TECHNICAL SUPPORTING DOCUMENT

Mary River Project | Phase 2 Proposal | FEIS Addendum | August 2018

TSD 18

Ballast Water Dispersion Modelling






BALLAST WATER DISPERSION MODELLING TECHNICAL SUPPORTING DOCUMENT SUMMARY

The Ballast Water Dispersion Modelling Technical Supporting Document provides the results of a three-dimensional hydrodynamic model of ballast water dispersion for both 2018 marine shipping traffic and the proposed increase in marine shipping activities included in the Phase 2 Proposal. The Phase 2 Proposal builds on the extensive baseline studies and assessments carried out since 2011 for the larger Approved Project and is thus closely linked to the FEIS and previous addendums. This document is used as input to the assessment of effects on the marine environment.

The model simulates the tidal water level variations, currents, and density structure of Milne Inlet and its response to the addition of ballast water taken aboard ore ships in the mid-Atlantic or Labrador Sea which has a greater salinity (and therefore density) than the ambient ocean water in Milne Inlet. A long-term simulation of the open water season was run including ballast water discharges at both the existing and proposed ore docks.

Results of the modelling indicate that the strongest gradient in ballast water dilution is within a 2 km radius of the existing ore dock where the ballast water concentration dilutes by up to a factor of 1,000. Ballast water discharged at the existing and proposed dock is expected to reach Ragged Island where the dilution is between 500,000 and 1,000,000 times that of the discharge point.

As with current conditions, it is expected that ballast water dilution will follow a similar pattern of dispersion and dilution following the close of the shipping season with a continued overall dilution and dispersion of ballast water out of Milne Inlet and into Eclipse Sound where the residual concentrations are expected to be insignificant.

RÉSUMÉ DU DOCUMENT D'ASSISTANCE TECHNIQUE SUR LA MODÉLISATION DE LA DISPERSION DES EAUX DE BALLAST

Le document d'assistance technique sur la modélisation de la dispersion des eaux de ballast comporte les résultats d'un modèle hydrodynamique tridimensionnel de dispersion des eaux de ballast du trafic maritime de 2018 et l'augmentation proposée des activités de transport maritime comprise dans la proposition de la phase 2. La proposition de la phase 2 est fondée sur les études préliminaires et les évaluations complètes réalisées depuis 2011 pour l'ensemble du projet approuvé et est donc étroitement liée à l'énoncé des incidences environnementales (EIE) et aux addendas précédents. Ce document est utilisé pour l'évaluation des impacts sur le milieu marin.

Le modèle simule les variations de niveau des marées, les courants et la structure de densité de Milne Inlet et sa réponse à l'ajout d'eaux de ballast des navires de minerai qui ont été prélevées dans le milieu de l'Atlantique ou dans la mer du Labrador et qui présentent une salinité (et donc une densité) plus élevée que l'eau océanique ambiante de Milne Inlet. Une simulation à long terme de la saison des eaux libres a été réalisée, y compris des décharges d'eaux de ballast dans les quais de minerai existants et proposés.

Les résultats de la modélisation indiquent que le plus fort gradient de dilution des eaux de ballast se trouve dans un rayon de 2 km du quai de minerai existant, où la concentration des eaux de ballast est diluée jusqu'à un facteur de 1 000. Les eaux de ballast rejetées au quai existant et proposé devraient atteindre l'île Ragged, où la dilution se situe entre 500 000 et 1 000 000 fois celle du point de rejet.

Dans les conditions actuelles, il est prévu que la dilution des eaux de ballast devrait suivre un schéma de dispersion et de dilution similaire à la fin de la saison de navigation, avec une dilution et une dispersion globales continues des eaux de ballast à Milne Inlet et dans Eclipse Sound, où les concentrations résiduelles devraient être non significatives.

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ᑖᒪᓇ ᐃᒃᑕᖅᑯᑎᒧᑦ ᐃᒥᖅ ᑯᕙᔭᐅᑎᓪᓗᒍ ᓇᒧᙵᓚᕋᔭᕐᓂᐊᓄ ᑕᑯᓐᓈᙳᐊᕈᑏᑦ ᐱᔭᓇᐊᑐᔪᑦ ᐃᑲᔪᐃᔾᔪᑎᑦ ᑎᑎᕋᖅᓯᒪᔪᑦ ᐱᑕᖃᖅᑎᑦᑎᕗᑦ ᓴᖅᑭᑕᐅᓯᒪᔪᓂᒃ ᐱᖓᓱᐃᓕᖓᔪᒥᒃ–ᑕᐅᑦᑐᒐᓕᖕᒥᒃ ᐃᒪᖅᑎᒍᑦ ᑕᐅᑐᙳᐊᕈᑎᒥᒃ ᖃᓄᖅ ᐃᒃᑕᖅᑯᑎᐅᑉ ᐃᒥᖓ ᑯᕙᔭᐅᔪᖅ ᑕᒪᐃᓐᓄᑦ 2018 ᐅᒥᐊᕐᔪᐊᓄᑦ ᑎᑭᕋᖅᑐᓄᑦ ᐊᒻᒪᑦᑕᐅᖅ ᐅᒃᑑᑎᑦᓯᔭᐅᔪᖅ ᐊᖏᓕᕆᐊᕈᑖ ᑕᕆᐅᕐᒥᑦ ᐅᒥᐊᕐᔪᐊᑦ ᐅᓄᖅᓯᕆᐊᕐᓂᖓᓄᑦ ᐱᖃᓯᐅᑎᓪᓗᑎᒃ ᐃᓗᐊᓄᑦ ᐱᓕᕆᐊᑉ ᒪᕐᑭᕆᓕᖅᑕᖓᓄᑦ ᐅᑦᑑᑎᖓᑕ. ᐱᓕᕆᐊᑉ ᒪᕐᑭᕆᓕᖅᑕᖓᓄᑦ ᐅᑦᑑᑎᖓ ᐃᓚᒋᐊᕆᔭᕐᖃᖅᑐᖅ ᖃᖓᒍᑦ ᐊᖏᔫᑦ ᑐᙵᕕᑦ ᖃᐅᔨᓴᕕᐅᑦ ᐊᕙᑖᓄᑦ ᑕᒪᓇᓗ ᕿᒥᕐᕈᐃᓂᖅ ᑕᐃᑲᖓᑦ 2011–ᒥ ᑖᔅᓯᒪᖓ ᐃᓗᐃᑦᑑᔪᒧᑦ ᐊᖏᖅᓯᒪᔪᒧᑦ ᐅᔭᕋᓐᓂᐊᕐᓂᕐᒧᑦ ᑕᐃᒫᒡᒍ ᐊᒃᑐᐊᓂᖃᖅᐳᑦ ᑭᖑᓪᓕᖅᐹᑉ ᐊᕙᑎᒧᑦ ᐊᒃᑐᐃᓂᐊᕐᓂᐅᔪᓄᑦ ᐅᓂᒃᑳᖏᓐᓄᑦ (FEISᔪ ᓯᕗᓂᐊᒍᓪᓗ ᐅᐃᒍᕆᐊᖅᑕᐅᓂᑰᔪᒃᑯᑦ. ᐅᓇ ᑎᑎᕋᖅᓯᒪᔪᖅ ᐊᑐᖅᑕᐅᔪᖅ ᑐᓐᓂᖁᔭᐅᓪᓗᓂ ᕿᒥᕐᕈᓇᖕᓂᐊᓄᑦ ᐊᒃᑐᐃᓂᕐᓄᑦ ᑕᓇᐅᑉ ᐊᕙᑖᓄᑦ.

ᐅᓇ ᑕᐅᑐᙳᐊᕈᑎ ᐊᐅᓚᑎᑦᑎᔪᖅ ᐅᓕᑦᑕᕐᓂᐅᑉ ᐊᔾᔨᒋᔭᓐᓃᖅᑕᕐᓂᐊᑕ ᓇᐃᓴᐅᑎᖏᓐᓂᒃ, ᐃᖏᕐᕋᓂᖏᓐᓂᒃ, ᐊᒻᒪ ᑕᓇᐅᑉ ᐃᒪᖓᑕ ᐊᔾᔨᒌᖏᕆᓕᓈᖏᓐᓂᖏᑦ ᕿᙳᐊᑕ ᑲᖏᖅᖢᐊᓂ ᖃᓄᕐᓗ ᐊᓯᔾᔨᖅᑕᕐᒪᖔᑦ ᐃᒪᖓ ᑯᕙᕝᕙᐅᑎᓪᓗᒍ ᐊᖏᔪᒥᒃ ᐃᒃᑕᖅᑯᑎᕙᓂᐅᑉ ᐃᒥᖓᓂᒃ ᓴᕙᕋᔭᒃᓴᓂᒃ ᐅᓯᑲᖅᑕᐅᑎᓄᑦ ᐊᖏᔪᓄᑦ ᐊᑦᓛᓐᑎᒃ ᑕᓇᐅᕐᔪᐊᒥ ᐊᒻᒪᓘᓐᓃᑦ ᓛᐸᑐᐊ ᑕᓇᐅᖓᓂ ᑖᒃᑯᐊ ᑕᓇᓯᒪᓂᖅᓴᐅᖓᑕ (ᐊᒻᒪ ᑕᐃᒪᐃᒻᒪᑦ ᐅᕐᑯᒪᐃᖅᓂᖅᓴᖅ) ᑕᒪᒃᑯᓇᙵᑦ ᑖᒪᓃᕐᓇᔪᒥᒃ ᑕᓇᐅᑉ ᐃᒪᖓᓂᒃ ᐃᓗᐊᓂ ᕿᙵᐊᑉ ᑲᖏᖅᖢᐊᑕ. ᐊᕐᕌᒍᓗᓴᙵᐊᓄᑦ ᐃᖏᕐᕋᑎᑕᐅᙵᐊᕐᖢᓂ ᐊᐅᔭᒃᑯᑦ ᐅᓯᒃᑕᕐᕕᐊᒍᑦ ᐊᐅᓚᑎᑕᐅᓪᓗᓂ ᐱᕐᖃᓯᐅᑎᓪᓗᑎᑦ ᑖᒃᑯᐊ ᐃᒃᑕᖅᑯᑏᑦ ᐃᒦᑦ ᑯᕙᔭᐅᑎᓪᓗᑎᑦ ᑕᒪᐃᑎᒍᑦ ᐅᓪᓗᒥ ᐊᑐᖅᑐᒧᑦ ᓴᓇᔭᐅᔪᒪᔪᒧᓪᓗ ᓴᕙᕋᔭᒃᓴᒧᑦ ᐅᓯᑲᖅᓯᐃᕝᕕᖏᓐᓂᑦ.

ᓴᖅᑭᑎᖅᓯᒪᔪᑦ ᑕᐅᑐᙳᐊᕈᑎᒃᑯᑦ ᓇᓗᓇᐃᕆᕗᑦ ᓴᙲᒋᓛᖑᔪᖅ ᑲᑕᒋᐊᕐᓂᖓ ᑕᒪᒃᑯᓄᖓ ᐃᒃᑕᖅᑯᑎᑦ ᐃᒥᖏᑕ ᓄᖑᒪᕆᐊᕈᑎᖏᑦ ᐃᓗᐊᓃᑦᑐᖅ 2 ᑭᓛᒥᑕᐅᑉ ᐊᕙᓗᐊᓂᒃ ᑖᔅᓯᒪ ᐊᑐᖅᑕᐅᕙᕆᖅᑑᑉ ᓴᕙᕋᔭᒃᓴᓄᑦ ᐅᓯᑲᖅᓯᐃᕝᕙᐊᑕ ᑕᒪᓇ ᐃᒃᑕᖅᑯᑎᕙᓂᖅ ᐃᒥᖅ ᓄᖑᒪᕆᐊᓯᓰᖅ ᐊᕗᑎᓪᓗᓂ ᓄᖑᕆᐊᕐᓂᖅᑲᖅᓗᓂ ᓇᐋᓴᐅᑎ ᑲᑎᖅᓰᑦ ᐊᑐᖅᓗᒍ 1,000. ᐃᒃᑕᖅᑯᑎᐅᑉ ᐃᒥᖓ ᑯᕙᔭᐅᔪᖅ ᐅᓪᓗᒥ ᐊᑐᖅᑕᒧᑦ ᓴᓇᔭᐅᔪᒪᔫᓪᓗ ᐅᓯᑲᖅᓯᐃᕝᕙᐊᓂᒃ ᓂᕆᐅᒋᔭᐅᔪᑦ ᐃᒥᓕᐅᑉ ᖃᖃᖅᑖᓄᑦ ᑎᑭᒃᑲᔭᕐᓂᐊᓂᒃ ᓄᖑᒪᓕᕐᓗᓂ ᐃᒻᒪᖄ 500,000 ᐊᒻᒪᓗ 1,000,000–ᖏᖅᓱᓪᓗᐊᖅᓗᒍ ᓄᖑᒪᓂᓕᒃ ᑕᐃᑲᙵᑦ ᑯᕙᔭᐅᕝᕙᐊᓂᑦ.

ᑕᐃᒪ ᐅᓪᓗᒥᑐᑦ ᐃᓕᖅᑯᓯᐅᓲᑎᑐᑦ, ᓂᕆᐅᒋᔭᐅᕗᖅ ᑕᒪᓇ ᐃᒃᑕᖅᑯᑎᐅᓲᑉ ᐃᒥᖓ ᓄᖑᒪᕗᓪᓕᐊᓂᖓ ᒪᓕᒃᑲᔭᖅᑐᖅ ᓯᐊᒻᒪᒃᐸᓪᓕᐊᓂᖓᓄᑦ ᐃᖏᕋᓂᖅᑐᒧᑦ ᓄᖑᑉᐸᓪᓕᐊᓂᖓᓗ ᐃᓯᓕᓕᕈᓂ ᐅᒥᐊᕐᔪᐊᒃᑯᑦ ᐅᓯᑲᖅᑕᐅᕝᕙᐊᑕ ᐅᓪᓗᖏᒍᑦ ᑲᔪᓯᓗᓂ ᓄᖑᑕᐅᕙᓪᓕᐊᓂᖓ ᓯᐊᒻᒪᒃᐸᓪᓕᐊᓂᖓᓗ ᐃᒃᑕᖅᑯᑎᕙᓂᐅᑉ ᐃᒪᖓ ᓯᓚᑖᓄᑦ ᕿᙵᐊᑕ ᑲᖏᖅᖢᐊᑕ ᑕᓯᐅᔭᐅᑉ ᑕᓇᐅᖓᓄᓪᓗ ᑕᒪᒃᑯᐊ ᕿᒻᒪᒃᑯᕙᓃᑦ ᓇᓂᔭᒃᓴᐅᔪᑦ ᐃᒃᐱᙵᕐᓈᖅᑲᔭᖅᓗᑎᒃ ᑕᓇᐅᑐᐃᓐᓇᐅᖃᑕᐅᓕᕐᓂᖓᓄᑦ.

REPORT

Baffinland Iron Mines Corporation
Mary River Project - Phase 2 Proposal

Technical Supporting Document No.18
Ballast Water Dispersion Modelling

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31 July 2018

LIST OF ACRONYMS

Term	Abbreviation
Baffinland Iron Mines Corporation	Baffinland
Canadian Hydrographic Service	CHS
Conductivity and temperature with depth	CTD
Global Self-consistent Hierarchical, High-resolution Geography Database	GSHHG
Golder Associates Ltd	Golder
High water level	HWL
Mean sea level	MSL
Million tonnes per annum	Mtpa
North American Regional Reanalysis	NARR
Nunavut Impact Review Board	NIRB
Technical Support Document	TSD
Topex Poseidon	TPXO

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TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

The Mary River Project (the Project) is an operating iron ore mine located in the Qikiqtani Region of Nunavut (Figure 2.1). Baffinland Iron Mines Corporation (Baffinland; the Proponent) is the owner and operator of the Project. As part of the regulatory approval process, Baffinland submitted a Final Environmental Impact Statement (FEIS) to the Nunavut Impact Review Board (NIRB), which presented in-depth analyses and evaluation of potential environmental and socioeconomic effects associated with the Project.

In 2012, NIRB issued Project Certificate No 005 which provided approval for Baffinland to mine 18 million tonnes per annum (Mtpa) of iron ore, construct a railway to transport the ore south to a port at Steensby Inlet which operates year-round, and to ship the ore to market. The Project Certificate was subsequently amended to include the mining of an additional 4.2 Mtpa of ore, trucking this amount of ore by an existing road (the Tote Road) north to an existing port at Milne Inlet, and shipping the ore to market during the open water season. The total approved iron ore production was increased to 22.2 Mtpa (4.2 Mtpa transported by road to Milne Port, and 18 Mtpa transported by rail to Steensby Port). This is now considered the Approved Project. The 18 Mtpa Steensby rail project has not yet been constructed, however 4.2 Mtpa of iron ore is being transported north by road to Milne Port currently. Baffinland recently submitted a request for a second amendment to Project Certificate No.005 to allow for a short-term increase in production and transport of ore via road through Milne Port from the current 4.2 Mtpa to 6.0 Mtpa.

1.1 Phase 2 Proposal Overview

The Phase 2 Proposal (the third project certificate amendment request) involves increasing the quantity of ore shipped through Milne Port to 12 Mtpa, via the construction of a new railway running parallel to the existing Tote Road (called the North Railway). The total mine production will increase to 30 Mtpa with 12 Mtpa being transported via the North Railway to Milne Port and 18 Mtpa transported via the South Railway to Steensby Port. Construction on the North Railway is planned to begin in late 2019. Completion of construction of the North Railway is expected by 2020 with transportation of ore to Milne Port by trucks and railway ramping up as mine production increases to 12 Mtpa by 2020. Shipping from Milne Port will also increase to 12 Mtpa by 2020. Construction of the South Railway and Steensby Port will commence in 2021 with commissioning and a gradual increase in mine production to 30 Mtpa by 2024. Shipping of 18 Mtpa from Steensby Port will begin in 2025.

Phase 2 also involves the development of additional infrastructure at Milne Port, including a second ore dock (Figure 2.1). Shipping at Milne Port will continue to occur during the open water season, and may extend into the shoulder periods when the landfast ice is not being used to support travel and harvesting by Inuit. Various upgrades and additional infrastructure will also be required at the Mine Site and along both the north and south transportation corridors to support the increase in production and construction of the two rail lines.

In order to account for the increased tonnage of ore being transported under the Phase 2 Proposal, an increase in total vessel traffic serving Milne Port is proposed. Vessels ranging in size from Supramax to Cape Size will be retained by Baffinland depending on availability. An estimated 176 ore carrier round trips (upper range) will occur per season, with an average voyage time per vessel of 26 days. Shipping will occur seasonally over a period of approximately 90 days between 1 July and 15 November, with each chartered vessel making one to three round trips per season.

1.1 Scope of the Assessment

This Technical Support Document (TSD) examines the dispersal of ballast water discharged from vessels docking at the existing and proposed ore docks during the ice-free season within Milne Inlet. This TSD supports an Environmental Impact Statement under preparation by Baffinland for the Phase 2 Proposal. The main purpose of the report is to determine the fate of ballast water discharged from ships during ice free months and to compare the relative changes in ballast water accumulation and dispersion in Milne Inlet between the Phase 2 Proposal and existing operations.

This TSD presents a three-dimensional (3D) hydrodynamic model developed in MIKE3 which simulates the tidal water level variations, currents and density structure of Milne Inlet and its response to the addition of ballast water taken aboard ore ships in the mid-Atlantic or Labrador Sea which has a greater salinity (and therefore density) than the ambient ocean water in Milne Inlet. Section 2.0 of the report presents the physical environment data used in the setup, calibration, validation and application of the hydrodynamic model. These physical data are described in greater detail in Appendix A. Section 3.0 of the report provides an abbreviated description of the development of the hydrodynamic model with additional detail regarding setup and calibration provided in Appendix B as well as the assumptions and limitations inherent in the model. Section 4.0summarizes the results of a hydrodynamic simulation representing the existing condition that includes the operation of a single ore dock. Section 5.0 summarizes the hydrodynamic simulation of the Proposed Phase 2 Project including a summary of the assumed ore shipment scenarios, ballast water properties and the results of the simulation of discharge from two ore docks over the open water season. Section 5.0 summarizes the potential effects in terms of ballast water dispersion and changes to salinity over time.

2.0 PHYSICAL ENVIRONMENT DATA USED IN MODEL SETUP

Milne Inlet is located along the Northwest coast of Baffin Island in the Qikiqtani Region of Nunavut. The inlet is at the southern extent of a network of fjords connecting to Baffin Bay. Milne Inlet runs nearly north-south extending to Eclipse Sound and Navy Board Inlet (Figure 2-1). Milne Port is being developed at the southern end of Milne Inlet to support Baffinland's iron ore exports via the Northern Shipping Route (from Milne Inlet to Baffin Bay) during open-water season (July-October). Air temperature typically ranges from -35 °C to 4.5 °C from winter to summer respectively. Sea ice covers the inlet from approximately November to mid- or late July the following year. Mean sea ice thickness is estimated as 1.6 m in most years (Knight Piésold 2010).

The general physical conditions at the site are controlled by wind and atmospheric systems, tides and tidal currents, waves, runoff, and sea ice. Physical characteristics of the project site are described in greater detail in Appendix A and in several previous reports (e.g. Knight Piésold 2010; CORI 2014).

LEGEND

- PROJECT SITE
- COMMUNITY
- FUTURE SOUTH RAILWAY
- MILNE INLET TOTE ROAD
- NUNAVUT SETTLEMENT AREA
- SHIPPING ROUTE
- SIRMILIK NATIONAL PARK
- WATER

0 125 250

1:5,000,000 KILOMETRES

REFERENCE(S)

BASE MAP: © ESRI DATA AND MAPS (ONLINE) (2016). REDLANDS, CA: ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE. ALL RIGHTS RESERVED.

CLIENT
BAFFINLAND IRON MINES CORPORATION

PROJECT
MARY RIVER PROJECT - PHASE 2 PROPOSAL

TITLE
PROJECT LOCATION

CONSULTANT

GOLDER

YYYY-MM-DD	2018-07-31
DESIGNED	YT
PREPARED	AA
REVIEWED	WDC
APPROVED	PO

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	8000	0	2.1

3.0 HYDRODYNAMIC MODEL DEVELOPMENT

The hydrodynamic model used for this project MIKE3 – which is developed and maintained by DHI. MIKE3 is an industry standard commercially available computational fluid dynamics modelling program which simulates three-dimensional free surface flows and it is widely used to simulate coastal and estuarine hydrodynamics as well as other applications in physical oceanography. A transport module was used to model the dispersal of ballast water.

The model consisted of a computational domain informed with measured bathymetry and fit to local land boundaries as described in Appendix B. Boundary conditions in the model were forced with tidal constituents derived from a global database (TPXO 8.0). Additionally, representative winds and measured salinity and temperature profiles for selected dates (2014 dataset) were used to force the model. The model was calibrated using on-site measurements of water level and verified with currents measured within the domain. For a more detailed description of the hydrodynamic model, refer to Appendix B.

3.1 Key Assumptions and Model Limitations

At the time of preparing the model no direct field measurements of currents, water levels, salinity and temperature data were available to describe or characterize hydrodynamic conditions and density structure proximal to the proposed port expansion or to validate the numerical models which are applied in the immediate Port region for assessment of project effects. As outlined in Appendix B, calibration of the hydrodynamic model is limited to comparison with measured water levels and currents in the wider model domain and a broad comparison with the results from previous modelling studies (e.g. CORI, 2014). Given the complexity of physical oceanographic processes within Milne Inlet and the limited data available for a modeling study, several key assumptions and limitations should be considered with respect to the interpretation of the results presented in this report as follows:

- Model prescribed stratified temperature and salinity profiles were considered constant over short time scales. This assumption is consistent with relatively small changes in temperature and salinity measurements during August 2014 in Milne Inlet and with recent measurements in the same period in 2017. It is understood that more substantial short term variations in temperature and salinity structure can occur especially early in the ice-free season.
- Changes in water temperature due to solar heating are prescribed as a function of the heat flux using the meteorological data at Milne port.
- Inputs of fresh water and heat flux are considered rough order of magnitude estimates only and based on very limited relevant data.
- Bed roughness was prescribed uniformly throughout the domain as the composition of the substrate across the domain was unknown outside of the immediate Port area.
- The ballast water discharge estimates are based on the number and capacity of ore ships expected to be calling at the Port during peak operations at the time of preparing the report. The schedule of discharges is based on the total monthly shipping traffic and assumed to be equally spaced in time (Ore shipment scenarios are described further in Section 3.2.1.).

- NARR (North American Regional Reanalysis) wind data are available with a spatial resolution of 32 km in the model domain. No model grid nodes lie directly within Milne Inlet and the conformity of wind speeds and directions with respect to local topographic effects is understood to be relatively poor based on comparison with direct measurements from the Port site and local observations.
- Available measurements of currents are limited to 3 locations which are located in areas of complex bathymetry and at significant distances from the Port site. Baseline data characterizing the circulation in the Port area during a complete open water season is not available.
- Bathymetry is generally well defined in Milne Inlet but poorly defined in many of the tributary fjords and Eclipse Sound.

3.2 Shipping Scenarios and Ballast Water Discharge Characteristics

This section describes the considerations and assumptions made in the modeling of ballast water discharge using the hydrodynamic model described in the previous sections. The ballast water is defined as a point source with associated discharge rate, temperature and salinity. The ballast water is evaluated in terms salinity, temperature and concentration. The effect of ballast water on the salinity and temperature variation of Milne inlet was evaluated by comparing the ballast water scenarios with the model of existing conditions. The transport module in MIKE3 was used for evaluating the concentration of ballast water which is assumed to be a passive tracer. The passive tracer approach allows the visualization of the ballast water dispersal and mixing. For the purpose of this model, the ballast water is assumed to be discharged only at the Milne port. The estimation of the quantity of ballast water as well as the interval at which it is discharged is based on the expected shipping traffic of each category of shipping vessels. The open water season, during which the shipping takes place, is assumed to be from mid-July to mid-October similar to a previous study (CORI 2014).

3.2.1 Ore Shipment Scenarios

The ballast water dispersal is modeled based on two operating conditions or scenarios. The first scenario considers only the existing ore dock to be operational and the second scenario considers both the existing and the proposed ore docks to be operational. The shipping schedule for the existing ore dock is 15 July to 15 October, while the proposed shipping schedule for the proposed ore dock is 1 July to 15 November.

The total number of vessels discharging ballast water at the exiting dock is 84. The total cumulative number of vessels discharging ballast water at the existing and the proposed dock is up to a maximum of 176

The vessel classes expected at the existing dock are Panamax and Supramax vessels. The shipping traffic is assumed to be uniform and so the frequency is one ship per day during August and September. For July and October, the frequency increases to two ships per day on certain days since the months are only considered partially for the shipping season. The capacity of the proposed dock is greater than the existing dock and it can accommodate cape sized vessels. The shipping traffic is slightly higher than the existing dock in terms of the total incoming vessels per month but the frequency is comparable. One ship per day is expected for the months of July, August and September but for October, certain days will have two ships per day.

The content of ballast water is estimated as a percentage of the total capacity or deadweight tonnage of the vessel class. Literature derived values of ballast water discharge are between 25% and 33% (David et al., 2012); CORI (2014) used 25% in their study. For the current model, we have assumed that ballast water discharge will be 30% of the deadweight tonnage of the vessel. The ballast water is assumed to be discharged at the same rate as the ore is loaded. The ore loading rate is assumed to be approximately 4,000 m^3/hour at the existing dock and 16,000 m^3/hour at the proposed dock. The proposed ore dock is assumed to use two loaders of 8,000 m^3/hr capacity. Panamax vessels are assumed to discharge at 4,000 m^3/hr at both docks. Table 3.1 summarizes the ballast water content and discharge rates for the respective vessel classes.

Table 3.1: Ballast Water Content and Discharge Rate

Vessel Class	Deadweight Tonnage (metric tonnes)	Ballast Water Content (m^3)	Discharge Rate (m^3/hour)
Supramax	50,000	15,000	4,000
Panamax	65,000	19,000	4,000
Cape Sized	150,000	45,000	16,000

3.2.2 Ballast Water Properties

Ballast water is assumed to be taken on in the North Atlantic over a distance along the ship track. Therefore, the density, salinity and temperature of the ballast water intake is variable and mixing occurs in the ship. However, for the purpose of modeling, the salinity and temperature is taken to be a constant value of 34 PSU and 6℃ respectively at the time of discharge (CORI 2014). The dispersal of ballast water is considered to be equivalent to a passive tracer.

3.3 Summary of model calibration

The hydrodynamic model was calibrated and validated by comparing the model output with measured data at Alfred Point, Ragged Island and Stephens Island. The parameters considered for the calibration and validation processes are the water levels and the currents at different depths.

The direct measurements of the water levels at Alfred Point, Ragged Island and Stephens Island from 8 August 2014 to 31 August 2014 are compared with the modelled water levels. The root mean square error (RMSE) between measured and modelled water levels for all cases was below 0.25 indicating a reasonable or acceptable margin of error. In general, this RMSE is attributed to the model underestimating peak amplitudes. The coefficient of determination indicates a favourable agreement between the measured and modelled data with all points higher than 90%.

Velocity measurements at Alfred Point and Ragged Island, are difficult to compare with model results at these locations for the purpose of quantitative calibration and validation of the model. This is primarily due to geometric complexity in the location at which the data was collected, uncertainty regarding the precise location and vertical extent of measurements and the poor signal to noise ratio of the measured data. Nevertheless, current speeds are on the same order of magnitude as the measured current speeds, and their direction tends to vary in a reasonable pattern with the tidal signal. Overall there is a relatively poor level of agreement, particularly in terms of current directions, much of the discrepancy may be attributed to the poor choice of measurement location due to the relatively high complexity of flows which can be anticipated in the areas where measurements were obtained.

Modelled current speeds and directions at Stephens Island are in reasonable agreement with the measured data. The overall level of agreement with measurement and calibration of the model is at least consistent with or an improvement on previous modelling efforts.

A detailed summary of model calibration and validation is presented in Appendix B.

4.0 HYDRODYNAMIC SIMULATION OF EXISTING CONDITION

A long-term simulation of the open water season was run including ballast water discharges at the existing ore dock. Results of simulated ballast water concentrations at the end of the shipping season and at 30 days after the end of simulated shipping season are shown in Figure 4.1 and Figure 4.2 respectively. Observations derived from a review of the model results are as follows:

1) The strongest gradient in dilution is within a 1.5 km radius of the existing ore dock where the ballast water concentration dilutes by a factor of up to 1,000.

2) Ballast water discharged at the existing dock is expected to reach Ragged Island where it is diluted by a factor of 500,000 to 1,000,000 times that of the discharge point

3) Following the shipping season diluted ballast water appears to reach the entrance to Milne Inlet and enter Eclipse Sound at very low concentrations, and the overall concentrations of ballast water continue to decrease over time following the end of the shipping season.

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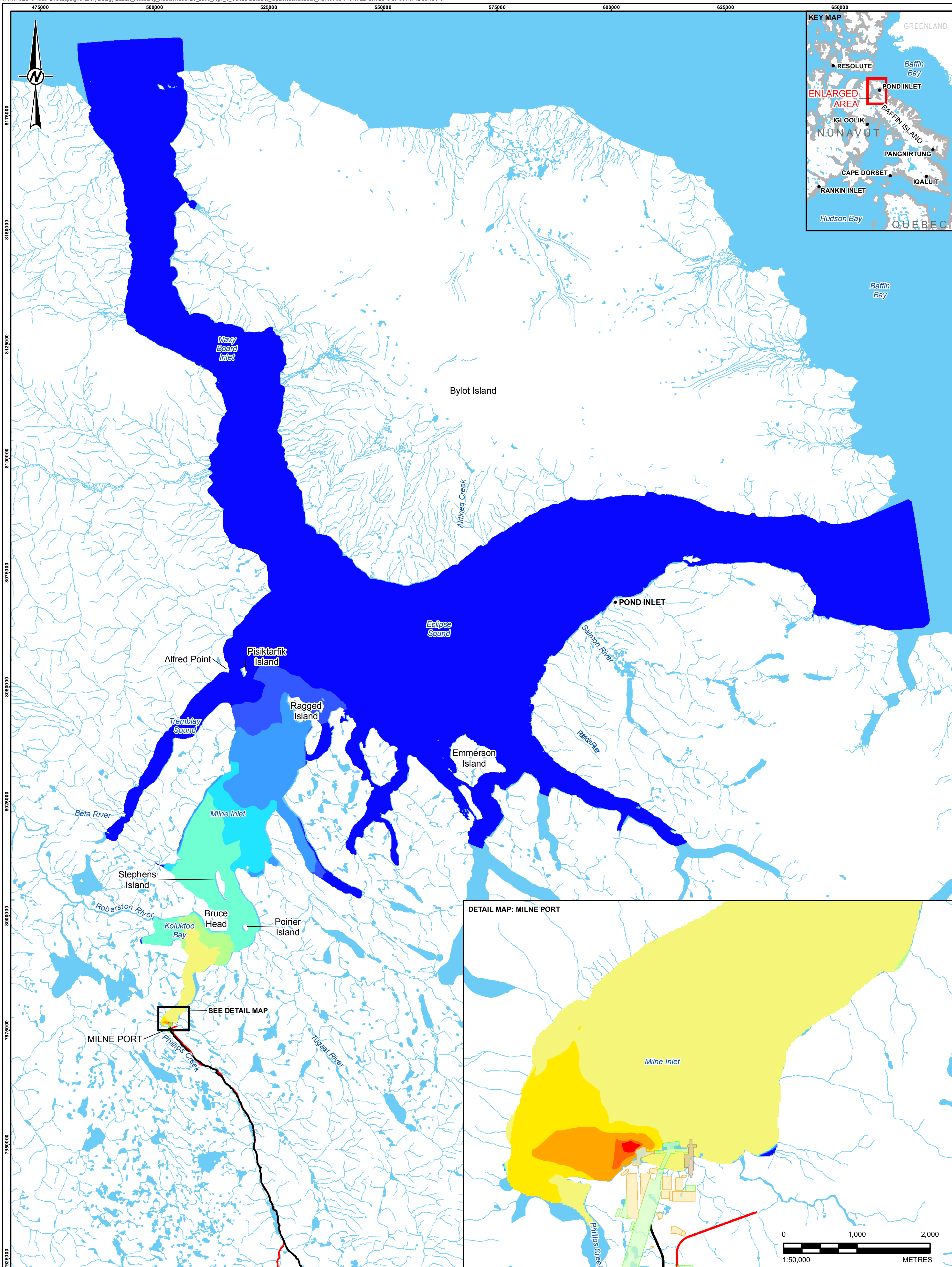

LEGEND

- COMMUNITY
- WATERCOURSE
- EXISTING FREIGHT DOCK AND CAUSEWAY
- EXISTING ORE DOCK
- NEW ORE DOCK AND CAUSEWAYS
- WATERBODY

SUMMER TRACER 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
MAXIMUM SIMULATED BALLAST WATER CONCENTRATIONS DURING OPEN WATER SEASON
SCENARIO: DISCHARGE ONLY AT EXISTING PORT

CONSULTANT

GOLDER

YYYY-MM-DD	2018-07-31
DESIGNED	YT
PREPARED	AA
REVIEWED	WDC
APPROVED	PO

PROJECT NO.	CONTROL	REV.	FIGURE
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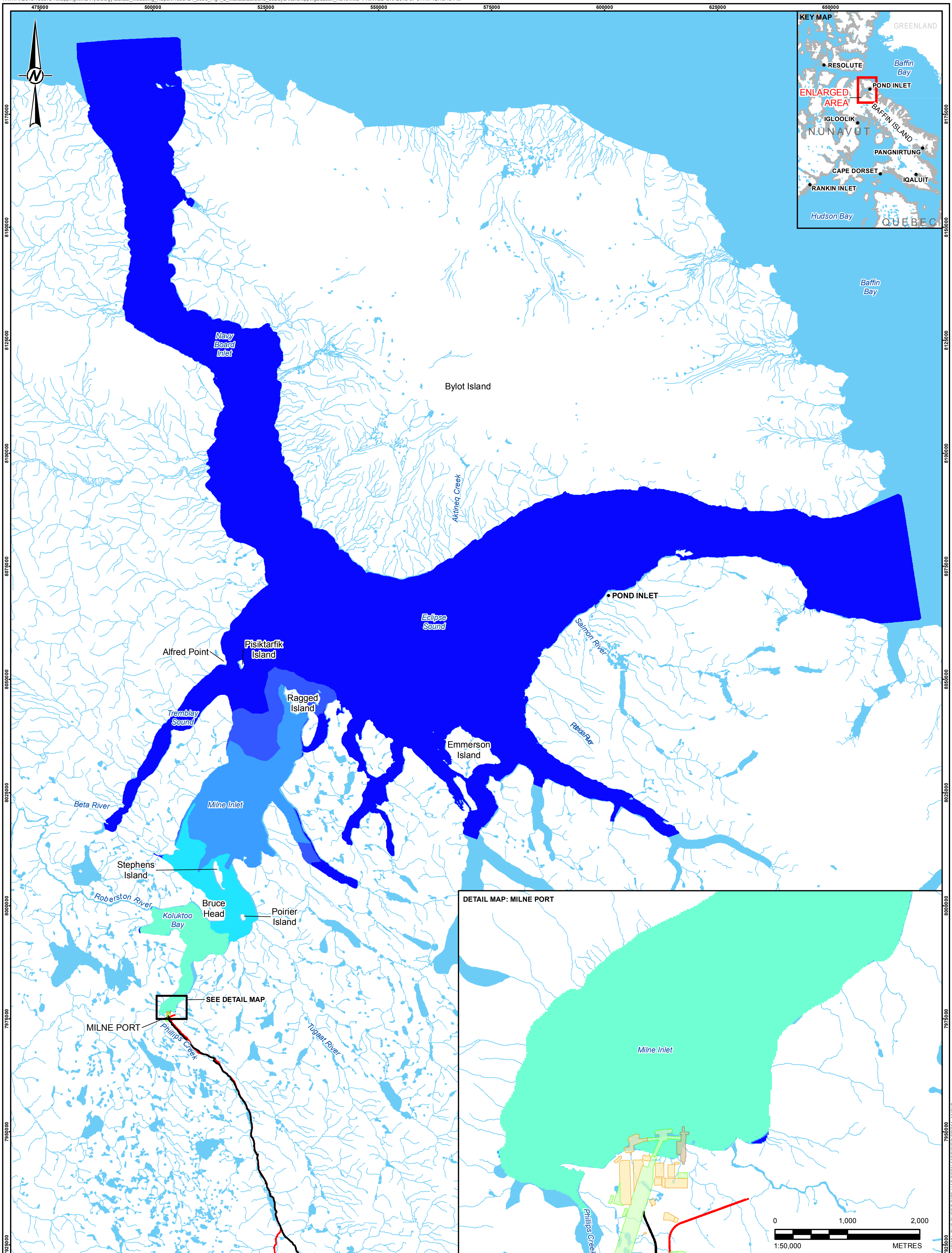

LEGEND

- • COMMUNITY
- WATERCOURSE
- EXISTING FREIGHT DOCK AND CAUSEWAY
- EXISTING ORE DOCK
- NEW ORE DOCK AND CAUSEWAYS
- WATERBODY

SUMMER TRACER 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. 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
MAXIMUM SIMULATED BALLAST WATER CONCENTRATIONS 30 DAYS AFTER SHIPPING SEASON
SCENARIO: DISCHARGE ONLY AT EXISTING PORT

CONSULTANT
GOLDER

YYYY-MM-DD	2018-07-31
DESIGNED	YT
PREPARED	AA
REVIEWED	WDC
APPROVED	PO

PROJECT NO.	CONTROL	REV.	FIGURE
1663724	8000	0	4.2

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25mm

5.0 HYDRODYNAMIC SIMULATION OF PROPOSED PORT CONSTRUCTION

A long-term simulation of the open water season was run including ballast water discharges at both the existing and proposed ore docks – Figure 5.1. The following observations are derived from the results of the long term simulation:

1) The strongest gradient in ballast water dilution is within a 2 km radius of the existing ore dock where the ballast water concentration dilutes by a factor of up to 1,000.
2) Ballast water discharged at the existing and proposed dock is expected to reach Ragged Island where the dilution is between 500,000 to 1,000,000 times that of the discharge point.

The incremental average change in ballast water concentrations associated with the proposed ore dock is estimated to be a 104% increase from existing conditions. A summary of the incremental changes associated with specific dilution zones can be found in Table 5.1.

Table 5.1: Estimated Incremental Change in Ballast Water Concentration Associated with the Proposed Ore Dock

Dilution Zone	Existing Port	Existing and Proposed Port	Relative Change (%)
	Area (km^2)		
1-50	0.03	0.11	297%
50-100	0.07	0.19	189%
100-500	0.66	2.48	278%
500-1,000	1.63	5.07	211%
1,000-5,000	79.88	96.82	21%
5,000-10,000	47.30	47.59	1%
10,000-50,000	324.18	473.60	46%
50,000-100,000	158.09	177.35	12%
100,000-500,000	317.84	395.13	24%
500,000-1,000,000	176.81	309.28	75%
>1,000,0000	6,515.08	6,116.24	-6%

As with the existing condition, it is expected that ballast water dilution will follow a similar pattern of dispersion and dilution following the close of the shipping season with a continued overall dilution and dispersion of ballast water out of Milne Inlet and into Eclipse Sound where the residual concentrations are expected to be insignificant.

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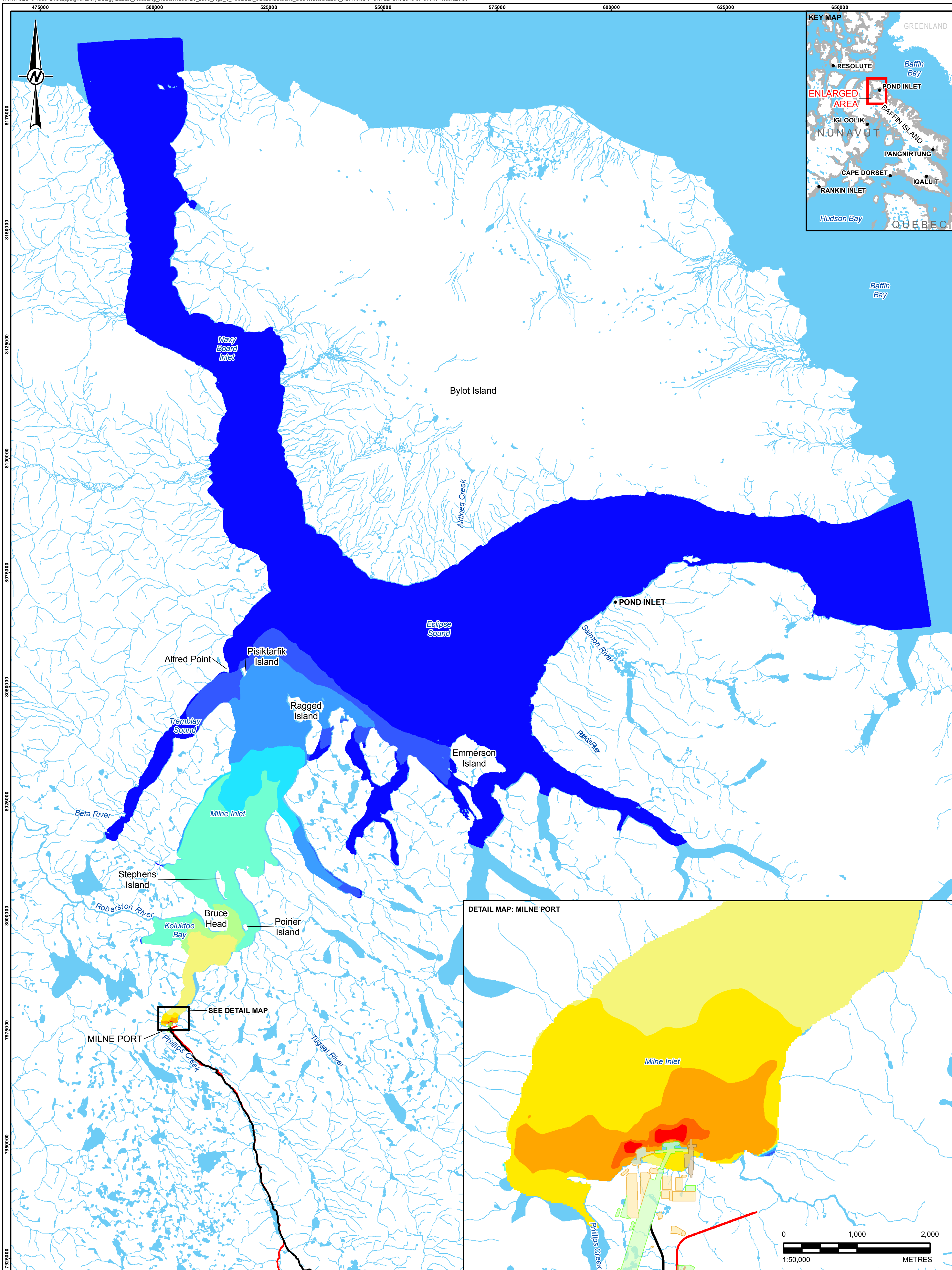

LEGEND

- COMMUNITY
- WATERCOURSE
- EXISTING FREIGHT DOCK AND CAUSEWAY
- EXISTING ORE DOCK
- NEW ORE DOCK AND CAUSEWAYS
- WATERBODY

SUMMER TRACER DILUTION

- 1 - 50
- 50 - 100
- 100 - 500
- 500 - 1,000
- 1,000 - 5,000
- 5,000 - 10,000
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- 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
MAXIMUM SIMULATED BALLAST WATER CONCENTRATIONS DURING OPEN WATER SEASON
SCENARIO: DISCHARGE BOTH AT EXSITING AND PROPOSED PORTS

CONSULTANT		
GOLDER	YYYY-MM-DD	2018-07-31
	DESIGNED	YT
	PREPARED	AA
	REVIEWED	WDC
	APPROVED	PO

PROJECT NO.	CONTROL	REV.	FIGURE
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31 July 2018

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Water Resources Engineer

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Principal, Senior Coastal Geomorphologist

WDC/PO/syd

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David, Matej, et al. "A generic ballast water discharge assessment model as a decision supporting tool in ballast water management." *Decision support systems* 53.1 (2012): 175-185.

Golder 2017c. Baffinland Milne Port Tide Gauge Data Collation – 2017 Ice Free Season. Draft Report in progress.

Knight Piésold Consulting. (2010). *Marine Baseline Synthesis: Physical, Chemical, and Biological Oceanography, Baffinland, Mary River Project, Addendum to Final Environmental Impact Statement, December 2010, Appendix 8-A1: Oceanography, Report submitted to Baffinland Iron Mines.* Toronto, ON.

APPENDIX A

Metocean Data and Physical Characterization

A-1.0 INTRODUCTION

The purpose of this Appendix is to provide a review and summary of data used as a basis for the hydrodynamic modelling conducted as part of the Environmental Impact Statement (EIS) regarding for the Mary River Phase 2 Expansion Project (Phase 2). The hydrodynamic modelling was used to assess the potential project effects on the marine environment due the proposed construction and operation of a second ore dock to accommodate Cape sized vessels at the Port Site.

This appendix includes the following sub-sections:

- A-2.0 Site Conditions – Available data
- A-2.1 Topography and bathymetry
- A-2.1.1 Shoreline
- A-2.2 Water levels
- A-2.2.1 Tides
- A-2.2.2 Storm surge
- A-2.2.3 Sea level rise
- A-2.3 Water Column Properties
- A-2.3.1 CTD Profiles
- A-2.3.2 Salinity and temperature time series
- A-2.4 Wind
- A-2.5 Currents
- A-2.6 Creek hydrology
- A-3.0 References

This Appendix should be read in conjunction with the "*Important Information and Limitations of this Appendix"* as this forms an integral part of this document.

A-2.0 SITE CONDITIONS – AVAILABLE DATA

Milne Inlet is located along the Northwest coast of Baffin Island in the Qikiqtani Region of Nunavut. The inlet is at the southern extent of a network of fjords connecting to Baffin Bay. Milne Inlet runs nearly north-south extending to Eclipse Sound and Navy Board Inlet (Figure 1-1).

Milne Port is being developed at the southern end of Milne Inlet to support the Baffinland's iron ore exports via the Northern Shipping Route (from Milne Inlet to Baffin Bay) during open-water season (July-October). The general physical conditions at the site are controlled by wind and atmospheric systems, tides and tidal currents, waves, and sea ice. Air temperature typically ranges from -35 °C to 4.5 °C from winter to summer respectively. Sea ice covers the inlet from approximately November to mid- or late July the following year. Mean sea ice thickness is estimated as 1.6 m in most years (Knight Piésold, 2010).

The following subsections list the available data and information pertaining to the site.

A-2.1 Topography and Bathymetry

Milne Inlet is part of a complex and deep fjord system with several deep basins and mid-channel islands. The water depth near Milne Port is approximately 30 to 50 m and increases to 100 to 150 m water depth approximately 200 m north of the Port site. The inlet is U-shaped with consistent water depths along the middle of the channel with steeply sloping shorelines. A series of three sills are present along the fjord of Milne Inlet separating the deep basins of the inlet and play a role in the circulation and dynamics. Phillips Creek is located to the west of Milne Port and has created a deltaic feature along the southern fjord-head of Milne Inlet. A deep basin is present in the channel near Koluktoo Bay with water depths reaching 318 m. Robertson River feeds into the west side of Koluktoo Bay. North of Koluktoo Bay are a series of small mid-channel islands and deep basins. The deepest portion of Milne Inlet reaches 841 m water depth. North of Ragged Island Milne Inlet joins Eclipse Sound to the east-northeast and Navy Board Inlet to the north.

The following is a summary of topographic and bathymetric datasets available to support the hydrodynamic model set up and ballast water modelling at the Milne Inlet and Port site (Figure A-2.1):

- Detailed geophysical surveys of the seafloor were undertaken by Terra Remote Sensing in September 2008 in the Milne Port vicinity. Subsequent single-beam surveys were undertaken by Enterprises Normand Juneau Inc. (ENJI) in September of 2010. These data were subsequently merged into a unified XYZ dataset, referenced vertically to Chart Datum and geodetic datum.
- Hydrographic surveys collected by Canadian Hydrographic Service (CHS) were collected in a series of depth soundings from 1964 to 1966. The data sets acquired from CHS include the following file numbers (year of collection):
  - 3380, 3395, 3477 (1964-1965)
  - 28956, 28962, 2301836 (1965-1966)
  - 66215 (1974)
- Hydrographic surveys collected by CHS were collected by multi-beam survey 2008 to 2014. The data sets acquired from CHS include the following file numbers (year of collection):
  - 4012386 (2008)
  - 4013439, 4013646, 4013647, 4013648 (2013-2014)

The data is referenced vertically to Canadian Geodetic Vertical Datum, CGVD28.

Recent CHS and contractor multibeam surveys provide good coverage of the Milne Inlet study area and good coverage for hydrodynamic model requirements. Data coverage becomes sparser in Eclipse sound.

A-2.1.1 Shoreline

Shoreline delineation is evaluated to develop the closed boundaries of the modeling grid. The following sources are used to construct the shoreline implemented in the model:

- GSHHG – A Global Self-consistent, Hierarchical, High-resolution Geography Database (NOAA 2016).
- Satellite imagery (Baffinland 2016, Bing Online Imagery 2003).
- Previous model boundary provided by Coastal and Ocean Resources Inc. (CORI 2014)

A comparison of the shoreline sources with the aerial images showed offsets in the horizontal position near the project site. Although the sources of the CORI shoreline data are unknown, it matches the full resolution GSHHG shoreline data sourced by NOAA. In the previous study (CORI 2014) the shoreline was not improved on the south boundary where the Milne Port is located. A high-resolution shoreline was digitized close to the project site and replaced the GSHHS boundary to improve the geometry of the modelling mesh in this region and better capture the circulation in the intertidal zones of the upper fjord. The shoreline represents the high water level. The latter is considered important for resolution of wave and current processes in the vicinity of the Port.

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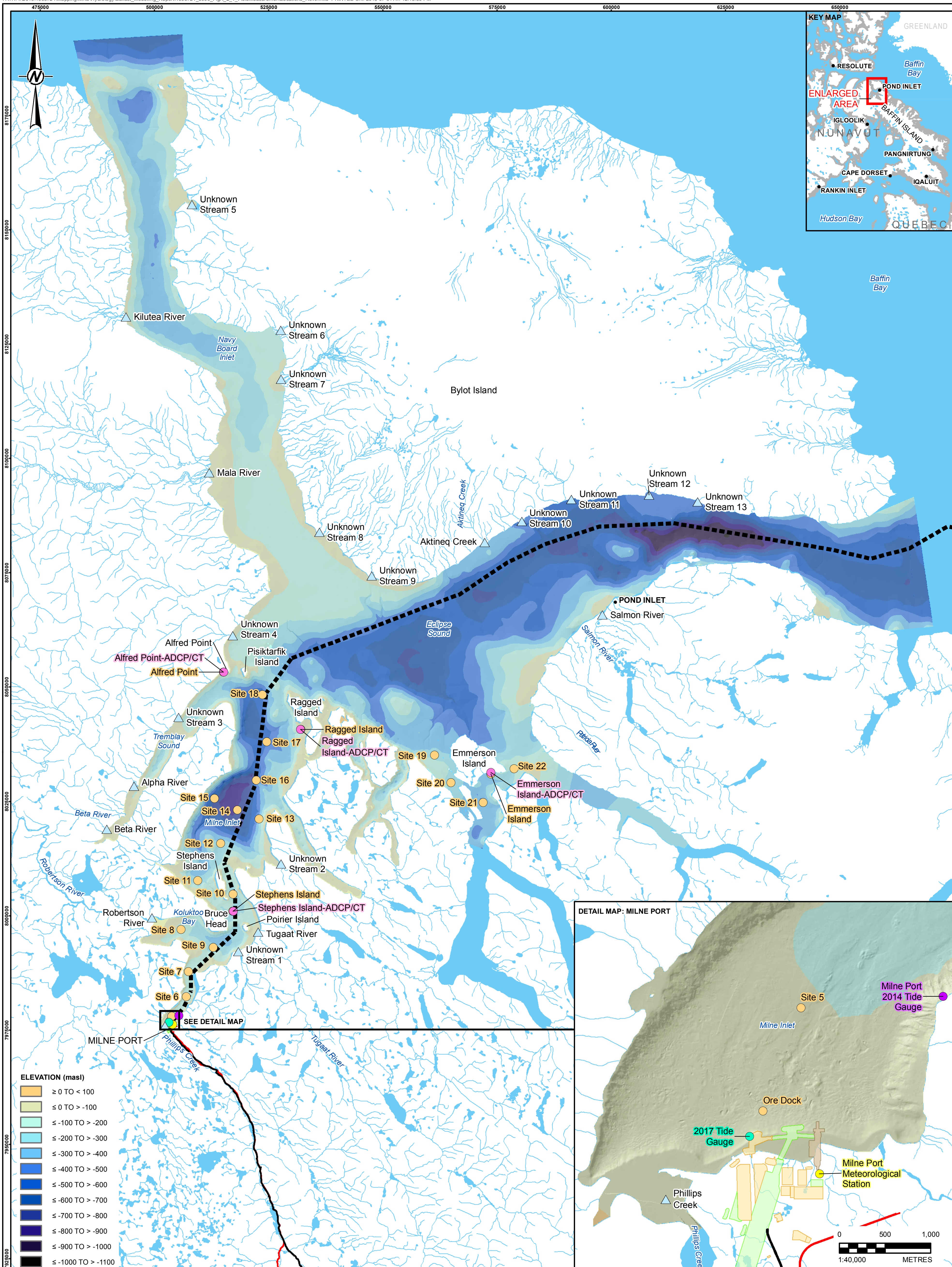

LEGEND

- COMMUNITY
- FRESH WATER SOURCE

OCEANOGRAPHIC SOURCES

- 2014 TIDE GAUGE
- 2017 TIDE GAUGE
- CTD PROFILE
- METEOROLOGICAL STATION - WIND
- MOORING
- MILNE INLET TOTE ROAD
- PROPOSED NORTH RAILWAY
- SHIPPING ROUTE (APPROXIMATE)
- WATERCOURSE
- EXISTING FREIGHT DOCK AND CAUSEWAY
- EXISTING ORE DOCK
- NEW ORE DOCK AND CAUSEWAY
- WATERBODY

0 20 40
1:800,000 KILOMETRES

NOTE(S)

masl = METRES ABOVE SEA LEVEL

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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PROJECT
MARY RIVER PROJECT - PHASE 2 PROPOSAL

TITLE
SUMMARY OF BATHYMETRIC DATA AND FIELD MEASUREMENT LOCATIONS

CONSULTANT

GOLDER

YYYY-MM-DD	2018-07-19
DESIGNED	YT
PREPARED	AA
REVIEWED	WDC
APPROVED	PO

PROJECT NO.	CONTROL	REV.	FIGURE
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A2.2 Water Levels

Temporal and spatial variation in water level is a key forcing condition of hydrodynamics in Milne Inlet. Water levels at coastal sites reflect the combined contribution from:

- Mean sea level
- Astronomical tides
- Meteorological effects ("water level residuals")

The tidal component of water levels is cyclical and largely predictable, being generated primarily by astronomical forcing.

Storm surge typically represents the greatest contribution to the residual water level, which is the difference between the absolute / total water level (as measured by a tide gauge) and the astronomical (tidal) component. The terms "storm surge" and "residual water level" are therefore used interchangeably in this report.

A2.2.1 Tides

Astronomical tides and winds are important mechanisms forcing water level variation and circulation within the study area. Based on a review of potential data sources, direct water level measurements were available for the period between August and October 2014 at four locations within the modeling domain: Alfred Point, Ragged Island, Emmerson Island, and Milne Port. In addition, Golder extracted harmonic constants from the Topex Poseidon (TPXO) 8.0 database. This database is built from track average data obtained with OSU Tidal Software (OTIS) and Laplace Tidal Equations (Egbert & Erofeeva, 2010).

The tides at the project site are semidiurnal. Minimum and maximum tidal ranges at the end of Milne Inlet are approximately 2.2 m to 2.3 m respectively (Knight Piésold 2010, CHS, tide station 5791). Five temporary tide stations were installed by CHS from 1964 -1988 in the region near Milne Inlet. A tide station was installed in Milne Inlet, near Milne Port by ASL Environmental Sciences Ltd (ASL) and Coastal and Ocean Resources Ltd (CORI) in the 2014 ice free season. Table A-2.1 summarizes the calculated tidal amplitudes and phases of the five CHS stations from 1964 -1988 analysed by Rabinovich and Fine (2010).

Table A-2.1: Tidal Range and Phases of Temporary Tide Stations near Milne Inlet

Tidal Harmonic	Milne Inlet		Koluktoo Bay		Pisiktarfik Island		Pond Inlet		Nova Zembla Island	
	H (cm)	G (°)	H (cm)	G (°)	H (cm)	G (°)	H (cm)	G (°)	H (cm)	G (°)
Q_1	1.3	180.9	0.3	251.9	0.8	261.9	0.7	200.0	0.9	134.2
O_1	7.3	207.0	8.1	213.8	7.7	207.4	8.8	211.0	7.9	202.8
K_1	23.3	262.9	25.7	264.2	23.0	249.4	25.8	252.6	20.9	257.5
N_2	12.2	103.0	12.8	105.5	18.1	103.5	11.4	110.6	10.3	114.3
M_2	56.5	137.2	57.8	139.9	51.6	134.3	53.8	136.7	41.5	139.6
S_2	23.5	187.6	19.3	196.6	26.6	178.7	18.6	179.9	18.9	182.5
F (tidal factor)	0.38		0.44		0.39		0.48		0.48	

Note: H= height; G= tidal phases referenced to Greenwich, England. F= tidal factor ($\frac{K_1+O_1}{M_2+S_2}$); Table source: Rabinovich and Fine (2010).

Water level measurements recorded in 2014, 2015, and 2016 by ASL Environmental and CORI show good agreement with the tidal harmonics analysis results in Table A-2.1 (ASL 2014; CORI 2014).

A2.3 Water Column Properties

The Arctic Ocean and Atlantic Ocean are both water mass sources for Baffin Bay and Milne Inlet. The structure of the water temperature and salinity in Milne Inlet changes seasonally and with depth. Observations of the vertical structure during winter with sea ice cover showed nearly uniform values with water temperature near -1.5 °C and salinity at 32 (Knight Piésold, 2010; Buckley et al., 1987). In open water season, the water column structure becomes stratified with less saline warmer water in the surface layer extending to the pycnocline at approximately 5 to 10 m water depth. Below the pycnocline is a thin cold-saline water mass extending approximately to 30 m water depth. The lowest water mass is relatively uniform extending to water depths of >100 m (Fine and Rabinovich, 2013; Knight Piésold, 2010).

Water column data collection was undertaken in the study area in 1980, 1981, 2008, 2010, 2014, 2015, and 2016. The measurements of water column properties include conductivity, temperature and depth profiles (CTD) and stationary measurements at select locations, with results summarized in the below sections.

A2.3.1 CTD Profiles

The water column structure of Milne Inlet varies with depth and from ice-cover season to open water season. During ice-cover season CTD profiles collected near Cape Hatt in June 1980 by Buckley et al (1987), showed the water column was well mixed with water temperature near freezing (-1.5 °C) and salinity values of 32 PSU from near the surface to 35 m water depth. Below 35 m the salinity gradually increased to 32.5 and above. A uniform water column density for under the ice conditions are typical for the region and reflect convective overturning driven by water cooling near the surface layer and brine rejection (Knight Piésold, 2010; Buckley et al, 1987).

In open water season, the water column becomes stratified with three distinct density layers. The surface layer has the highest freshwater input from surface runoff, creek/river discharge, and sea ice melt. The thin surface layer has been observed to be 2 to 5 m thick with a temperature range of 0.5 °C up to 10 °C and a salinity range from 5 to 30 PSU (CORI, 2014; Buckley et al, 1987). The pycnocline typically begins at depths between 5 to 10 m water depth and extends to 30 to 50 m water depth (Buckley et al., 1987; Fissel et al. 1981). The intermediate water layer below the pycnocline is generally from 50 to 100 m water depth and can be characterized by nearly steady temperature and salinity year-round and spatially along Milne Inlet to Eclipse Sound. In the stable intermediate water layer, temperature is around -1.5 °C and salinity is 32.3 PSU (CORI, 2014). Below 100 m water depth the temperature and salinity gradually increase to relatively warmer and saltier water as values approach -0.5 °C and 33.5 PSU respectively at depths below 200 m (CORI, 2014).

Of the three distinct water masses, only the surface layer varies spatially and temporally. Spatially, slight differences were observed along and across Milne Inlet. Surface water temperature was highest Milne Port, with surface water temperature gradually decreasing along Milne Inlet towards Eclipse Sound and Cape Hatt. The upper water mass tended to extend to 3 m water depth close to Milne Port and increase to 5 m water depth moving north. Salinity follows a similar trend along the channel with the upper layer thickness slightly increasing along the channel (CORI 2014). Slight local variations in across channel stratification were observed near Ragged Island to Alfred Point, while across Milne Inlet near Eskimo Inlet temperature and salinity were horizontally layered. The majority of CTD profiles collected in the region were measured in August, while a few additional samples were collected later in the open water season in October. The surface water mass was variable from the August profiles to the October profiles (CORI 2014). In the upper 5 m, salinity varied from 5-10 PSU in August to 29-30 in October. Additionally, salinity decreased from 10 m water depth through to the seabed by 0.5-1 PSU from August to October. Similarly, temperature in the upper 5 m varied from 4-7 °C in August to -0.5 °C in October. At depths below 15 m temperature increased by 1-2 °C for all locations (CORI 2014).

The spatial and temporal trends described for the 2014 data collection effort by CORI (2014) and ASL (2014) were consistent with observations of CTD profiles measured by Buckley et al (1987), Knight Piésold (2010), and CORI (2016). The consistency indicates that seasonal trends and variability, particularly in the surface layer, have been relatively stable for the extent of the studies conducted in the region (1987 to 2016).

Recent available CTD profile data collected at Milne Inlet include 23 profiles collected in August 2014, and 3 profiles collected October 2014 (ASL 2014, CORI 2014). In August 2015, 18 CTD profiles were collected, and 13 additional CTD profiles were collected in August 2016 (ASL 2015; CORI 2016). Table A-2.2 provides a summary of CTD profiles collected from 2014-2016 and profile locations. Plots of CTD profiles measured in 2014 can be found in the CORI 2014 report in section 3.7.

The CTD data coverage provides good spatial distribution of water column properties within Milne Inlet. The majority of profiles were collected in the month of August. Time series data and the profiles collected in October demonstrate that there are temporal variations, primarily in the upper water column structure, and the transition from August to October is not as well documented in CTD profiles.

Table A-2.2: CTD profile locations and sampling events

Station	Latitude (°N)	Longitude (°W)	Approx. Max. Sample Depth (m)	Dates Sampled			
Ore Dock	71.89218	80.90273	47	Aug-14	-	Aug-15	Aug-16
Stephens Island	72.10737	80.49917	145	Aug-14	-	Aug-15	Aug-16
Ragged Island	72.46245	80.048	50	Aug-14	Oct-14	Aug-15	-
Alfred Point	72.57606	80.54727	47	Aug-14	Oct-14	Aug-15	-
Emmerson Island	72.36517	78.8226	57	Aug-14	Oct-14	-	-
Site 5	71.90228	80.89075	92	Aug-14	-	Aug-15	Aug-16
Site 6	71.94029	80.79725	146	Aug-14	-	Aug-15	Aug-16
Site 7	71.98953	80.78345	116	Aug-14	-	Aug-15	Aug-16
Site 8	72.07235	80.82967	137	Aug-14	-	Aug-15	Aug-16
Site 9	72.03675	80.62513	230	Aug-14	-	Aug-15	Aug-16
Site 10	72.14095	80.49721	233	Aug-14	-	Aug-15	Aug-16
Site 11	72.16817	80.72319	283	Aug-14	-	Aug-15	Aug-16
Site 12	72.24073	80.57346	193	Aug-14	-	Aug-15	Aug-16
Site 13	72.28783	80.32516	263	Aug-14	-	Aug-15	Aug-16
Site 14	72.30577	80.46474	236	Aug-14	-	Aug-15	Aug-16
Site 15	72.3285	80.6109	220	Aug-14	-	Aug-15	Aug-16
Site 16	72.36382	80.34004	274	Aug-14	-	Aug-15	-
Site 17	72.43878	80.26983	285	Aug-14	-	Aug-15	-
Site 18	72.53128	80.29395	292	Aug-14	-	Aug-15	-
Site 19	72.40543	79.18366	160	Aug-14	-	-	-
Site 20	72.3508	79.08184	268	Aug-14	-	-	-
Site 21	72.30959	78.87793	289	Aug-14	-	-	-
Site 22	72.37353	78.66968	193	Aug-14	-	-	-

A2.3.2 Salinity and Temperature Time Series

Time series of salinity and temperature were measured at four locations (Stephens Island, Ragged Island, Alfred Point, and Emmerson Island) for two months in 2014, and additional measurements were collected at Stephens Island from August 2015 to August 2016 (ASL 2014; CORI 2014; CORI 2016). The CT sensors on the Ragged Island, Alfred Point, and Emmerson Island moorings were deployed at approximately 40-45 m water depth, while the Stephens Island CT sensor was deployed at approximately 151 m water depth during the 2014 deployment and 81 m water depth during the 2015-2016 deployment. Table A-2.3 summarizes the station, data collection duration, depth, and location. Time series plots for the temperature and salinity can be found in CORI 2014 (page 71 and 76), ASL 2015 (page 16 to 18), and CORI 2016 (page 17 to 19). Time series of temperature and salinity values correspond with CTD profiles collected along Milne Inlet. The time series data provide good representation of temporal variances at the four deployment sites.

Table A-2.3: Summary of Salinity and Temperature Timeseries Data

Station	Deployment Date	Recovery Date	Mean Depth (m)	Latitude (DD.dddd)	Longitude (DD.dddd)	Mean Salinity (PSU)/ Mean Temperature (°C)	Minimum Salinity (PSU)/ Mean Temperature (°C)	Maximum Salinity (PSU)/ Mean Temperature (°C)
Alfred Point	08-Aug-2014	09-Oct-2014	42	72.57605N	78.54648W	31.5 / 0.4	30.0 / -1.6	32.3 / 2.6
Ragged Island	08-Aug-2014	09-Oct-2014	44	72.46223N	80.04913W	31.7 / 0.0	30.5 / -1.5	32.3 / 1.7
Emmerson Island	08-Aug-2014	09-Oct-2014	41	72.36787N	78.82102W	31.6 / 0.4	30.6 / -1.1	32.5 / 1.8
Stephens Island	07-Aug-2014	03-Dec-2014	151	72.10712N	80.49693W	32.8 / -1.1	32.7 / -1.2	32.9 / -1.0
Stephens Island	23-Aug-2015	17-Aug-2016	81	72.10683N	80.49708W	32.3 / -0.9	31.0 / -1.6	32.8 / 1.2

Note: Data summarized above were measured and reported by ASL Environmental, ITR, and CORI (ASL 2014; ASL 2015; CORI 2014).

A2.4 Wind

Wind induced circulation is one contributing factor to the hydrodynamics and circulation patterns of Milne Inlet. The near surface water layers are typically stratified during the open water season, so wind plays an important role in mixing near surface layers, and supressing or promoting upwelling and downwelling patterns and estuarine circulation in the fjord.

There are two sources of wind data near the project site; a meteorological station near Milne Port and North American Regional Reanalysis (NARR) data. The meteorological station is located at Milne Port at 71.886°N and 80.885°W. Data are available for the station from 2006 to 2015. CORI (2014) conducted an analysis comparing NARR wind data with the measured wind data at the Milne Port station and found there was good agreement between the two data sets from July 1 to October 31, 2014 to use the NARR spatial data for modelling (CORI, section 3.5, 2014).

The North American Regional Reanalysis (NARR) is a regional reanalysis of North America containing temperatures, winds, moisture, soil data, and dozens of other parameters. Produced by the National Centers for Environmental Prediction (NCEP), the NARR model takes in, or assimilates, a great amount of observational data to produce a long-term picture of weather over North America.

The NARR products are on the Eta 221 32 km grid at 29 pressure levels in the Lambert conformal conic projection. The 3-hourly u- and v-wind data at 10 m were downloaded for January 2014 to January 2017, extracted and gridded to a regular geographical grid with a horizontal resolution of 0.25° latitude and longitude. The extracted data were concatenated into a single wind time series. The closest grid cell centered at: 72.0371° N and 81.111° W approximately 17 km from Milne Port. (https://www.esrl.noaa.gov/psd/data/narr/format.html)

Figure A-2.2 shows the time series of monthly average wind data of the NARR grid and Milne Port Station. Historical NARR data were analyzed in the current study (i.e. from 1979 to 2006) along with available meteorological data measured at the Milne Port meteorological station. Measured wind data shows a higher wind speed compared to NARR grid points. Table A-2.4 provides a summary of the statistics of wind speeds at select NARR grid points and the Milne Port Station. Both measured and modelled wind speed time series are in good agreement. However, wind speeds at the NARR grid point closest to the project site are lower in magnitude compared with the measured data at the Milne Port Station.

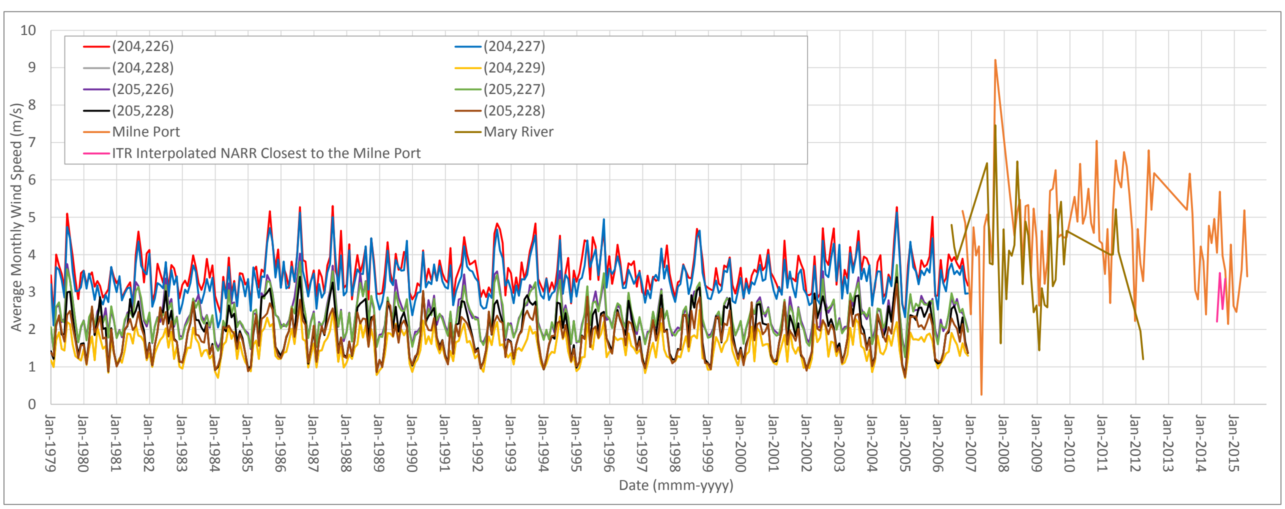

Figure A-2.2: Monthly mean wind speed time series for ten grid points of NARR network

Table A-2.4: Wind Speed Statistics

Station ID	Monthly Mean Wind Speed (m/s)	Monthly Max wind Speed (m/s)	Monthly Min Wind Speed (m/s)
NARR (204,226) 1979 - 2006	3.5	5.3	2.3
NARR (204,227) 1979 - 2006	3.4	5.1	2.1
NARR (204,228) 1979 - 2006	1.5	2.6	0.7
NARR (204,229) 1979 - 2006	1.5	2.6	0.7
NARR (205,226) 1979 - 2006	2.4	4	1.4
NARR (205,227) 1979 - 2006	2.4	3.8	1.3
NARR (205,228) 1979 - 2006	2	3.4	0.8
NARR (205,229) 1979 - 2006	1.8	3.2	0.7
NARR ITR 2014	2.9	3.5	2.2
Measured Milne Port 2006 - 2015	4.5	9.2	0.3
Measured Mary River 2006 - 2012	3.9	7.5	1.2

The wind speeds measured at Milne Port Station, an approximately 9-year data set, were used in an extreme value analysis to determine return intervals for select wind events. Figure A-2.3 shows the wind speed and direction distributions for wind measured during the ice-free season (July to October) and in all seasons. The dominant wind direction during the ice-free season is from the Northeast. While wind directions for all records throughout the year show dominant winds from the Northeast and Southeast. Average wind speed during the ice-free season from the Northeast is 6.7 m/s.

Table A-2.5 provides a summary of return intervals for wind events from the Northeast based on the Milne Port Station data.

The dominant wind direction from the Northeast aligns with the largest fetch direction for Milne Port. Wind speed and direction near the surface of Milne Inlet are expected to be topographically controlled to a significant degree.

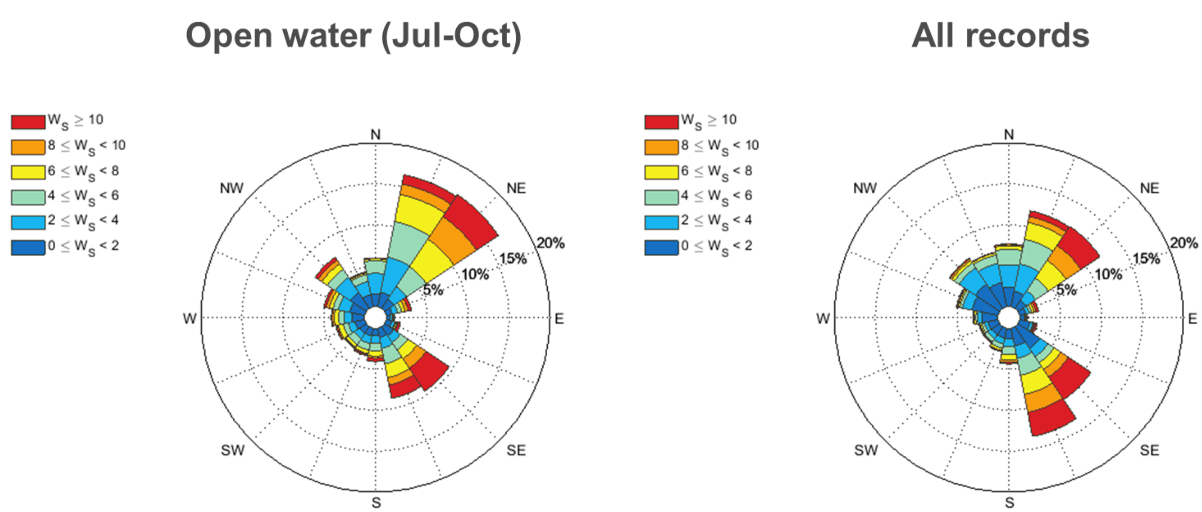

Figure A-2.3: Wind rose of the open water season (left) and all records (right) measured at Milne Port Station from 2006 to 2015.

Table A-2.5: Milne Port Return Intervals for Wind Events from the Northeast (30 to 60 degrees) During the Ice-Free Season (July to October)

Return Interval (years)	Wind Speed (m/s)	95% Confidence Interval (m/s)
1	17.1	16.0 to 18.1
2	18.5	16.9 to 20.1
5	20.2	17.7 to 22.3
10	21.0	18.2 to 23.7
25	22.1	18.8 to 25.5
50	22.9	19.2 to 26.7
100	23.7	19.6 to 27.8

A2.5 Currents

Current circulation in the region is determined by the northward flowing West Greenland Current moving along the Greenland coast and the southward flowing Baffin Current moving along western Baffin Bay (Fissel et al., 1982; Tang et al., 2004). Within Milne Inlet the mean measured current speeds are generally 5 cm/s or lower and maximum speeds reaching 20 to 30 cm/s (CORI 2014; ASL 2014; ASL 2015; Fine and Rabinovich 2013; Rabinovich and Fine 2010; Buckley et al., 1987). Circulation within the inlet is driven by three primary processes; tidal circulation, wind induced circulation, and estuarine circulation. Tidal circulation is considered to be the primary driver of currents in the inlet, with wind induced currents as the secondary driver (CORI 2014). Due to the low current speeds in the inlet, current circulation in general is low, however, counter clockwise rotation was observed by Buckley et al (1987) along Ragged Channel near Cape Hatt, and similar surface counter clockwise rotation was observed in hydrodynamic models and acoustic Doppler current profiler (ADCP) data collected at site in 2014 and 2015 (ASL 2014; ASL 2015; CORI 2014).

The counter clockwise rotation was associated with tidally driven currents and mean barotropic circulation from long term wind induced currents. Tidally driven current circulation is primarily from the M2 semidiurnal frequency and K1 diurnal frequency (Buckley et al 1987; CORI 2014). A spectral analysis of the measured currents at the project site showed near surface counter clockwise rotation associated with the M2 tidal constituent (CORI 2014). Although the winds at Milne Inlet do not have a dominant direction, the mean wind induced currents also showed mean counter clockwise circulation with flows moving into the inlet (south) along the western side (including the Alfred Point mooring location) and flows moving out of the inlet (north) along the eastern side (including the Ragged Island mooring location) (CORI 2014). The vertical structure measured along the inlet showed surface currents were generally the strongest, with current speeds weakening with depth (CORI 2014; ASL 2014; ASL 2015; Knight Piésold 2010).

Current data available at the project site includes:

- Two bottom-mounted ADCP measurements collected in September 2010 at the Milne Port facility, and select vessel based ADCP transects in August 2010 collected by Knight Piésold.
- Current profiles collected from ADCP tautline moorings from August 2014 to October 2014 at three sites near Ragged Island, Alfred Point, and Stephens Island.
- Current profiles collected from ADCP tautline moorings from August 2014 to March 2015 near Stephens Island.
- Current profiles collected from ADCP tautline moorings from August 2015 to August 2016 near Stephens Island.

Additional current data and drogue drifter data were measured near Cape Hatt in 1980 and 19881 by Buckley et al (1987); however, that data was not used for this scope of work as it was not within our model domain.

A2.6 Creek Hydrology

The two primary sources of fresh water discharge into the Milne Inlet system are Phillips Creek and Robertson River. Phillips Creek is adjacent to Milne Port on the west side of the project site and has an estimated drainage basin of 1,000 km^2 (Knight Piésold 2010; CORI 2014). Robertson River flows into Koluktoo Bay and has an estimated drainage area of 4,000 km^2 (Knight Piésold 2010; CORI 2014). ITR and CORI used estimated monthly average discharges based on gauged stream river flow measurements collected at Phillips Creek to generate daily discharge estimates for both Phillips Creek and Robertson River. The flow measurements collected at Phillips Creek are from a point upstream from the mouth where the drainage basin area is approximately 250 km^2. Estimates for discharge at Phillips Creek at the entrance to Milne Inlet are multiplied by 4 to linearly increase the flow for a 1000 km^2 drainage area. The average monthly river flows at Phillips Creek used are 41.9 litres/second/square kilometers (l/s/km2) in July, 21.1 l/s/km2 in August, and 9.2 l/s/km^2 in September (Knight Piésold 2010; CORI 2014). The flow measurements collected in 15 minute intervals at the Phillips Creek station from 2011-2015 were obtained through Knight Piésold Consulting. Monthly averages and the raw data provide adequate information regarding freshwater inputs that can be scaled to apply to Phillips Creek and Robertson River.

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IMPORTANT INFORMATION AND LIMITATIONS OF THIS APPENDIX

This appendix was prepared for the exclusive use of Baffinland Iron Mines Corporation, its assignees and representatives, and is intended to serve as a summary of available data on Milne Inlet oceanography and previous ballast water modelling efforts. This appendix is limited to a summary of existing data and oceanography conditions related to the Project. This appendix is not intended to identify or evaluate potential project related effects.

The conditions of the study area are based on information obtained from a literature review, publicly available data sources, and field investigations conducted by previous consultants on behalf of Baffinland.

The findings documented in this appendix have been prepared for specific application to this Project. Golder makes no other warranty, expressed or implied.

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APPENDIX B

Numerical Model Set-Up and Calibration

B-1.0 INTRODUCTION

This appendix describes the numerical hydrodynamic model, its domain and set-up employed in this study. The details regarding the computational mesh, bathymetry, boundary conditions, forcing inputs, and model controls applied to the model are described in the following sections.

B-2.0 HYDRODYNAMIC MODEL DESCRIPTION

The hydrodynamic model was developed in the MIKE3 platform by DHI Water and Environment Inc. MIKE3 is a commercial computational fluid dynamics modelling program which simulates three-dimensional free surface flows and it is widely used to simulate coastal and estuarine hydrodynamics as well as other applications in physical oceanography. This section describes the process of developing the model, including the data used, the assumptions and the calibration and validation process.

B-2.1 Computational Mesh and Bathymetry

The computational domain of the hydrodynamic model covers the entirety of Milne Inlet and has a varying resolution (coarser near the open boundaries and finer near Milne Port). The domain has two open boundaries at Eclipse Sound leading into Pond Inlet and Eclipse Sound leading into Navy Board Inlet. The open boundaries are located at the Northeast and Northwest part of the computational domain, denoted by red lines in Figure B- 2.1.

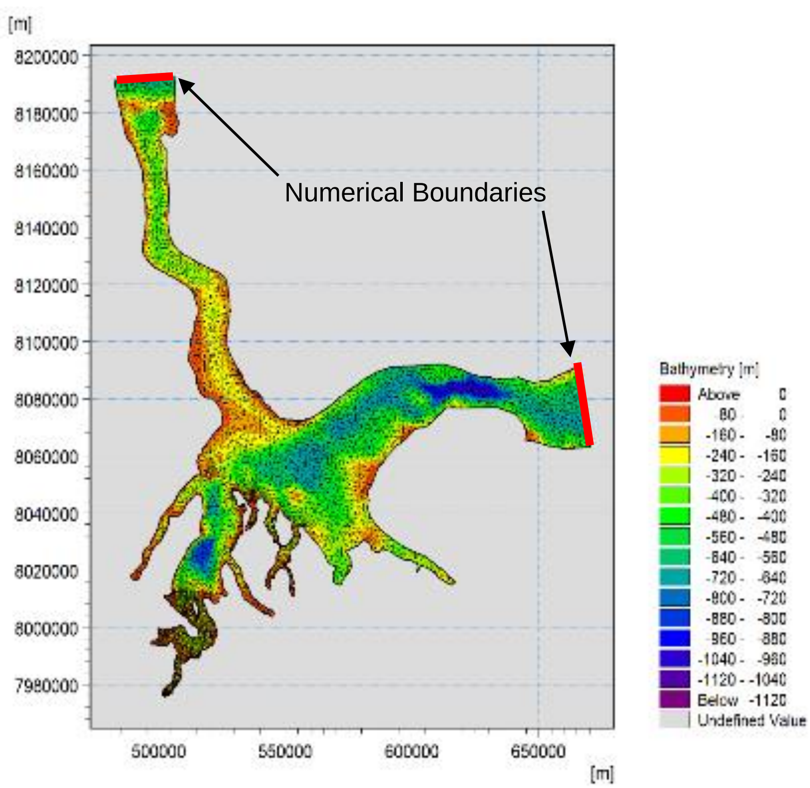

Figure B-2.1: Computational domain of the hydrodynamic model. Open boundaries are denoted by the red lines.

The model land boundaries and bathymetry is compiled from various sources, described in APPENDIX A, and taken at mean high water level. The bathymetry of the area is complex and highly variable with shallow (<20 m) and deep areas (>400 m) adjacent to each other. The sources and the description of the bathymetry data can be found in APPENDIX A.

The computational domain consists of a flexible mesh with triangular elements. The mesh is developed using the mesh generator tool in the MIKE suite of software. The flexible mesh option allows the computation to be done more efficiently as the geometry of the domain can be captured more accurately and the resolution can be adjusted by the user to refine where needed. The resolution of the mesh ranges from 2km (edge length of the element) around Eclipse Sound to about 10m around the port site. Local refinements are also done to capture the complex geometry of the domain closer to the Milne Port area. In the vertical direction, the mesh is made of a sigma-Z hybrid coordinate. The sigma layers are topography conforming and the Z layers are absolute depth values. The top 3m of the vertical mesh is made of 7 sigma layers to cover the tidal range and the sharp pycnocline near the surface. Below the sigma layers, there are 35 Z layers of fixed but varying thicknesses. The use of the hybrid sigma-Z vertical mesh enables the model to capture the hydrodynamics and density (salinity and temperature) parameters in the complex bathymetry.

B-2.2 Boundary and Environmental Forcing

The primary hydrodynamic driving force of the model is the tidal water level variation. In the current model, the tides are prescribed as a time series of water level variations at the Northeast and Northwest boundaries. The tidal harmonic constituents are obtained from the MIKE DTU10 global tidal model, which is based on the observations from the TOPEX/Poseidon and Jason satellites with ¼ degree resolution. A total of 10 constituents, as listed in Table 1, were used. The constituents are then developed into a water level time series using the MIKE21 toolbox tidal elevation prediction tool.

The salinity and temperature forcing was prescribed to the boundary and initial conditions of the model. The seasonal variation of salinity and temperature is approximated by taking the average of the data available at Alfred Point, Ragged Island and Stephens Island for each month. The model is initialized using the average profile in August and the boundary is regulated by the seasonal variation.

Wind effects were included as forcing in the regional model with a time series over the simulation period taken from the NOAA (National Oceanic Atmospheric Administration) global atmospheric model (APPENDIX A section 2.4), which provides spatially varying wind forcing for the simulation period at a 0.25 x 0.25 degree. The CFSR (Climate Forecast System Reanalysis) wind is not corrected for local topographic effects.

Freshwater discharge into upper Milne Inlet, Eclipse Sound, and Navy Board Inlet was estimated for 22 primary sources. There is very limited information regarding surface water discharges from catchments in the region of the model domain. Stream gauge measurements for Phillips Creek are available at a location further inland from 2011 to 2015. Discharge estimates at Phillips Creek were scaled by a factor of four to account for the full drainage basin at Phillips Creek assuming a linear increase in flow. Discharge estimates for the remaining 21 freshwater discharge points were estimated assuming the same linear increase in flow to watershed area. Robertson River inputs were scaled from Phillips Creek to represent the larger drainage basin. Estimates of the discharge of glacial meltwater from glaciers on Bylot Island were also included as inputs of freshwater to Eclipse Sound to provide additional freshwater contribution to ocean stratification.

B-2.3 Model Verification

The hydrodynamic model is calibrated and validated by comparison of the model output with the measured oceanographic data at Alfred Point, Ragged Island and Stephens Island. The parameters considered for the calibration and validation processes are the water levels and the currents at different depths.

B-2.3.1 Water levels

The direct measurements of the water levels at Alfred Point, Ragged Island and Stephens Island from 15 August 2014 to 14 September 2014 are compared with the modelled water levels. Figure B-2.2, Figure B-2.3 and Figure B-2.4 show comparisons of the measured and modelled water level time series. A good agreement in both amplitude and phases between the measured and modelled time series can be seen. The statistical parameters considered for quantifying the agreement are the root mean square error (RMSE) and the coefficient of determination (R-squared). The RMSE measures the scatter of residuals and the closer to zero the better the results. The coefficient of determination presents the strength of association between the measured and modelled dataset with a value of 1 representing a perfect association. As shown in Table B-2.1, the RMSE value for all cases are below 0.25, which is a reasonable margin of error. The measured and modelled water levels are generally in good agreement but the model underestimates the amplitude at certain times. The coefficient of determination values also suggests a favourable agreement between the measured and modelled data with all points higher than 0.90. This quantifies the phase agreement visually observed in the figures.

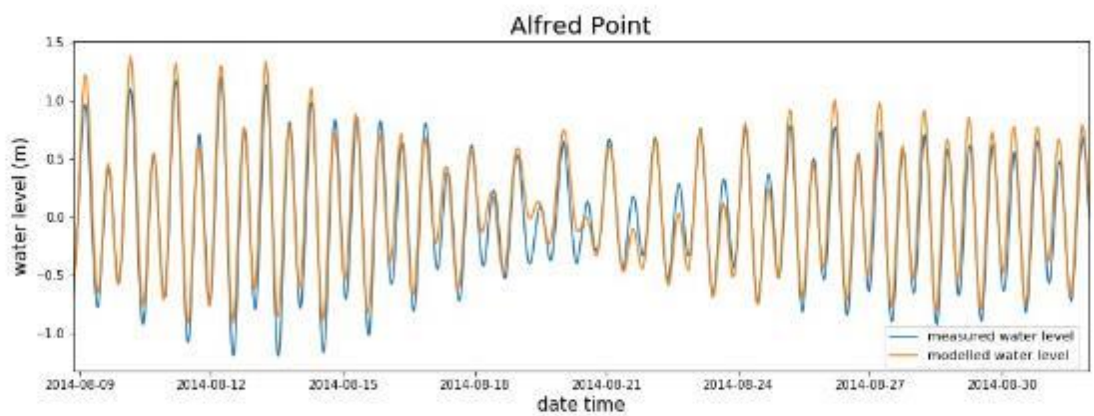

Figure B-2.2: Modelled and measured water levels at Alfred Point during the period 8 August 2014 to 31 August 2014.

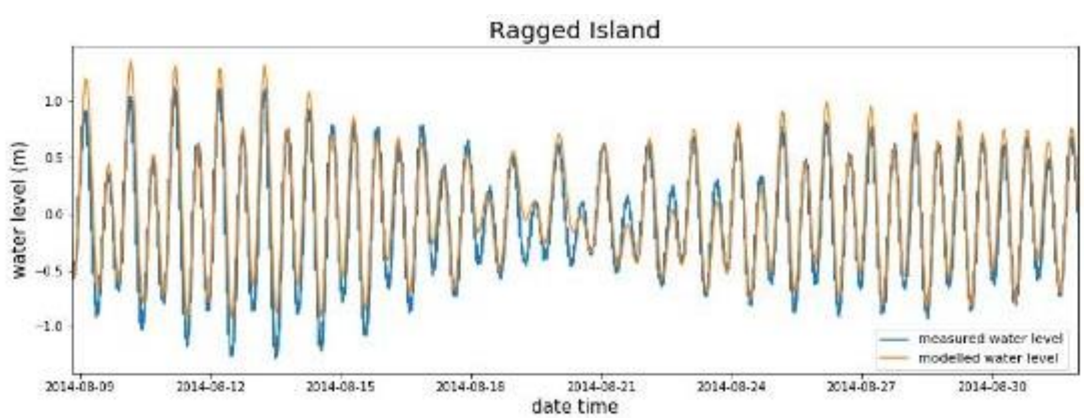

Figure B-2.3: Modelled and measured water levels at Ragged Island during the period 8 August 2014 to 31 August 2014.

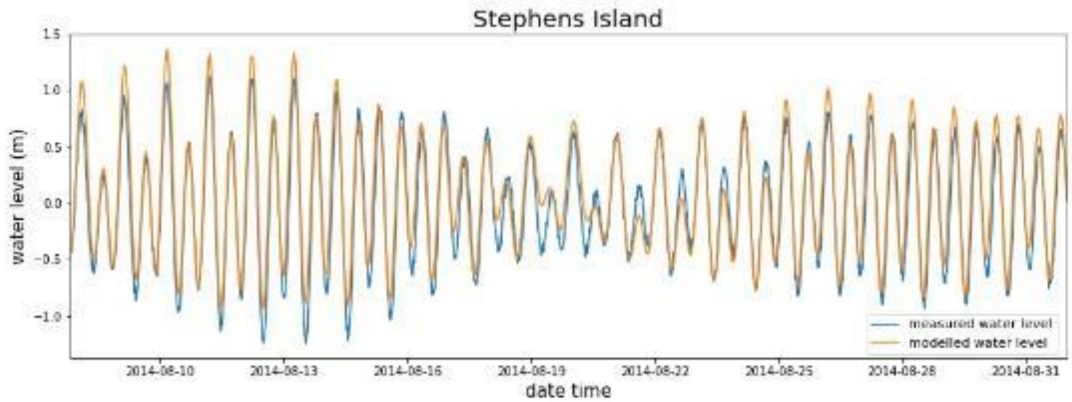

Figure B-2.4: Modelled and measured water levels at Stephens Island during the period 8 August 2014 to 31 August 2014.

Table B-2.1: Root Mean Square Error and Correlation Between Model Results and Measured Water Levels

Location	Root Mean Square Error	Coefficient of Determination
Alfred Point	0.16	0.96
Ragged Island	0.23	0.91
Stephens Island	0.18	0.95

B-2.3.2 Surface and Mid-Depth Currents

Figure B-2.5 and Figure B-2.6 show the surface and mid-depth current speed and direction during a flood and ebb tide. During the flood cycle the water moves from Eclipse Sound into Milne Inlet and during an ebb cycle the water moves from Milne Inlet outwards towards Eclipse Sound. The current patterns display a general flushing with more complex patterns (i.e. gyres) overlaid. The circulation patterns are generally in agreement with the conceptual model of fjord type inlets, and the boundaries show no signs of instabilities.

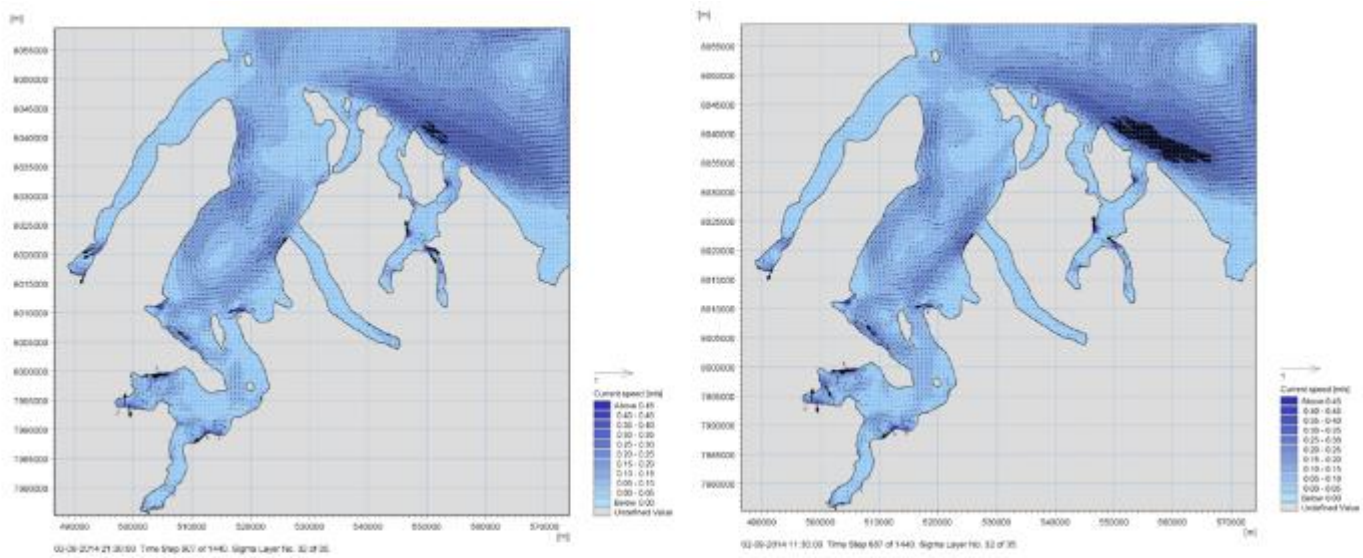

Figure B-2.5: Background surface currents during a flood (Left) and Ebb (Right) tide.

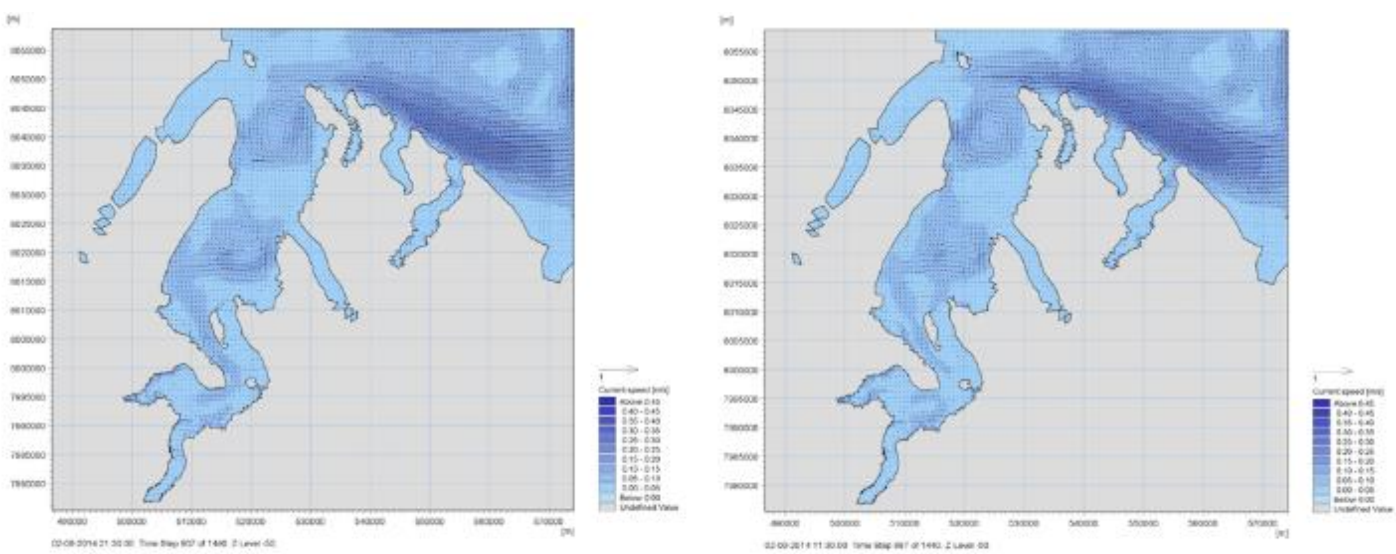

Figure B-2.6: Background mid-depth currents during a flood (Left) and Ebb (Right) tide.

B-2.3.3 Currents, Salinity and Temperature at Alfred Point

Figure B-2.7 through Figure B 2-12 show the comparison of measured and modelled currents, salinity and temperature at Alfred Point for the calibration period (August 15 – September 14, 2014). Figure B-2.7 and Figure B-2.8 are colour isopleth time series of current speed and direction profiles. Figure B-2.9 and Figure B 2-10 are colour isopleth time series of salinity and temperature predicted by the MIKE3 model. Figure B 2-11 and Figure B 2-12 show comparison of measured and modelled currents as compass rose plots at two different depths in the water column. Table B-2.2 is a summary of root mean square error and correlation between model results and measured current speeds at different bins at Alfred Point.

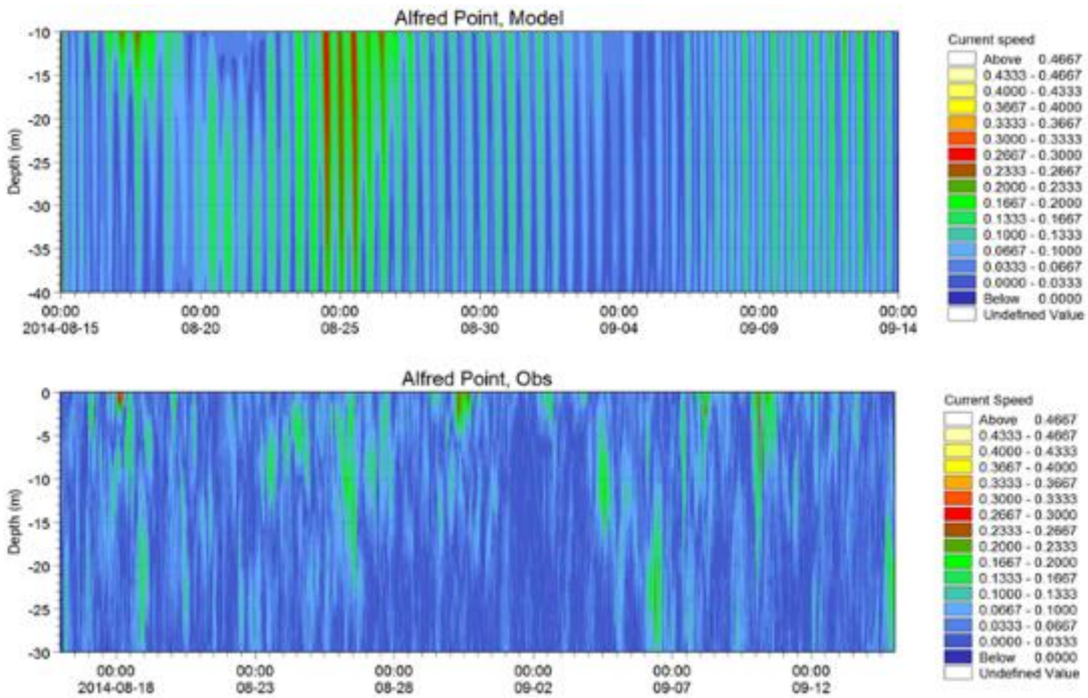

Figure B-2.7: Modelled (Top) and observed (Bottom) current speeds at Alfred Point in the upper water column during the period 15 August 2014 to 14 September 2014.

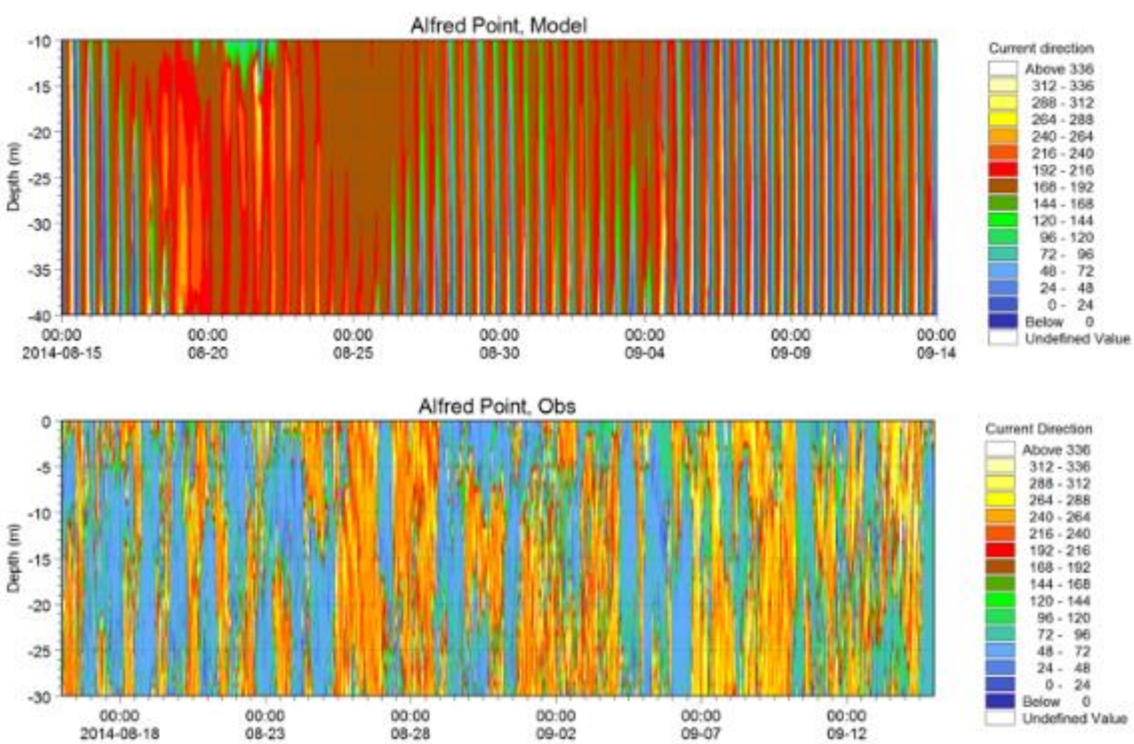

Figure B-2.8: Modelled (Top) and observed (Bottom) current directions at Alfred Point in the upper water column during the period 15 August 2014 to 14 September 2014.

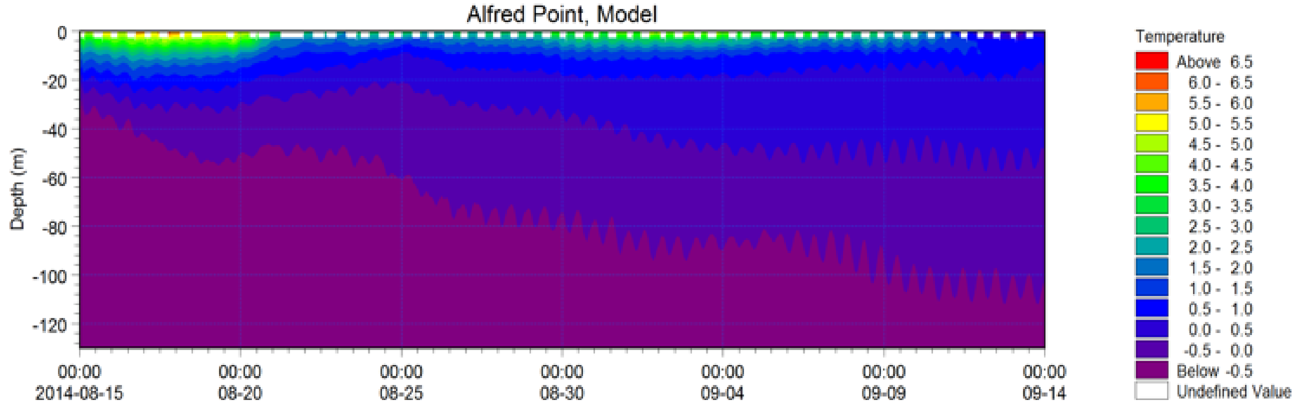

Figure B-2.9: Modelled evolution of the through water column temperature at Alfred Point during the period 15 August 2014 to 14 September 2014.

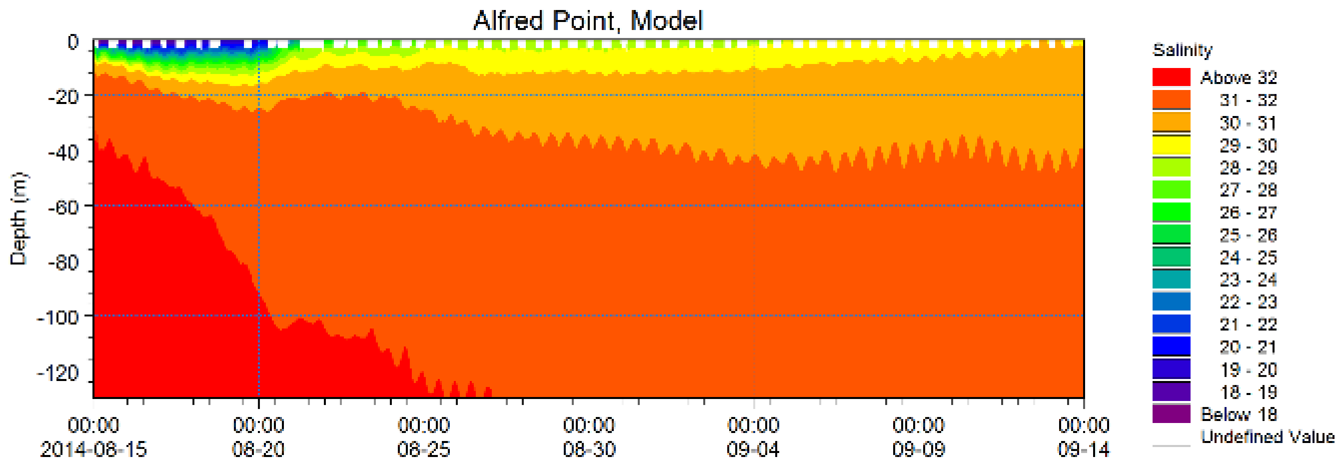

Figure B-2.10: Modelled evolution of the through water column salinity at Alfred Point.

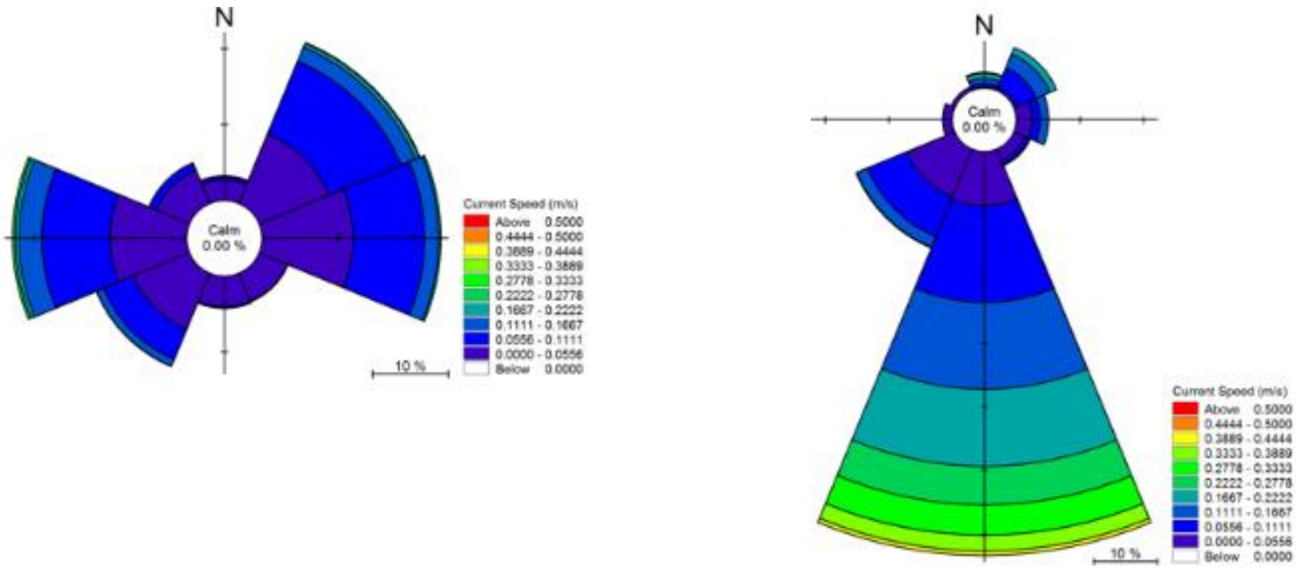

Figure B-2.11: Modelled (Right) and observed (Left) currents at a depth of 11 m below mean sea level (MSL) for Alfred Point

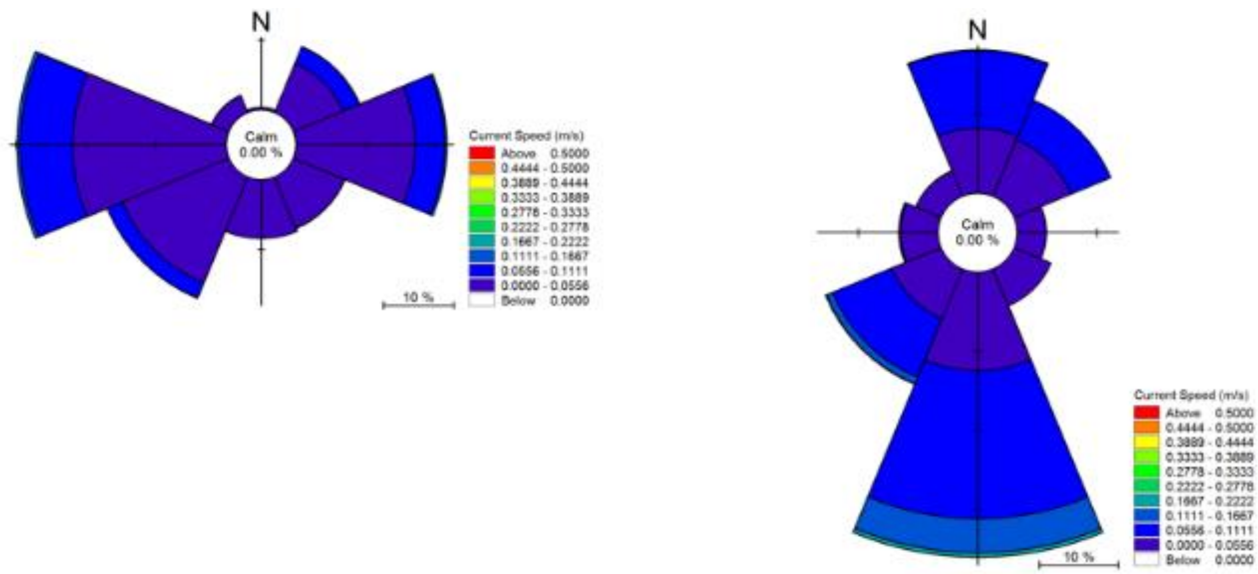

Figure B-2.12: Modelled (Right) and observed (Left) currents at a depth of 41 m below mean sea level (MSL) for Alfred Point.

Table B-2.2: Root Mean Square Error and Correlation Between Model Results and Measured Current Speeds at Different Bins at Alfred Point

Depth	Measured			Modelled		
	Max	Min	Mean	Max	Min	Mean
-11.5m	0.357	0	0.0628	0.0768	0.005	0.0486
-21.5m	0.236	0.001	0.0536	0.0649	0.0045	0.0407
-41.5m	0.178	0	0.0355	0.0428	0.0074	0.023

The following is a brief summary of the comparison of modelled and measured currents at Alfred Point:

- Modelled current speeds are on the same order of magnitude as measured current speeds.
- Modelled and measured currents speeds and directions vary with the tidal signal and exhibit significant changes under wind forcing.
- Modelled current direction and measured direction are out of phase and off in direction, this is likely a result of the complicated flows at Alfred Point.

B-2.3.4 Currents, Salinity and Temperature at Ragged Island

Figure B-2.13 and Figure B-2.18show the comparison of measured and modelled currents, salinity and temperature at Ragged Island for the calibration period (8-31 August 2014). Figure B-2.13 and Figure B-2.14 are colour isopleth time series of current speed and direction profiles. Figure B-2.15 and Figure B-2.16 are colour isopleth time series of salinity and temperature predicted by the MIKE3 model. Figure B-2.17 and Figure B-2.18 show comparison of measured and modelled currents as compass rose plots at two different heights in the water column. Table B-2.3 is a summary of root mean square error and correlation between model results and measured current speeds at different bins at Alfred Point.

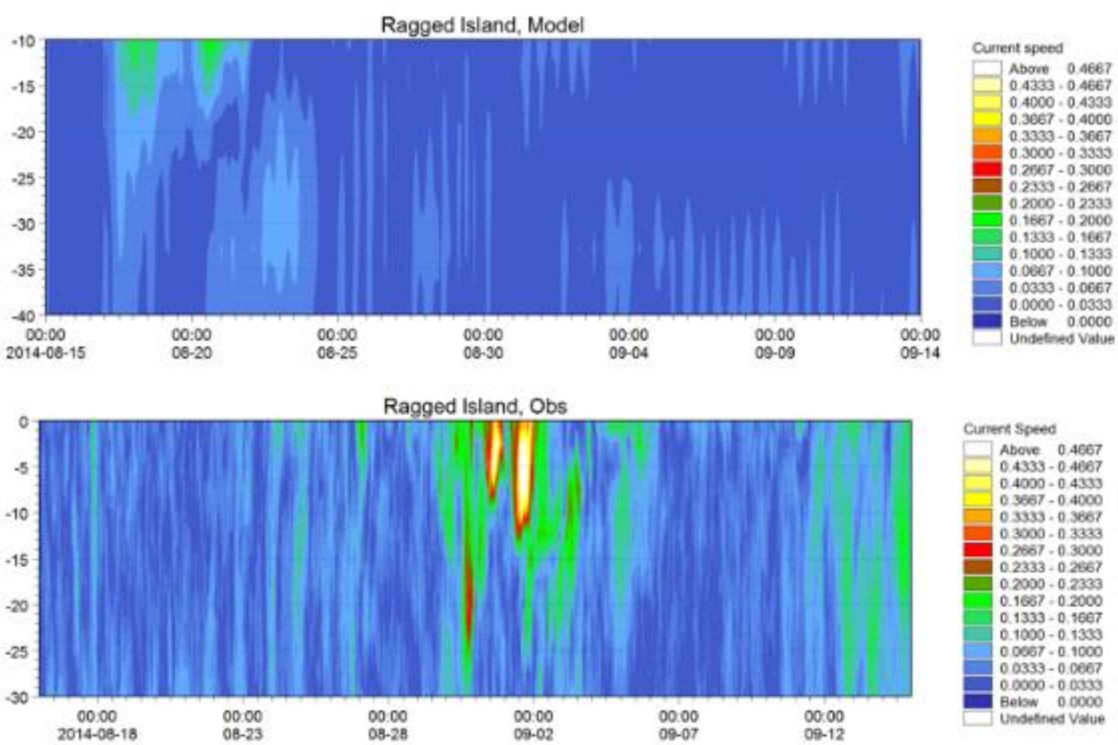

Figure B-2.13: Modelled (Top) and observed (Bottom) current speeds at Ragged Island in the upper water column during the period 15 August 2014 to 14 September 2014.

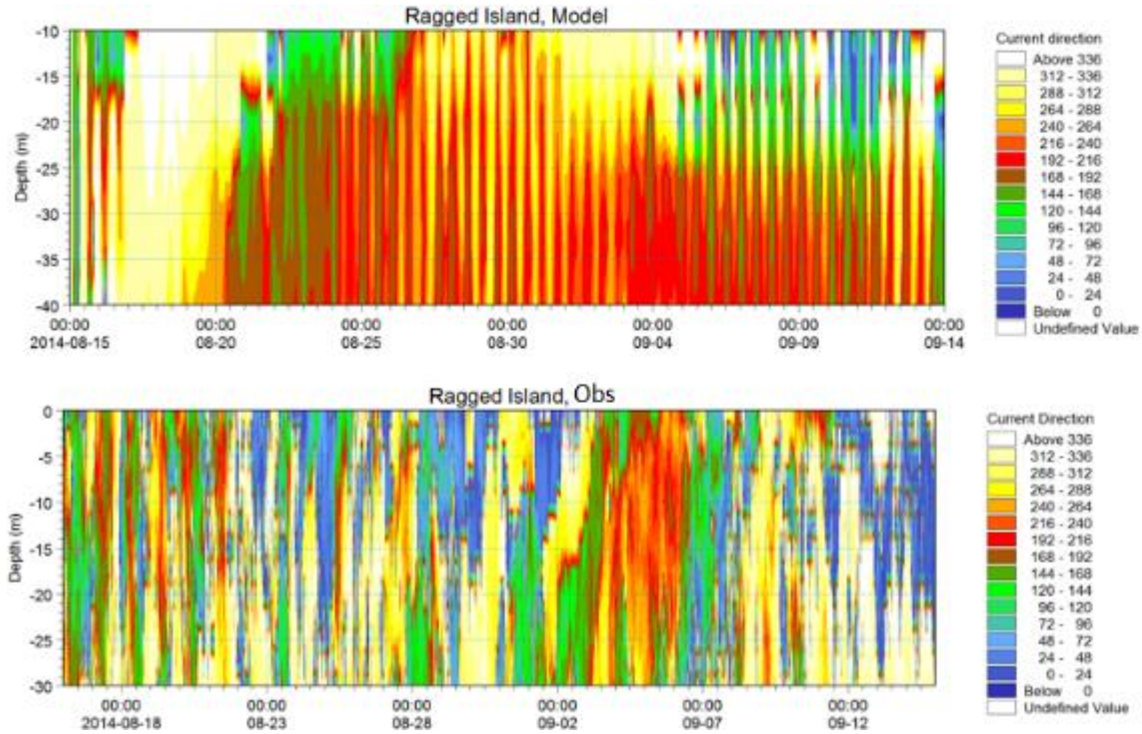

Figure B-2.14: Modelled (Top) and observed (Bottom) current directions at Ragged Island in the upper water column during the period 15 August 2014 to 14 September 2014.

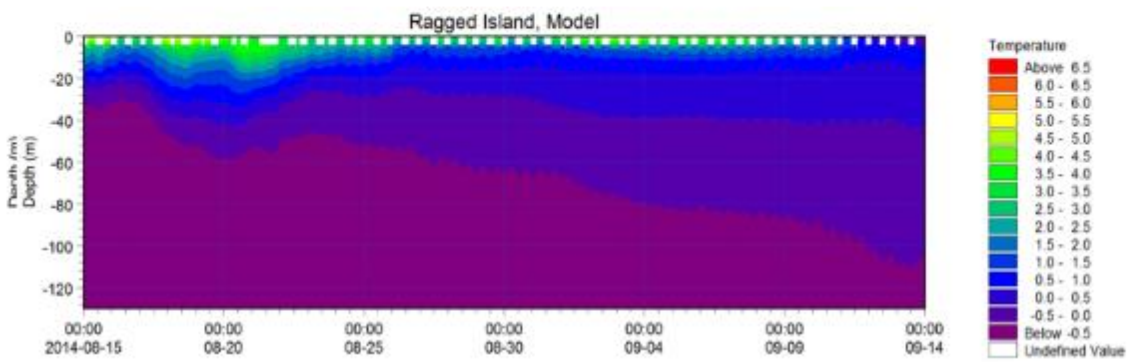

Figure B-2.15: Modelled evolution of the through water column temperature at Ragged Island during the period 15 August 2014 to 14 September 2014.

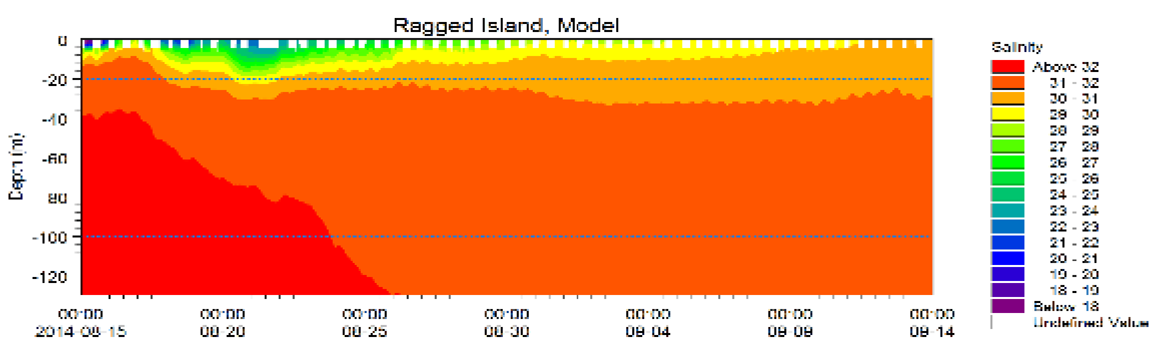

Figure B-2.16: Modelled evolution of the through water column salinity at Ragged Island.

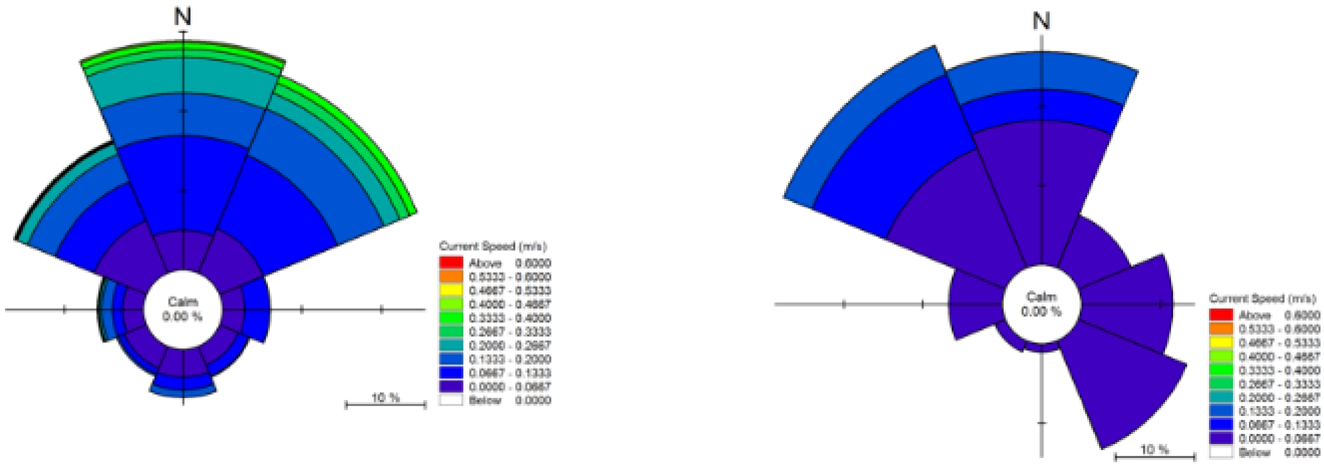

Figure B-2.17: Modelled (Right) and observed (Left) currents at a depth of 11 m below mean sea level (MSL) for Ragged Island.

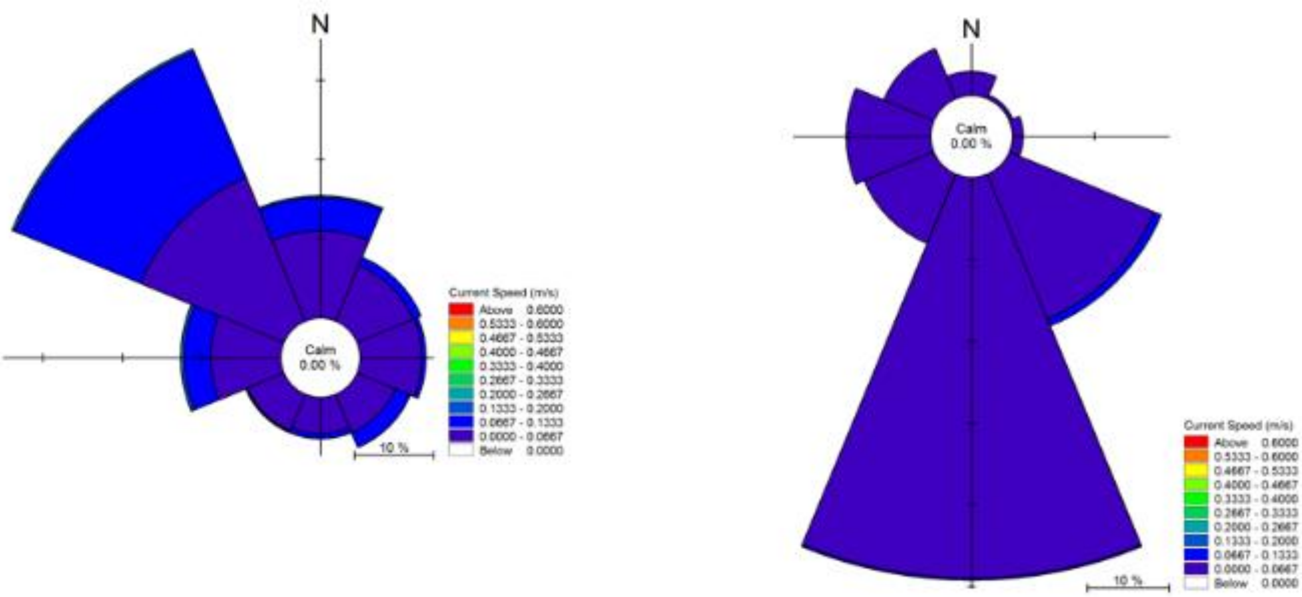

Figure B-2.18: Modelled (Right) and observed (Left) currents at a depth of 41 m below mean sea level (MSL) for Ragged Island.

Table B-2.3: Root Mean Square Error and Correlation Between Model Results and Measured Current Speeds at Different Bins at Ragged Island

Depth	Measured			Modelled		
	Max	Min	Mean	Max	Min	Mean
-11.5m	0.427	0.001	0.1	0.0445	0.0064	0.0165
-21.5m	0.379	0	0.0787	0.0297	0.0048	0.0121
-41.5m	0.181	0	0.0551	0.039	0.00592	0.0162

The following is a brief summary of the comparison of modelled and measured currents at Ragged Island:

- Modelled current speeds are on the same order of magnitude as measured current speeds.
- Modelled and measured currents speeds at Ragged Island indicated significant forcing from wind but are out of phase in the timing of events (i.e. September 02, 2014 in the measured profile).
- The modelled and measured near surface current speeds and directions are similar, as indicated by Figure B-2.17.
- Modelled current direction and measured direction are out of phase and off in direction, this is likely a result of the complicated flows at Ragged Island.

B-2.3.5 Currents, Salinity and Temperature at Stephens Island

Figure B-2.19 and Figure B-2.25show the comparison of measured and modelled currents, salinity and temperature at Stephens Island for the calibration period (August 8 – 31, 2014). Figure B-2.19 and Figure B-2.20are colour isopleth time series of current speed and direction profiles. Figure B-2.21 and Figure B-2.22 are colour isopleth time series of salinity and temperature predicted by the MIKE3 model. Figure B-2.23 and Figure B-2.24 and Figure B-2.25 show comparison of measured and modelled currents as compass rose plots at three different heights in the water column. Table B-2.4 is a summary of root mean square error and correlation between model results and measured current speeds at different bins at Stephens Island.

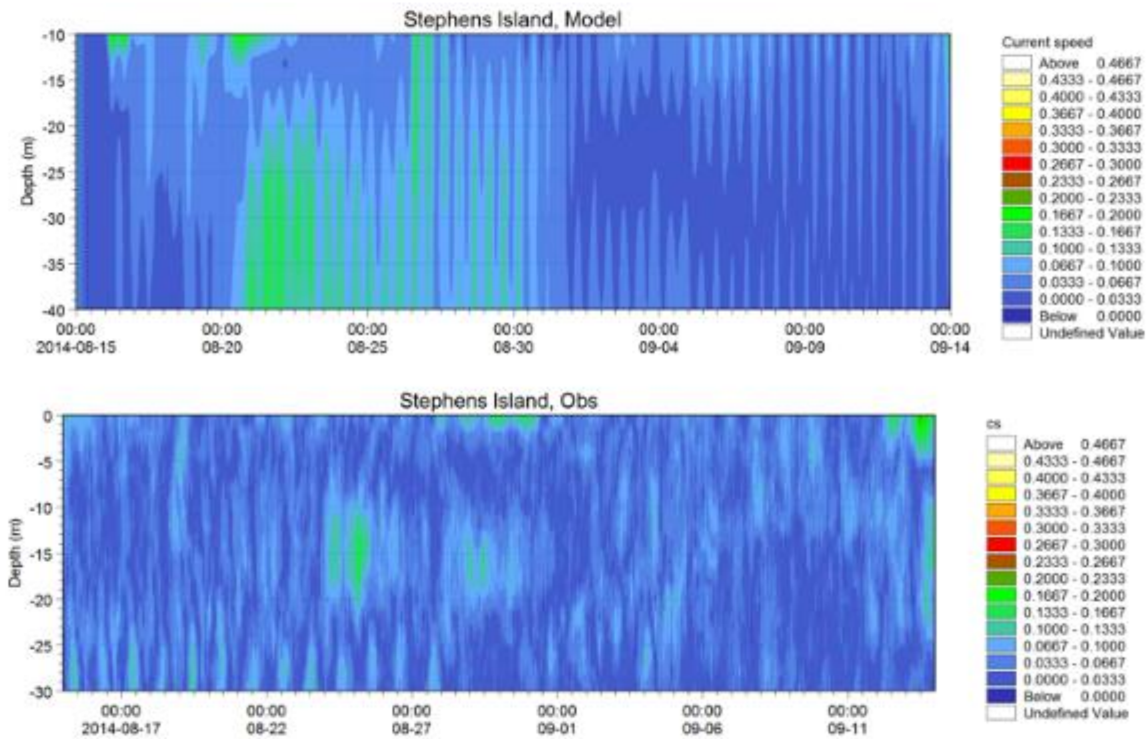

Figure B-2.19: Modelled (Top) and observed (Bottom) current speeds at Stephens Island in the upper water column during the period 15 August 2014 to 14 September 2014.

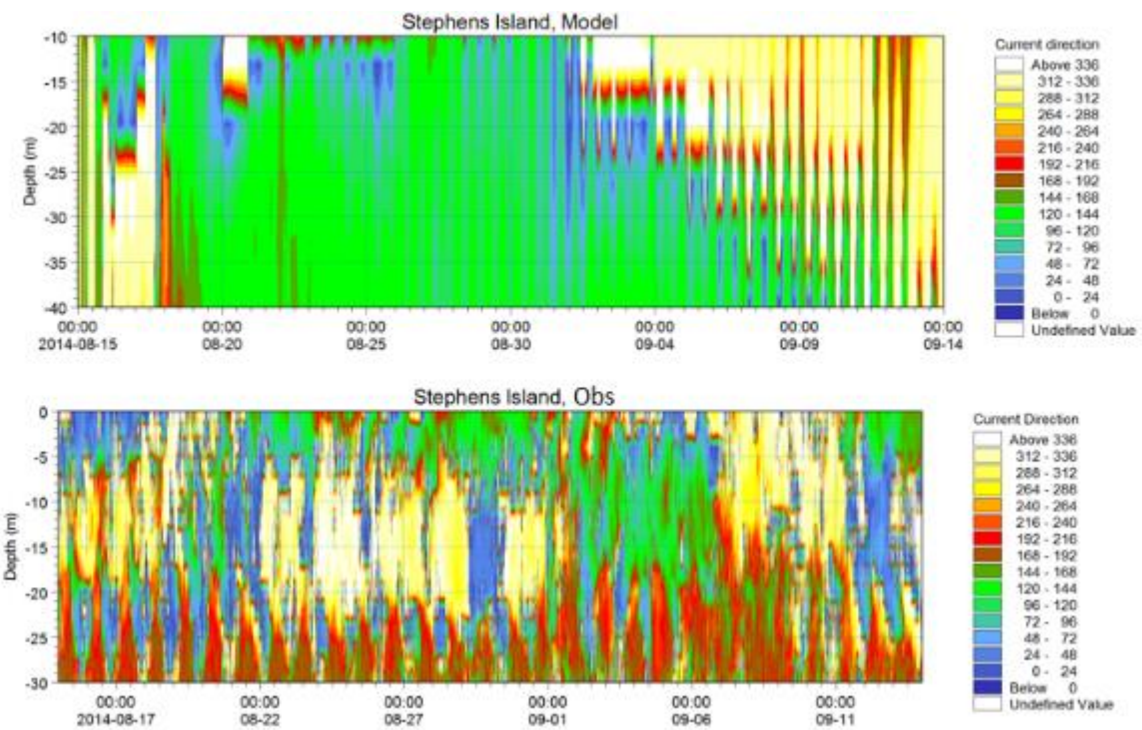

Figure B-2.20: Modelled (Top) and observed (Bottom) current speeds at Stephens Island in the upper water column during the period 15 August 2014 to 14 September 2014.

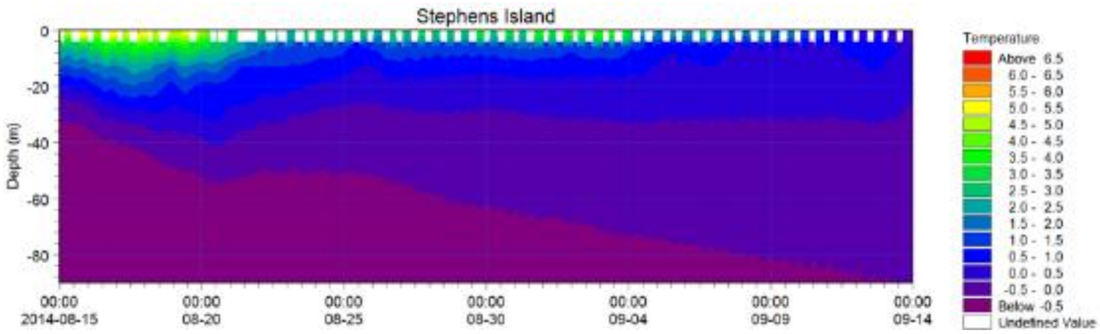

Figure B-2.21: Modelled evolution of the through water column temperature at Stephens Island during the period 15 August 2014 to 14 September 2014.

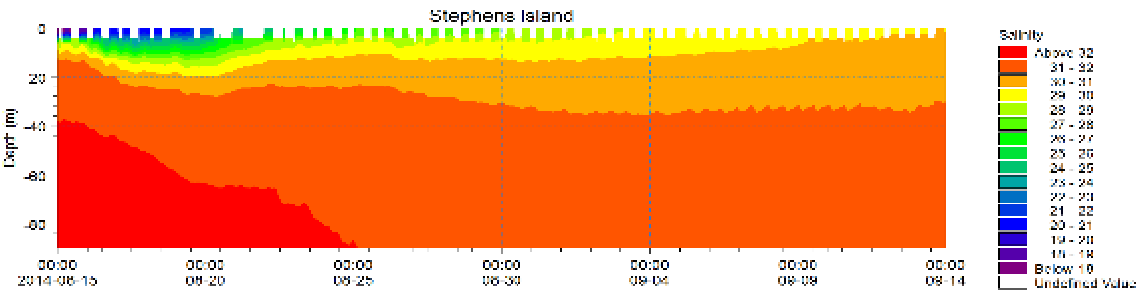

Figure B-2.22: Modelled evolution of the through water column salinity at Stephens Island during the period 15 August 2014 to 14 September 2014.

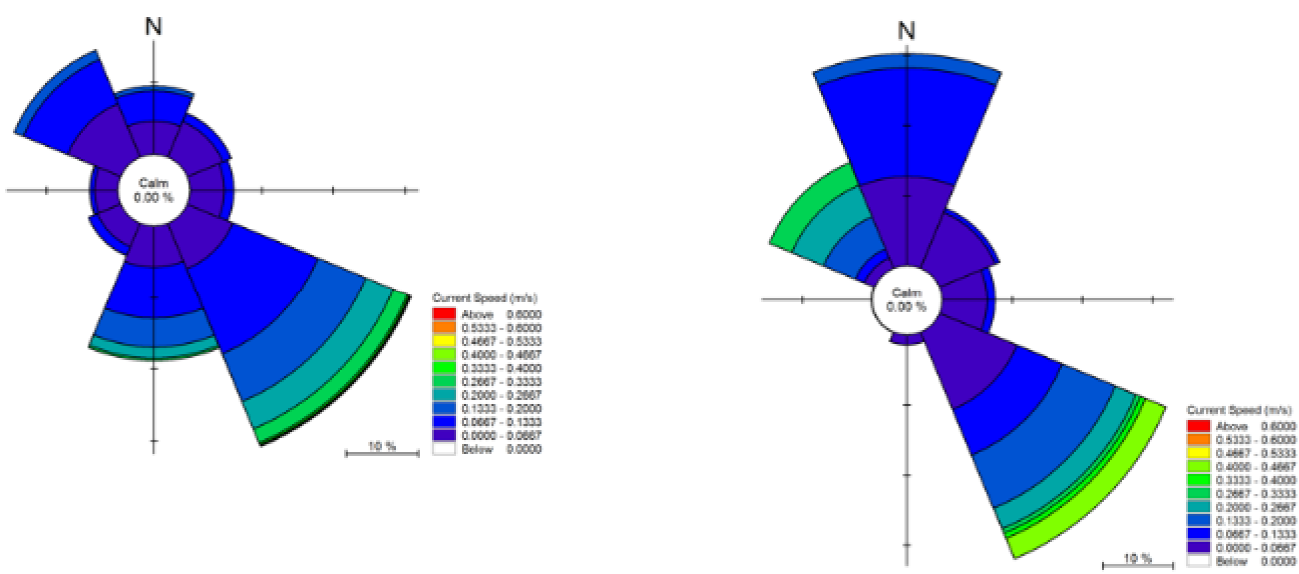

Figure B-2.23: Modelled (Right) and observed (Left) currents at a depth of 20 m below mean sea level (MSL) for Stephens Island.

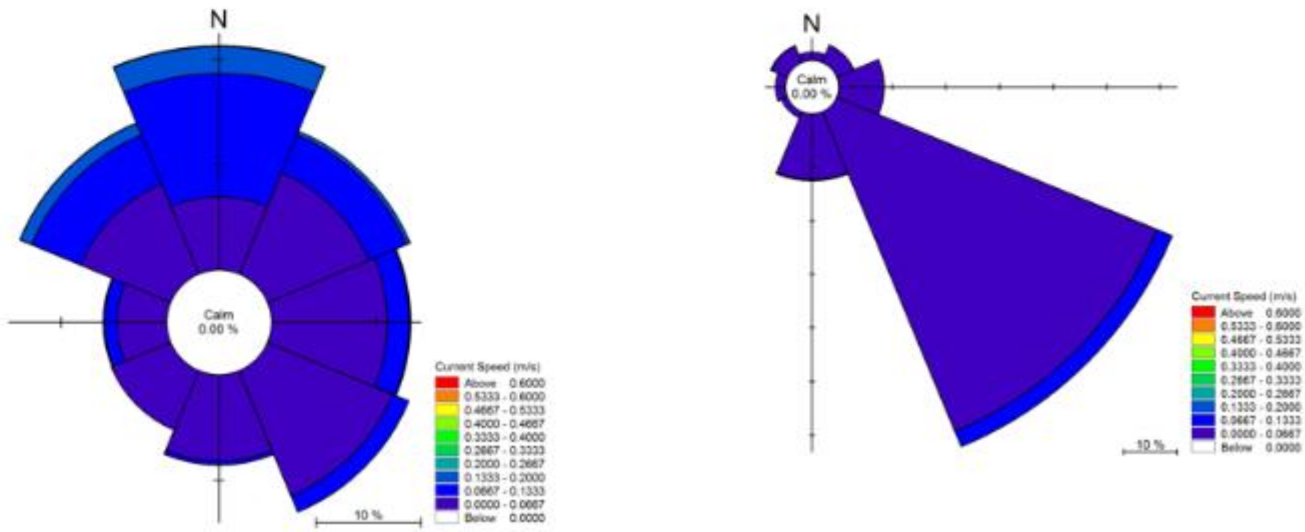

Figure B-2.24: Modelled (Right) and observed (Left) currents at a depth of 84 m below mean sea level (MSL) for Stephens Island.

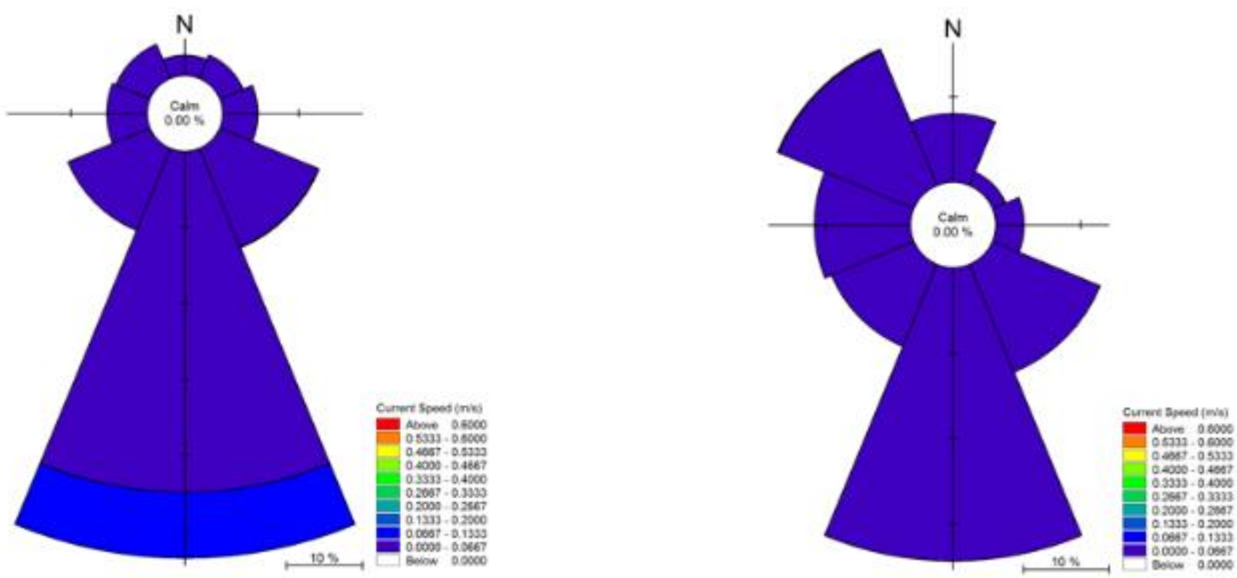

Figure B-2.25: Modelled (Right) and observed (Left) currents at a depth of 140 m below mean sea level (MSL) for Stephens Island.

Table B-2.4: Root Mean Square Error and Correlation Between Model Results and Measured Current Speeds at Different Bins at Stephens Island

Depth	Measured			Modelled		
	Max	Min	Mean	Max	Min	Mean
-20m	0.3254	0	0.0874	0.0804	0.010	0.0368
-60m	0.1714	0	0.0456	0.037	0.0061	0.0175
-140m	0.1408	0	0.0347	0.0288	0.0046	0.0057

The following is a brief summary of the comparison of modelled and measured currents at Stephens Island:

- Modelled current speeds are on the same order of magnitude as measured current speeds and generally in phase (i.e. events occur at the same time).
- Modelled and measured current speeds and directions are generally in good agreement throughout the water column, particularly the direction and speed of stronger currents (Figure B-2.23, Figure B-2.24 and Figure B-2.25).
- Modelled current direction and measured direction are generally in phase and tidally drive. Differences are likely due to coarse model resolution of the thermocline and wind forcing effects.

B-3.0 CALIBRATION SUMMARY

The following is a summary of the hydrodynamic model calibration:

- Good water level calibration is achieved at all three measurement locations.
- The current speeds and direction at Stephens Island are generally in good agreement with the observations.
- The current direction in the upper water column at Ragged Island is in fair agreement with the observations.
- The locations of velocity measurements are not ideal in relation to project needs. Near surface measurements and measurements away from complex bathymetry are needed.
- There is considerable uncertainty in the locations where measurements were obtained as a result of incomplete metadata provided with the data.
- No useful measurements were obtained in the area near Milne Port for model validation.
- Vertical mixing processes and salinity / temperature structure of flow could be improved (i.e. the thermocline mixes out over a month long simulation); however, there are inadequate inputs and verification data regarding salinity and temperature structure in the appropriate locations of the domain to verify the model.

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