LA GRANDE ALLIANCE

PRE-FEASIBILITY STUDY – PHASES II & III – TRANSPORTATION INFRASTRUCTURE

TECHNICAL NOTE 13B

HARBOUR CONCEPT DESIGN

FINAL VERSION

DATE: MARCH 25, 2024

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EXECUTIVE SUMMARY

The purpose of this Technical Note 13B is to describe the harbour infrastructures proposed as part of La Grande Alliance Phase III study.

This technical Note 13B follows the previously issued Technical Note 13A that focuses on identifying the site with the highest potential for this foreseen harbour facility. Using the results of a Multi Criteria Analysis, one of the four shortlisted zones near Whapmagoostui/Kuujjuarapik was selected as the preferred site. That study was based on the available physical and environmental conditions including ice conditions, coastal geomorphology, coastal processes and accessibility along the Hudson Bay's shoreline coastline and near the Great Whale River mouth.

Based on the conclusion of Technical Note 13A, the market survey and cargo forecast study conducted by WSP showed that expected demand in the near and intermediate future is not sufficient to sustain a deep-water harbour investment. This current Technical Note 13B, which has been prepared in continuation to the Technical Note 13A, utilizes the output of the market survey and cargo forecast study, and presents the conceptual design developed for a SCH, to be located along the Whapmagoostui/Kuujjuarapik coastline between the mouth of Great Whale River and the entrance of the Manitounuk Sound, and in the vicinity of Îles Qikirtaaruit. The selected site and proposed SCH arrangement answer community needs, accommodating fishing vessels and transporting goods from sealift vessels (e.g. *Desgagnés*, which has been specially designed with dedicated barge/tugboat for offloading and transfer of cargo to remote locations) to the shore, and allow for a future development of a Deep-Water Harbour when required. Considering the recent landslide upstream from the mouth of Great Whale River and the perceived risk of excessive sedimentation, the proposed SCH can also be considered as a potential mitigation measure serving the community needs in the event that the existing natural beach harbour would become non-operational.

This Technical Note provides a summary of the parameters needed for developing the SCH conceptual design including design standards and datums, design vessels, bathymetric and topographic data, environmental conditions (water level, wind, wave, current and ice), morphology, and geotechnical and geological conditions. It also presents constraints, design criteria including wave height limit, required water depth and damage criteria for the breakwater and revetments, and also assumptions made in case required information were not available.

The conceptual design proposed for the Whapmagoostui/Kuujjuarapik SCH includes a description of this potential infrastructure’s requirements (harbour space, fishing fleet berthing/support zones and onshore facilities), harbour layout (as shown in the following sketch) and conceptual design of harbour elements including:

- Floats, or floating platforms/docks, that allow a relatively dense berthing pattern for 20 small boats (fishing boats) and easy access to get boats on and off at low initial cost. A floating system has the added advantage that the level of access to boats does not change with the tides. The proposed concept consists of modular timber frame floating docks to facilitate removing and storage of floats annually before the winter (ice) season and transporting/installing them once open season starts. The size and number of vessels are determined based on the community needs and the boats available in the area.
- A shore access ramp located within the protected area of the harbour, which will be primarily used for loading/offloading of goods and commodities transferred from the Sealift provider to shore via dedicated barges. As an additional criterion related to community use and to maximize the harbour utilization, the ramp will also be able to accommodate local boats.
- A shore-connected breakwater to shelter the berths/floats from the incident waves. The proposed rubble-mound breakwater structure consists of core (relatively small stones to build the breakwater structure), armour stones to protect the core from reshaping and damage by waves and ice, and underlayer placed between the core and armour layer to prevent the core material escaping through the armour layer voids.

- A reclaimed onshore area to accommodate potential onshore operations and functions including service areas, office and parking areas, storage areas (including areas to store the floats during winter seasons), and access roads/approaches. The onshore area slope protection is expected to be affected by ice, therefore, a similar conceptual design as proposed for the breakwater may be used for that segment.
- An access causeway connecting the onshore area to the local roads.

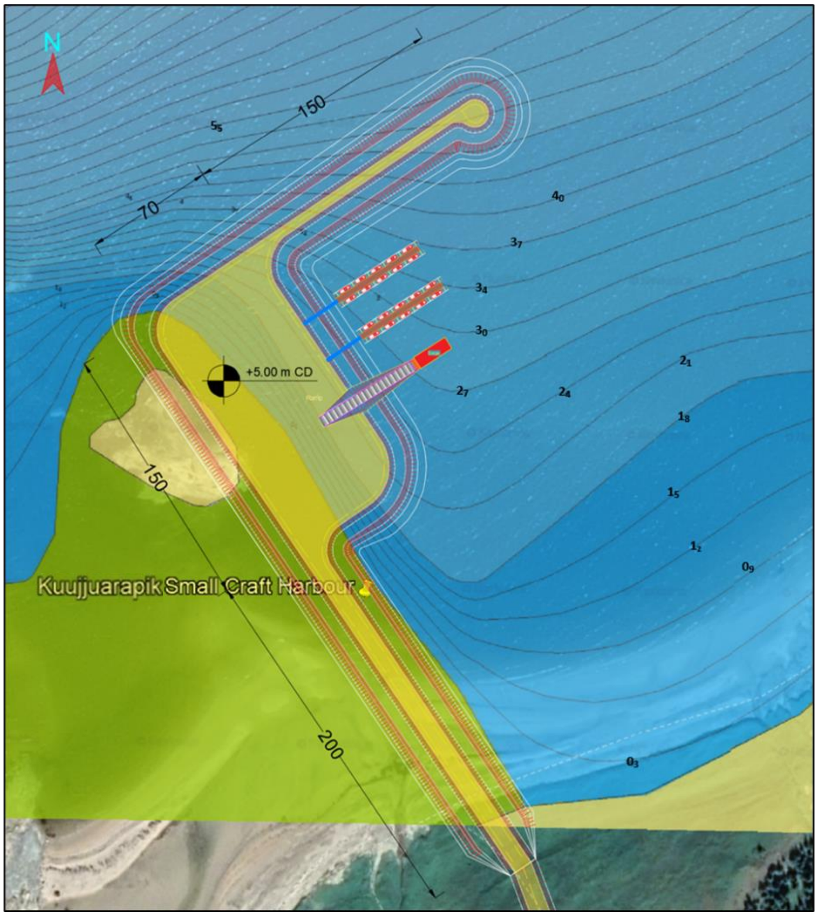

Figure Proposed Harbour Layout

The proposed concept for the harbor development and its components is based on the design elements collected and presented in this Technical Note. This pre-feasibility/conceptual plan will need to be developed/advanced based on the results of the upcoming field data collection campaign(s) and more detailed site-specific studies and analyses, including analysis of the limits within which SCH cannot be used due to unfavorable ocean weather conditions, assessment of ice conditions, topographic and bathymetric data, geotechnical parameters, assessment of geomorphology, and constructability aspects. Coastal environmental and geomorphic impacts of the proposed SCH construction will also be investigated in future phases of this study.

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1 INTRODUCTION

The purpose of this Technical Note 13B is to describe the harbour infrastructures proposed as part of La Grande Alliance Phase III study.

This technical Note 13B follows the previously issued Technical Note 13A that focuses on identifying the site with the highest potential for this foreseen port facility. Using the results of a Multi Criteria Analysis, one of the four shortlisted zones near Whapmagoostui/Kuujjuarapik was selected as the preferred site. That study was based on the available physical and environmental conditions including ice conditions, coastal geomorphology, coastal processes and accessibility along the Hudson Bay's shoreline coastline and near the Great Whale River mouth (Figure 1-1). This is an element that can be a part of a comprehensive plan to improve the standard of living and extend the transport network.

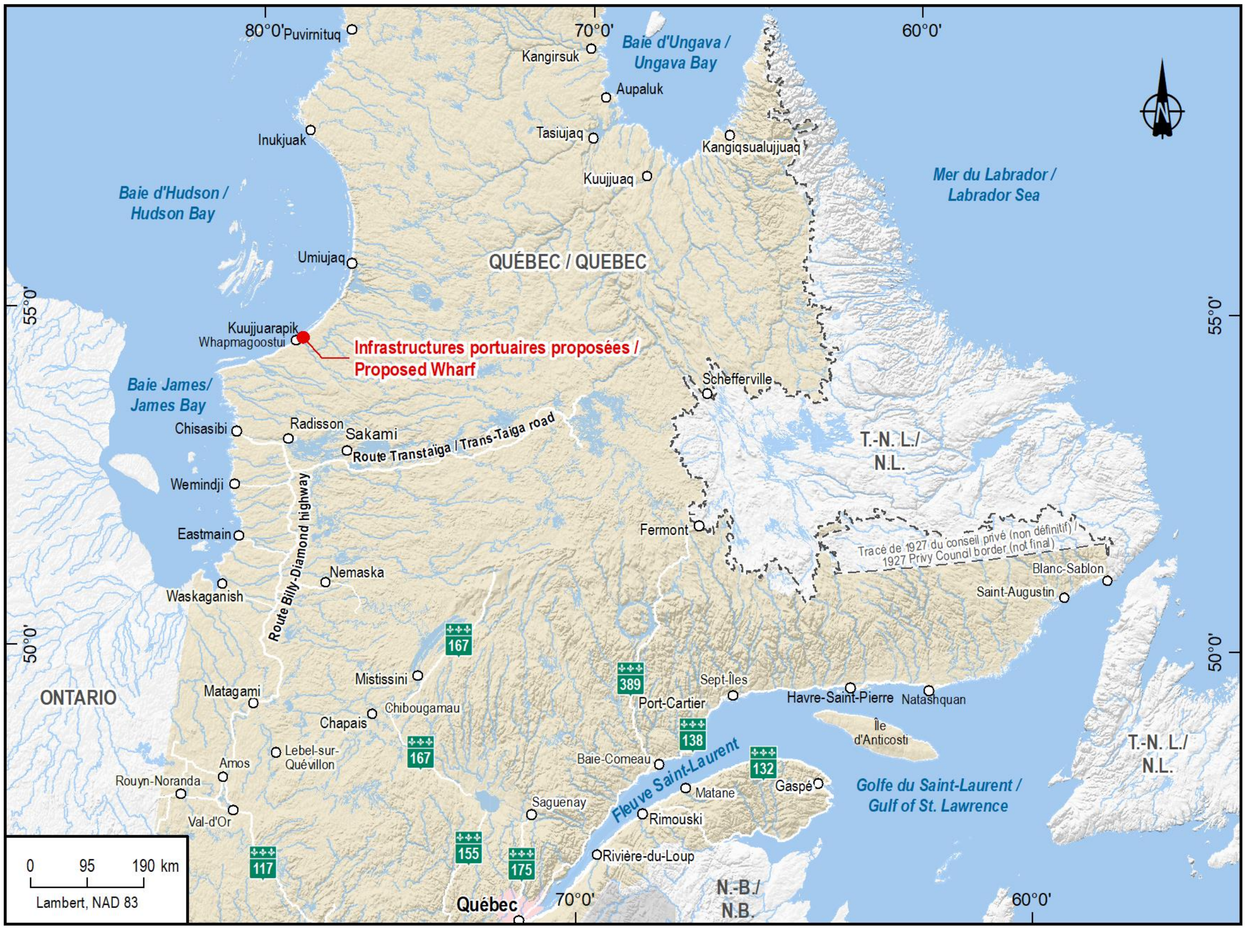


Figure 1-1 Location map

TECHNICAL NOTE 13B – HARBOUR CONCEPT DESIGN

Based on the conclusion of Technical Note 13A, the market survey and cargo forecast study conducted by WSP showed that expected demand in the near and intermediate future is not sufficient to sustain a deep-water harbour investment. This current Technical Note 13B, which has been prepared in continuation to the Technical Note 13A, uses the output of the Cargo Market Study and provides a conceptual design of the Whapmagoostui/Kuujjuarapik SCH to answer community needs, accommodating fishing vessels and transporting goods from sealift vessels to the shore. Considering the recent landslide upstream from the mouth of Great Whale River and the perceived risk of excessive sedimentation, the proposed SCH is also considered as a mitigation measure providing an alternative to the community in the event that the existing natural beach harbour would become non-operational.

Section 2 of this note outlines a summary of the basis of design, including the information obtained earlier and presented in the Technical Note 13A.

Section 3 presents the high-level conceptual design proposed for the harbour layout and its components.

This pre-feasibility / conceptual design will require to be further developed/refined based on the outcome of field data collection campaign and more detailed site-specific studies and analysis.

2 SUMMARY OF DESIGN CRITERIA

As noted earlier, based on the output of the Cargo Market Study, WSP has developed a conceptual design of a SCH at the potential site considering the community needs, to accommodate fishing vessels and transporting goods from sealift vessels to the shore. Potential future development of a Deep-Water Harbour is also considered in the site selection and preparation of the harbour layout, so that the same facilities can be used as a part of the Deep-Water Harbour and to facilitate its construction.

Considering recent landslide upstream from the mouth of Great Whale River and the perceived risk of excessive sedimentation, the proposed SCH can also be considered a potential mitigation measure serving the community needs, as an additional design criterion, in the event that the existing natural beach harbour would become non-operational.

The Whapmagoostui/Kuujjuarapik Small Craft Harbor will consist of seasonal floating docks for berthing 20 fishing boats, a ramp for a dedicated barge to transfer the goods and commodities offloaded from a Sealift vessel, an onshore area connected to shore via a causeway and a breakwater to protect the berthing area from incident waves. The size and number of vessels are determined based on the community needs and the vessels available in the area.

This section provides a summary of the parameters needed for developing the harbour conceptual design.

2.1 DESIGN STANDARDS

2.1.1 UNITS

All dimensions on the engineering, calculations and drawings will be in SI (metric) units.

2.1.2 STANDARDS AND DESIGN MANUALS

Harbour Accommodations Guidelines for Small Craft Harbours Branch Fisheries and Oceans Canada by Public Works and Government Services Canada, 2015, - referred as *Canadian SCH Design Guideline* here after - was used as the primary standard/guideline for developing the harbour conceptual design.

Below is a list of other standards and references which were used for this work:

- US Army Corps of Engineers, *Coastal Engineering Manual*, 2002.
- Unified Facilities Criteria (UFC), *Small Craft Berthing Facilities*, 2009.

2.2 DESIGN DATUMS

Elevations are with the respect to Chart Datum or CD (see Section 2.9.1).

2.3 LOCATION

As indicated in the Technical Note 13A, four zones (A, B, C, and D) were selected for the foreseen harbour along the Whapmagoostui/Kuujjuarapik coastline between the mouth of Great Whale River and the entrance of the Manitounuk Sound as shown in Figure-2-1.

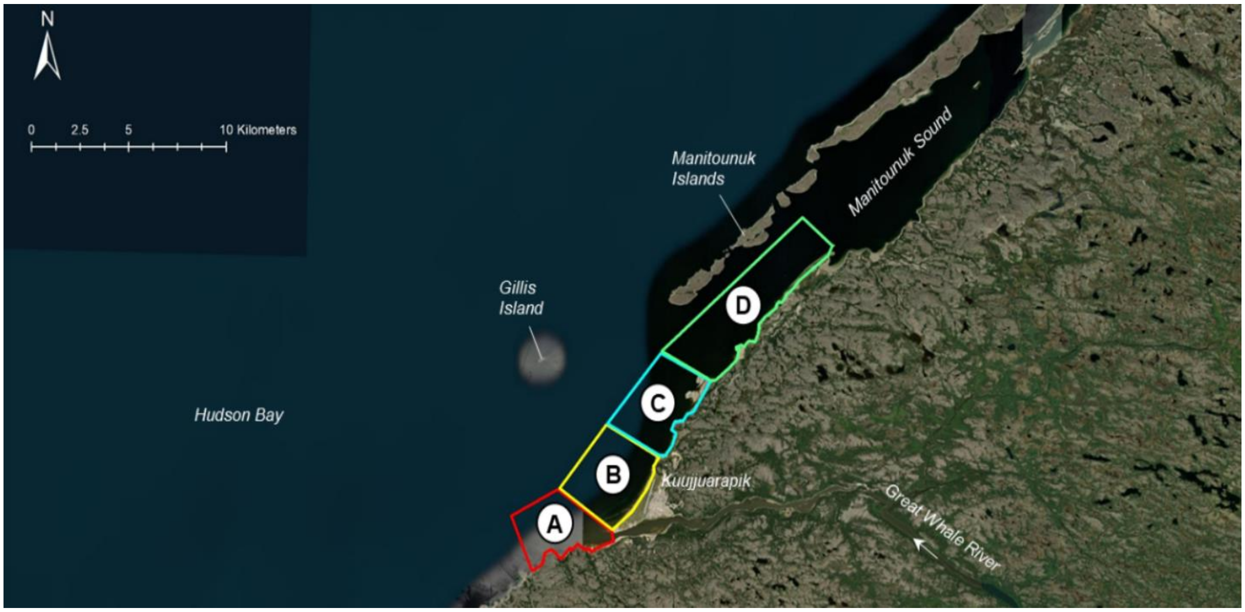


Figure-2-1 Study Zones A, B, C, and D at the Whapmagoostui/Kuujjuarapik Coastline

A site selection study was conducted using high level understanding of key physical environmental conditions including ice conditions, coastal geomorphology, coastal processes (water level/wind/waves/currents), and accessibility, to identify the preferred site. The results of a Multi Criteria Analysis (MCA) showed that Zone C and Zone D have the higher scores, and therefore an area at the border of these two zones was proposed for developing the harbour conceptual design. The parameters collected for the site selection, the MCA methodology and site selection results have been presented in the Technical Note 13A.

Based on aerial imagery, there is a roadway within 1.0 km of the shoreline, and the community of Whapmagoostui/Kuujjuarapik is located approximately 10 km from the proposed site.

2.4 DESIGN LIFE

The proposed design life of the harbour facility is 20 years for the floats and 50 years for the breakwaters, to be reviewed and approved by the client.

Extreme Value Analysis and estimation of design conditions is expected to be less reliable for return periods larger than 3-4 times of the length of available data. For this conceptual design, WSP has selected extreme events with 100-year return period. For design lives of 20 and 50 years, there is ~20% and ~40% possibility of the selected 100 -year design event being equalled or exceeded during the life of the structure, accordingly.

2.5 DESIGN VESSEL

The following vessels (Table 2-1) are used for the design based on obtained information from the region and Canadian SCH Design Guideline. The “Barge” listed in Table 2-1 will be used for transportation of the goods and commodities from Sealift vessels to shore and its dimensions has been scaled using available pictures (See Section 3.1).

Table 2-1 Design Vessels

TYPE	CANADA REGION	FISHERY	TYPICAL VESSEL WIDTH	TYPICAL VESSEL LENGTH	VESSEL DRAFT (ASSUMED BASED ON EXTERNAL DATA)
Fishery Boats	Central & Arctic	Gill Net – Western	2.4 m	6.7 m Skiffs	1.2 m
Barge	-	-	7 m	20 m	<1.2 m

2.6 BATHYMETRY

The bathymetry of the area is characterized by general trends that reflect the underlying bedrock morphology, including discontinuous ridges and troughs running northeast-southwest (Figure 2-2 and Figure 2-3). The ridges form cuestas steeply sloping on the east, and with shallow slopes on the west. The cuestas extend offshore for 40 km west of Great Whale River.

West of Great Whale River, the depth increases to 60 m within 3 km of the shore but rarely exceeds 100 m relative to Chart Datum. Approximately 8 km west from the river mouth the seafloor rises to depths less than 20 m. The discontinuous rises trend northeastward and are contiguous extensions of the Manitounuk Islands. Southwest of Great Whale River, the trend of the ridges is cut by a west-southwest oriented trough, generally aligned with Great Whale River channel.

Manitounuk Sound is located ~10 km northeast of Great Whale River and is bounded by the northeast trending mainland coast and the Manitounuk Islands. Manitounuk Sound is 58 km long, with a minimum and maximum width of 1 and 5.7 km, respectively. The mouth of Manitounuk Sound is 3.5 km wide and opens to the southwest. Waters progressively deepen westward from the mainland. The maximum water depth is >100 m near the mouth of the sound, and shallower toward the northeast. Near the head of Manitounuk Sound, the maximum water depth is >30 m. Intertidal flats are present in the shelter of promontories or headlands and are generally <100 m wide in the southeast of the sound and widen to 1 km near the head of the Manitounuk Sound.

Great Whale River delta bathymetry has a shoal margin (<5 m) with shallow sand bars (<2 m). The delta extends 2 km from shore near the mouth of Great Whale River with a slope break between 5 and 10 m water depth. The shoal margin narrows toward the northeast. In general, the coastal margin has a slope break at 5-10 m depth within 150 m from shore. In places the slope of the coastal margin is steeper, such as southwest of the mouth of Great Whale River and in the northeast of the study area, opposite Manitounuk Island, with depths in the range of 10-20 m within 50 m from shore.

The offshore bathymetry is not expected to be a major concern for navigation except for isolated small shoals near Gillies Island, and at the eastern side of the entrance of Manitounuk Sound.

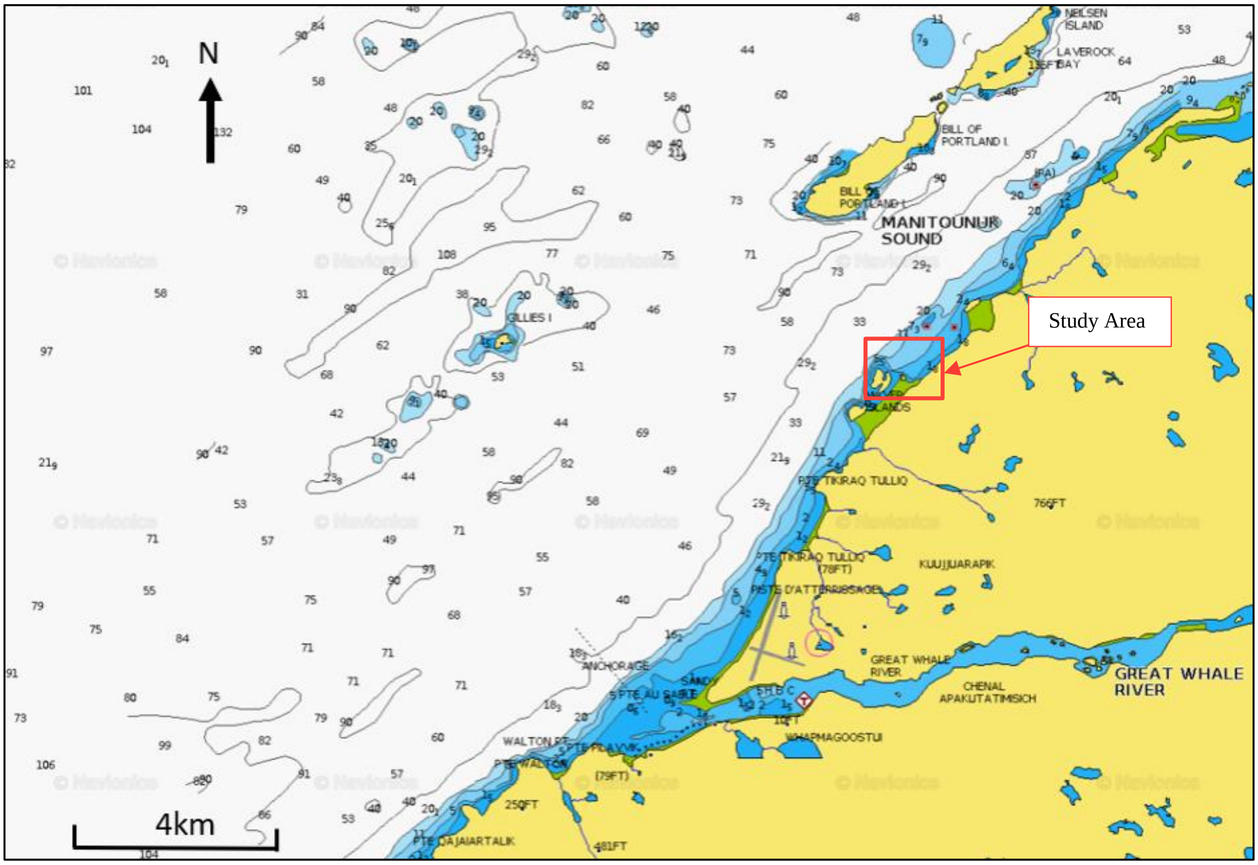


Figure 2-2 Bathymetry of Study Area (Navionics Chart Viewer)

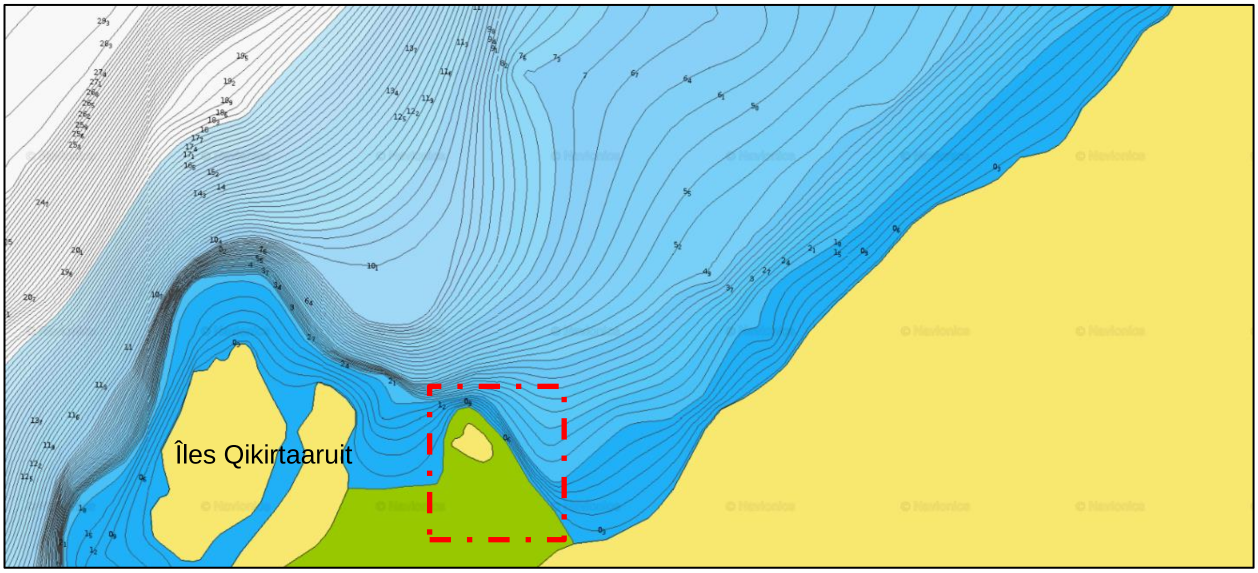


Figure 2-3 Close View of the Bathymetry of the Study Area (Navionics Chart Viewer)

Bathymetry is an important consideration for a SCH or Deep-Water Harbour design. In the absence of site-specific bathymetric data, the information obtained from Navionics Chart Viewer was used in this conceptual design (Figure 2-3). This figure shows the Qikirtaaruit Islands, a small island (~80 m by ~40 m) on the east, an intertidal area and relatively steep slope to -2 m/CD contour.

2.7 TOPOGRAPHY

The general topography of the study area is a northeast trending coastline. The nearshore coastal zone has a low relief, with elevations generally less than 20 m above mean sea level. The profile of the coastal terrain located northeast of Great Whale River has gradual seaward dipping slope – the elevation decreases 70 to 90 m over a distance of about 2 km. The coastline is also fringed by bedrock ridges, behind which there are subtidal flats. Southwest of the mouth of Great Whale River terrain has a steep seaward dipping slope – over a distance of 1.5 km the elevation decreases 150 m.

To the northeast of the study area, there are a series of low-elevation northeast trending cuesta shaped islands that form the western edge of Manitounuk Sound. The islands have steep slopes on the eastern shoreline, and gentle slopes on western shore. The islands include Bill of Portland Island and Neilsen Island. Bill of Portland Island is ~3 km long, has maximum width of 0.8 km and elevation of 45 m above MSL. Neilsen Island is located to the north, it is ~3 km long, has a maximum width of ~1 km and a maximum elevation of 30 m above MSL. Both islands are ~3 km long.

In the absence of site-specific topographic data, it has been assumed that nearshore coastal zone topography of the study area was generally not steep with gentle gradients near the shoreline, and the elevation of the small island shown in Figure 2-3 and the intertidal area in its vicinity is 0.0 m/CD. The harbour arrangement, including access causeway, will be revisited and updated (if required) once the topographic surveyed data within the site is available.

2.8 ICE

The results of a high-level ice condition assessment in Hudson Bay and Strait (see Technical Note 13A) show the ice cover on the East coast appears to form later and break earlier; therefore, a marine infrastructure at Whapmagoostui/Kuujjuarapik is expected to experience a longer ice-free season compared to one located along the West coast; for example, the existing Harbour of Churchill (Manitoba). Regular ice-free seasons along the east coast of Hudson Bay usually last for a period of about five months, from July to November. A climate change study shows that the number of ice-free weeks could increase by more than six weeks by 2041-2070 (Ouranos, 2020).

It is expected that the site selected for the harbour will not be exposed to incursions of ice floes from offshore. Ice thickness is controlled by thermal growth over the full winter and ice breakup occurs thermally, as the ice mainly melts in place.

This section provides an overview of the ice thickness in the study area and its potential impact on the harbour elements.

2.8.1 ICE THICKNESS

Ice thickness is a key design parameter for assessing ice loading and interaction with marine infrastructures.

Figure 2-4 illustrates the maximum annual ice thickness, measured by the Government of Canada (GC, 2022) near Whapmagoostui/Kuujjuarapik at the mouth of the Great Whale River, for the period 1973-1991. The average maximum annual ice thickness is 1.4 m and the maximum ice thickness measured was 2.2 m, on April 4, 1983.

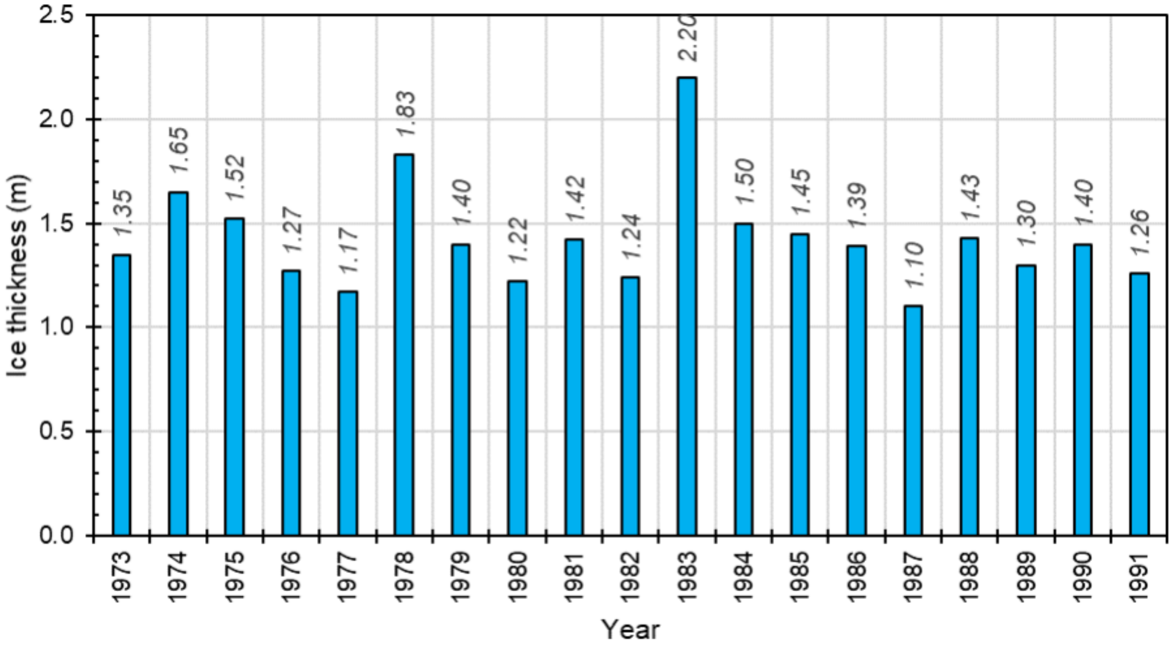


Figure 2-4 Maximum Annual Ice Thickness Measurement Over the Period 1973-1991 (Government of Canada, 2022)

In the absence of statistical data and using the available information, an ice thickness of 2.0 m was used for this conceptual design.

2.8.2 ICE LOADING

Ice loading is an important consideration for the SCH design. The area selected is shallow (water depth < 6 m), which would generally place the harbour within the landfast ice zone and also tend to protect it against ice incursions from offshore. Furthermore, the low water depth would prevent deep-draft ice features (e.g., ridge keels) from reaching the harbour.

The approach proposed for the Whapmagoostui/Kuujjuarapik SCH consists of floating berthing structures, which will be collected and transported to shore during wintertime, to prevent ice impact. Therefore, the ice loading will be applicable to only the harbour breakwater and revetment/slope protection components.

Rubble mound structures such as breakwaters and causeways typically have high lateral resistance, so sliding due to ice load is not expected to be a concern for the structure. However, ice may dislocate the armour stones by pushing them up, or pluck/move/carry them away and reshape the profiles and therefore ice needs to be considered as one of the parameters in the design of armour layer.

Ice may also ride-up and encroach the crest; however, considering there will be no/minimal facilities on the crest, which is vulnerable to ice damage, ice encroachment has not been considered in this high-level design.

It is noted that constructing a breakwater to shelter the berthing facilities from waves may also delay the ice clear-out in the spring. Considering the size and type of boats/vessels expected to visit the harbour, presence of ice is expected to shorten the SCH operating season and limiting it to open water period.

2.9 WATER LEVELS

The water levels near Whapmagoostui/Kuujjuarapik are subject to fluctuations mainly due to tides and also storm surge during extreme events. The water level is also expected to change because of Sea Level Rise (SLR) due to climate change.

2.9.1 *TIDES*

Tidal water level data, provided by the Canadian Hydrographic Service (CHS), for the mouth of the Great Whale River are shown in Table 2-2.

Tides near Whapmagoostui/Kuujjuarapik are semidiurnal and high tide range is 2.0 m.

Table 2-2 Tidal Water Levels, Whapmagoostui/Kuujjuarapik Tides (CHS – Canadian Tides and Current Tables 2021).

Region	Whapmagoostui/Kuujjuarapik		
Reference Harbour	Churchill*		
Index Number No.	4645		
Tide Type	Semidiurnal		
Range	Mean Tide		1.5 m
	High Tide		2.0 m
Tide Level	Higher High Water	Mean Tide	1.7 m
		Large Tide	2.0 m
	Lower Low Water	Mean Tide	0.2 m
		Large Tide	0.0 m (Chart Datum)
Mean Water Level			1.0 m

* Tide data provided for Whapmagoostui/Kuujjuarapik use Churchill as a reference harbour which is approximately 1000 km NW of the site.

It should be noted that there are seasonal variations to the tides due to annual ice cover. During the ice-covered season, Hudson Bay experiences smaller tidal variations in addition to a tidal advancement (Freeman, 1986).

2.9.2 STORM SURGE

Storm surges resulting from low atmospheric pressure and westerly winds can induce an extra sea-level increase above mean sea level and tide fluctuations. In the fall of 1999, a study at the mouth of the Great Whale River was conducted by *Université du Québec, Institut des Sciences de la Mer* which included the measurements of waves, currents, and suspended sediments in 10 m water depth over 15 days, capturing a four-day storm event. During that storm event, wave heights over 3 m for 15 hours and a storm surge of over 1 m height was recorded. Through the fair-weather days of the data collection period, only local waves with significant heights less than 1 m were observed (Hill et al., 2003). The latter is consistent with storm surge of more than 1 m reported by Hydro-Quebec (Hydro-Quebec, 1980).

Based on the available information presented in the Technical Note 13A, a storm surge of 1.0 m is considered in this stage of the study.

2.9.3 RELATIVE SEA LEVEL CHANGE

The information related to sea level changes due to climate change is obtained from the Government of Canada, *Canada's Changing Climate Report* (CCCR 2019). Globally, for most of the 20th century (up to 1990), sea level rose at a mean rate slightly larger than 1 mm/year. Recently, the rate of mean sea-level rise has increased, and the rate of global mean sea-level rise after 1993 is nearly three times as large or approximately 3 mm/year on average.

The long-term trends in relative sea level observed at tide gauges in Canada vary substantially from one location to another. Some of the variability is due to oceanographic factors affecting the absolute elevation of the sea surface, but a major determinant of relative sea-level change in Canada is vertical land motion, i.e., land subsidence (sinking) and land uplift.

Across much of Canada, land uplift or subsidence is mainly due to the delayed effects of the last continental glaciation (Ice Age), called Glacial Isostatic Adjustment (GIA). GIA is still causing uplift of the North American continental crust in areas close to the centre of former ice sheets, such as Hudson Bay, and subsidence in regions that were on the edge of former ice sheets, such as the southern part of Atlantic Canada, as shown in Figure 2-5. On the west coast, active tectonics, and, on the Fraser delta, sediment consolidation (Mazzotti et al., 2009), contribute to vertical land motion.

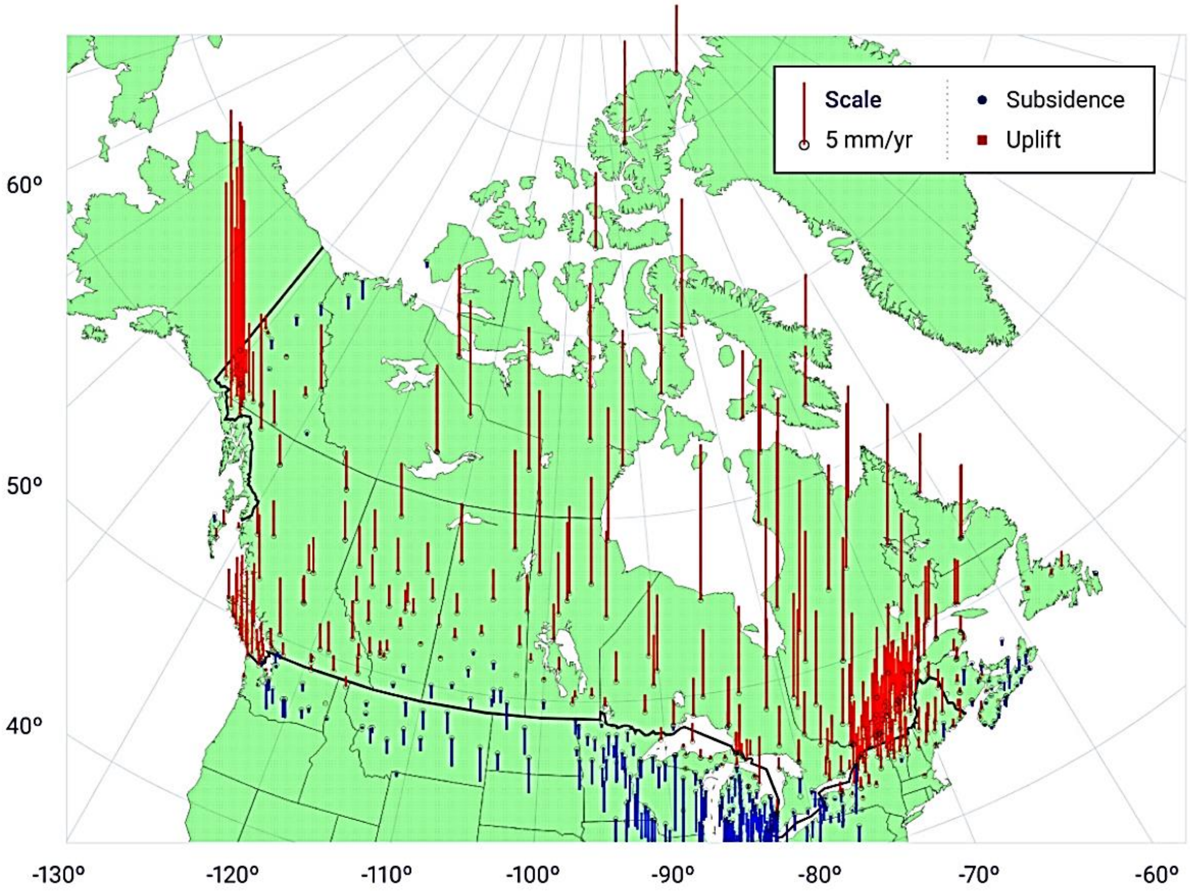


Figure 2-5 Crustal Uplift and Subsidence Rates for the Canadian Landmass (Craymer and Robin, 2016)

Future projections of climate change in the marine environment indicate that rising sea level and declining sea ice will cause changes in extreme water levels, which will impact Canada's coastlines and the infrastructure. Relative Sea Level (RSL) is defined as the sea level that is observed with respect to a land-based reference frame. RSL changes because of sea level rise, and due to vertical motion of the land.

Hudson Bay coastlines are rising at a rate of 10 mm per year or more. Significant portions of the Canadian Arctic Archipelago coastline are uplifting at a rate of a few millimetres per year from a combination of GIA and the response of Earth's crust to present-day changes in ice mass, whereas the Beaufort Sea coastline in the western Arctic is subsiding due to GIA at a rate of 1–2 mm per year. The effects of vertical land motion are evident in tide gauge records (see Figure 2-6), where the land is uplifting rapidly due to GIA, such as at Churchill, Manitoba (on Hudson Bay).

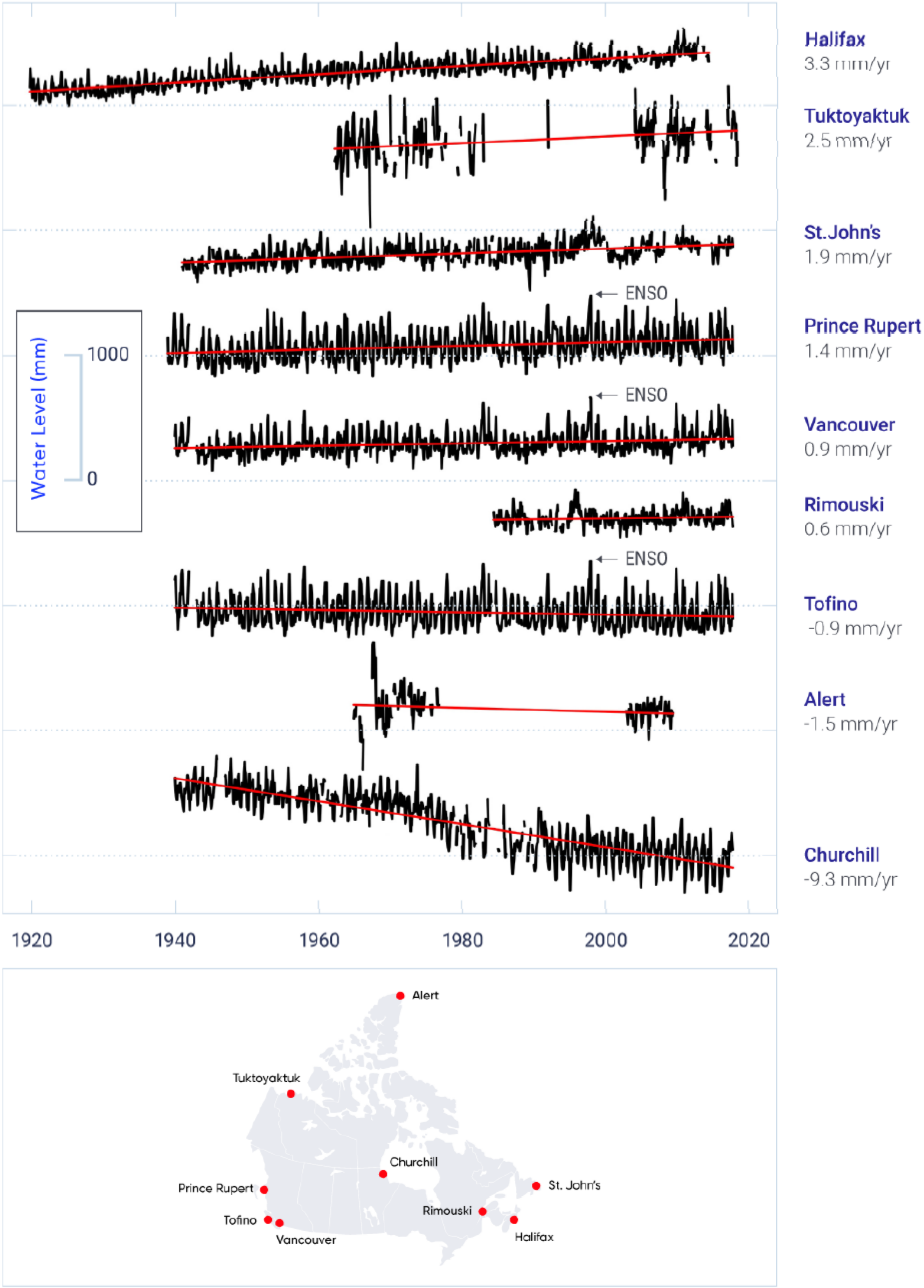


Figure 2-6 Long-Term Trends of Relative Sea-Level Change at Representative Sites Across Canada (Ref: CCCR 2019)

This graph shows that due to the land uplifting at Churchill, Manitoba (on Hudson Bay) due to GIA, sea level has been falling rapidly, at a rate of 9.3 mm per year. Assuming the same condition is applicable for the east coastline of the Hudson Bay, a RSL level change of -9.3 mm/yr is expected at the study site in the long term.

For this conceptual design, the design water level was estimated as 2.7 m/CD by summing the higher high water, mean tide (HHWMT) (+1.7 m/CD) and 1.0 m storm surge, without considering estimated RSL (9.3 mm/year of land uplifting).

2.10 WIND

In the absence of site-specific data, recorded wind information at the Kuujjuarapik Airport, located at 55°17’00” N, 77°45’00” W, approximately 1.2 km east of the Hudson Bay shoreline in the village of Whapmagoostui/Kuujjuarapik, and ~6 km south-west of the study site, was used to evaluate the wind condition at the proposed harbour area.

Wind records at the airport station are available between 1957 and present day. The wind rose graph below (Figure 2-7) shows the overall wind condition from 1957 to 2022 recorded at the Kuujjuarapik airport.

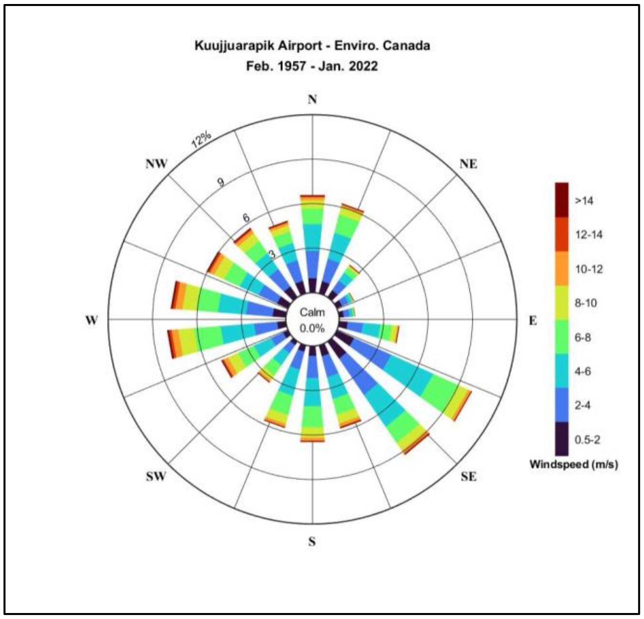


Figure 2-7 Windrose - Kuujjuarapik Airport 1957-2022

The predominant direction in the wind rose is southeasterly but stronger winds also occur from westerly sector. The average wind speed is approximately 5 m/s.

Figure 2-8 present a comparison between wind data measured during the ice seasons and ice-free seasons between 1957 and 2022. These two wind roses show that during the winter (ice) season, there is an increase of winds approaching from the southeast and east-southeast, whereas in the open water (ice-free) months, the prevailing wind direction is from the west. The southeasterly winds are from overland and do not influence the wave condition at the site.

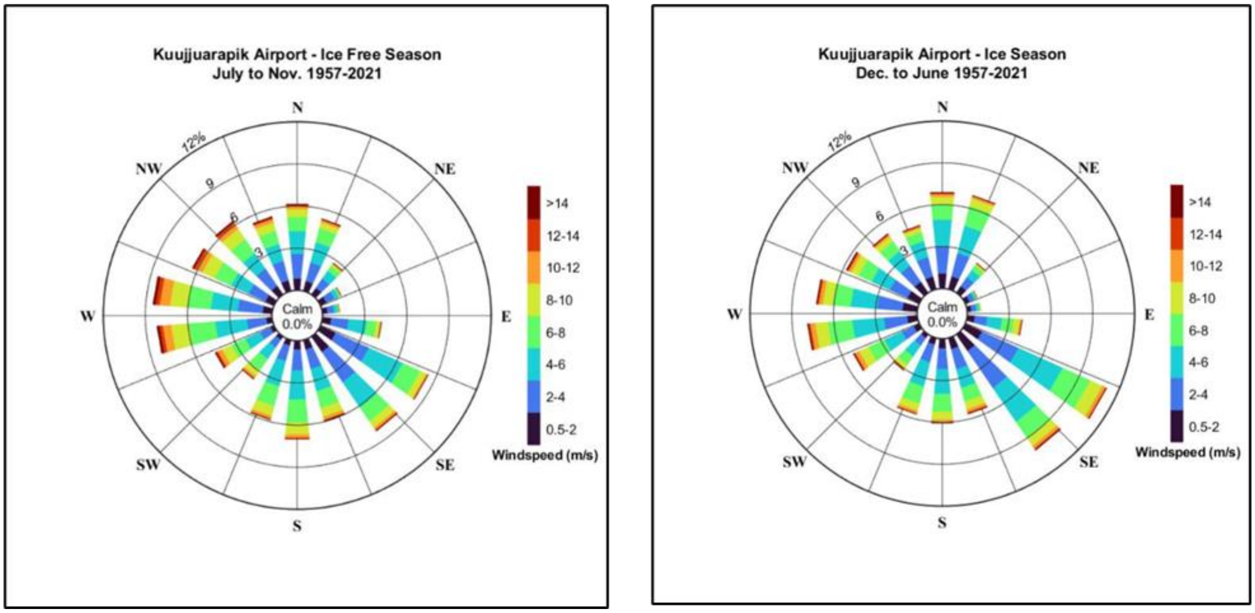


Figure 2-8 Windrose - Kuujjuarapik Airport 1957-2022 Ice-Free Season (Left) and Ice Season (Right)

Figure 2-9 presents the Extreme Value Analysis (EVA) performed on the wind data for all sectors (omni-direction), NW, and SE directions.

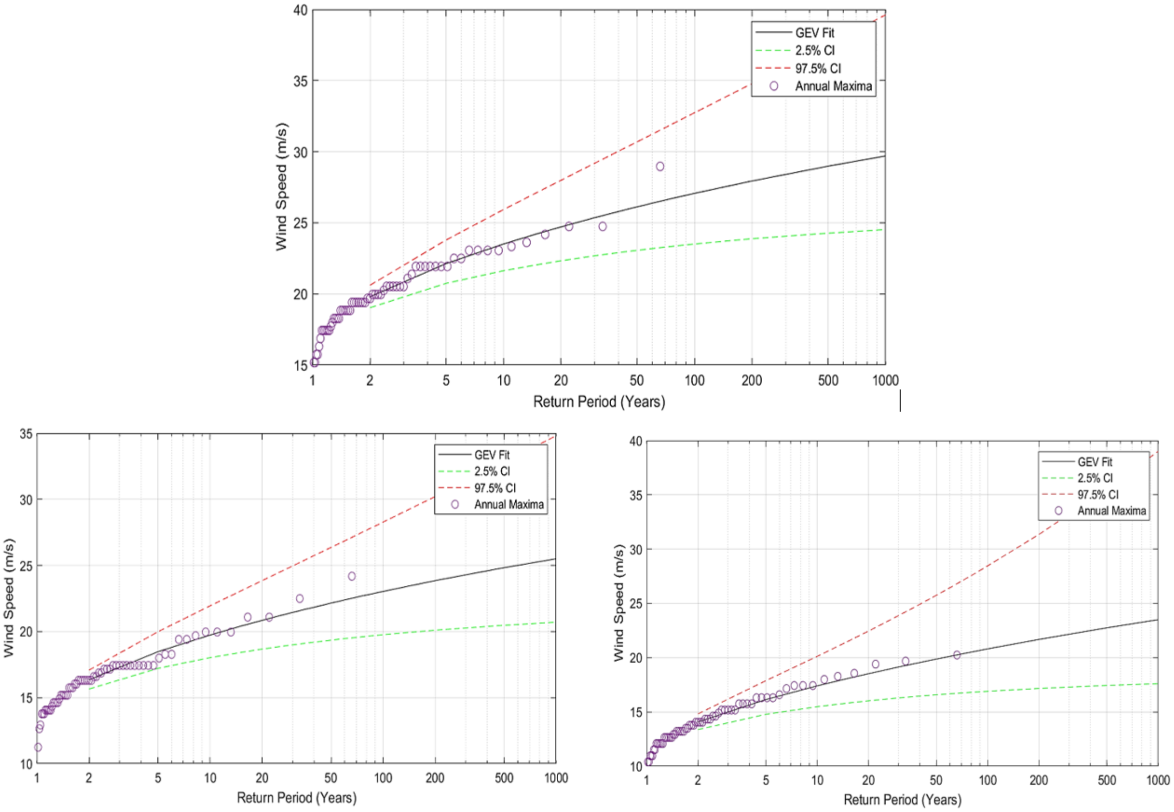


Figure 2-9 Extreme Value Analysis Results (Open Season): All Sectors (Above), NW (below left), and SE (Below right)

Based on the available information and high-level assessment of wind data, design wind speeds of 27 m/s, 23 m/s, and 21 m/s were selected as 100-year events for all sectors, NW, and SE directions, accordingly.

2.11 WAVES

Published wave data for the southeastern area of Hudson Bay is sparse. Below is the high-level information gathered regarding the wave condition in the vicinity of the studied area, and presented in the Technical Note 13A:

- Based on limited observations during the summers of 1991 and 1992 at the Whapmagoostui/Kuujjuarapik beach, wave heights vary between 0.2 – 1.2 m (median wave height of 0.5 m) with wave periods of 2 – 5 seconds (Ruz, 1994a).
- During the summer months, the Whapmagoostui/Kuujjuarapik area is dominated by westerly waves (Ruz, 1994a), which is expected due to the increase of westerly winds during the ice-free season.
- As noted in Section 2.9.2, local waves with significant heights less than 1 m were recorded in the fall of 1999 at the mouth of the Great Whale River, while during a four-day storm event, wave heights over 3 m for 15 hours were also observed.
- Long fetch lengths of approximately 1000 km combined with strong W and NW winds during storms lead to the development of large wind generated waves. The Ropars 2011 report refers to a wave hindcasting done using wind data collected from the Kuujjuarapik airport, and the analysis generated significant wave heights exceeding 4.8 m on average per navigation season and 6.0 m for a 25-year return period at the entrance to the Manitounuk Sound. Nearer to the shoreline, the significant wave height of 1.7 m and 2.2 m for a 25-year return period was reported.

The area proposed for the SCH is relatively shallow (water depths of ~4 m/CD). Using the estimated design water level of +2.7 m/CD, the water depth during design storm event will be ~6.7 m. In the absence of a wave conditions assessment, a maximum breaking wave height of 3.4 m was used as the design wave condition in this conceptual design.

The estimated wave condition used in this conceptual design has not considered wave generation/hindcasting, wave/seabed interaction (e.g., shoaling and refraction) and also wave diffraction; therefore, it is recommended to simulate wave condition in the next phase of the study to determine operational and extreme waves at the proposed site, and also conduct a wave measurement program to calibrate/verify the results.

2.12 CURRENTS

Currents may be driven by a combination of winds, waves, and tides. A major portion of the current energy in the region is associated with the tides and winds. The nearshore currents in the surf zone will also be driven by waves. Ropars (2011) summarizes the currents for the considered areas near Whapmagoostui/Kuujjuarapik to be weak (and according to CSSA 1992, approximately 0.3 m/s). However, the study site may be impacted by stronger tidal and sometimes wind induced currents due to its location in the Manitounuk Sound (Ropars, 2011).

For this conceptual design, it has been presumed that ambient current will have minimal/no impact on the harbour arrangement and berthing facilities, and therefore has not been included in the design.

2.13 SEDIMENT CONDITIONS

As stated in the Technical Note 13A, sandy pocket beaches are present between bedrock headlands and pebble/cobble banks along the coastline in the vicinity of the studied site. Examples of beaches in the study area are presented in Figure 2-10. Because of local water circulation, the Great Whale River freshwater plume tends to extend northeastward, acting as a source of sediment for beach deposition in the study area (Hequette and Tremblay, 2009). A 1.6 km long beach located 4 km east of the mouth of Great Whale River was characterized by Hequette and Tremblay (2009).

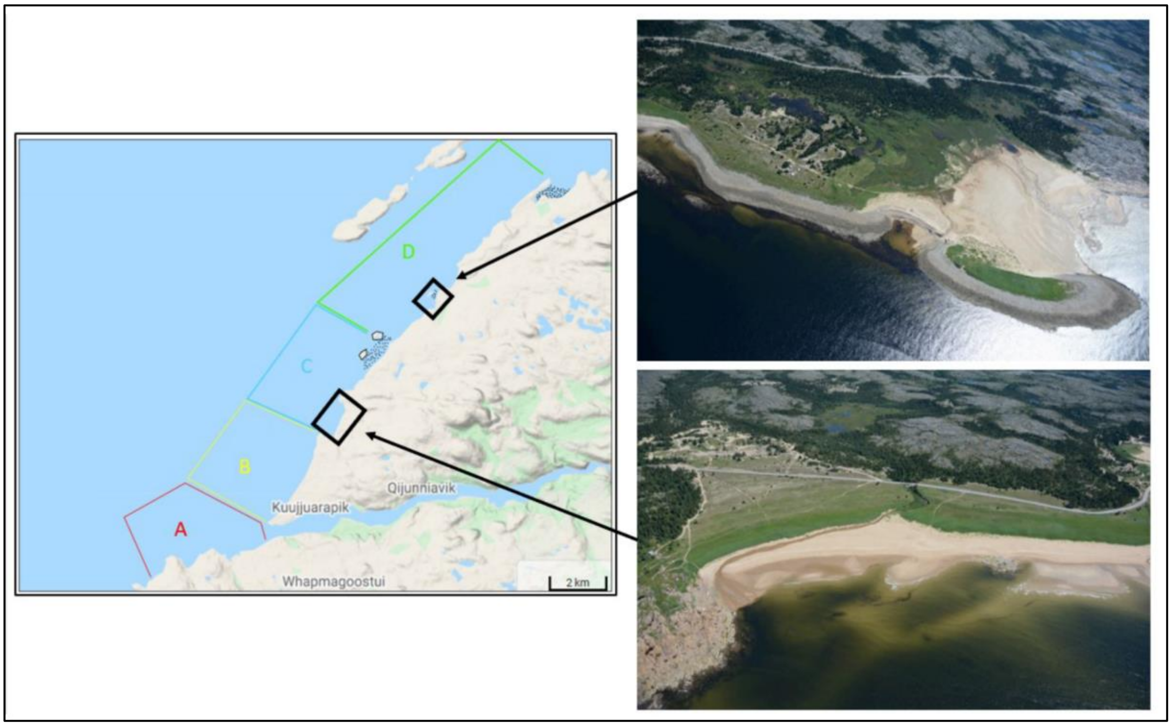


Figure 2-10 Examples of Pocket Beaches Located in the Study Area (Images from Boisson et Al. 2015)

The intertidal zone is approximately 100 m wide, with an average foreshore slope of 5%, decreasing to about 2% on the lower beach. The nearshore zone is characterized by parallel longshore bars and troughs that dissipate the energy of the incoming waves. The main parameters responsible for sediment movement along beaches are wave energy and velocity of longshore currents induced by obliquely incident waves (Hequette and Tremblay, 2009).

Low dunes (<5 m high) have formed landward of the sand beaches. Progressively raised dune ridges are also present, interpreted as relict dunes rose to higher elevations by isostatic uplift (Ruz and Allard,1994b). Dunes on the eastern Hudson Bay coast tend to form on open-ocean coasts with large fetch lengths (Boisson and Allard, 2018). To the northeast, because of more sheltered conditions within Manitounuk Sound, dunes are absent from the coastline.

It is recommended to conduct a site-specific geomorphological assessment and evaluate the potential impact of constructing a SCH on the shoreline morphology and longshore/cross shore sediment regimes in the next phase of the study.

As stated in the Technical Note 13A, landslides have been reported upstream from the mouth of Great Whale River. The landslides result in episodes of high sediment load and cause constrictions in the river. A potential concern is the impact of high sedimentation rates, which may result in a clogged waterway or navigation hazard, affecting operability of the existing natural beach harbour.

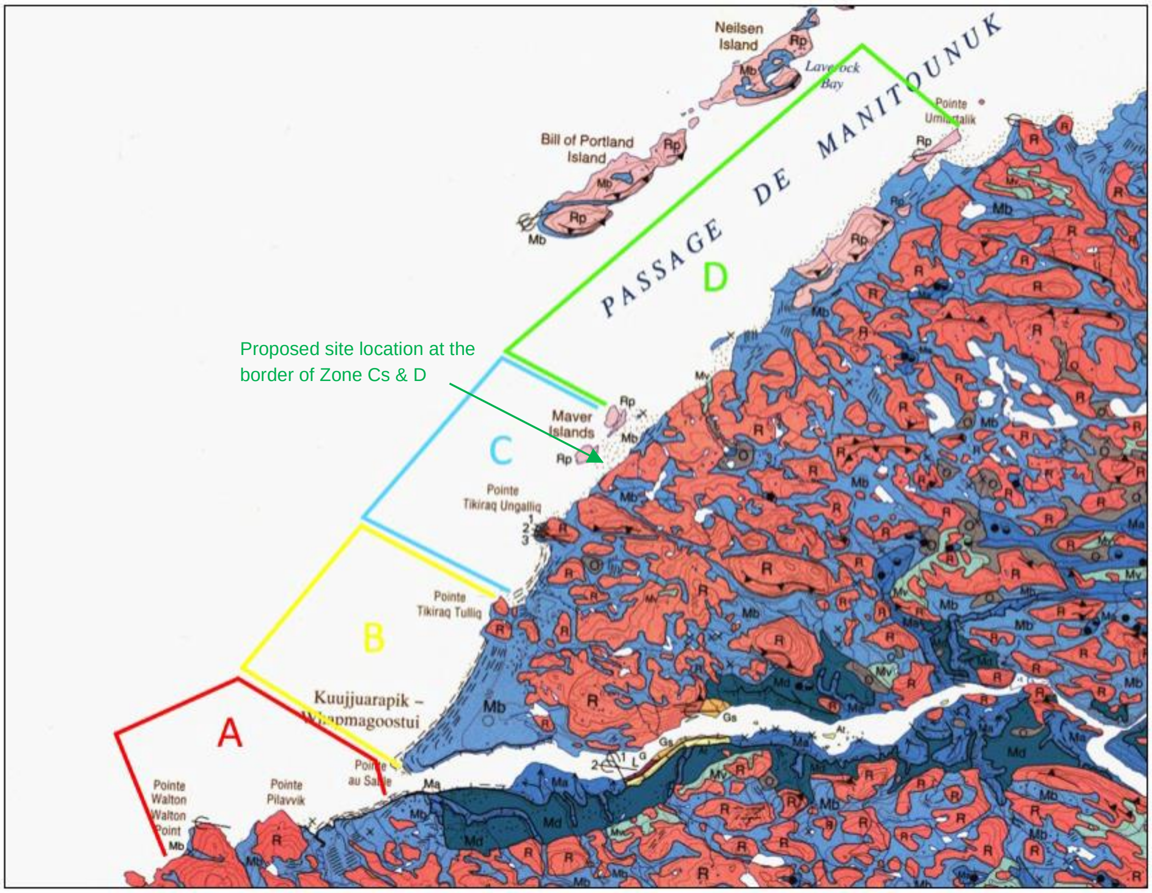
2.14 GEOTECHNICAL/GEOLOGICAL CONDITIONS

Most of the shoreline of the studied area is composed of bedrock and with smaller pocket beaches in the southwest portion of the site. The bedrock shoreline is stable in context of erosional processes, whereas beaches may potentially be susceptible to erosional processes. It is likely that most sediment from Great Whale River is driven northeast by longshore currents, though less than in Zone A or Zone B because of the sheltered conditions from dominant westerly wind conditions during ice-free conditions.

Figure 2-11 presents a morphology map from the study area produced by Le Bureau de la Connaissance Géoscientifique du Québec (BCGQ) (Brouard et al., 2020). According to the map, the shoreline of the study area is mainly composed of:

- Archean Bedrock which is a metasedimentary, metavolcanic and intrusive rocks of the Archean.
- Coastal and pre-coastal sediments which is from 0.5 to 5 m thick deposited along the relict shores of the Tyrell Sea, also including pro deltaic sediments close to large deltaic complexes. Surface generally marked by beach ridges and sometimes modified by wind action.

Within the estuary section of the Great Whale River, soil deposits are mainly composed of deltaic, pro deltaic, and deep water fine glaciomarine sediments (Md and Ma), consisting of clay, silt, and gravel. Landslides are recurring in these soils, often initiated by river processes and contribute to sediment yield into the study area (Owczarek et al. 2020). Table 2-3 presents the legend for the morphology map.



Proposed site location at the border of Zone Cs & D

.

Figure 2-11 Distribution of Morphology around the Study Area (Brouard et al., 2020).

Table 2-3 Coastal Morphological Unit Legend

CLASSIFICATION	CODE	GROUP	DESCRIPTION
Rock	Rp	Proterozoic Bedrock	Volcanic and sedimentary rocks of Proterozoic.
	R	Archean Bedrock	Metasedimentary, metavolcanic, and intrusive rocks of the Archean.
Sand, Gravel Pebbles, Blocks	Mb	Coastal and pre-coastal sediments	0.5 to 5 m thick; deposited along the relict shores of the Tyrell Sea; also including pro deltaic sediments close to large deltaic complexes; surface generally marked by beach ridges and sometimes modified by wind action.
	Mv	Thin prelittoral and reworked till	<0.5 m or till reworked on a thickness of <0.5 m deposited in shallow water deep in the Tyrell Sea; surface controlled by the bedrock topography of the underlying till.
Sand, Gravel	Md	Marine and Glaciomarine deposits	1 to 40 m thick; deposited at the mouth of rivers flowing into the Tyrrell Sea; surface generally marked by abandoned channels and sometimes modified by wind action.
Clay, Silt	Ma	Deep Water Marine Sediments	0.5 to 20 m thick; deposited by streams, gully and mass movements; surface generally covered with a thin peat layer and modified by the presence of palsas.

Figure 2-12 presents the morphology map superimposed on the aerial image of the studied area. This figure shows that competent rock accessible in the vicinity of the studied site.

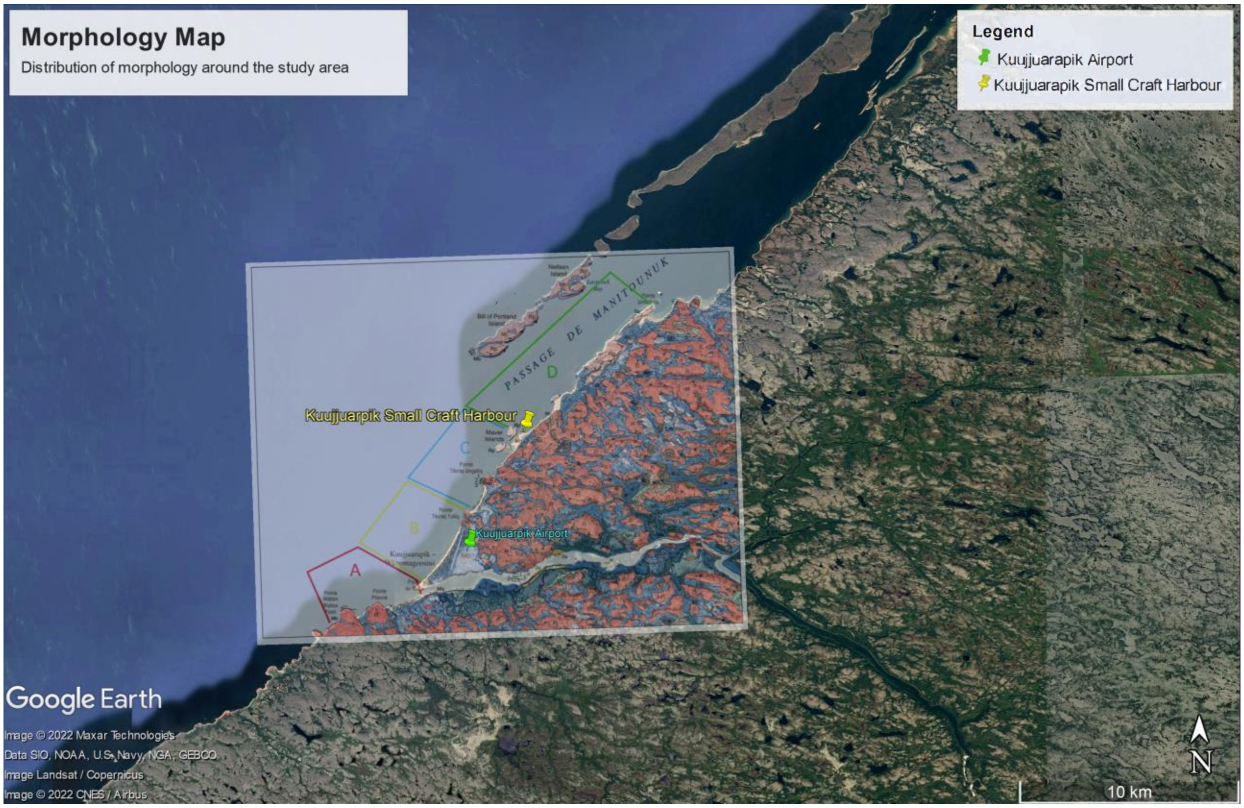


Figure 2-12 Aerial Imagery for Distribution of Morphology Around the Study Area

For areas of land above 20 m elevation landward of the studied site, the total estimate permafrost content is greater than 10-20%.

Based on the limited information provided, it is assumed that rock material in a variety of sizes needed for construction of the harbour, including large armour stones to be used for breakwater and slope protection construction, will be sources and quarried locally in the vicinity of the studied site.

2.15 DREDGING

In the absence of site-specific geotechnical data, and considering limited onshore information, a hard or rocky seabed may be expected. Therefore, the harbour conceptual arrangement is designed in such a way that it will provide sufficient water depth for safe arrival, departure, maneuvering and berthing of design vessels without any capital dredging.

2.16 WAVE HEIGHT LIMITS IN HARBOUR AREA

The harbour area where the vessels are moored, and load/unload needs to be protected from incident waves during the operating (ice free) season which is considered from July to November. As per the recommendations provided by the *Canadian SCH Design Guideline*, a significant wave height of 0.25 m is selected as the operating threshold condition for the Whapmagoostui/Kuujjuarapik harbour.

2.17 REQUIRED WATER DEPTH

The minimum water depth required for the design vessel is calculated using the maximum design draft and minimum Under Keel Clearance (UKC). Based on the available guidelines, the minimum allowance for UKC is equal to 0.5 to 0.6 m for soft bottom and 0.75 to 0.9 m for hard or rocky bottom basins/channels. In the absence of geotechnical information, hard bottom and 0.75 m UKC is assumed.

Minimum water depth required is summarized in Table 2-4.

Table 2-4 Minimum Required Water Depth

CRITERIA	VALUE (M)
Vessel Draft	1.2
Under keel Clearance	0.75
Maintenance dredging allowance	0.75
Minimum Water Depth Required (below Chart Datum)	2.70

Depending on the anchoring system selected for the dock floats, additional water depth may be required to provide sufficient clearance from the vessel to the top of the anchors. This needs to be designed in the next phase of the study.

2.18 BREAKWATER AND SLOPE PROTECTION DAMAGE CRITERIA

As explained in Section 3.3, the conceptual design proposed for the harbour layout includes a shore-connected breakwater to shelter the berths/floats from the incident waves. This rubble-mound structure primarily consists of:

- Core - relatively small stones to build the breakwater structure.
- Armour stones to protect the core from reshaping and damage by waves and ice.
- Underlayer placed between the core and armour layer to prevent the core material escaping through the armour layer voids and destabilizing the structure.

The armour layer protecting the breakwater is designed for “No Damage” criterion corresponding to 0-5% damage in design wave event consisting of HHWMT and 100-year wave condition (considering it will be depth limited).

3 CONCEPT DESIGN

3.1 INFRASTRUCTURES REQUIREMENTS

The primary step in developing a harbour design is to identify, assess, analyze the proposed infrastructures project's requirements and operations' needs. As the Whapmagoostui/Kuujjuarapik SCH will be a fisheries harbour, the infrastructure needs to include harbour space requirements, fishing fleet berthing/support requirements and onshore area/facilities requirements.

The total number of fishing boats and the berth length needed for each vessel (or vessel-meter) will provide a preliminary indication of the total berthage required in a harbour. As noted in Section 2, in addition to providing berthing facility to 20 fishing boats, the harbour will also include a ramp for accommodating a dedicated barge to transfer the goods and commodities offloaded from *Desgagnés* or others that perform the few annual Sealift operations (Figure 3-1). The barge is pushed and pulled by a tugboat such as the *Kodiak*. The *Kodiak* and the transfer barge are both parts of a typical Sealift operation and come on the deck of the vessel.

Section 2.5 provides the specifications for the design vessels visiting the harbours including fishing boats and the transfer barge. The fishing boat specifications have been obtained from the *Canadian SCH Design Guideline*, and the barge dimensions are approximate and have been scaled using available pictures.

Figure 3-1 Design B

3.2 HARBOUR GENERAL LAYOUT

It is likely that the construction of a SCH to serve the community would fall under the jurisdiction of the Department of Fisheries and Oceans (DFO). DFO has not yet been consulted about this concept and before this concept were to be explored any further, they would obviously need to be consulted. The permitting, funding and approval for such new facility is a lengthy process which needs to be carefully planned and for which all stakeholders, especially the nations involved in and benefiting from need to be identified and carefully consulted with.

Knowing, however, that DFO's guidelines for SCHs would likely need to be followed, WSP has used *Harbour Accommodations Guidelines for Small Craft Harbours (SCH) - Branch Fisheries and Oceans Canada* (Public Works and Government Services Canada, 2015) to complete the conceptual layout.

Figure 3-2 presents the conceptual layout proposed for the Whapmagoostui/Kuujjuarapik Small Craft Harbour, considering the infrastructures requirements and design criteria presented in Section 2.

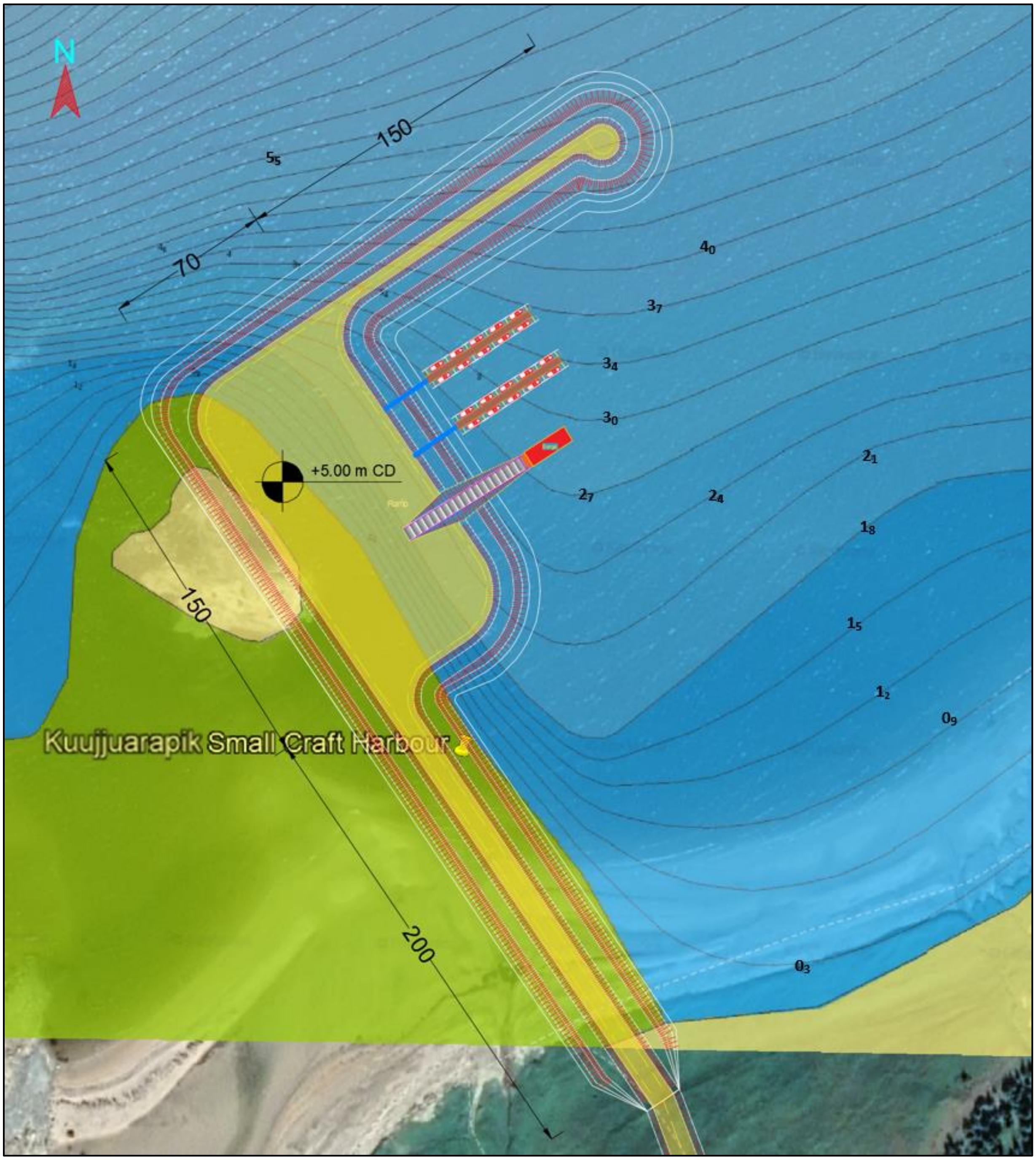


Figure 3-2 Proposed Harbour Layout

The proposed layout consists of harbour areas and floats to moor the fishing vessels, shore access ramp for transfer barge and launching boats, reclamation area for onshore facilities, breakwater to provide shelter for incident waves and access causeway to connect the harbour to local roads. As shown in Figure 3-2, in order to utilize the sheltering provided by Îles Qikirtaaruit for incident waves and reduce the fill volume, the proposed harbour is located on the edge of the intertidal area and connected to the small island.

This offers the extra advantage that if there were to be ever a requirement for a Deep-Water Harbour in the future, the causeway could become a shared causeway, and this prolongation could serve as a trestle and berth. Deep water (18.0 m) is the closest to the shoreline at this spot, for all areas A, B, C and D as described in Figure-2-1.

The harbour arrangement will be revisited and updated (if required) in the next phase of the study.

3.3 HARBOUR AREAS

The overall area required for a SCH depends on the fleet nature and size, the type of fisheries active in the area, whether the fishing seasons overlap, and the operational constraints/requirements.

The main functions of a typical fishing harbour include providing safe berthage for the fishing fleet while in harbour, providing service area to users to load gear, off-load their catch and maintain their vessels, and providing facilities to launch and remove boats from the water.

The harbour area and layout plan proposed for the Whapmagoostui/Kuujjuarapik harbour accommodates a combined berthage and service areas, floats, and fairways.

This section provides a brief description of harbour areas and the rationale for determining their arrangement.

3.3.1 BERTHAGE REQUIREMENTS

Two types of berthing structures, fixed and floating, are typically used in a SCH. In this conceptual design, floating structures, with multi-vessel tiers parallel with the face of the floats, have been selected as the preferred solution because:

- Floating structures are commonly more cost-effective for small harbours.
- Floating wharf docks remain at a constant height above the water surface; therefore, tidal range does not affect the deck freeboard, berthing face and mooring arrangement, and access to and from the vessels.
- A fixed berthing structure may not be feasible for the selected site due to potential ice loading. As briefly noted in Section 2.8.2, it is assumed that floating structures will be collected and transported to shore during wintertime, to prevent ice impact. This also implies that no piles or fixed structures should be used as part of the design to prevent being destroyed by the ice impact.

The length of the wharf required for safe and efficient berthing of a vessel depends on the exposure to wind, wave agitation in the harbour and tidal range. In the absence of harbour tranquility and wave agitation studies in this phase of the study, the following ratios of berth length to design boat length, as recommended in the *Canadian SCH Design Guideline*, are used for conceptual planning purposes (See Table 3-1).

Table 3-1 Ratios of Berth Length to Design Boat Length

Tidal Range	Wharf Tier Frontage Per Tier	Tier Spacing	Vessels Per Tier	Vessel-meters per metre of wharf vm/m
Tidal Range = 2 to 3 m	1.5 x L	1.0 x L	1	0.67

Using the design vessel characteristics and design criteria presented in Section 2, the total berthage length required for fishing boats is calculated as ~200 m.

3.3.2 SERVICE AREA

Harbour service areas are typically designated for handling of gears, off-loading of products and maintenance of the vessels. For planning purposes, the service areas are not to be used for berthing of vessels when not in use; however, for this conceptual design, it has been assumed the area requirements for these two functions can be combined.

3.3.3 FAIRWAYS

Fairways are required alongside and/or between berthage and service areas to provide access (see Figure 3-3).

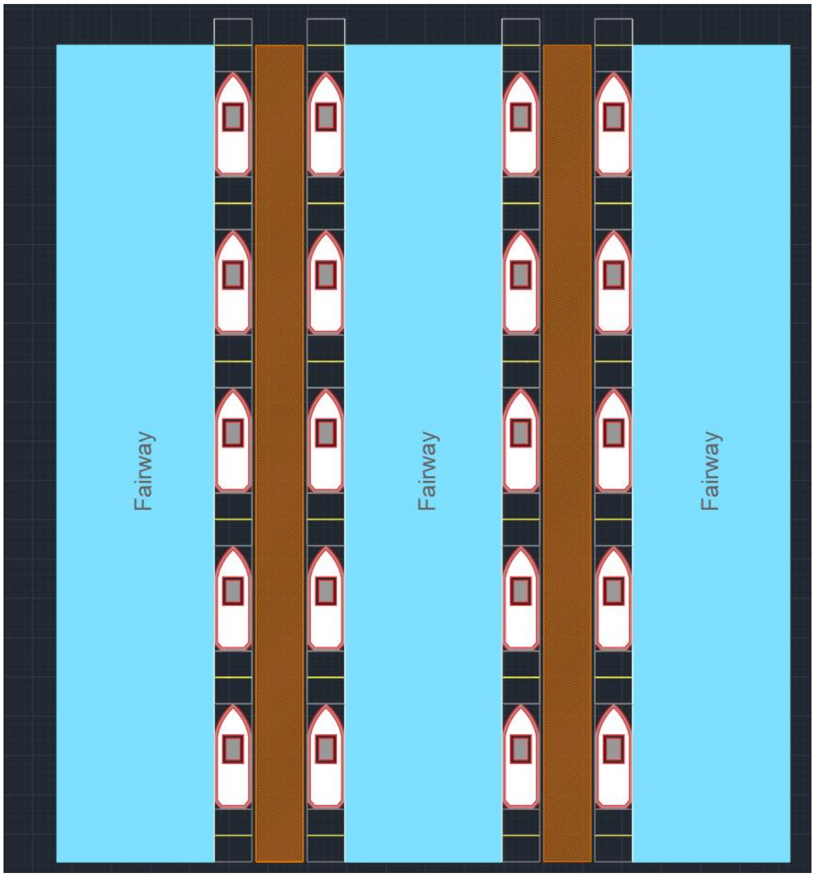


Figure 3-3 Harbour Fairways

As per the *Canadian SCH Design Guideline*, the minimum fairway width is equal to the overall length of the design vessel, so that the vessel will have enough space to swing and enter/leave the berth. In this conceptual design, a fairway width equivalent to approximate twice the overall length of the design vessel (15 m) is selected.

3.4 FLOATS

Floats, or floating wharves/docks, which are commonly used for SCHs, can provide relatively dense berthing patterns at low initial cost. Floats maintain a constant elevation relative to small vessels, and this reduces the rubbing and chaffing associated with berthing at fixed wharves while providing quick and easy access on and off the vessel.

3.4.1 FLOAT TYPE

According to the *Canadian SCH Design Guideline*, a variety of float types are in use across Canada and throughout the commercial fishing industry. In most cases, flotation is provided by discrete boxes or shells, constructed of treated timber cribs, or moulded from high-density polyethylene, filled with polystyrene flotation materials. Floating wharves are comprised of three basic components (Figure 3-4):

- Flotation elements to provide buoyancy for the deck itself.
- Structural frame to receive and distribute the horizontal and vertical loads.
- Deck surface or platform to support the live loads superimposed on the floats.

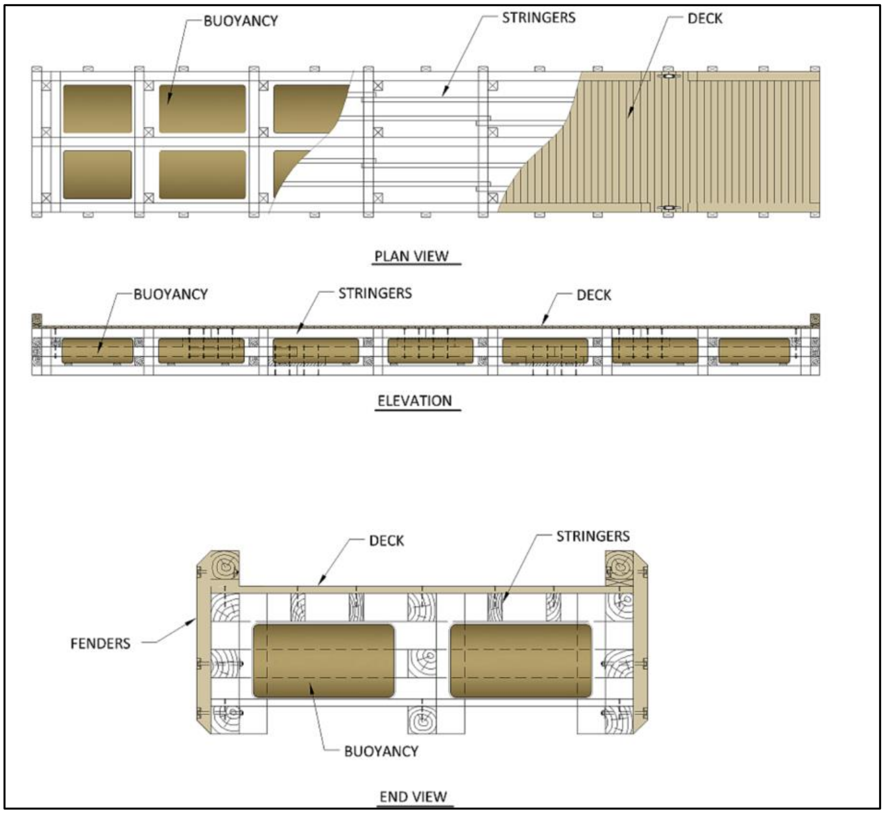


Figure 3-4 Typical Floats Plan view, Elevation, and End View (Ref. *Canadian SCH Design Guideline*)

In addition to separate flotation, the majority of floats in use separate the structural frame from the deck. The frames are usually fabricated of steel, aluminum, or timber. The deck surfaces available include timber decking, precast concrete panels with various finishes and fibreglass panels with a non-skid surface.

In this conceptual design, a modular timber frame floating dock approach is used to facilitate removing and storage of floats annually before the winter (ice) season and transporting/installing them once open season starts.

3.4.2 FLOAT DIMENSIONS

The floating wharves considered in the conceptual design are 3.0 m wide to accommodate safe access of personnel on the float. The length of floats is determined based on the arrangement and size of equipment available to remove the floats before the ice season.

3.4.3 FLOAT MOORINGS

Selection of the optimum harbour mooring system depends upon a number of factors including bottom conditions, water depth, environmental loading due to wind, currents, waves and ice, vessel induced loading, and allowable motions. Mooring systems fall into two basic categories:

- Fixed moorings such as guide piles or gravity structures where the float is fastened to the gravity structure through a guide system or arms; and
- Spread or cable mooring systems in which the floating structure is held in position by chains or cables attached to submerged anchors.

As noted earlier, to prevent ice impact on structures, it is assumed that floats will be collected and transported to shore during winter seasons and reinstalled once operating seasons starts. Therefore, a spread mooring system with submerged anchor blocks and chains attached to the modular floating dock is proposed for this conceptual design. Typical spread mooring system is shown in Figure 3-5.

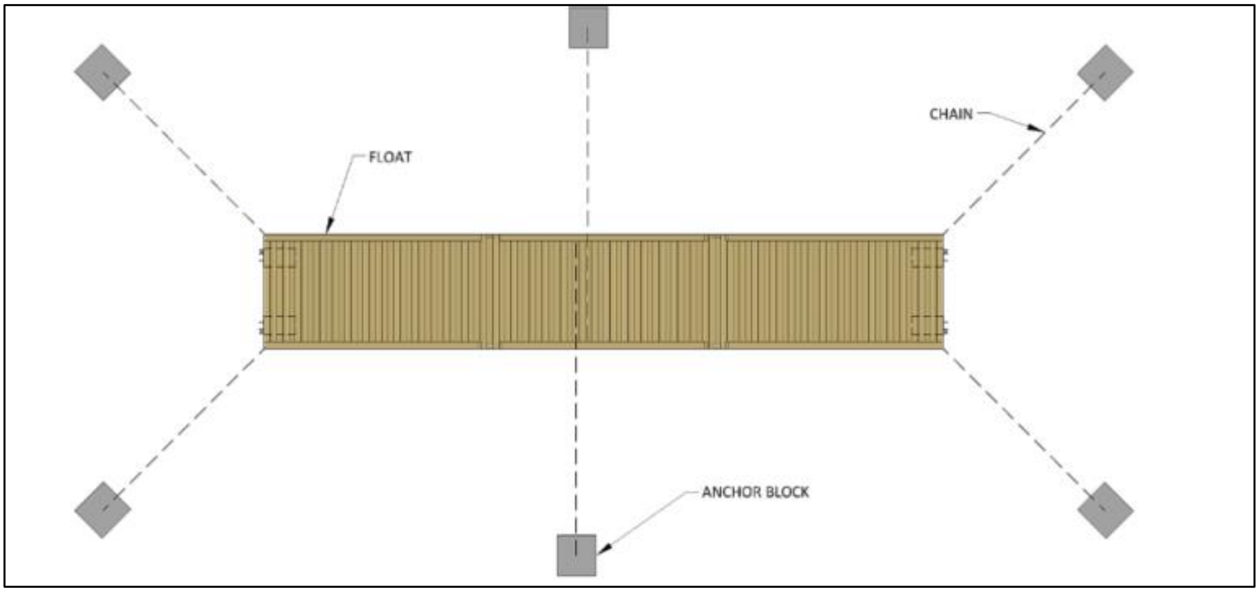


Figure 3-5 Typical Spread Mooring (Ref: *Canadian SCH Design Guideline*)

The float arrangement and mooring system will be revisited and updated (if required) in the next phase of the study.

3.5 SHORE ACCESS RAMP

As noted earlier, one of the elements of the Whapmagoostui/Kuujjuarapik harbour is a shore access ramp, which will be primarily used for loading/offloading of goods and commodities transferred from the Sealift provider to shore via a dedicated barge (See Section 3.1). It is expected that the ramp will also be used for launching fishing boats with a trailer / pickup truck combination.

Typically, access ramp structures are located within the protected area of the harbour and adjacent to the parking area, with adequate areas at the top for the tractor trailers to safely maneuver into a position to back down the ramp. The ramp slope depends on the characteristics of the vehicles to be used to launch the boats as well as the existing topo/bathy data.

The above water portion of the ramp can be either a cast-in-place reinforced concrete slab or a continuation of the precast concrete panels. In this conceptual design, the proposed shore access/launching ramp consists of precast concrete panels fitted with access voids and lifting bars for handling, transportation, and installation. Figure 3-6 illustrates a typical shore access ramp layout and cross section.

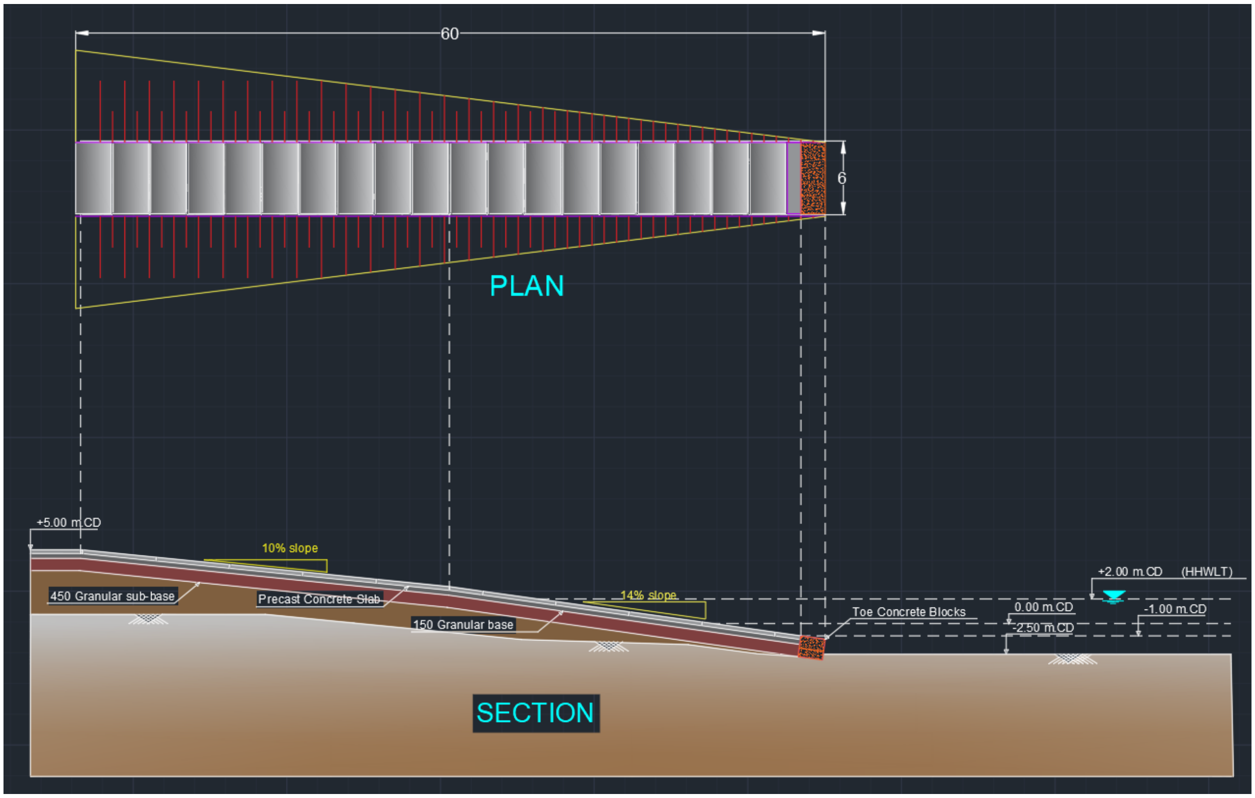


Figure 3-6 Access Ramp

3.6 BREAKWATER

In the absence of harbour tranquility and wave agitation studies in this phase of the study, a 150 m long shore connected breakwater, parallel to the shoreline, has been proposed to shelter the harbour area from incident waves.

Considering procuring armour stones large enough to remain stable in design ice condition (2 m thick) may not be practical, it has been assumed that armour stones with median mass (M_{50}) of 5 t will be used in multiple layers in a zone which will likely be affected by ice (i.e., between -1 m and +3 m/CD), to protect the breakwater. Although placing additional layers of armour stones is expected to improve the strength and durability of the design, the breakwater section may experience some reshaping in colder winters with thicker ice. Therefore, it is recommended to monitor the breakwater profiles and level of reshaping periodically, using bathymetric/topographical surveys, and add armour stones if needed to repair the damaged sections.

For the purpose of providing a high-level cost estimate, it has been assumed that armour stones with median mass of 5 t, underlayer with median mass of 500 kg and core rock with 100 - 1000 mm diameter will be used to construct the breakwater. In the proposed conceptual design, rock material with median mass of 500 kg will also be used to cover the crest (after completion of the breakwater head and moving backwards) and the breakwater profile above the elevation of +3 m/CD. In case maintenance/repair is needed, the contractor needs to remove/stockpile the armour/underlayer rock, build an access road and cover the crest once the repair work is finished.

In the absence of site-specific geotechnical information, it has been assumed that seabed consists of competent material.

Below is a sketch showing the conceptual design proposed for the breakwater (Figure 3-7), using the design criteria gathered/presented in Section 2 and considering the wave and ice impact on the breakwater.

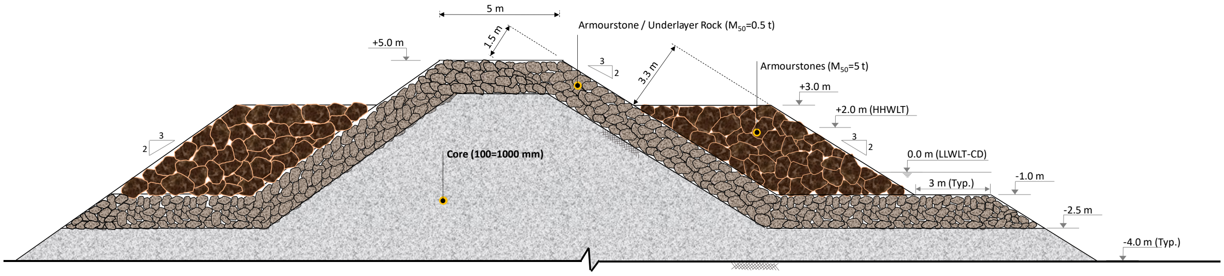


Figure 3-7 Breakwater Typical Cross Section

The breakwater arrangement (position, shape and orientation) and cross section will be further evaluated in the next phase of the design considering the results of metocean studies and berth downtime assessment (and allowable downtime, to be defined in collaboration with the client), geotechnical parameters, availability of rock material (size, gradation, quality, and quantity), constructability aspects (methodology/schedule/equipment/risks), and stakeholders' priorities.

The quarry for the rock is assumed to be located within 500 m from the causeway with competent rock easily accessible at the surface and in the right quantity and quality. Rock outcrops of what is believed to be Archean bedrock are clearly visible on Google Earth images just to the east of the harbour area.

3.7 ONSHORE AREA

In this conceptional design, a reclaimed area of ~70 m x 150 m is provided to accommodate potential onshore operations and functions including service areas, office and parking areas, storage areas (including areas to store the floats during winter seasons), and access roads/approaches.

The arrangement of onshore area will be revisited and updated, if needed, in the subsequent stages of the design considering facilities/operations/services (e.g., electrical, potable and fire water, fuel and waste) required, to be defined in collaboration with the client.

The onshore area slope protection is expected to be affected by ice, therefore, a similar design as proposed for the breakwater can be used for that segment of the infrastructure.

3.8 ACCESS TO LOCAL ROADS

The conceptual design of the harbour includes an access causeway connecting the onshore area to the local roads. Figure 3-8 presents the proposed causeway arrangement.

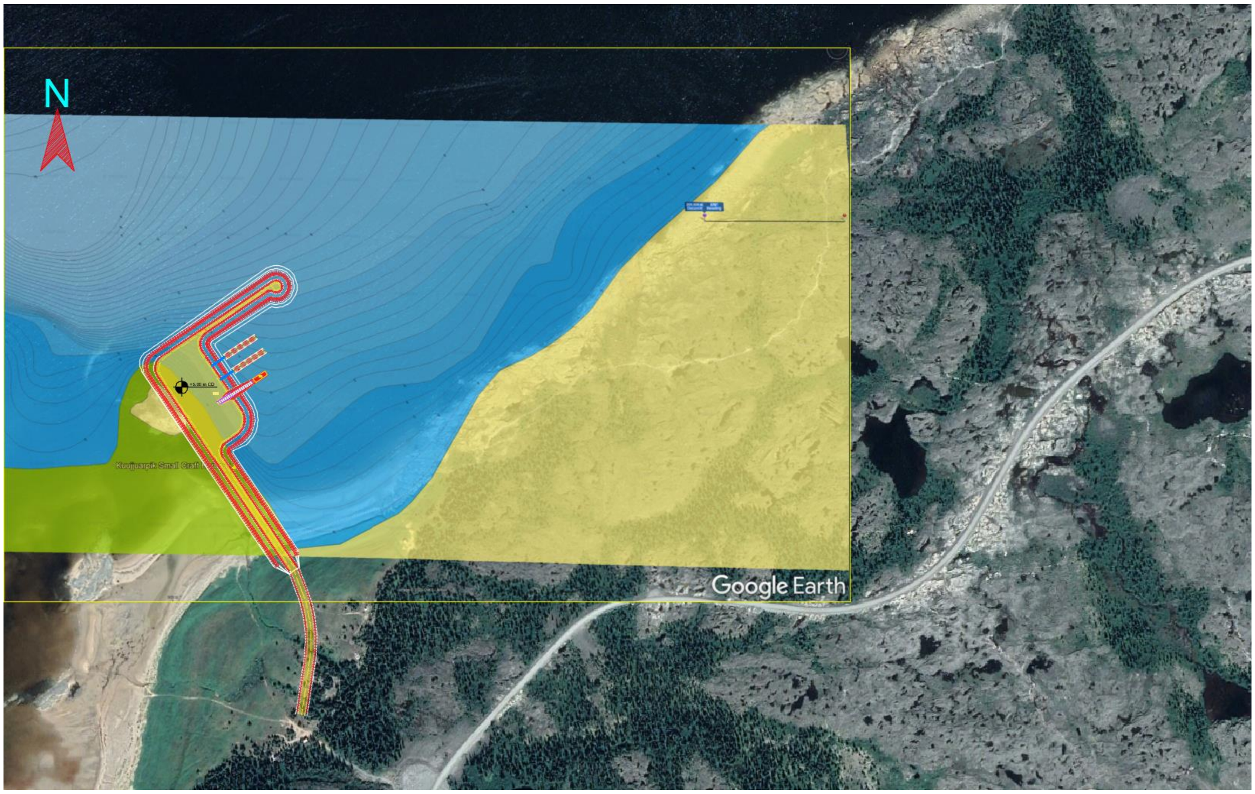


Figure 3-8 Causeway Connection to Local Roads

The high-level design provided for the causeway will be further evaluated in the next phase of the design considering metocean/ice conditions, topography and bathymetry, geotechnical parameters and constructability aspects.

4 CONCLUSION

This Technical Note presents a conceptual design developed for the Whapmagoostui/Kuujjuarapik SCH, to be located along the Whapmagoostui/Kuujjuarapik coastline between the mouth of Great Whale River and the entrance of the Manitounuk Sound in Quebec, and in the vicinity of Îles Qikirtaaruit. The proposed harbour location has been determined using a high-level site selection study and a Multi Criteria Analysis considering several parameters such as physical environmental conditions, coastal and marine morphology, ice dynamics along the coastline, and accessibility.

The selected site and proposed SCH arrangement answer community needs, accommodating fishing vessels and transporting goods from sealift vessels to the shore, and allow for a future development of a Deep-Water Harbour when required. Considering the recent landslide upstream from the mouth of Great Whale River and the perceived risk of excessive sedimentation, the proposed SCH is considered as a mitigation measure providing an alternative to the community in the event that the existing natural beach harbour would become non-operational.

The conceptual harbour design includes several components: floating wharfs for berthing 20 fishing boats, a ramp for dedicated barges to transfer the goods and commodities offloaded from typical sealift vessels, a reclaimed area to be used for onshore facilities connected to shore via a causeway and a breakwater to protect the berthing area from incident waves.

The design proposed for the harbour layout and its components is based on the basis of design presented in this technical note. The basis of design section summarizes design parameters, requirements/constraints, and physical environmental condition gathered (and also assumptions made in case required information were not available). The design parameters selected for this conceptual design will be revisited in the next phase of the study, once site-specific data is obtained and required studies and analysis are conducted. The outcome will be used to revise/advance the harbour design.

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