Appendix G.19
Hatch Report – Pacific NorthWest LNG
Lelu Island
LNG Maintenance Dredging at the Materials Offloading Facility

Project Memo

H345670

December 11, 2014

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Pacific Northwest LNG
Lelu Island LNG

Maintenance Dredging at the Materials Offloading Facility

1. Introduction

Hatch conducted a study for PNW LNG to evaluate the maintenance dredging at the Materials Offloading Facility (MOF). The MOF is a temporary construction facility that is used to dock vessels transporting construction bulk materials and pre-fabricated modules. The MOF is located inside the Porpoise Channel and western side of Lelu Island (Figure 1-1). This location will be dredge creating a potential depositional area for the sediments transported by the local currents at Porpoise Channel.

This study also evaluated the sediment fate and depositional areas of the sediments transported during the Skeena River Freshet.

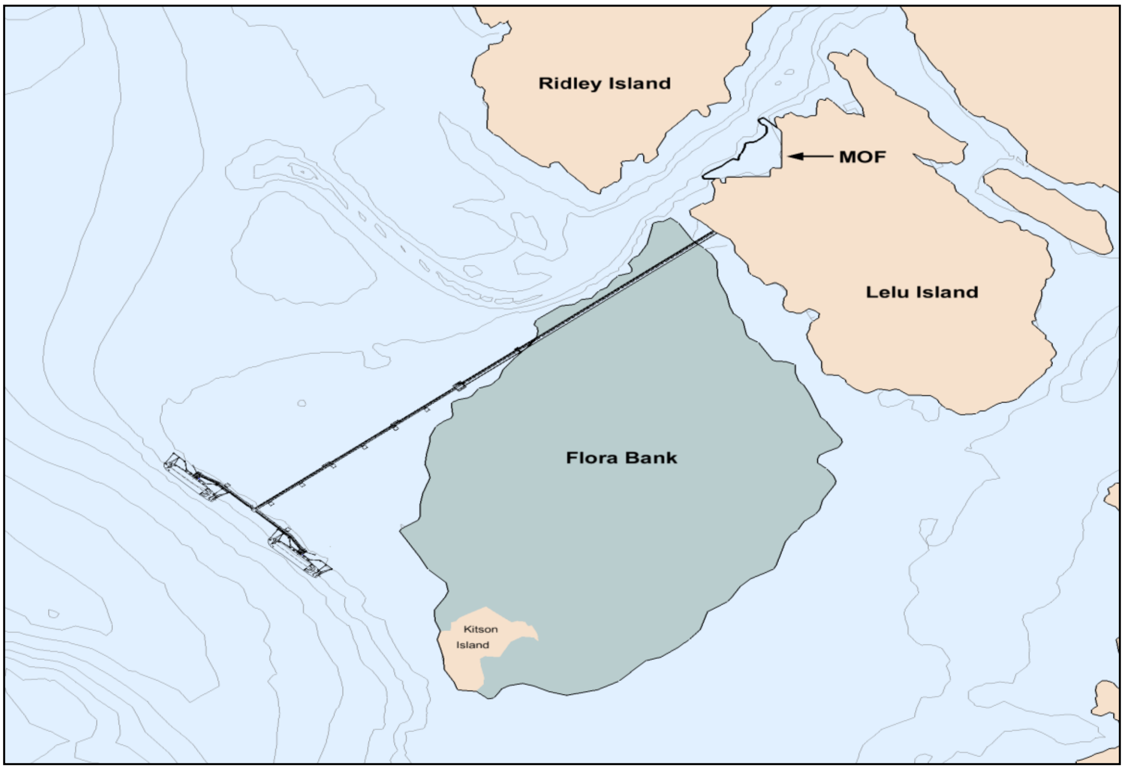

Figure 1-1: Location of the Material Offloading Facility (MOF) at Lelu Island

2. MOF Dredged Conditions

The MOF area will be dredged to -12 m Chart Datum (CD) allowing sufficient depth for the vessels using the facility. Details of the dredging area (plan view) are presented on Figure 2-1 and also on drawing H345670-1000-12-015-0006. Figure 2-2 shows one typical cross-sectional across the Porpoise Channel including the dredging depths.

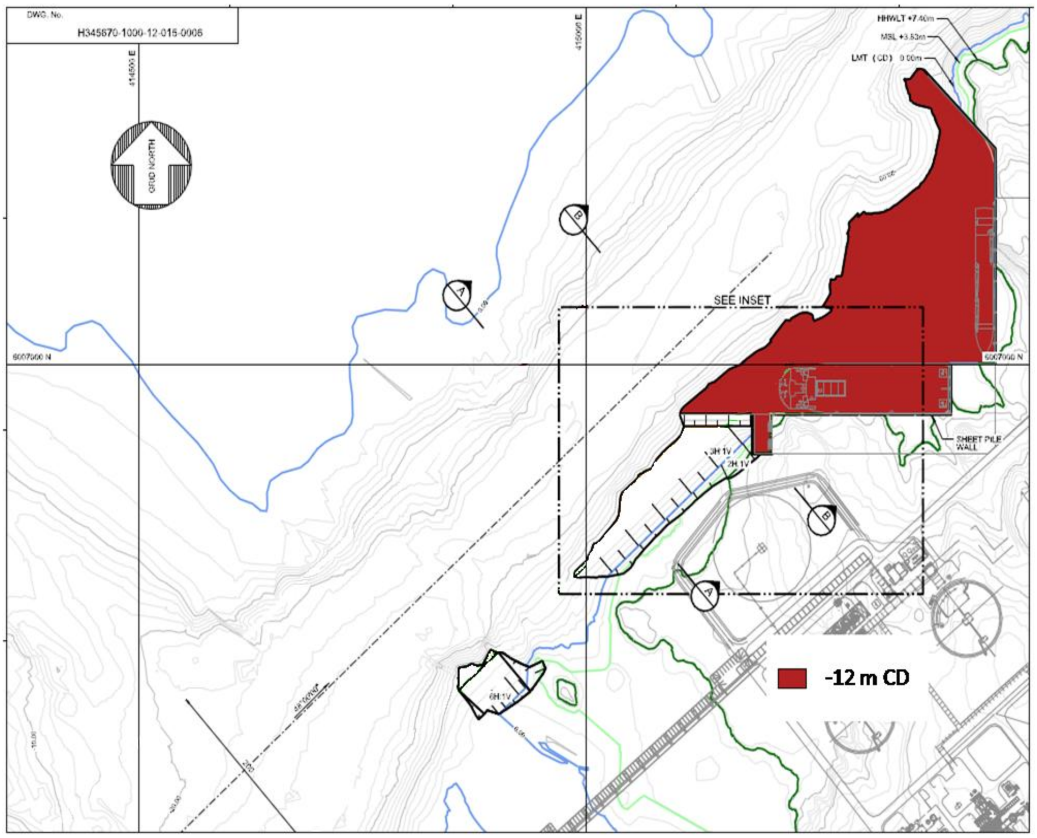

Figure 2-1: Dredged depths at the MOF (modified from H345670-1000-12-015-0006)

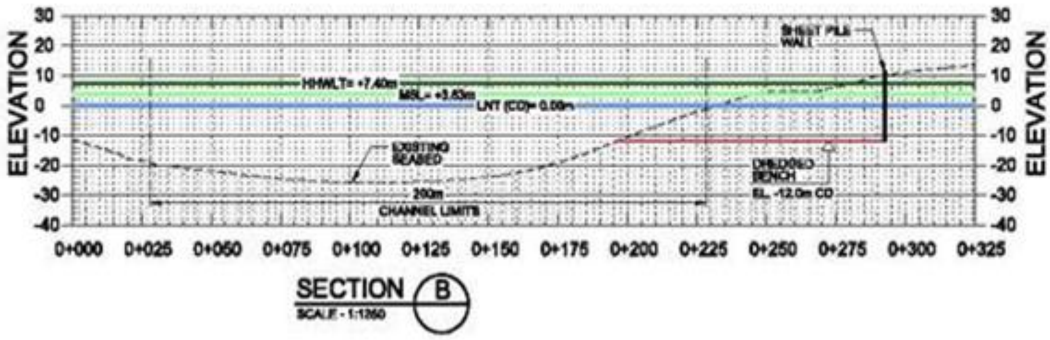

Figure 2-2: Cross-sections of Proposed Dredging Works at the MOF

Section B of Figure 2-2 shows the dredged depths at the MOF area of -12 m CD. Depths across the Porpoise Channel are deeper than -20 m CD and deeper than the proposed dredging depths. Details of the MOF dredging study can be obtained on Hatch's October 22, 2014 Report [2].

3. Hydrodynamic Conditions

3.1 Model Description

The hydrodynamic modelling was conducted using CMS Flow developed by the U.S. Army Corps of Engineers (USACE). CMS Flow is a 2D depth-integrated model for simulating hydrodynamics (currents and water level oscillations) and morphological changes. The model includes physical processes such as wetting and drying areas, river discharges, tides, wind effects and atmospheric pressure. All the results obtained with this model are depth averaged current velocities.

The hydrodynamic simulation included the Skeena River and Nass River discharges. Both rivers have a long time series of river discharge data available on the Canadian Hydrological Database, going back to 1928 (Skeena River – Usk Station) and 1929 (Nass River). The wind measured data was obtained from the Environment Canada Holland Rock wind station, located at 51.17°N, 130.36°W, which has been providing hourly wind data since 1994.

The water level results from the model were calibrated with water level data from Prince Rupert station (54.32°N, 130.32°W), which has measured data from January 1909 to November 2014.

The currents were calibrated using the buoy data located offshore of Flora Bank (54.19°N, 130.34°W) deployed by PNW specifically for this study and further verified with the currents measured by the ADCP inside Porpoise Channel (54.20°N, 130.30°W). Details about the model calibration are presented on a previous technical note [1].

3.2 Hydrodynamic Simulation with the MOF

The hydrodynamic simulation included the dredged area for the MOF, the access bridge from mainland to Lelu Island, the trestle, SW Anchor Block and SW Tower (last two are the structures on the water supporting the suspension bridge). These structures were included in the simulations because they have the potential to change the currents in the area and the sediment pathways.

The period selected to observe the depositional pattern at the MOF caused by the changes in the hydrodynamics was between January 18th 2014 and February 22nd 2014. This is the period when the most severe physical environmental conditions are expected to occur, suspending sediments on shallow areas (Flora Bank, Agnew Bank and Horsey Bank) and when larger deposition is expected at the MOF.

Four different conditions are presented to characterize the hydrodynamic circulation. An ebb tide condition during spring tide (Figure 3-1), where the strongest currents are located on the east and west side of Lelu Island (Porpoise Channel and Inverness Passage) driven by the narrower areas in the channels. The currents are also higher on the shallow areas on Flora Bank and decrease their velocities offshore.

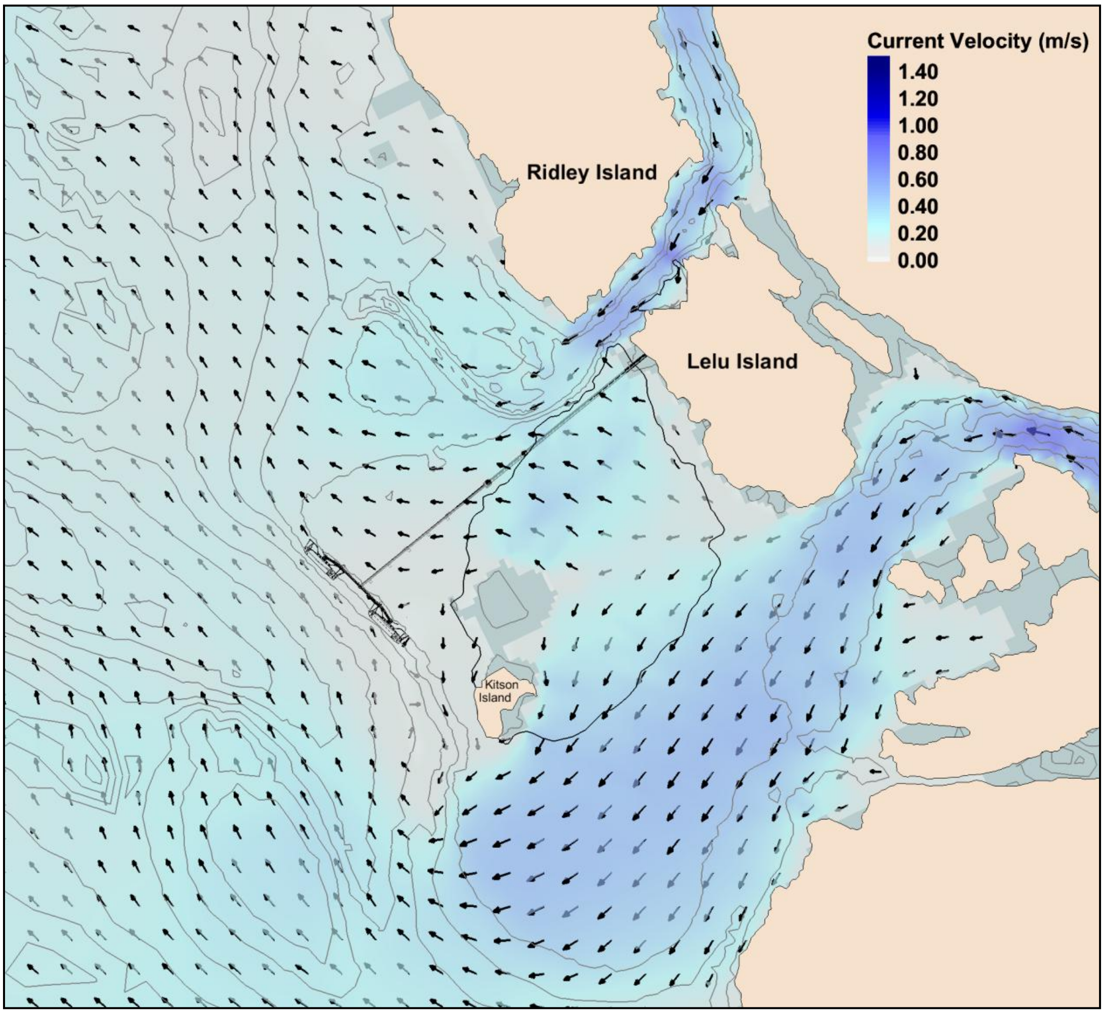

Figure 3-1: Characteristics of the hydrodynamic circulation during ebb tide conditions

The currents during a flood tide condition also accelerate at the Porpoise Channel and Inverness Passage entrances. The MOF dredged area has a localized effect on the currents, however the currents at Porpoise Channel are still strong during flood tides (Figure 3-2).

Figure 3-3 shows the currents during a low tide, when Flora Bank is entirely above water. The currents are weak when compared with the other two situations (ebb and flood tides), since this is a transitional phase between ebb and flood tides and the currents are expected to be weak.

The depth averaged current velocities are generally weak in the LNG terminal area during high tides, this is another transitional period between flood and ebb tides. Flora Bank is underwater during spring tides and the currents are slightly stronger above it, since the depths are relatively shallow (Figure 3-4).

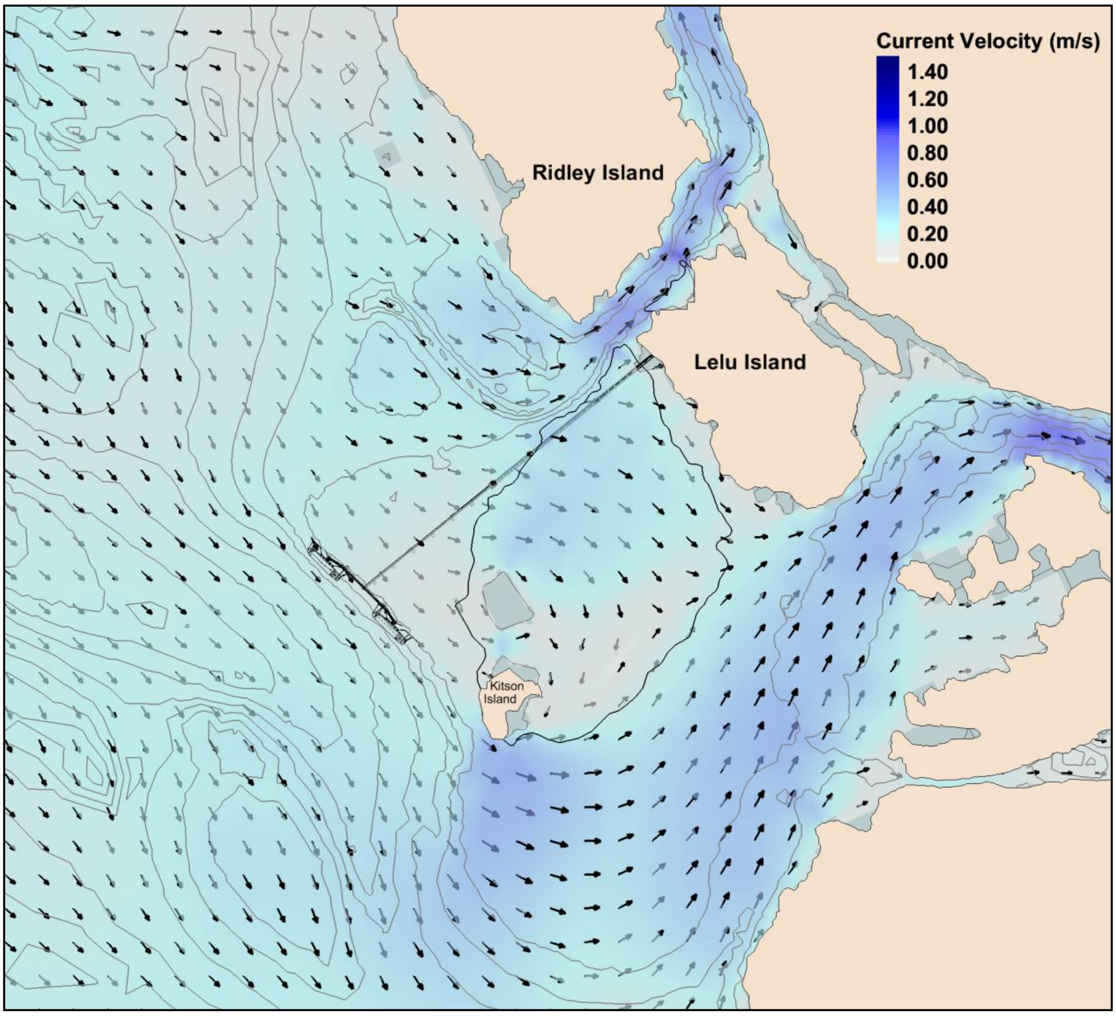

Figure 3-2: Characteristics of the hydrodynamic circulation during flood conditions

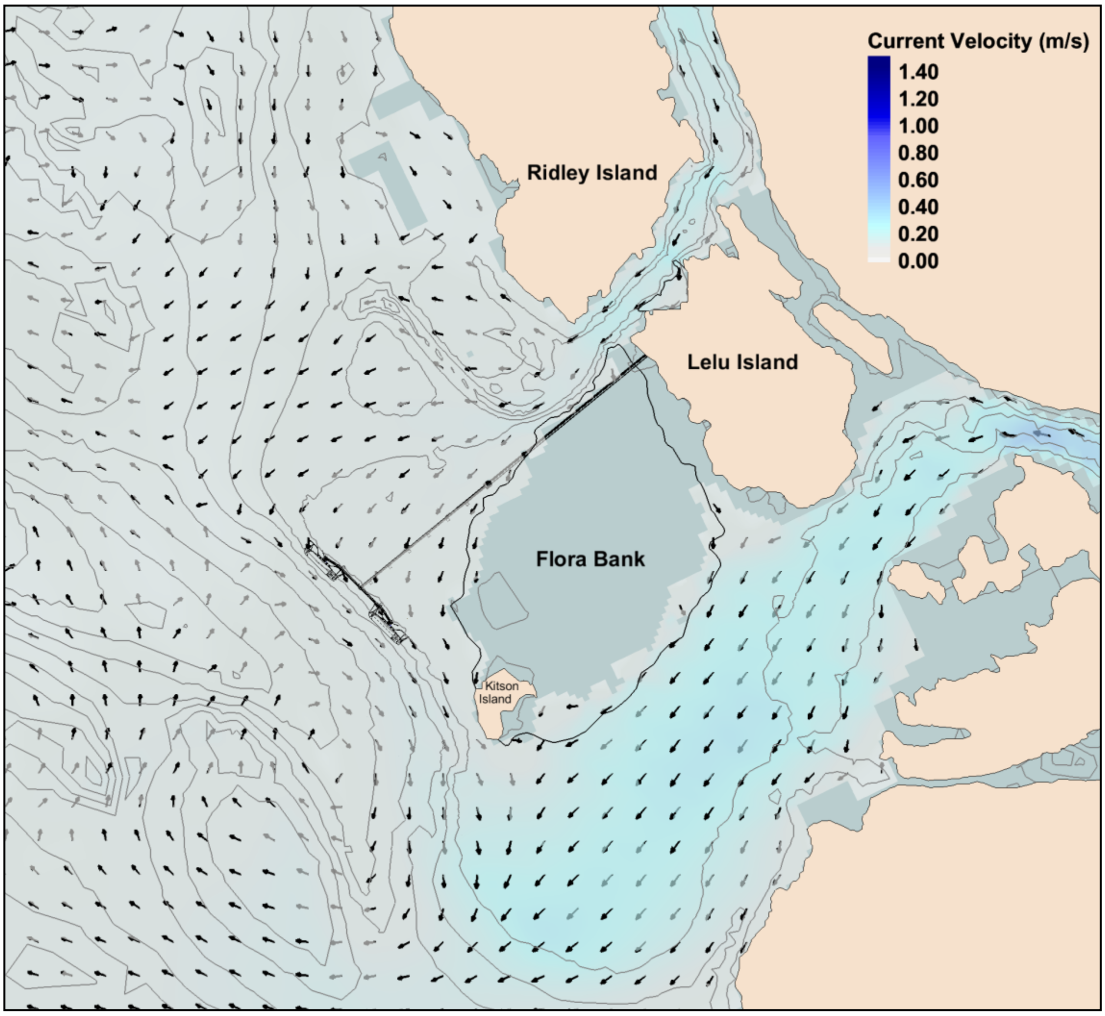

Figure 3-3: Characteristics of the hydrodynamic circulation during low tides

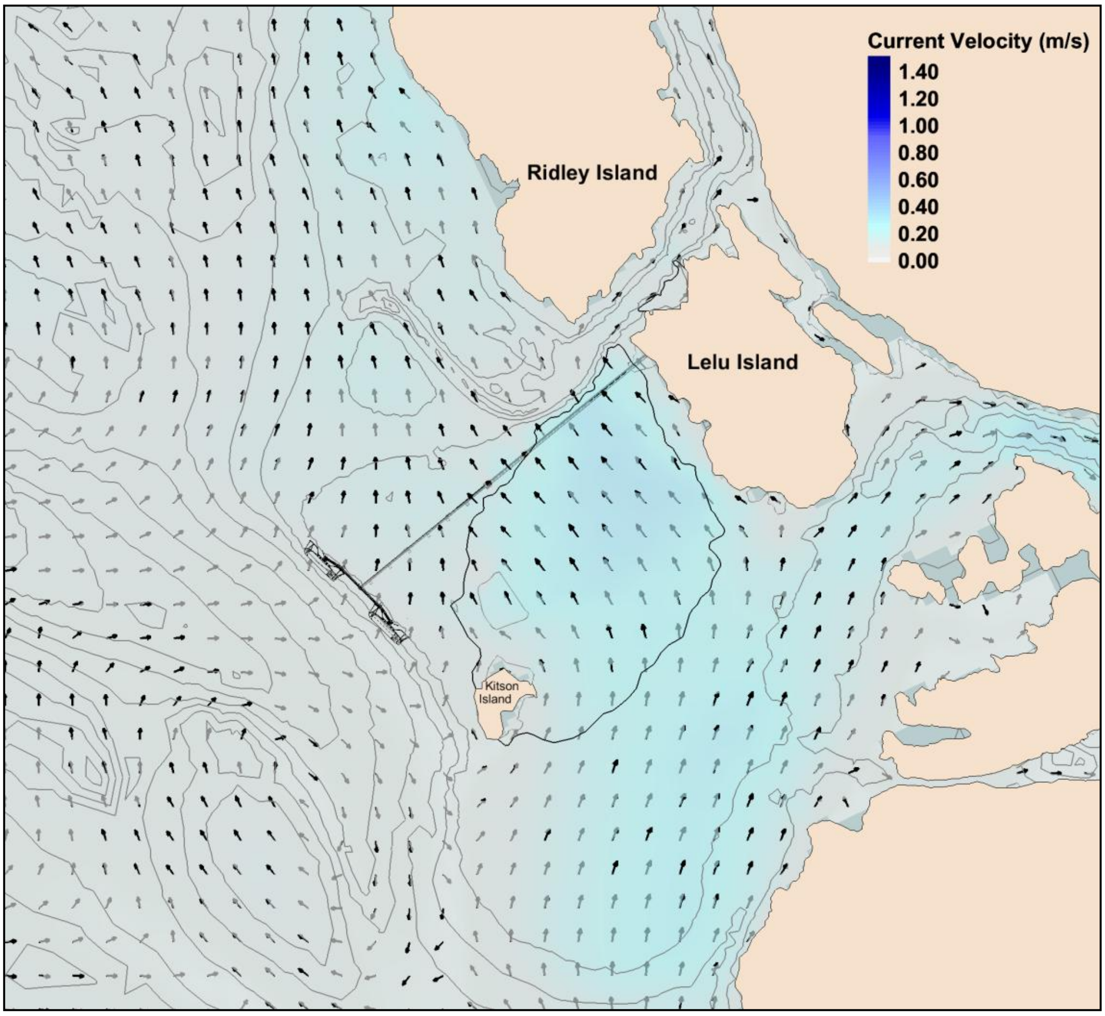

Figure 3-4: Characteristics of the hydrodynamic circulation during high tides

The depth averaged current velocities obtained every hour during the simulation in the middle of Porpoise Channel and inside the MOF dredged area are presented on Figure 3-5.

The current directions are aligned with the channel direction (approximately NE-SW) on both locations. The maximum depth averaged current velocity at the MOF and at the channel occurred during flood tide, where the maximum modeled current velocity is about 0.4 m/s at the MOF and 0.8 m/s at the channel.

The currents at the MOF location are weaker than at the channel, since this area will be slightly isolated from the channel after dredging. The maximum depth averaged current is about 0.4 m/s at this location and the currents are below 0.2 m/s during 90% of the time.

The current velocity time series during the simulation period for these two locations is presented on Figure 3-6, showing that the depth averaged currents in both locations have the same pattern (increasing and decreasing during the same time), but the currents inside the channel are always higher than the currents at the MOF.

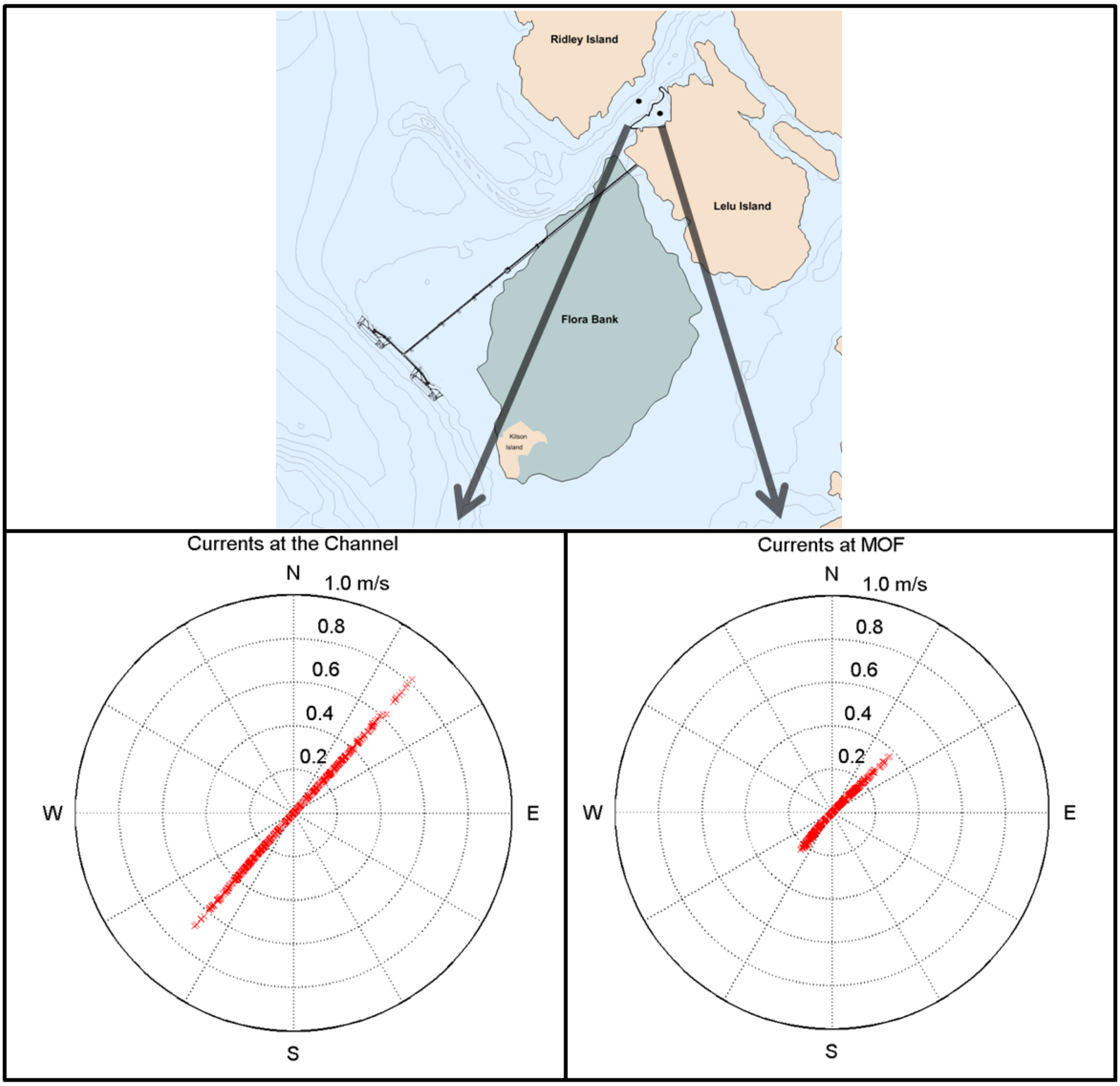

Figure 3-5: Hourly depth averaged current velocities obtained during one month of simulation

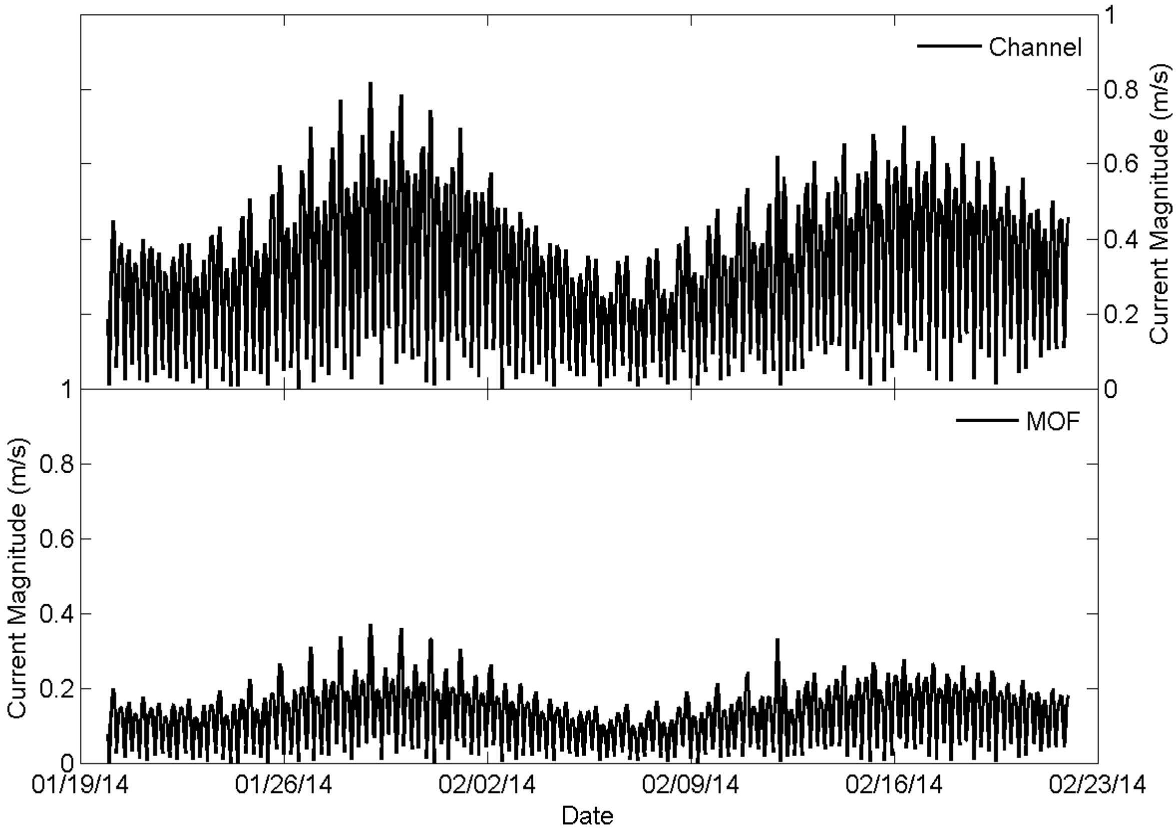

Figure 3-6: Time series of the depth averaged current magnitudes at the MOF and Porpoise Channel

4. Sediment Deposition at the MOF

A sedimentation study was conducted using the Particle Tracking Model (PTM), developed by the USACE. PTM investigates the sediment pathways and fate after sediments are eroded or transported by the currents. After the sediments are suspended, the particles are transported by the local hydrodynamic conditions predicted with CMS Flow hydrodynamic simulations. The hydrodynamic simulations presented on Section 3 are used as input conditions for the PTM simulations.

4.1 Sediment Sources

Different sources of sediments were considered in the sedimentation study at the MOF area. The major sources are the sediments suspended by high tidal flows in shallow areas (e.g. Agnew Bank and non-vegetated areas on Flora Bank, since the vegetation is a natural trap of sediments). Secondary contributions are the suspended sediments from Skeena River and the sediments suspended by the LNG vessels arriving and departing the LNG terminal (during operational phase). The propeller scour report [3] showed that most of the sediments suspended by the LNG vessels are not transported towards the MOF location and thus this contribution is not considered.

The deposited sediments are eroded by the currents when the critical bed shear stress exceeds the threshold limit of erosion. The Hjulstrom diagram (Figure 4-1) shows the relation between the current velocities and sediment grain sizes, indicating threshold current velocities for different grain sizes [4]. Using a median grain size of 0.038 mm as an example, Hjulstrom diagram shows that current velocities above 0.28 m/s are capable to suspend the sediments at the bottom. The sediments will only deposit during very low current velocities (below 0.003 m/s); the current velocities between these values are capable to transport the sediments already in suspension, but are not capable to resuspend sediments from the bottom.

Figure 4-1 indicates the current velocities that are capable of suspending sediments considering the range of sediments observed on the site.

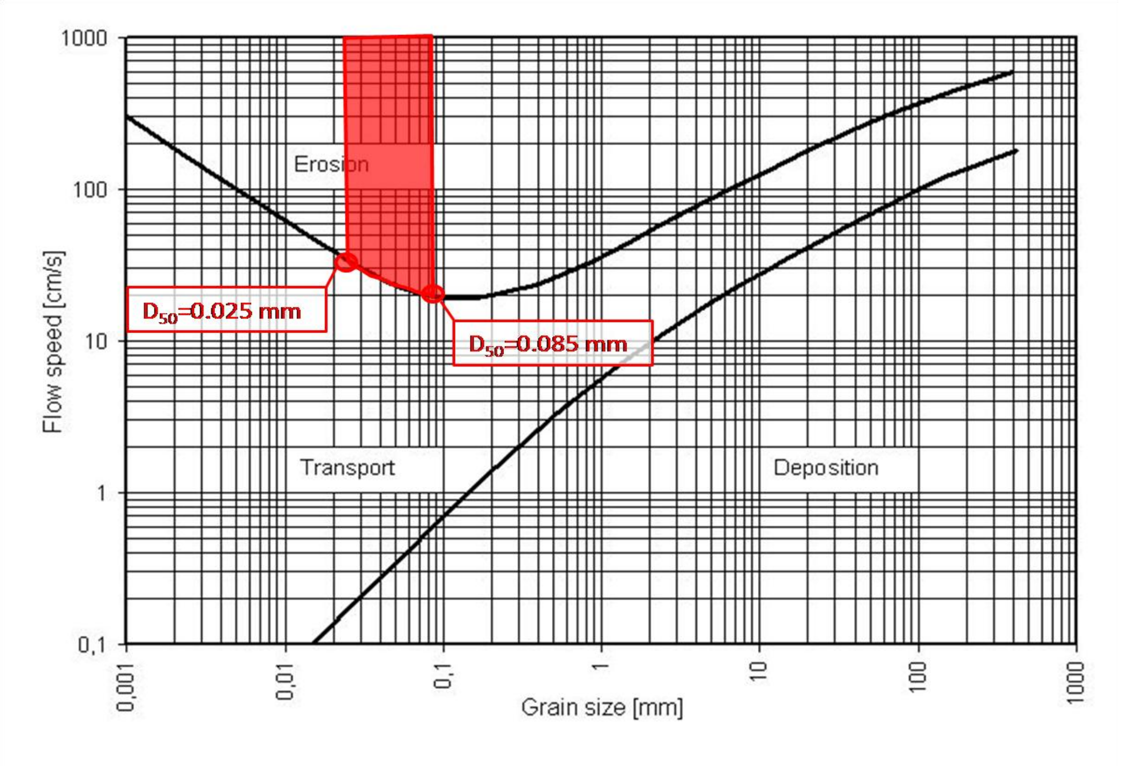

Figure 4-1: Hjulstrom Diagram highlighting the flow velocities capable of suspending sediments around the LNG terminal

4.2 Skeena River Sediment Fate

The fate of the Skeena River sediments was evaluated during an extreme freshet (when the maximum discharge above 9,000 m^3/s), during 33 days of hydrodynamic simulation from May 22nd to June 24th 2007. A correlation between the Total Suspended Solids (TSS) and the river discharge was corroborated based on Horowitz [5] and further used as input conditions for the PTM simulations.

The results from this simulation (Figure 4-2) showed that a small amount of sediments is transported and deposited around the LNG terminal, Flora Bank and Agnew Bank. Assuming the present hydrodynamic conditions and the sediment particles being released on Skeena River (Figure 4-2), the majority of the sediments are deposited around Kennedy Island. Only the finer fractions of the sediments are carried for longer distances by the currents, since their settling velocities are smaller, and are still in suspension around Flora Bank.

The results also showed that the Inverness Passage is not the preferred sediment route, usually the sediments are transported South (towards Kennedy Island) inside the main Skeena River body.

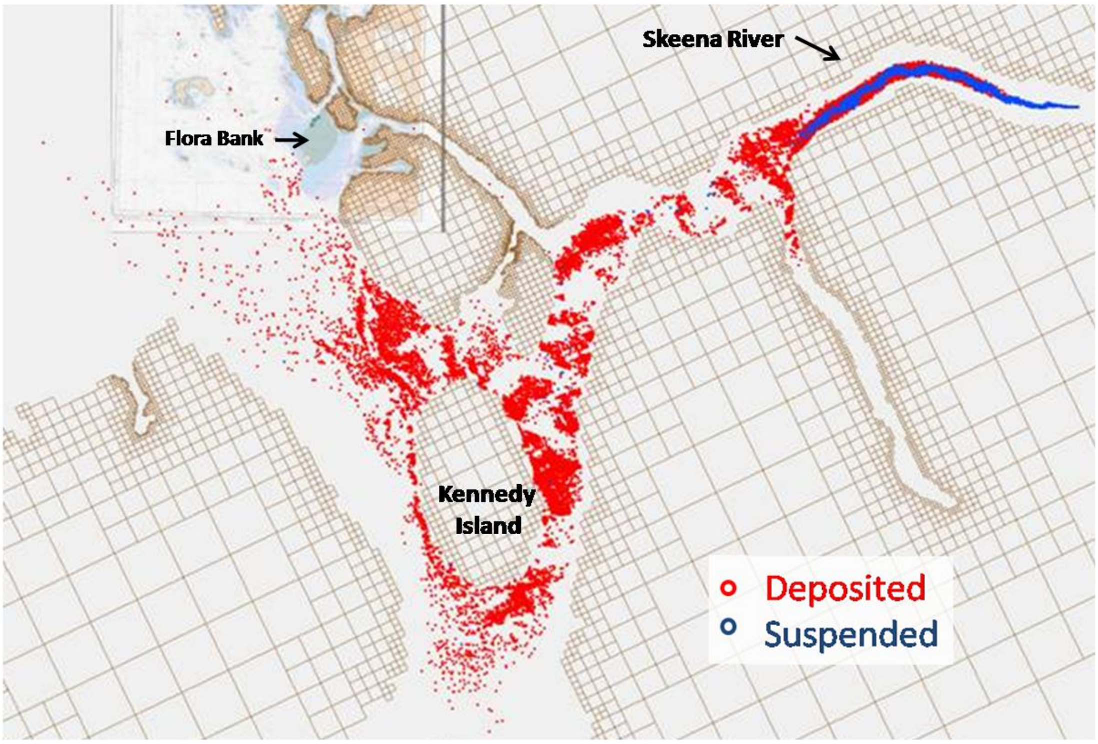

Figure 4-2: Fate of sediment from Skeena River after 1 month of freshet simulations

4.3 Depositional Pattern at the MOF

The characteristics of currents transporting suspended sediments in the LNG terminal area are presented on Section 3.2.

Based on the hydrodynamics and PTM simulations, it was concluded that the sediments with potential to be deposited at the MOF area are especially transported through Porpoise Channel during flood tides. The sediments can also enter the channel during flood and deposit at the MOF area on the consecutive ebb tide or during transitional periods when the currents are less strong.

The current velocities in Porpoise Channel are strong, even after the proposed MOF dredging. Therefore, the MOF is not a preferred location where sediments will deposit.

In general, suspended sediments passing the entrance of Porpoise Channel will deposit on regions further North of the MOF or offshore of Lelu Island, depending on the tides. However, a small deposition inside Porpoise Channel is also observed during the transitional periods between ebb and flood tides, when the currents velocities are relatively weak.

Figure 4-3 shows the fate of sediments carried by the hydrodynamic simulations during the storm simulation period (between January 18th 2014 and February 22nd 2014), considering the suspended sediments that are entering Porpoise Channel.

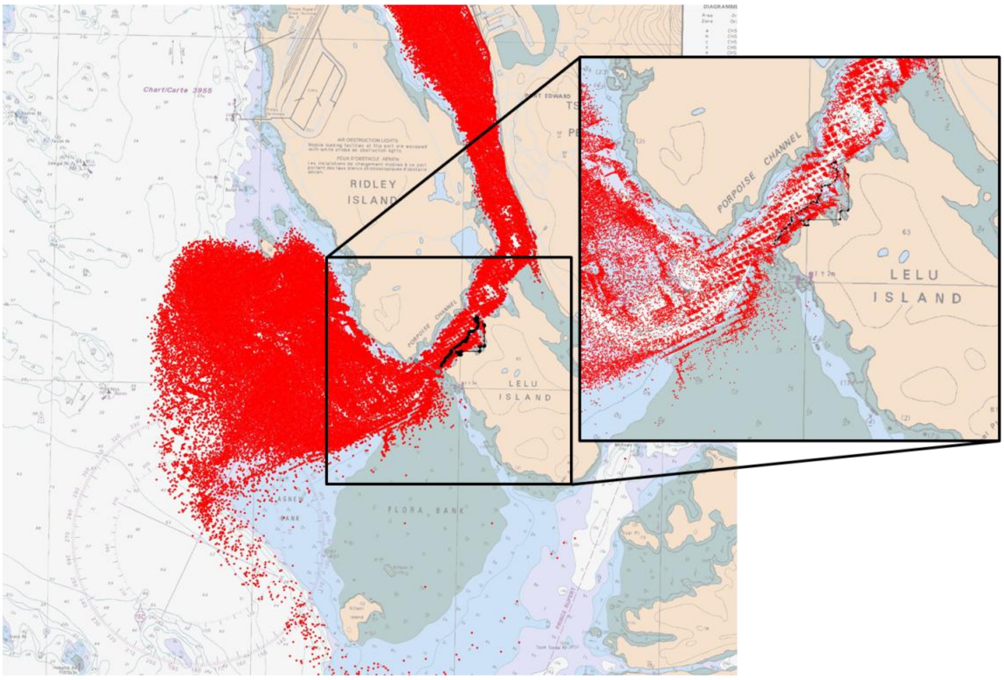

Figure 4-3: Sediment fate at the end of the simulation for the storm period (January 18th 2014 and February 22nd 2014)

Calculating the deposition inside the MOF area for this simulation period (January 18th to February 22nd 2014) and extrapolating these rates to annual rates, the maximum depositional rate is about 5 cm/y on the North limit of the MOF. The maximum deposition rate on the South limit of the MOF is about 3 cm/yr. The depositional rates in the central part of the MOF area are smaller.

More sediments are deposited on the Northern limit of the MOF area because they are driven by the flood currents and are transported towards the Northern boundary. When the sediments move towards this location, the differences in the bathymetric contours and the reduction in current velocities induce their deposition.

It was assumed that the MOF lifetime is in total 20 years, when the MOF will receive vessels during the construction phase of the LNG terminal.

The predicted sedimentation at the MOF area is very small and focused on specific portions of the facility. Thus, the need for maintenance dredging is low and any depositional spot that is created over time (after several years) may be dredged by mechanical means, using a crane and a clam-shell for removing localized sediments in specific areas. The deposition near the quay wall may even be dredged with land based equipment if there is any need of maintaining the water depth in front of the berth.

Thus, during the lifetime of the facility a higher concentration of sedimentation may be expected in a small area (less than 100 m^2) on the northern border of the MOF.

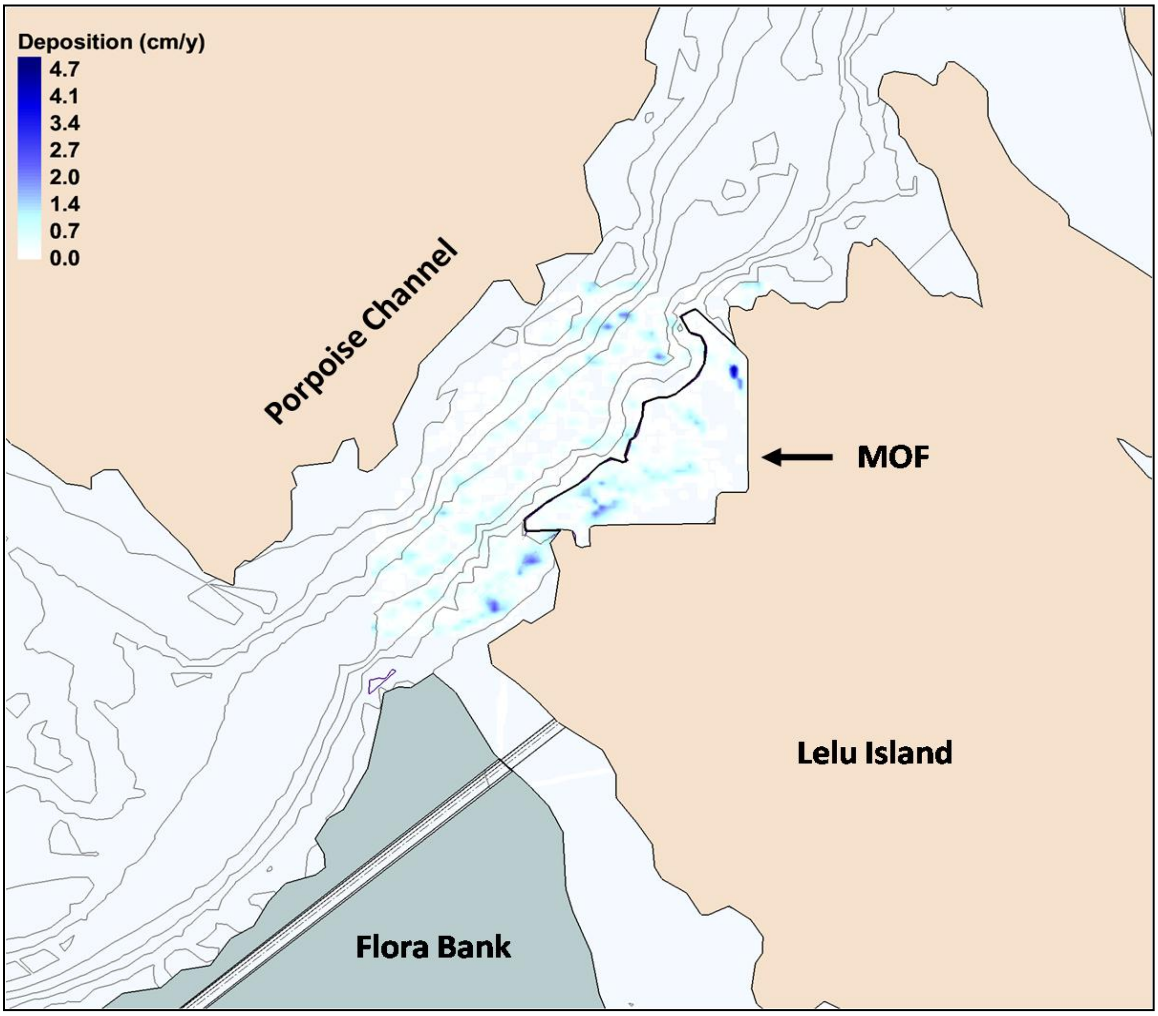

Figure 4-4: Depositional rate (cm/y) inside the MOF area

5. Conclusions

The main findings during the maintenance dredging study for the PNW LNG Materials Offloading Facility (MOF) are presented below.

Only a small and fine fraction of the sediments from Skeena River are transported towards the LNG terminal, Flora Bank and Agnew Bank. The predicted preferred depositional zone of these sediments is around Kennedy Island.

The currents at the Porpoise Channel remain considerably high, even after dredging of the MOF area. The high currents inside the Porpoise Channel keep sediments in suspension, which are carried by the tidal currents in suspension upstream of the MOF or offshore of Lelu Island, without creating a significant depositional zone within the MOF area.

The current velocities at the center of the MOF are relatively low, below 0.2 m/s during 90% of the time. In general, only a small portion of the sediments carried along Porpoise Channel will be transported towards the new dredged MOF area and may be deposited in this location.

A small deposition inside Porpoise Channel is also observed during the transitional periods between ebb and flood tides, when the currents velocities are lower.

The maximum deposition rate inside the MOF area is about 5 cm/y near the Northern portion of the MOF and 3 cm/y at the Southern limit. Any dredging needed to maintain vessel draft depths will not require regular scheduling. Dredging may be focused when needed in specific locations at the MOF area.

6. References

1. Hatch, 2014. Modelling Scour and Sediment Fate – Option F Layout – Preliminary Technical Note 2 (H345670-0000-12-220-0020). Project Memo issued April 25, 2014.

2. Hatch, 2014. MOF Dredging Study (H345670-0000-12-124-0010). Project Memo Issued October 22, 2014.

3. Hatch, 2014. Propeller Scour Analysis (H345670-0000-12-124-0009, Rev. 0). Report Issued November 26, 2014.

4. Hjulstrom, F., 1935. Studies of the morphological activity of rivers as illustrated by River Fyris. Bulletin of the Geological Institute University of Uppsala, 25,221-527. 1935.

5. Horowitz, A.J., 2002. The use of rating (transport) curves to predict suspended sediment concentration: A matter of temporal resolution. U.S. Geological Survey. 2002.