



# Pond Inlet Marine Infrastructure

## Shoreline Evolution Modelling

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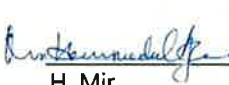
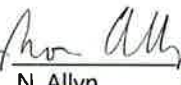

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## **Project No: 307071-01148-01-CS-REP-0001 – Pond Inlet Marine Infrastructure: Shoreline Evolution Modelling**

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## Table of Contents

1	Introduction.....	1
2	Model Development and Results .....	2
2.1	Data and Model Forcing .....	3
2.1.1	Bathymetry.....	3
2.1.2	Wind Data.....	3
2.1.3	Tides and Currents .....	4
2.1.4	Sediment Properties and Nearshore Morphology.....	4
2.2	Modelling.....	6
2.2.1	Hydrodynamic Modelling .....	6
2.2.2	Wave Modelling.....	6
2.2.3	Shoreline Evolution Modelling.....	7
3	Conclusion .....	11
4	References.....	11

## Table List

Table 2-1	Percent of Occurrence of Wind from Different Directions during Open Water Season for Pond Inlet Airport .....	3
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## Figure List

Figure 1-1	Project Site and Domain for Wave Modelling.....	1
Figure 2-1	Diagram Showing the Steps used for Modelling .....	2
Figure 2-2	(a) Wind-Rose Showing the Wind Climate over 41 Years for the Open-Water Season at Pond Inlet and (b) Wind-Rose of the 2014 storms with Wind Speed above 10 m/s, used for Shoreline Modelling.....	4
Figure 2-3	Particle Size Distribution for Sediment Samples Collected from the Nearshore Areas in Pond Inlet.....	5



Figure 2-4	Shoreline Evolution at the Existing Breakwater (Source: Google Earth August 31, 2010) .....	5
Figure 2-5	Comparison of Measured and Simulated Wave Heights at a Nearshore Location 200 m off the Shoreline in Pond Inlet.....	6
Figure 2-6	Beach Profile Location Used for Modelling .....	8
Figure 2-7	Project Site Beach Profile Used for Shoreline Evolution Modelling.....	8
Figure 2-8	Predicted 5, 10 and 25 Year Shoreline (0 m CD contour) Positions at the South West (Updrift) and North East (Downdrift) Side of the Harbour .....	10



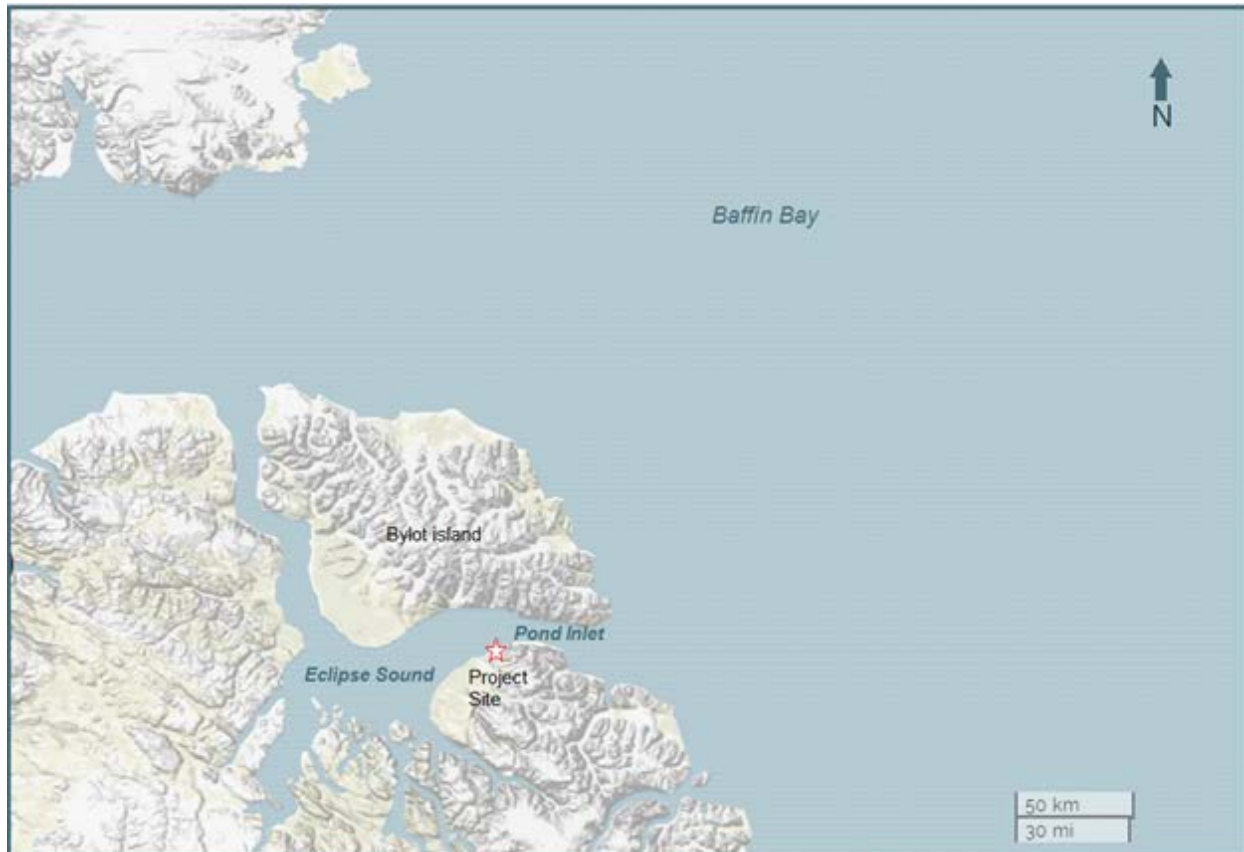
# 1 Introduction

Shoreline evolution modelling was performed to inform the environmental screening assessment and engineering design of the proposed Small Craft Harbour (SCH) development in the Hamlet of Pond Inlet (the Hamlet), Nunavut. The project site is located on the southeastern shoreline of Eclipse Sound (Figure 1-1), which is bordered by Bylot Island to the north and northern Baffin Island to the south. The proposed SCH (the Project) includes two rock breakwaters (northeast and southwest) extending approximately 200 m offshore.

The scope of the modelling work includes:

- Evaluation of the wave climate based on historical wind data and the effect of development on the nearshore waves at the project site.
- Quantification of the littoral drift (longshore transport of sediment) at the project site based on the wave climate and tidal currents.
- Prediction of the change in the shoreline (erosion and deposition of sediment) to the east and west of the project site due to the development.

A summary of the model development including data inputs and results are also presented in this report.



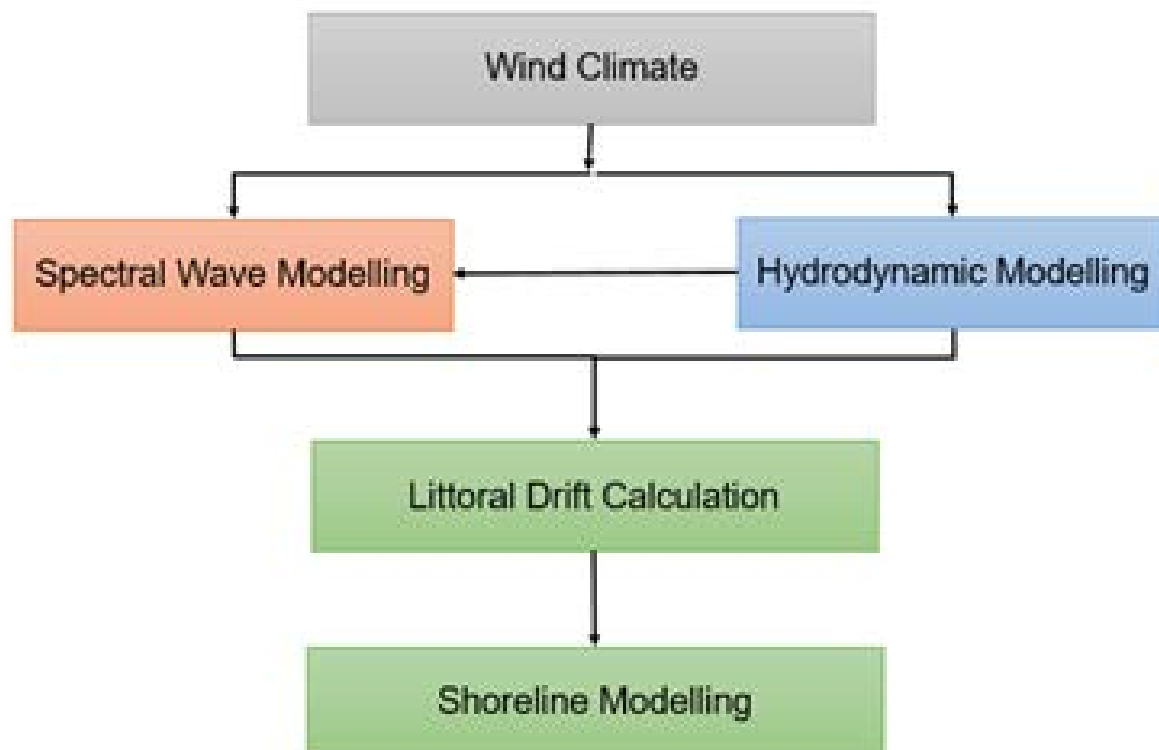
**Figure 1-1 Project Site and Domain for Wave Modelling**

## 2 Model Development and Results

The following steps were used for the shoreline modelling:

1. A representative wind climate condition was derived using the historical wind record at Pond Inlet (Station location: 72.689444 N, 77.968889 W, Climate ID: 2403206).
2. Hydrodynamic modelling was performed to simulate tidal currents at the project site.
3. Wave generation and transformation modelling was performed using the storm climate and simulated tide to simulate waves at the project site.
4. Littoral drift modelling was conducted to calibrate and estimate the annual sand transport volume.
5. The long-term shoreline evolution modelling was performed on the basis of the simulated littoral drift.

The diagram in Figure 2-1 illustrates the modelling approach used in the study.



**Figure 2-1** Diagram Showing the Steps used for Modelling

The following sub-sections present descriptions of metocean data, key model forcing and model development, calibration and assessment.

The key inputs into the modeling include:

- Beach and seabed profile, which dictates how the waves interact with the beach.
- Tides and currents that have the potential to move sediment.
- Wave climate, which is the main driver for movement of sediment along the beach.
- Sediment grain size, which dictates the potential for erosion of the seabed and beach and the transport of the material.

## 2.1 Data and Model Forcing

### 2.1.1 Bathymetry

Bathymetry data from the following sources were used for the modelling:

- Global bathymetric database, C-Map.
- Eclipse Sound from the Navigation Chart 7212 published by the Canadian Hydrographic Service.

### 2.1.2 Wind Data

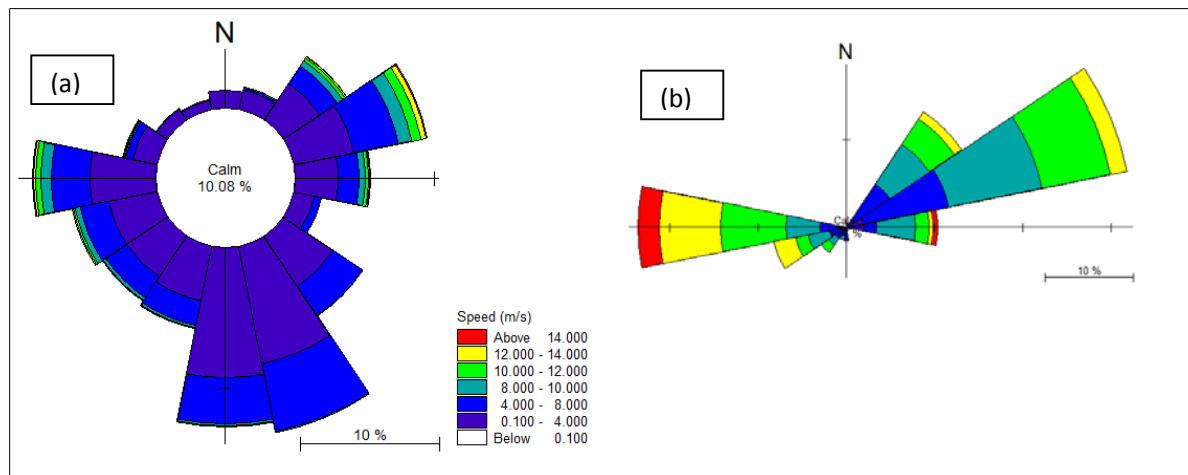
Historical wind records were obtained from Environment and Climate Change Canada's (ECCC) online database for Pond Inlet Airport. The wind record covers a period of 41 years, from 1975 to 2016.

For modelling and analysis, only data for the open water season (August-October) were used. A frequency table (Table 2-1) is provided below to present the frequency of wind occurrence during the open-water season from 16 directional sectors. This analysis was used to define representative climate conditions used for the shoreline modelling.

**Table 2-1 Percent of Occurrence of Wind from Different Directions during Open Water Season for Pond Inlet Airport**

Speed (m/s)	Percent of occurrence															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0-3	1.9067	1.9625	3.1878	3.7039	3.1152	1.8475	3.4905	6.0015	7.229	3.6614	3.3107	3.2437	4.4522	2.187	1.509	1.3381
3-6	0.0581	0.2312	1.5224	3.0594	1.3806	0.7093	3.5319	7.3876	5.2196	2.0977	1.9904	2.1435	2.4685	0.5306	0.1184	0.0536
6-9	0.0045	0.0748	0.8634	2.0586	0.9606	0.1374	0.4412	0.7584	0.8657	0.7026	0.7651	1.0801	1.6676	0.2703	0.019	0.0022
9-12	0.0011	0.0491	0.43	1.1594	0.4479	0.0067	0.0112	0.0257	0.0793	0.1206	0.1363	0.3183	0.6903	0.115	0.0011	0
12-15	0	0.0089	0.1083	0.3574	0.0994	0.0022	0	0.0011	0.0156	0.0067	0.0156	0.0514	0.1508	0.0357	0	0
15-18	0	0.0011	0.029	0.0882	0.019	0	0	0	0.0045	0.0022	0.0045	0.0145	0.0246	0.0056	0	0
18-21	0	0	0.0022	0.0145	0.0045	0	0	0	0	0	0.0034	0.0078	0.0067	0.0011	0	0
21-24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24-27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27-30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	1.97	2.33	6.14	10.44	6.03	2.70	7.47	14.17	13.41	6.59	6.23	6.86	9.46	3.15	1.65	1.39

Wind data for 2014 were selected for modelling as this year was identified as being a typical year for wind speed and direction. All storm events with wind speed greater than 10 m/s and the corresponding onset periods were included for the analysis by considering that the beach sediment would only be mobilized when wave induced bed shear stress exceeds a certain threshold (Fredse and Deigaard 1992). Wind-roses presenting the full wind dataset and the storm climate for 2014 are shown in Figure 2-2.



**Figure 2-2 (a) Wind-Rose Showing the Wind Climate over 41 Years for the Open-Water Season at Pond Inlet; and (b) Wind-Rose of the 2014 storms with Wind Speed above 10 m/s, used for Shoreline Modelling**

### 2.1.3 Tides and Currents

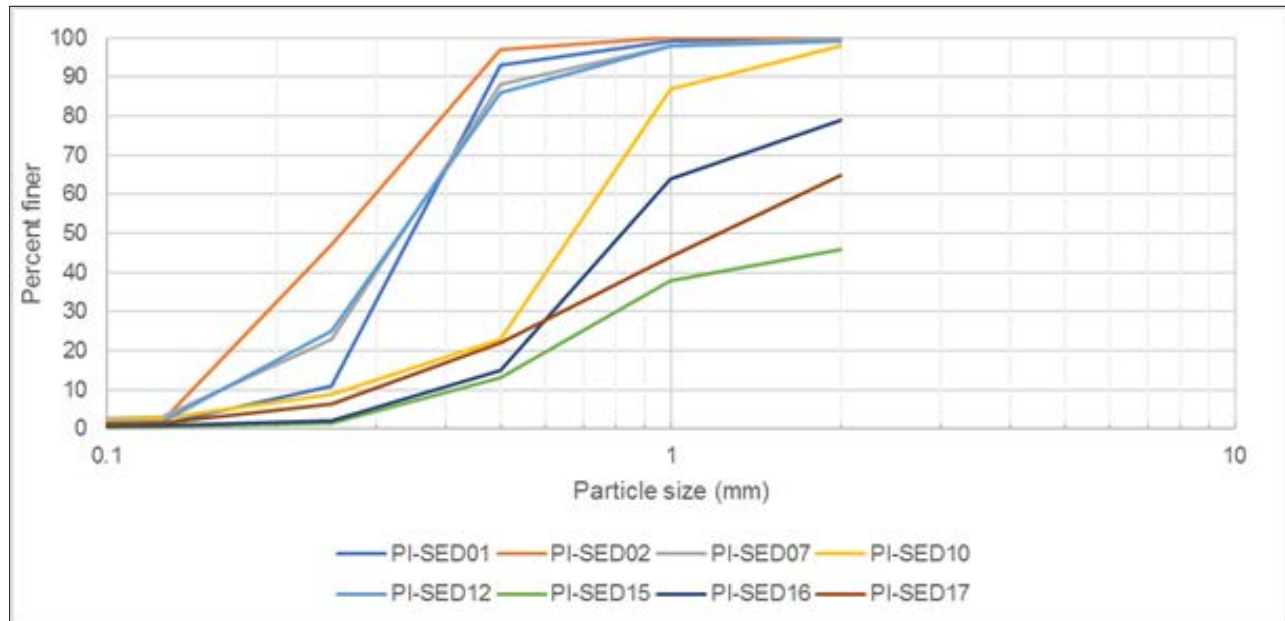
Astronomical tidal parameters were available from a tidal constituent atlas maintained by the Danish Hydraulic Institute (DHI). The constituents reported in the atlas were: M2, S2, K1, O1, N2, P1, K2 and Q1. The constituents were used to drive the hydrodynamic model at the boundaries. The description of the tidal constituents can be found in Pugh (1987).

Nearshore currents were measured during 2015 and 2016 at the project site by PND Engineering Canada Inc. (PDI 2016) and this data was used to validate current speeds along the Hamlet coastline.

### 2.1.4 Sediment Properties and Nearshore Morphology

Sediments were collected via grab sampling at selected locations in the vicinity of the SCH Study Area. Grain size distribution for eight different samples is shown in Figure 2-3. The median grain size (D50) of the samples is approximately 0.3 mm and the distribution grading ( $\sqrt{[D84/D16]}$ ) is 1.6.





**Figure 2-3 Particle Size Distribution for Sediment Samples Collected from the Nearshore Areas in Pond Inlet**

The nearshore area of Pond Inlet is characterized by pronounced littoral drift. Residents reported that the small existing breakwater silted up on the southwest side within a year or two after construction (PND 2016). Aerial imagery shows that smooth beaches evolved at the breakwater from both sides (Figure 2-4).

Based on a modelling study, ADI Limited (ADI 2004) reported that the average annual "potential" longshore sediment transport rate may range from 1,000 to 2,000 m<sup>3</sup>/yr mainly from southwest to northeast, with minimal transport towards the opposite direction.



**Figure 2-4 Shoreline Evolution at the Existing Breakwater (Source: Google Earth August 31, 2010)**

## 2.2 Modelling

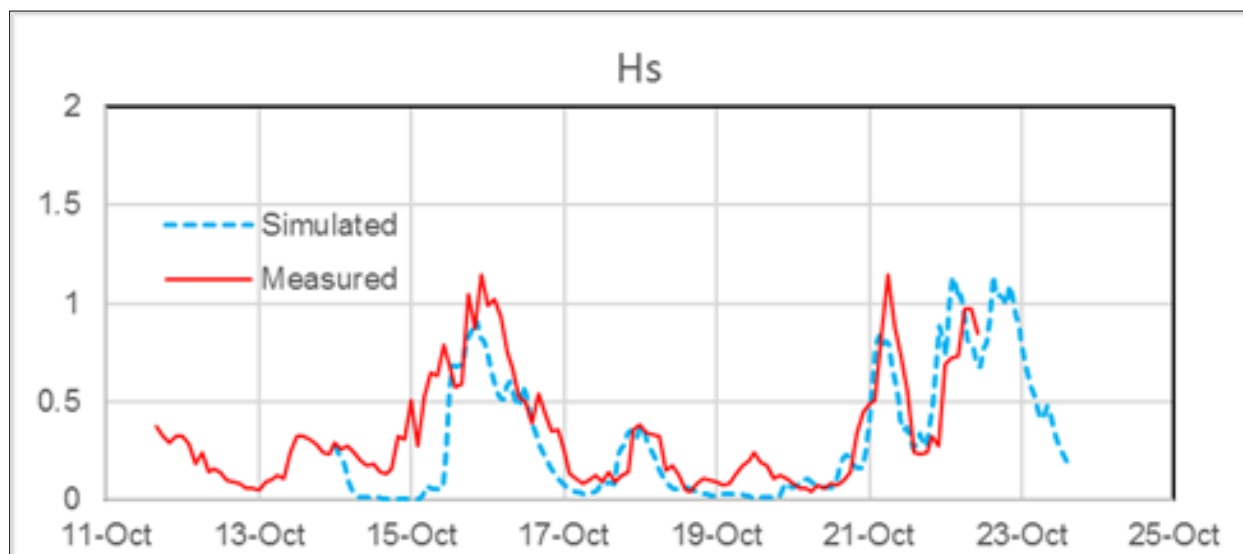
### 2.2.1 Hydrodynamic Modelling

Coastal currents and hydrodynamics at the project site were assessed using a two dimensional numerical model using MIKE 21 FMHD, developed by the Danish Hydraulic Institute (DHI). MIKE21 FMHD utilizes a flexible mesh grid system that allows variable grid sizes within a single model domain. The model domain used for the hydrodynamic modelling is shown in Figure 1-1. Variable grid sizes were used for setting up the model to achieve optimum model run time with accuracy of the results.

Tidal dynamics were simulated using the oceanographic boundary and wind data described in Section 2 and current speeds were validated using the PND (2016) results showing that modelled current speeds were in general correlation with the measured data. Currents are not the driving force for sediment transport at the site.

### 2.2.2 Wave Modelling

The nearshore wave conditions characterizing the annual climate are the most important forcing parameter for shoreline evolution modelling. A spectral wave model, MIKE21 FMSW, developed by DHI was used to simulate the nearshore waves using the same model grid used for hydrodynamic modelling. The wave model was calibrated against measured nearshore waves using 2015 data (PND 2016). Comparison between the calibrated and measured wave heights are presented in Figure 2-5. The comparison between measured and modelled waves is good and within expected accuracy.



**Figure 2-5 Comparison of Measured and Simulated Wave Heights at a Nearshore Location 200 m off the Shoreline in Pond Inlet**

Subsequently, the calibrated model was applied to simulate the storm events (winds greater than 10 m/s) of 2014. Simulated nearshore wave parameters (significant wave height, peak wave period and mean wave directions) were extracted for shoreline evolution modelling in described in Section 2.2.3.



## **2.2.3 Shoreline Evolution Modelling**

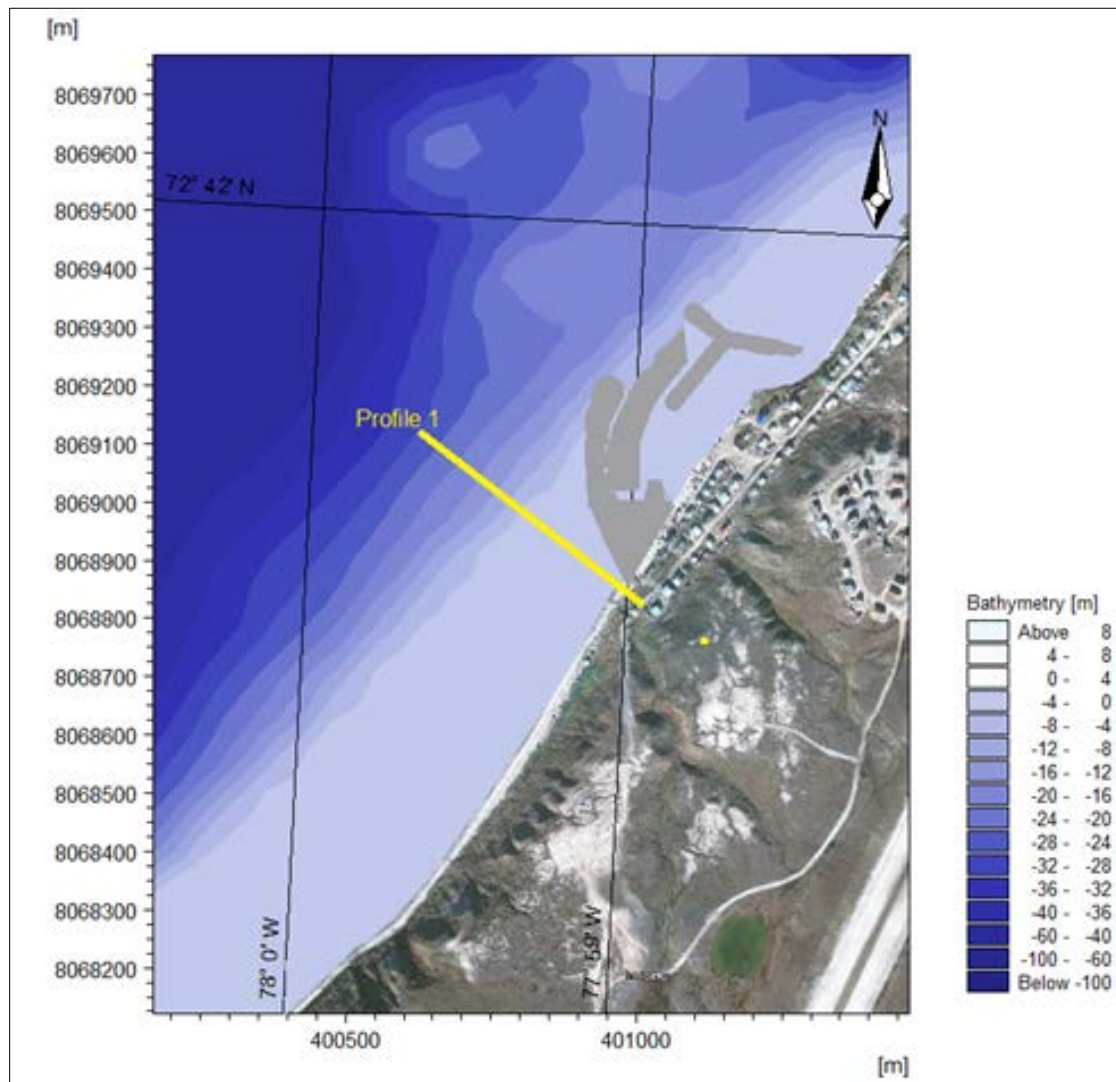
### **2.2.3.1 Model Set Up**

The shoreline evolution modelling is performed using Littoral Process FM module which is included in the LITPACK modelling package developed by DHI. The Littoral Processes FM module is an integrated modelling system that simulates sand (non-cohesive sediment) transport along coastlines using a one dimensional (1-Line) approach by linking the shore profile to wave propagation, water level and current variations and sediment properties. Detailed technical information on the model is available in DHI (2016).

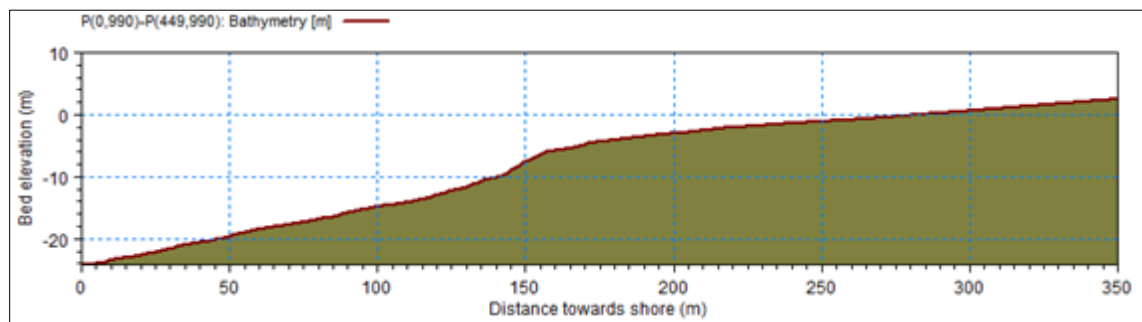
The model was set up for a 1.8 km long coastline that includes the Project site. A beach profile which is extended 400 m offshore was used to represent the nearshore zone (Figure 2-6 and Figure 2-7). The shoreline position was defined as 0 m Chart Datum (CD). Tidal fluctuations were not considered.

The simulated storm wave climate for 2014, tidal conditions and sediment data were used for the simulation of littoral drift. In the absence of sediment transport volume data, the model results were compared against the ADI study (ADI 2004). It was found that the northeastward sediment transport rate with no shoreline structures was in general agreement with the annual littoral drift volumes provided in ADI (2004).

Subsequently, the structural configuration of the SCH was included in the model using a set of features representing groyne and detached breakwater. Finally, the model was applied to predict shoreline evolution for periods of 5, 10 and 25 years.



**Figure 2-6 Beach Profile Location Used for Modelling**



**Figure 2-7 Project Site Beach Profile Used for Shoreline Evolution Modelling**



Key assumptions used for the shoreline modelling are as follows:

- Cross-shore profile represents uniform conditions along a straight coast.
- During major storms, seaward currents (undertow) generates cross shore transport and develop offshore bars approximately along the edge of the broken wave zone (Fredse and Deigaard 1992). During the non-storm seasons, wakes and smaller waves moves the sediment back towards the shoreline (Benassai 2006). Typically, this process of cross shore sediment movement causes temporary changes to beach profiles and therefore, for the long-term shore line evolution modelling, the effect of cross shore sediment transport is neglected.
- By adopting the model default, it is considered that 5% of longshore transport bypasses around the offshore end of the structure.
- Modelled shoreline positions, volumes and areas are approximate and provide an indicative overview of potential sediment accumulation and erosion along the shoreline.

### 2.2.3.2 Results

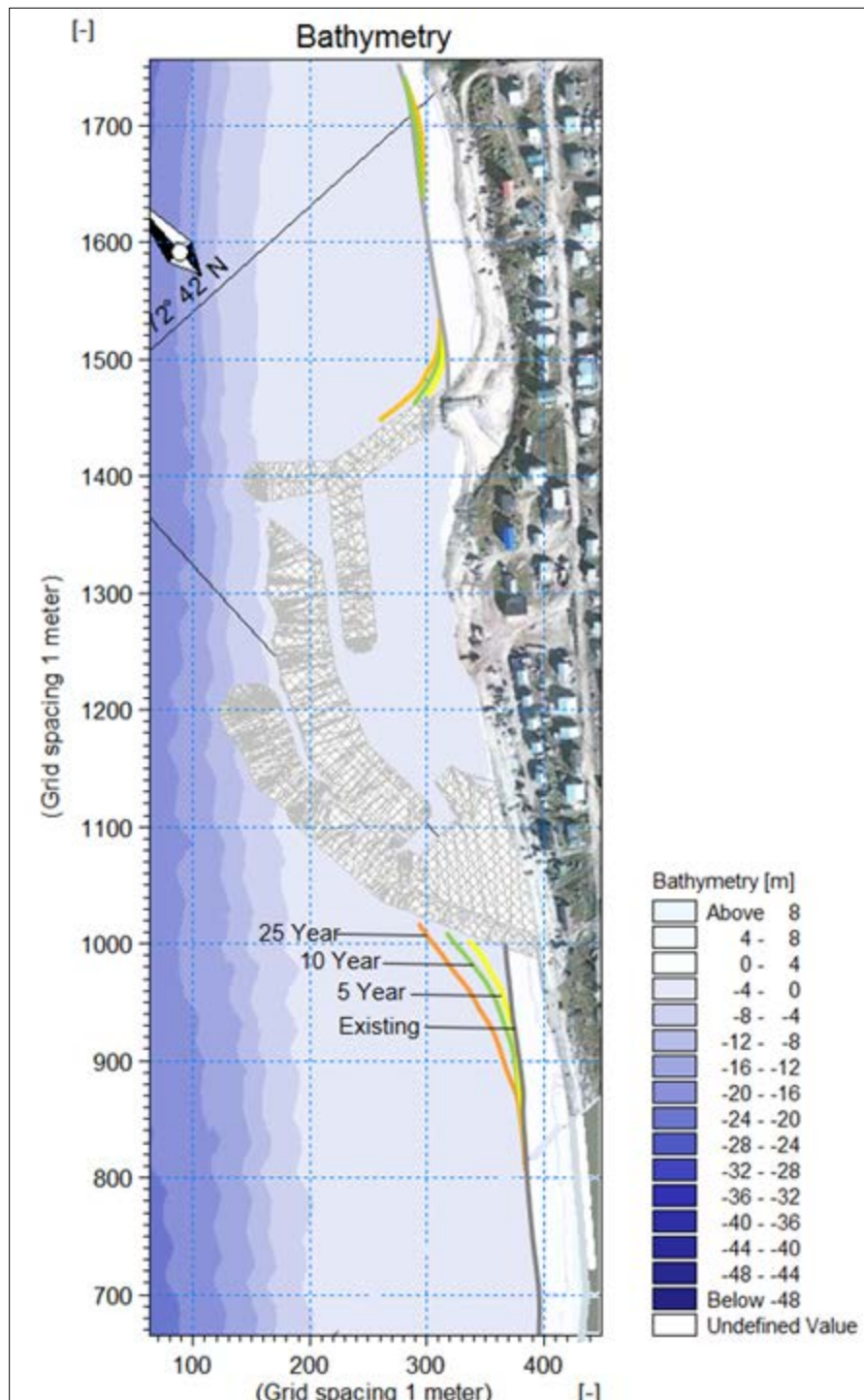
For the existing the shoreline condition, the modelling results show that the annual littoral drift from southwest to northeast direction for a typical year is 2,100 m<sup>3</sup>. The annual transport in the opposite direction is estimated to be approximately one third of this volume. The net or resulting littoral drift is northeastward with an annual transport rate of 1,300 m<sup>3</sup> at the project site.

The results of shoreline evolution modelling for the post development condition are presented in Figure 2-8, which shows the predicted shoreline changes for 5, 10 and 25-years. The shore line at the southwest side of the harbour moves 23 m, 33 m and 50 m offshore measured along the structure after 5, 10 and 25 years respectively. This amounts to an area of approximately 630 m<sup>2</sup>, 1,265 m<sup>2</sup>, and 3,175 m<sup>2</sup>, after 5, 10, and 25 years respectively. Approximately 50,000 m<sup>3</sup> of sediment is predicted to accumulate at this location in 25 years.

The model also predicted sediment accumulation and resulting shoreline change at the northeast side of the harbour. The shoreline at the northeast side of the harbour moves 20 m, 23 m and 27 m offshore measured along the structure after 5, 10 and 25 years respectively. This amounts to an area of approximately 141 m<sup>2</sup>, 295 m<sup>2</sup>, and 762 m<sup>2</sup>, after 5, 10, and 25 years respectively. Sediment accumulation of 7,500 m<sup>3</sup> is predicted at the northeast side of the harbour over 25 years. Accumulation on the northeast side of the breakwater results in a more arch-shaped and smaller area of beach in comparison to the changes on the southwest of the harbour.

A trend of beach erosion is predicted approximately 200 m northeast of the harbour. The shoreline moves landward 3 m, 5 m, and 9 m, after 5, 10, and 25 years respectively. This amounts to an area of 490 m<sup>2</sup>, 750 m<sup>2</sup>, 1,350 m<sup>2</sup>, after 5, 10, and 25 years respectively. Sediment erosion of approximately 15,000 m<sup>3</sup> is predicted over 25 years. A percentage of the eroded beach material is transported southwestward and deposits along the northeast breakwater.





**Figure 2-8 Predicted 5, 10 and 25 Year Shoreline (0 m CD contour) Positions at the South West (Updrift) and North East (Downdrift) Side of the Harbour**

### 3 Conclusion

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The shoreline modelling for a typical year shows that the annual sand transport rate from southwest to northeast direction is  $2,100 \text{ m}^3$ . The transport rate is approximately one third for the opposite direction with a resulting net littoral transport to the northeast of  $1,300 \text{ m}^3$ .

For the post development condition, approximately  $50,000 \text{ m}^3$  of sand was modelled to accumulate at the southwest side of the harbour resulting in an approximate 50 m seaward shift of the shoreline along the structure over a 25-year period. Sediment accumulation of approximately  $7,500 \text{ m}^3$  is also modelled at the northeast side of the harbour over 25 years.

A trend in erosion is predicted approximately 200 m northeast of the harbour. Erosion of approximately  $15,000 \text{ m}^3$  of sand is predicted over a 25 year period causing an approximate shift of 9 m in shoreline position towards the land. The shoreline modelling was performed for a typical year condition.

### 4 References

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