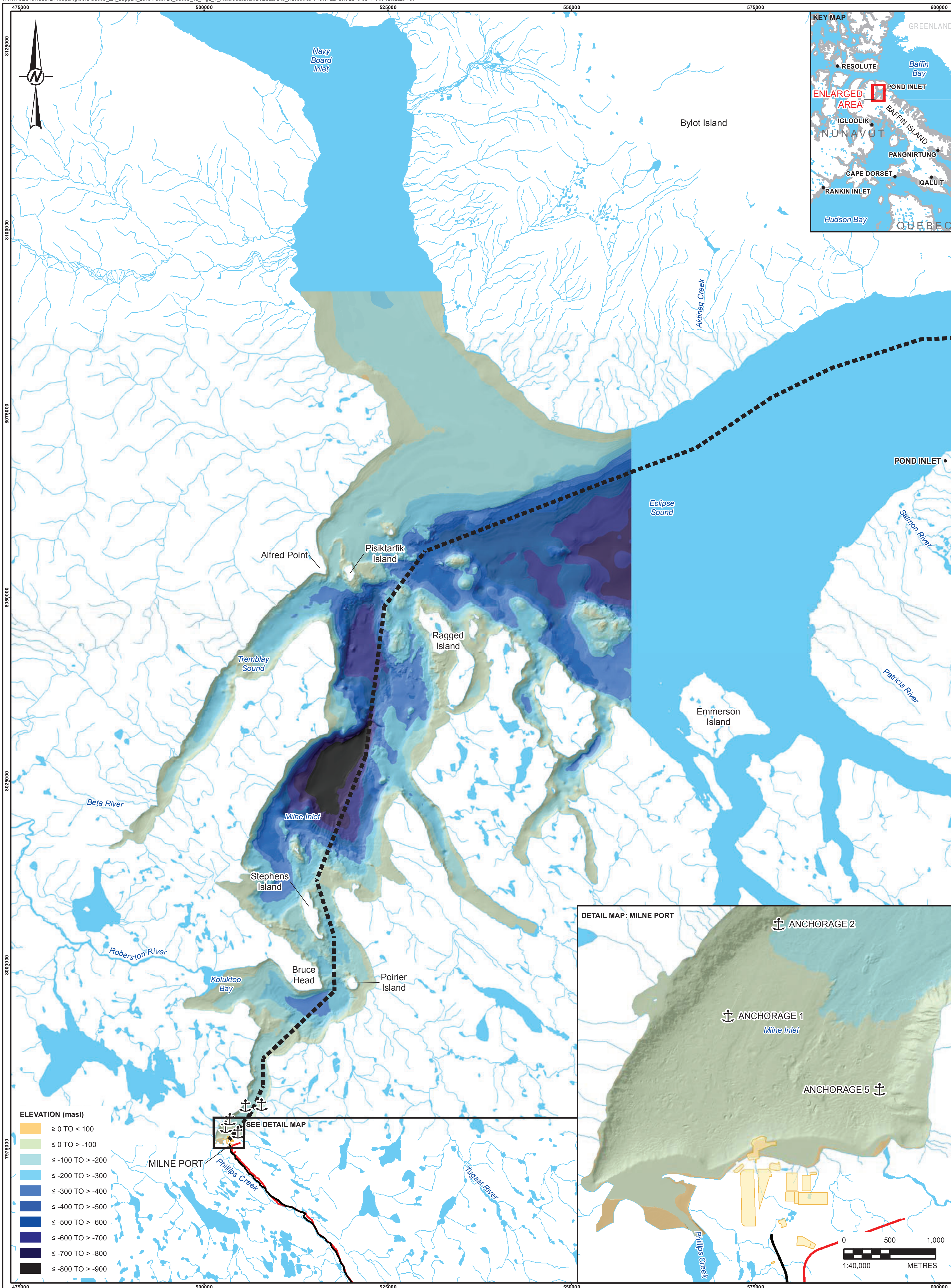

LEGEND

- VESSEL ANCHORAGE
- COMMUNITY
- MILNE INLET TOTE ROAD
- PROPOSED NORTH RAILWAY
- SHIPPING ROUTE (APPROXIMATE)
- WATERCOURSE
- EXISTING ORE DOCK
- WATERBODY

0 10 20
1:500,000 KILOMETRES

NOTE(S)
masl = METRES ABOVE SEA LEVEL

REFERENCE(S)
MILNE PORT INFRASTRUCTURE DATA BY HATCH, JANUARY 25, 2017, RETRIEVED FROM KNIGHT PIESOLD LTD. FULCRUM DATA MANAGEMENT SITE MAY 19, 2017. BATHYMETRY CREATED BY GOLDER FROM MULTIPLE DATA SOURCES. GEOGRAPHIC NAMES, HYDROGRAPHY, POPULATED PLACE, AND PROVINCIAL BOUNDARY DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
PROJECTION: UTM ZONE 17 DATUM: NAD 83

CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT - PHASE 2 PROPOSAL

TITLE
SUMMARY OF BATHYMETRIC DATA AND MILNE INLET VESSEL ANCHORAGES

CONSULTANT
GOLDER

YYYY-MM-DD	2019-06-14
DESIGNED	DH
PREPARED	AA
REVIEWED	DH
APPROVED	PO

PROJECT NO.	CONTROL	REV.	FIGURE
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3.0 HYDRODYNAMIC MODEL DEVELOPMENT

The 3-dimensional hydrodynamic model was developed in the MIKE3 platform by DHI Water and Environment Inc. MIKE3 is an industry standard commercially available hydrodynamic modelling program which simulates three-dimensional free surface flows in ocean, coastal, and inland waters. The hydrodynamic module of MIKE3 uses prescribed boundary conditions of water level or current velocity along with effects of heat flux, wind, and entering water courses to simulate the evolution of the water column profile. The transport module of MIKE3 is used in conjunction with the hydrodynamic module to simulate the dispersal of ballast water. This section describes the process of developing the model, including the model domain and bathymetry, model inputs (i.e., metocean data), and modelled ballast water discharge scenarios.

3.1 Model Domain and Bathymetry

The model consisted of a computational domain informed with measured bathymetry and fit to local land boundaries. The computational domain of the hydrodynamic model is a flexible mesh with triangular elements that covers the entirety of Milne Inlet, Eclipse Sound and Navy Board Inlet with varying resolution. The resolution of the mesh ranges from 2 km near the open boundaries in Baffin Bay to approximately 10 m near Milne Port and Anchorage 1. In the vertical direction, the mesh consists of 35 vertical layers, enabling the model to capture the hydrodynamics, including density stratification, in complex bathymetry.

3.2 Model Boundary and Initial Conditions

The model accounted for time varying water levels, ocean-atmosphere heat flux, and wind and hydraulically driven circulation. Model boundary and initial conditions were forced using measured and modelled data from August 2018, including:

- Modelled tidal constituents from the global tidal database TPXO 8.0
- Modelled meteorological data (i.e. wind speed and direction, surface pressure, air temperature, humidity, and solar intensity) at 4 km resolution extracted from a downscaled Weather Research and Forecasting model (WRF).
- Estimated discharge of Phillips Creek at Milne Port based on upstream hydrometric station records.
- Estimated freshwater flux from surface runoff, creek/river discharge, and sea ice, snow and glacial melt parameterized from known catchment areas and in calibration.
- Measurements of through water column temperature and salinity near Milne Port and on a transect extending from Milne Port to Ragged Island.

3.3 Ballast Water Discharge Scenarios

The discharge rate in all modelled ballast water discharge scenarios was based on data reported in the 2018 Canadian Ballast Water Reporting Forms (CBWF) and 2018 Fednav Statement of Facts for selected vessels travelling to Milne Port. From available CBWF and Fednav documents it was determined that the average discharge per vessel during the August 2018 period was approximately 24,000 m^3 over 20 hours (i.e., 1,200 m^3/hour). Further, for each scenario, it was assumed that one vessel per day discharged its ballast water and that the discharge occurred at Milne Port Anchorage #1 (502950.00 m E, 7978000.00 m N). The discharge location was based on communication with Baffinland and Fednav (Cooper 2019, pers. comm.).

Table 1 presents statistics of measured onboard ballast water salinity and temperature for vessels during the 2018 shipping season. It was found that ballast water had an average salinity of 33.2 PSU and 5.7 degrees Celsius. Additionally, as defined in the Ballast Water Control and Management Regulations (Canada SOR/2011-237, 2017) the salinity of discharged ballast water must be equal to or greater than 30 parts per thousand (ppt) or 30 PSU (practical salinity units). As the objective is to model the sensitivity of ballast water dispersion, both horizontally and vertically, the ballast water salinity and temperature values used in the simulations were selected to bound the measured maximum and minimums determined from the above sources. The density of selected salinity and temperature combinations were then compared to a density profile measured on August 07 2018, during the 2018 physical oceanographic program (Golder, 2019), to gain an understanding of how the density of ballast water for each of the different scenarios compared with ambient sea water (Figure 4.1). Table 2 presents a summary of the salinity and temperature combinations used to determine the density of six ballast water discharge scenarios that were modeled.

Table 1: Descriptive statistics of measured onboard ballast water salinity and temperature during the 2018 shipping season

	Min	Mean	Max
Salinity (PSU)	30.0	33.2	34.8
Temperature (Deg C)	-1.5	5.7	16.2

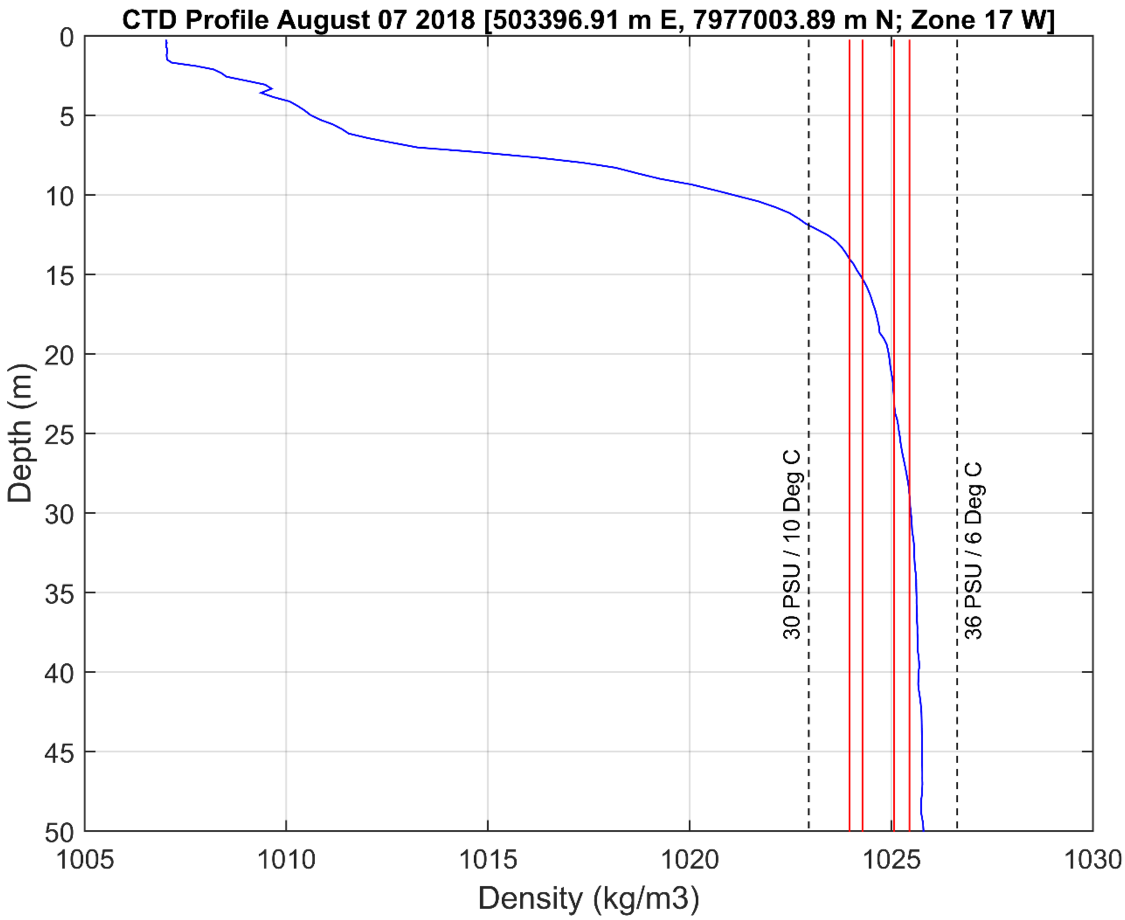


Figure 2: CTD measured density profile near Milne Port for 7 August 2018 (blue). The density of selected ballast water discharge scenarios is shown in black and red.

Table 2: Prescribed salinity and temperature and resulting density for each ballast water discharge simulation developed

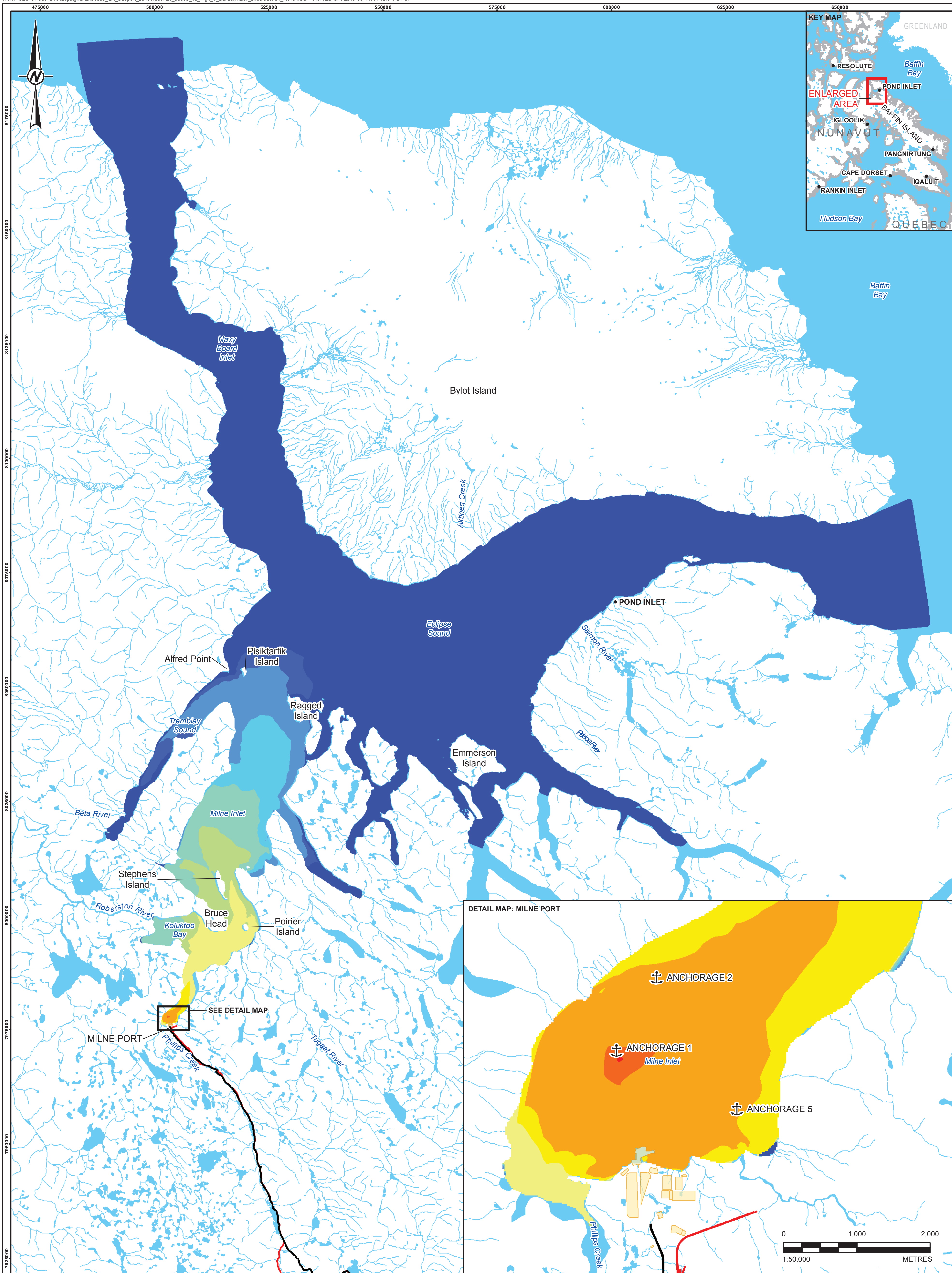
	Simulation 01	Simulation 02	Simulation 03	Simulation 04	Simulation 05	Simulation 06
Salinity (PSU)	36	30	31	32	32	32
Temperature (deg C)	6	10	6	6	2	13
Density (kg/m3)	1026	1023	1024	1025	1025	1024

4.0 BALLAST WATER DISCHARGE SIMULATION RESULTS

The results of the ballast water discharge simulations for the six scenarios are presented in Figure 4.1 through Figure 4.5. These figures present the minimum ballast water dilution at each horizontal location over the 30-day simulation period. The minimum dilution is calculated as the integration of model results through time and space (vertical). The larger the dilution factor the lower the concentration value and so the minimum dilution is a proxy for the highest ballast water concentration.

In all six scenarios, the concentration of ballast water is diluted by a minimum factor in the range of 50 to 100 immediately following the discharge. Given the ratio of the volume of ballast water discharged to the volume of water in the head of Milne Inlet, as well as the tidal flushing of the Inlet, this factor of dilution is expected. In general, the movement and dispersion of ballast water responds to the reversing flows of flood and ebb tide and is gradually transported away from the head of Milne Inlet along the thalweg. In all scenarios there is no measurable trace of ballast water simulated beyond Ragged Island and in general the dilution is such that simulated ballast water concentrations are negligible within 5 km of the discharge. Near the mouth of Phillips Creek, the simulated concentration of ballast water is diluted further as the freshwater inputs drive mixing processes.

Overall, the differences in ballast water dispersion and dilution between varying scenarios is subtle. For example, in Scenario 2 the same amount of ballast water dilution moves further down Milne Inlet than in Scenario 1, but the difference is only slight and considered insignificant to the pattern of dispersion. This suggests that ballast water dispersion in Milne Inlet is relatively insensitive to the salinity and temperature of onboard ballast water.



LEGEND

- VESSEL ANCHORAGE
- COMMUNITY
- WATERCOURSE
- EXISTING ORE DOCK
- WATERBODY

DILUTION

- 1 - 50
- 50 - 100
- 100 - 500
- 500 - 1,000
- 1,000 - 5,000
- 5,000 - 10,000
- 10,000 - 50,000
- 50,000 - 100,000
- 100,000 - 500,000
- 500,000 - 1,000,000
- > 1,000,000

0 20 40
1:800,000 KILOMETRES

REFERENCE(S)

MILNE PORT INFRASTRUCTURE DATA OBTAINED FROM CLIENT, MAY 28, 2108, AND BY HATCH, JANUARY 25, 2017, RETRIEVED FROM KNIGHT PIESOLD LTD. FULCRUM DATA MANAGEMENT SITE MAY 19, 2017. BATHYMETRY CREATED BY GOLDER FROM MULTIPLE DATA SOURCES. GEOGRAPHIC NAMES, HYDROGRAPHY, POPULATED PLACE, AND PROVINCIAL BOUNDARY DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
PROJECTION: UTM ZONE 17 DATUM: NAD 83

CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT - PHASE 2 PROPOSAL

TITLE
MINIMUM SIMULATED BALLAST WATER DILUTION DURING AUGUST 01 TO AUGUST 31 2018
SCENARIO: DISCHARGE AT ANCHORAGE 1 (36 PSU AND 6 DEG C)

CONSULTANT

GOLDER

YYYY-MM-DD	2019-06-14
DESIGNED	DH
PREPARED	AA
REVIEWED	DH
APPROVED	PO

PROJECT NO.	CONTROL	REV.	FIGURE
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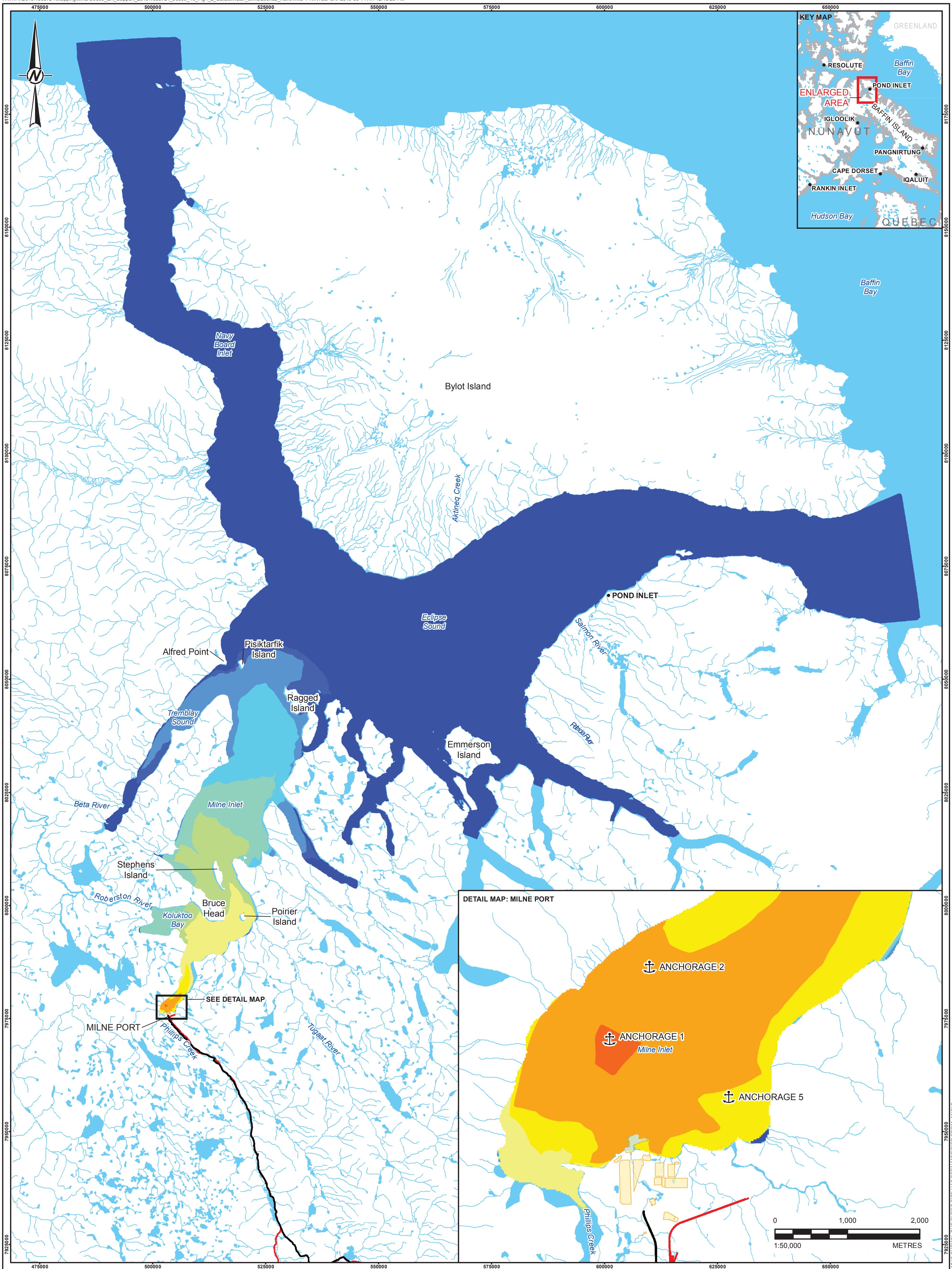

LEGEND

⚓	VESSEL ANCHORAGE
•	COMMUNITY
	WATERCOURSE
	EXISTING ORE DOCK
	WATERBODY

DILUTION

- 1 - 50
- 50 - 100
- 100 - 500
- 500 - 1,000
- 1,000 - 5,000
- 5,000 - 10,000
- 10,000 - 50,000
- 50,000 - 100,000
- 100,000 - 500,000
- 500,000 - 1,000,000
- > 1,000,000

0 20 40

1:800,000 KILOMETRES

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PROJECTION: UTM ZONE 17 DATUM: NAD 83

CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT - PHASE 2 PROPOSAL

TITLE
MINIMUM SIMULATED BALLAST WATER DILUTION DURING AUGUST 01 TO AUGUST 31 2018
SCENARIO: DISCHARGE AT ANCHORAGE 1 (30 PSU AND 10 DEG C)

CONSULTANT

GOLDER

YYYY-MM-DD	2019-06-14
DESIGNED	DH
PREPARED	AA
REVIEWED	DH
APPROVED	PO

PROJECT NO.	CONTROL	REV.	FIGURE
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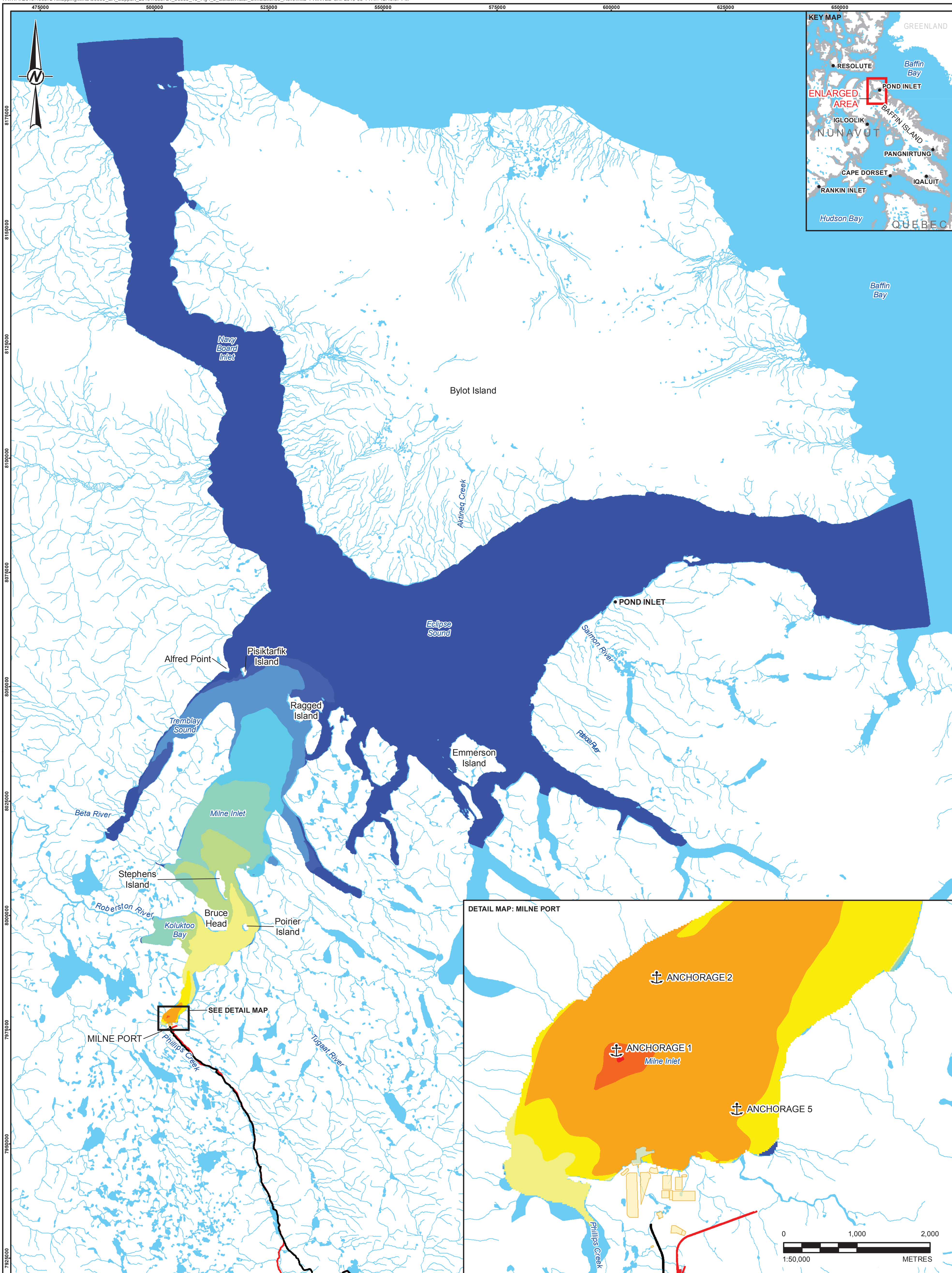

LEGEND

- VESSEL ANCHORAGE
- COMMUNITY
- WATERCOURSE
- EXISTING ORE DOCK
- WATERBODY

DILUTION

- 1 - 50
- 50 - 100
- 100 - 500
- 500 - 1,000
- 1,000 - 5,000
- 5,000 - 10,000
- 10,000 - 50,000
- 50,000 - 100,000
- 100,000 - 500,000
- 500,000 - 1,000,000
- > 1,000,000

0 20 40
1:800,000 KILOMETRES

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PROJECTION: UTM ZONE 17 DATUM: NAD 83

CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT - PHASE 2 PROPOSAL

TITLE
MINIMUM SIMULATED BALLAST WATER DILUTION DURING AUGUST 01 TO AUGUST 31 2018
SCENARIO: DISCHARGE AT ANCHORAGE 1 (32 PSU AND 6 DEG C)

CONSULTANT

GOLDER

YYYY-MM-DD	2019-06-14
DESIGNED	DH
PREPARED	AA
REVIEWED	DH
APPROVED	PO

PROJECT NO.	CONTROL	REV.	FIGURE
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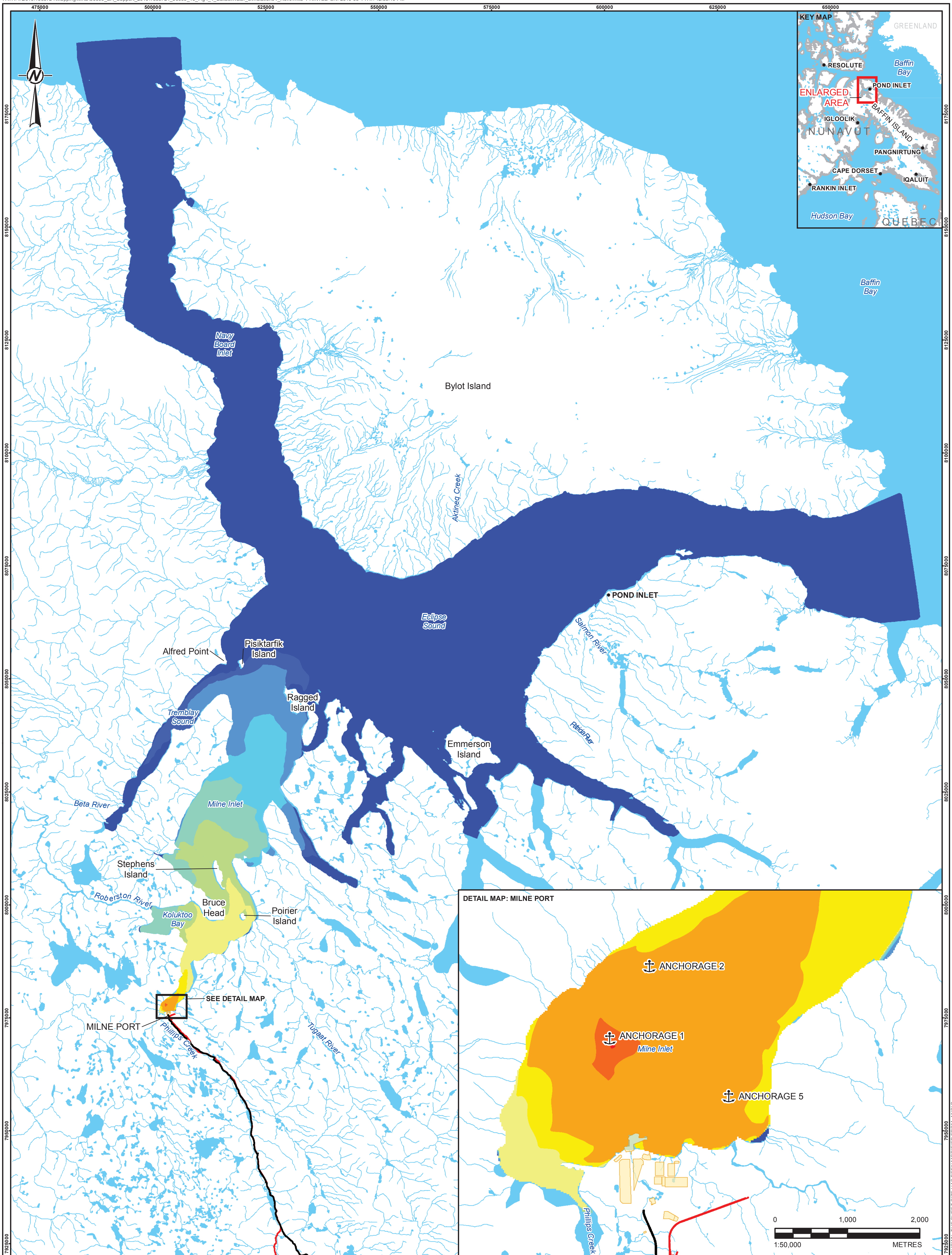

LEGEND

- VESSEL ANCHORAGE
- COMMUNITY
- WATERCOURSE
- EXISTING ORE DOCK
- WATERBODY

DILUTION

- 1 - 50
- 50 - 100
- 100 - 500
- 500 - 1,000
- 1,000 - 5,000
- 5,000 - 10,000
- 10,000 - 50,000
- 50,000 - 100,000
- 100,000 - 500,000
- 500,000 - 1,000,000
- > 1,000,000

0 20 40
1:800,000 KILOMETRES

REFERENCE(S)

MILNE PORT INFRASTRUCTURE DATA OBTAINED FROM CLIENT, MAY 28, 2108, AND BY HATCH, JANUARY 25, 2017, RETRIEVED FROM KNIGHT PIESOLD LTD. FULCRUM DATA MANAGEMENT SITE MAY 19, 2017. BATHYMETRY CREATED BY GOLDER FROM MULTIPLE DATA SOURCES. GEOGRAPHIC NAMES, HYDROGRAPHY, POPULATED PLACE, AND PROVINCIAL BOUNDARY DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
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CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT - PHASE 2 PROPOSAL

TITLE
MINIMUM SIMULATED BALLAST WATER DILUTION DURING AUGUST 01 TO AUGUST 31 2018
SCENARIO: DISCHARGE AT ANCHORAGE 1 (31 PSU AND 6 DEG C)

CONSULTANT

GOLDER

YYYY-MM-DD	2019-06-14
DESIGNED	DH
PREPARED	AA
REVIEWED	DH
APPROVED	PO

PROJECT NO.	CONTROL	REV.	FIGURE
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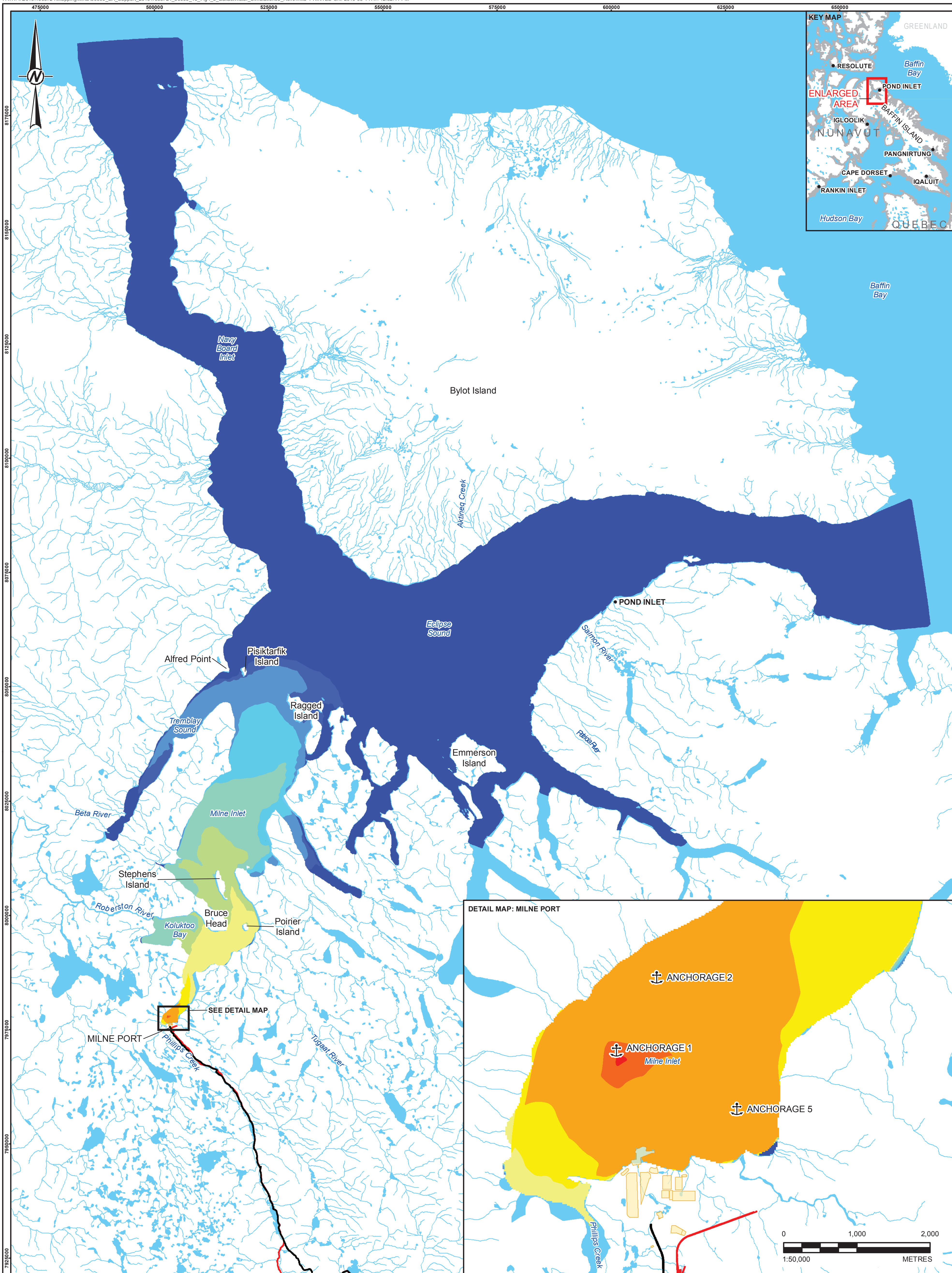

LEGEND

- VESSEL ANCHORAGE
- COMMUNITY
- WATERCOURSE
- EXISTING ORE DOCK
- WATERBODY

DILUTION

- 1 - 50
- 50 - 100
- 100 - 500
- 500 - 1,000
- 1,000 - 5,000
- 5,000 - 10,000
- 10,000 - 50,000
- 50,000 - 100,000
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CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT - PHASE 2 PROPOSAL

TITLE
MINIMUM SIMULATED BALLAST WATER DILUTION DURING AUGUST 01 TO AUGUST 31 2018
SCENARIO: DISCHARGE AT ANCHORAGE 1 (32 PSU AND 2 DEG C)

CONSULTANT

GOLDER

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PREPARED	AA
REVIEWED	DH
APPROVED	PO

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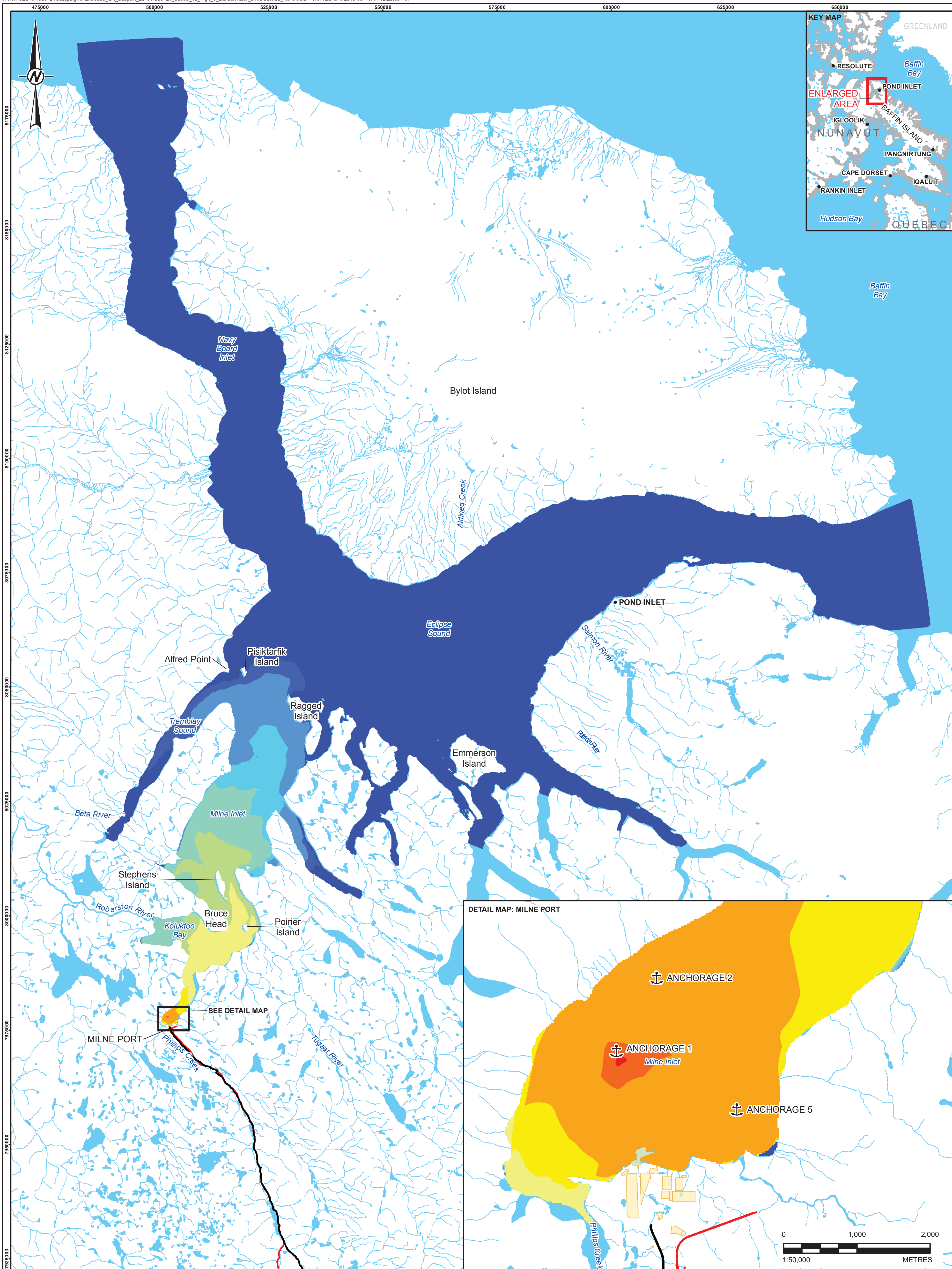

LEGEND

- VESSEL ANCHORAGE
- COMMUNITY
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- WATERBODY

DILUTION

- 1 - 50
- 50 - 100
- 100 - 500
- 500 - 1,000
- 1,000 - 5,000
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PROJECTION: UTM ZONE 17 DATUM: NAD 83

CLIENT
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PROJECT
MARY RIVER PROJECT - PHASE 2 PROPOSAL

TITLE
MINIMUM SIMULATED BALLAST WATER DILUTION DURING AUGUST 01 TO AUGUST 31 2018
SCENARIO: DISCHARGE AT ANCHORAGE 1 (32 PSU AND 13 DEG C)

CONSULTANT

GOLDER

YYYY-MM-DD	2019-06-14
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PREPARED	AA
REVIEWED	DH
APPROVED	PO

PROJECT NO.	CONTROL	REV.	FIGURE
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5.0 KEY ASSUMPTIONS AND MODEL LIMITATIONS

The following are key assumptions and limitations of the model.

- Bathymetry is generally well defined in Milne Inlet but poorly defined in many of the tributary fjords and Eclipse Sound.
- Model prescribed temperature and salinity initial conditions were based on CTD profiles collected at discrete points between Milne Port and Ragged Island. It is understood that additional temperature and salinity variations may exist between these locations and beyond (i.e., Eclipse Sound).
- Changes in water temperature resulting from variations in ocean-atmosphere heat flux were included in the model using 4 km resolution modelled meteorological data (i.e., air temperature, solar intensity, humidity, etc.). Heat flux is considered within an order of magnitude.
- Effects of wind were incorporated using 4 km resolution modelled 10 m wind speed and direction. It is noted that additional variation in wind speed and direction due to topographic steering and sub-kilometer processes may exist.
- Inputs of fresh water sources are considered to be within an order of magnitude of actual values and based on knowledge of Arctic hydrology and limited observations concentrated near Milne Port.
- Bed roughness was prescribed uniformly throughout the model domain as the composition of substrate across the domain is unknown outside the immediate Milne Port area.
- The model domain and calibrated/validated model parameters (i.e., horizontal and vertical eddy diffusivity) are taken from the 2018 ballast water model (Golder, 2018).
- Estimates of ballast water discharge volumes and characteristic (i.e., salinity and temperature) were based on 2018 ballast water discharge records and observed density profiles near Milne Port.

GOLDER ASSOCIATES LTD.

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