Executive Summary

Description of Project

Pacific NorthWest LNG is a proposed natural gas liquefaction and export facility on Lelu Island which is located within the District of Port Edward and on land administered by the Prince Rupert Port Authority (PRPA). The proposed project includes a marine export terminal located offshore of Lelu Island, in the naturally deep waters of Chatham Sound.

The proposed marine structures include a long span suspension bridge and piled trestle and berths. The bridge spans approximately 1600 m along the northwest edge of Flora Bank from Lelu Island to Agnew Bank, supported by two isolated in-water supporting structures – the Southwest Tower and Southwest Anchor Block. The trestle and berths are generally composed of widely spaced pile bents supporting a traffic deck. In hydrodynamic terms, the proposed structures consist of two isolated individual "islands" of approximately 0.2 ha each located along the north edge of Flora Bank, and an extended field of sparse support piles located between approximately 50 to 500 m north of Flora Bank.

About this Report

This report summarizes results of modelling efforts conducted subsequent to the May 5, 2015 3D Modeling report (Hatch, 2015), including continued refinement of previous hydrodynamic and morphology efforts using Delft3D, extensive new high resolution modelling efforts to closely examine behaviour in the immediate vicinity of the proposed tower and anchor block, and additional supporting analysis. Although this report supplements previously completed work, the analytical and modelling efforts to date, taken in combination with works by others (incl. SedTrend, 2015ab), have yielded a strong understanding of the coastal processes acting on Flora Bank and its environs, providing further confidence that the predicted impacts of the marine structures are well understood.

Project Site and Environment

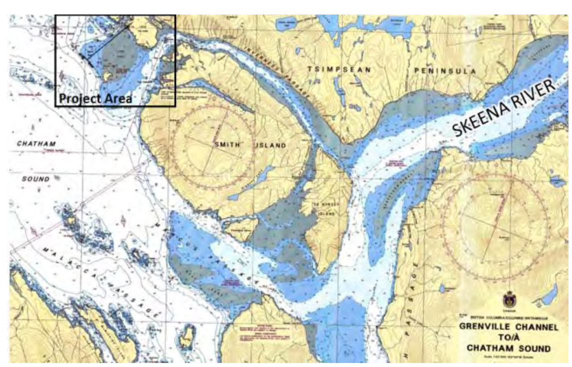
Flora Bank is large, flat, inter-tidal area, roughly 2 km by 1.7 km (325 ha in area) above lowest normal tide elevation (0 m Chart Datum or -3.8 m Mean Sea Level). Due to a relatively large tidal range, water depth varies to a maximum of approximately 7 m.

Flora Bank is believed to be a glacial relict formed during the most recent glacial retreat roughly 8,000 years ago. The shape and extent of Flora Bank has not changed significantly over a period of many years, and appears to be very stable.

Flora Bank sediments consist of fine to medium sands (SedTrend, 2015b), which are distinct from the clays and silts found on the deeper waters of Agnew and Horsey Banks, and the clays and fine to medium silts found in the deeper troughs of Chatham Sound. Sediment grain sizes and the SedTrend (2015b) analysis indicate that sediment transport and erosion/deposition patterns are spatially variable in this area of Chatham Sound, which includes many depositional deeper-water areas that likely receive fine sediments from the Skeena River plume.

The combination of coarser sandy material and very wide and flat configuration, results in very gradual dissipation of wave and current energy (which are relatively low at the site), infrequent sediment transport due to mild conditions and exposure at low tide, low levels of net transport off of Flora Bank, and finally low levels of bed erosion or deposition. The low levels of transport and erosion/deposition are consistent with the results of the SedTrend (2015) analysis, which was unable to discern any transport trends over the vast majority of Flora Bank.

Eel Grass coverage of Flora Bank varies from year to year, but typically is found over an area of approximately 35-45 ha, or approx. 10-15% of the extent of Flora Bank.



Agnew Bank is a sub tidal flat located on the west side of Flora Bank, with elevations ranging from 0 to -5 m(CD). Agnew Bank differs greatly from Flora Bank in that it is generally deeper and does not become exposed at low tide. It is also different in that it is a depositional environment, with much finer surficial sediments than found on Flora Bank. Most of Agnew Bank is relatively flat and slopes gradually to the offshore, with the exception of the southwest side which slopes more quickly to deeper water near the proposed tanker LNG carrier berths, and along its boundary with Porpoise Channel.

Modelling Inputs / Modelling Efforts

A series of modelling efforts have been undertaken to develop an understanding of Flora Bank. Several tools have been utilized in a range of broadly parallel efforts, in order to fully explore the various processes relevant to understanding both Flora Bank and the potential effect of the proposed structures on hydrodynamics and morphology. Numerical modelling was performed to simulate coastal processes on both a large/regional scale (hundreds of kilometers down to tens of meters) and a highly localized scale (meters) to ensure accurate simulation of relevant physical processes.

These efforts build on previous work undertaken over the course of the project development to date, and have directly incorporated a wide range of relevant data sources, including Environment Canada and National Oceanic and Atmospheric Administration (NOAA) wind and wave data; data collected directly by PNW LNG; and sediment data and resulting analysis developed by SedTrend (2015b). Results from numerical modelling and supporting analyses have been compared with results of SedTrend (2015ab) and indicate broad consistency.

The Delft3D (Deltares 2014ab) coastal processes modelling system has the capability to simulate all coastal processes mentioned above, and pre-eminence in the coastal engineering industry for accurate simulation of morphological change under complex coastal conditions. Delft3D simulates wave growth and transformation, and 3D hydrodynamics, salinity transport, sediment transport, and morphological change. The Delft3D far-field model domain stretches beyond the west coast of Haida Gwaii, while the nested domain encompasses an area of approx. 80 x 80 km centered at the project site, including the lower 20 km of the Skeena River.

The MORPHO modelling system (Kolomiets et al 2014) was selected to simulate fine-scale physical processes around the proposed SW Tower and SW Anchor Block. MORPHO is an unstructured, finite volume coastal processes modelling system that simulates fully nonlinear depth-averaged hydrodynamics, sediment transport and morphological change. The scale of the processes simulated in the MORPHO model spanned from hundreds of meters down to meter-scale resolution around the structures. The MORPHO model domain is approximately 3 x 3 km, centred on Flora Bank, and the MORPHO models were driven using Delft3D-generated velocity and water level input conditions, but generate independent results.

Range of Conditions Examined

Many coastal processes play a role in the hydrodynamics, transport and morphology of Flora Bank. Coastal processes evaluated at the project site and incorporated into the 3D regional scale modelling effort include:

- Tides (water levels);
- Tidal currents;
- Winds and wind-driven currents;
- Local wind-driven waves;
- Offshore waves (swells);
- Salinity; and,
- Skeena River discharge.

Additionally a range of frequent, seasonal and extreme events were considered in order to evaluate relative contributions of these processes in varying circumstances, including:

- Typical "daily" conditions over extended durations within a typical year;
- Key seasonal periods (for example the stormier winter months, and the Skeena River freshet season); and,
- Extreme (large and infrequent) storm events, including 50- and 100-year return period events.

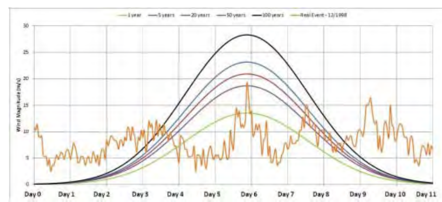
Inputs for typical modelling conditions utilize time histories of hindcast information from a combination of measurements and predictions as is typical in the industry. Extreme storm events, in contrast, are typically not reflected in available data (due to their highly infrequent occurrence) and were synthetically generated, typically by scaling appropriate measured events. Recent efforts have included synthesized extreme events which are significantly more conservative (larger in magnitude and duration) than are probable at a given return period based on actual measured events shown in available data.

5 Key Questions

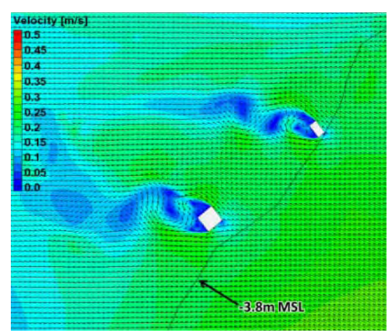
A key focus of recent efforts has been to further refine these modelling efforts in order to respond to a set of key concerns expressed by CEAA and relevant Federal Agencies, including:

1. Refinement of wind and wave inputs to account for spatial variability of the wind fields (gridded winds) and offshore waves (gridded offshore waves), to determine whether variability of offshore inputs results in improved predictions of waves at the project site. Analysis indicates that predictions of local and offshore waves at the project site (as compared with on-site measurements) are not appreciably affected by inclusion of the refined inputs.

2. Modifying representation of extreme storm events to include synthetic longer-duration events, from a broader range of directions. The refined modelling efforts have included development and modelling of extended duration, unidirectional storms with intensities appropriate for the relevant return periods, which will likely amplify modelled hydrodynamics and transport in comparison to "natural" records. Results indicate that Flora Bank remains stable due to significant attenuation of waves and currents; that the majority of the morphology changes arising during storms are driven by sediment transport only under strong wave attack. Results show that the proposed structures have only a modest, and mildly attenuating, effect on the predicted changes due principally to a modest reduction in wave energy from westerly and northwesterly waves.



3. Improved representation of the larger marine structures and their local effects. Significant additional modelling of local effects has been conducted in the vicinity of the proposed SW Tower and SW Anchor Block structures. This work has included development of a new high-resolution model driven by results from the regional Delft3D model, and examination of hydrodynamic and transport effects of these structures during typical, seasonal and extreme storm conditions. This effort has yielded further insights into the dominant natural flow conditions, which are broad, relatively uniform and mild (low current velocities that are below threshold of sediment motion most of the time). Modelling of the proposed structures shows modest local increases in current in the immediate vicinity of the structures as well as typical eddying effects downstream of the structures. Generally speaking the additional high-resolution modelling has confirmed the presence of local, transient current variations in the immediate vicinity of each of the proposed structures, and confirmed that the structures induce limited local erosion and



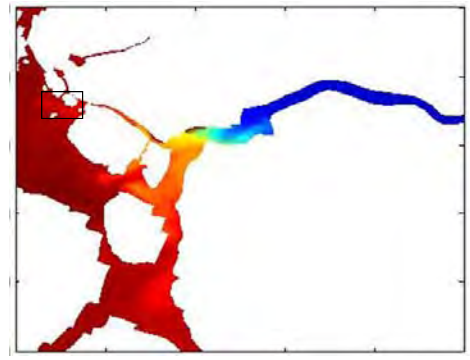
Safety • Quality • Sustainability • Innovation deposition patterns within an area located within tens of metres away from the structures themselves.

4. Performance of longer-period simulations with real continuous inputs (no input data averaging). A wide range of time-series simulations have been completed with continuous data inputs and without any morphological acceleration (MORFAC=1) in order to supplement insights gained through previously conducted time series studies and the extensive MORFAC=13.5 results presented previously. Continuous time-series analysis have been completed for circumstances including both typical daily and seasonal periods, and for the full range of extreme events discussed above, and over a series of extended time periods up to 1 year in duration covering the full annual cycle. While this effort has supported significant additional understanding of Flora Bank under a wide variety of conditions, the refined modelling approach continues to support the conclusion that Flora Bank is a highly dissipative feature and morphologically stable environment. Except as noted otherwise, all discussions within this report are based on continuous time-series modelling runs.

   "MORFAC" runs can utilize time-averaged inputs and discrete time intervals to represent longer time periods, allowing efficient estimation of effects over long-time periods (i.e. 5-years). "Continuous time series" runs, in contrast, update the wind and wave input conditions on an hourly or near-hourly basis (i.e. at the frequency available in the available wind and wave data sets), while the model itself calculates changes on a continuous basis (10-second time steps), uninterrupted over the modelled time period (i.e. a complete 11 day extreme storm cycle, or over an extended 12-month time period).

   The continuous time-series runs undertaken in recent months typically incorporate the full range of refined input parameters explained above, extended over an modelled domain of approximately 8000 km^2, resulting in a comprehensive simulation of the existing conditions.

5. Improve the presentation of results to better convey coastal processes being simulated. Significant efforts have been undertaken to quantitatively review and present model results, particularly sediment flux and net sediment transport across a wide range of modelled conditions. In general, the additional analysis and presentation results has been helpful in displaying the level of transport occurring for each sediment size, directions and magnitudes of net transport. Modelling results indicate large, wide and extremely homogeneous fields of transport (of primarily the finer materials) over Flora Bank which provide a very clear indication as to why Flora Bank experiences little bed elevation change. The extremely low gradients in wave heights and current speeds results in low gradients in transport, and hence little bed elevation change.



In addition, recent modelling efforts have refined a range of other inputs, including Skeena River freshwater discharge and salinity to further enhance the detail with which the Skeena river inputs to the site area are represented in the model. Efforts have included doubling the vertical resolution of the modelling domain, extending the model's initial salinity "spin-up" periods, and careful review of salinity variation in the model results. Additionally, the use of continuous time series modelling ensures that the full freshwater discharge and sediment load from the Skeena River are considered in the model. Based on extensive modelling efforts it is evident that the Skeena River freshwater discharge plays only a limited role in physical processes at the project site, owing principally to the distance to the site and the limited flow through Inverness Channel, and to the fact that only extremely fine sediments – too fine to influence morphology at the site - are present in the Skeena River plume.

Results: Conditions at Flora Bank

The analysis results confirm that the coastal processes surrounding Flora Bank are dominated by tidal currents, wind driven waves and storm events. Due to shelter provided by Haida Gwaii, ocean swells and offshore waves are significantly attenuated and have only a modest presence at Flora Bank. Flora Bank is located within the Skeena River estuary, but due to the significant distance from the mouth of the Skeena (approximately 18 km) and the intervening channel geometry, the annual Skeena freshet cycle has very limited effect on the morphology of Flora Bank.

Tidal currents are generally mild, with flood and ebb current velocities typically less than 0.25 m/s (0.5 knots). Significant wave heights under typical conditions are usually less than 0.3 to 0.5 m, as wave heights are gradually attenuated during approach to and travel over Flora Bank. Limited wave breaking occurs on Flora Bank except during extreme events and during a small range of low water levels.

Direct sediment transport analysis using multiple methods (mobility analysis, 1D profile modelling and 3D Delft3D modelling) indicates that sand on Flora Bank is typically mobilized where current velocities exceed approximately 0.3 m/s and/or wave action is significant. Given both the relatively low duration of most periods when these conditions are exceeded and the large flat extents of Flora Bank, transport distances are generally limited with relatively little material transported off of Flora Bank.

A range of extreme storm events have also been analysed to understand the effect of infrequent large events on Flora Bank. Generally, patterns evidenced in typical conditions are amplified by extreme events (since "typical" conditions include smaller storms), though even in very large events actual bed changes occur only during a portion of the storm and transport of fine to medium sand off Flora Bank is limited.

Owing in large part to the combination of coarser sediments, flat and gradual configuration and relatively benign typical coastal conditions, sediment transport on Flora Bank occurs principally during storm events. The synthetic extreme events that were created here represent an exaggeration of what typically occurs during real extreme events, and even within the synthetic storm events, changes in bed elevation are not likely to be measurable in the field.

Effect of Structures

Generally speaking the effects of the proposed structures within the environment discussed above are best understood by stepping progressively outward from the structures.

The direct physical footprint of the structures includes the footprint of the proposed SW Tower and SW Anchor Block, the trestle and berth support piles, and an allowance for scour protection intended to prevent seabed erosion immediately adjacent to the structures. The potential for local scour is well understood, and the extent of likely protection has been estimated in previous studies. The direct footprint of the proposed structures is approximately 2.15 ha.

High-resolution modelling has permitted examination of local currents and vortex shedding (eddying) effects arising in the immediate vicinity of the structures, under both typical conditions and extreme storm events. Model results evidence vortex formation and dissipation consistent with established literature, and localized and transient instantaneous velocity changes in the vicinity of the structures. This result is consistent with known processes around relatively small (relative to the flow field) and isolated structures in relatively homogeneous flow conditions.

Peak current velocities during both ebb and flood conditions typically remain below 0.3 m/s, and are of the same order as transient current velocities evidenced elsewhere on Flora Bank during typical tidal conditions. Over extended periods local hydrodynamic effects are likely to gradually develop local bedform changes within the immediate vicinity of the structures, but the predicted erosion and deposition around the structures remains remote from the extents of mapped eel grass habitat. Elevated levels of TSS within the water column are found only over very short periods of time, and only shortly after construction while the local erosion and deposition patterns develop.

Hydrodynamic effects that generate erosion and deposition, or TSS changes, dissipate within tens of meters away from the structures. High-resolution modelling has been performed using conservative, rectangular-shaped structures that have not benefited from future design refinement. A preliminary sensitivity analysis using larger, but circular, structures indicates that a substantial reduction in the predicted hydrodynamic and erosion/deposition effects is likely following subsequent design refinement.

Regional-scale modelling was performed using the continuous time-series simulations within the refined Delft3D model for the full range of conditions described above. Analysis results indicate that in all circumstances evaluated, the structures have a limited effect on the background coastal conditions, and generally evidence a mild attenuating effect on the predicted erosion and deposition patterns. This is primarily due to the trestle pile field's slight wave attenuation effects during west and northwest winds.

Neither the modelling results nor previous work undertaken by SedTrend evidence significant transport of fine to medium sand onto or off of Flora Bank. This indicates that for sand similar to that found on Flora Bank, there are limited natural sediment transport processes on and around Flora Bank that can be appreciably affected by the proposed marine structures.

Quantification of Flux and Transport

Analysis of the modelling results has included additional efforts to quantify sediment transport using several approaches, including both review of sediment transport spatial gradients, and volumetric analysis of bed elevation changes over defined areas. Generally these efforts evidence little net (residual) transport of material onto or off of Flora Bank under a range of conditions, and small differences between cases with and without the marine structures. Even in larger extreme storm events, the marine structures have only a mild attenuation effect, with the vast majority of the structure-induced changes being either a reduction in natural erosion, or reduction in natural deposition, that occurred during the event.

Generally speaking, analysis of the results indicates that bed elevation changes due to the marine structures are within or near the limits of the Delft3D model's error bands. That is to say that although the analysis of extreme events has validated the capability of the model to produce reasonable morphological changes, the scale of the morphological changes under typical and even extreme event conditions remains relatively low, reinforcing the conclusions that:

- The evident long-term stability of Flora Bank is a result of limited change under benign conditions; and,
- The relative effect of the proposed structures within this environment is marginal.

Analysis of modelling results indicates that Flora Bank is very stable, highly dissipative and only experiences bed elevation changes during strong perturbations, all behaviours which are in agreement with long-term observations. Measurable bed elevation changes are only likely during very rare extreme events. Therefore, measurable differences in bed change on Flora Bank that are attributable to the marine structures are also only likely to occur during extreme events, and only likely to occur in the form of a mild reduction in erosion and deposition, with the exception of the immediate vicinity of the SW Anchor Block and SW Tower.

Long-Term Analysis

Simulations have been performed covering a wide array of mild, typical and extreme coastal conditions. Some of these simulations were relatively short in duration, and some longer (up to 1 year) but all results provide information regarding the potential long-term impacts of the marine structures. In addition, important sensitivity testing simulations provide even more information about long-term effects.

Longer-term time series simulations that cover a complete year indicate the following:

1. Results of a range of simulations show consistent patterns;
2. Overall bed elevation changes predicted over a full year (absent the marine structures):
   a) remain moderate,
   b) are consistent with patterns/locations identified in other modelling results
   c) are concentrated in areas that make sense, for example erosion occurs in high-energy, high-elevation spots,
   d) continue to indicate that sand material moves around within Flora Bank
   e) show no evidence of divergence or instability over time even with exaggerated morphological changes
3. Relative bed elevation changes for cases with and without the marine structures:
   a) remain consistent in location/pattern/magnitude,
   b) show similar patterns of moderate bed change attenuation (reductions in both erosion, and deposition),
   c) show no evidence of increasing divergence or instability, and
   d) show no evidence of materially altering natural long-term trends.

Pathways

Evaluation of the modelling results in the context of potential impacts to fish and fish habitat has been strongly guided by efforts to articulate a set of key pathways connecting effects to potential impacts.

Key pathways may be broadly summarized as:

- Direct impacts: These are well understood relative to the present state of marine structures design, and conservatively accounts for scour protection. Total direct footprint is estimated at 2.13 ha.
- Erosion or deposition induced by marine structures that potentially affect eelgrass habitat: Modelling analysis indicates moderate direct effects on the bedform in the immediate vicinity of the bridge structures arising from localized tidal flow changes around the two bridge obstacles. Changes on Flora Bank are expected to be local (near the two bridge structures), and eroded sediments during tidal flow and wave action will be deposited nearby.
- Changes in currents around the southwest anchor block and southwest tower: modelling results indicate that localized current changes and eddies in the local vicinity of the proposed SW Tower and SW Anchor block (within tens of metres of the structures) are evident, but are transient, mobile and of limited magnitude.
- Changes in total suspended solids (TSS) relative to background levels are similarly focused around the SW Anchor Block and SW Tower, consistent with the localized current changes and eddies in the local vicinity. TSS variances are transient, mobile and of limited magnitude.

More generally, modelling results support continuing understanding of the coastal processes at work and support continuing confidence that Flora Bank is robust and stable, both prior to and following construction of the proposed marine structures. Analysis efforts have identified no potential for a fundamental state change impacting fish and/or fish habitat, as well as no evidence of divergent or run-away effects. This is principally due to the moderate, broad flow fields within which the structures are located.