TECHNICAL REVIEW OF ROBERTS BANK TERMINAL 2 ENVIRONMENTAL ASSESSMENT: SECTION 9.5 – COASTAL GEOMORPHOLOGY

1.0 Context

The Vancouver Fraser Port Authority, formerly Port Metro Vancouver (the Proponent), is proposing to construct and operate the Roberts Bank Terminal 2 Project (the Project), a new three-berth marine container terminal at Roberts Bank in Delta, British Columbia.

The Project is subject to an environmental assessment by a Review Panel pursuant to the Canadian Environmental Assessment Act, 2012. As a federal authority in the environmental assessment for the Project, Fisheries and Oceans Canada (DFO) will be asked to provide information to the review panel and at public hearings in relation to its expertise on the effects of the Project on fish and fish habitat, including aquatic species at risk, and the adequacy of mitigation and offsetting measures and monitoring/ follow-up programs proposed by the Proponent.

In developing the Environmental Impact Statement (EIS), the Proponent assessed future ecosystem productivity at Roberts Bank using the Ecopath with Ecosim and Ecospace (EwE) model (Port Metro Vancouver, 2015). These models are informed by a hydrodynamics and sediment transport model forecasting to 2050 the impacts of the placement of the terminal, expansion of the causeway, and the expansion of the tug basin on surrounding sediment due to changes in waves and ocean currents. The outcomes of the EwE models are then incorporated into the analysis of the potential project-related effects on the ongoing productivity of commercial, recreational, and Aboriginal fisheries.

DFO's Pacific Region Fisheries Protection Program (FPP) has requested that DFO Science Branch provide an evaluation of the Proponent's characterization of project-related effects using the EwE ecosystem productivity model. To inform the review and evaluation of the Proponent's use of EwE, an assessment of the hydrodynamics and coastal geomorphology modelling was required. Because Natural Resources Canada (NRCan) possesses federal expertise in sediment transport and coastal geomorphology, this Science Response was conducted jointly with NRCan, who provided advice related to sediment transport and morphodynamic modelling. This Science Response provides advice regarding the adequacy and applicability of the hydrodynamics and coastal geomorphology assessment presented by the Proponent. The assessment and advice arising from this Canadian Science Advisory Secretariat (CSAS) Science Response (SR) will be used to assist in the evaluation of the EwE model, and will contribute to the overall development of DFO's submission to the Review Panel during their review of the Roberts Bank Terminal 2 Project.

This Science Response will address the following objectives:

Review Section 9.5 of the EIS (Appendix 9.5-A and Appendix 9.5-B of the EIS), Coastal Geomorphology (Port Metro Vancouver, 2015) and:

1. Determine if the proposed models are appropriate for the purpose of projecting the impacts of the project development on currents, waves, and water quality in this environment, to inform the use of the Ecopath with Ecosim and Ecospace models.
2. Assess whether the parameters used by the hydrodynamics and geomorphology model are valid and defensible for this environment and this project.
3. Assess whether the limitations and uncertainties of the hydrodynamics and geomorphology models are identified and appropriately considered when determining the model's representation of current and possible future conditions.
4. Provide advice regarding whether the model results related to the potential effects of the project on hydrodynamics and sediment are credible and defensible.

This Science Response Report results from the Science Response Process of July 2016 on the Technical Review of Ecopath with Ecosim and Ecospace (EwE) Ecosystem Productivity Model application to the Roberts Bank Terminal 2 Environmental Assessment. This is the first of two Science Responses developed to provide advice regarding the EwE model application.

2.0 Background

The Vancouver Fraser Port Authority is proposing to construct and operate the Roberts Bank Terminal 2 Project, next to the existing Deltaport and Westshore Terminals in Delta, British Columbia. In addition to the construction of the new terminal, the Proponent has proposed to widen the north side of the existing Roberts Bank causeway from its east-end connection with the mainland to the entrance to the new terminal. The existing tug basin, connected to the northeast side of Deltaport Terminal, is also proposed for expansion. The new marine terminal is predicted by the Proponent to process up to 260 container ship calls per year at full capacity, with the assistance of two or three large berthing or escort tugs to manoeuver ships into or away from assigned berths. The terminal is designed to operate 24 hours per day year-round. The main project components have a proposed combined marine footprint area of approximately 179 hectares (ha), listed below by specific component:

- Marine Terminal: 133.5 ha, including terminal (116.1 ha) and dredged berth pocket and marine approach areas (17.4 ha)
- Widened Causeway: 42.4 ha
- Expanded Tug basin: 3.1 ha

Roberts Bank, in the Fraser River estuary, consists of complex intertidal and subtidal habitats, including intertidal eelgrass beds, which are an important stopover area for migrating shorebirds, and productive feeding and rearing habitats for many commercially valuable fish and invertebrate species, as well as providing habitat for endangered Southern Resident Killer Whales and other marine mammals. The environmental conditions at Roberts Bank are dynamic, and are influenced by a variety of oceanographic and atmospheric factors, including the Fraser River freshwater and sediment plume discharge, diurnal tidal currents, and prevailing and storm-generated wind and wave activity.

The hydrodynamic and morphodynamic modelling was conducted by Northwest Hydraulics Consultants Ltd. (NHC), using the TELEMAC-MASCARET model suite. This modeling system is an integrated suite of models based on the finite element method for which space is discretized in an unstructured grid of triangular elements. TELEMAC-MASCARET is managed by a consortium of European agencies and has been used in many coastal studies throughout the world. It consists of TELEMAC-3D (three-dimensional hydrodynamic model that solves the time-dependent Navier-Stokes equations with an evolving free surface, hydrostatic or not, finite element, wetting/drying), TOMAWAC (3rd generation spectral wave model that solves the wave action density balance equation and includes wind generation, whitecaps, nonlinear wave-wave interactions, refraction, shoaling, and dissipation), and SISYPHE (sediment transport and morphodynamic model that computes separately bedload and suspended sediment, and the resulting bed changes using the Exner equation). In this document, the local implementation of TELEMAC-3D, TOMAWAC and SISYPHE to the Roberts Bank area is analyzed.

The process followed in preparing this Science Response involved an initial review of the submitted EIS followed by an in-person meeting of the Proponent, its contractors, and representatives of DFO and NRCan to discuss and clarify questions arising (Vancouver, 23 November 2015). DFO and NRCan provided written questions to the Proponent based on preliminary review of the EIS on November 19, 2015. This large initial meeting was followed by smaller focussed meetings between the Proponent, its contractors, and DFO and NRCan, on 11 December 2015 to clarify hydrology and sediment modelling questions. Written responses to all of these meetings and questions were provided by the Proponent to DFO, and NRCan as the “PMV Response 2016-03-02” and “PMV Response 2016-05-30”. VFPA’s answers to questions posed by DFO and NRCan regarding coastal geomorphology modelling have been posted to the Canadian Environmental Assessment Registry (CEAR) (Vancouver Fraser Port Authority, 2016).

3.0 Analysis and Response

To prepare this response, the following sections of the EIS / additional documents were reviewed:

Document/Section	Title
EIS Section 9.5 (Appendix 9.5-A and 9.5-B) (Port Metro Vancouver, 2015)	Coastal Geomorphology
CEAR document #547 (Including Appendices) (Vancouver Fraser Port Authority, 2016)	Vancouver Fraser Port Authority to the Review Panel re: Answers to preliminary technical questions submitted during the completeness phase from Fisheries and Oceans Canada, Natural Resources Canada, and Environment and Climate Change Canada, concerning the ecosystem modelling to support the Roberts Bank Terminal 2 Project environmental review

3.1 Hydrodynamic modelling

3.1.1 Local model implementation

The model grid includes Juan de Fuca Strait (east of Port Renfrew), Puget Sound, the lower Fraser River (up to 36 km upstream of New Westminster), and the Strait of Georgia (south of Ballenas Island) (Fig. 1). The grid has 28000 nodes in the horizontal and 11 vertical levels. The horizontal resolution varies from 3 km in the Strait of Georgia to about 25 m in the vicinity of the project.

The TELEMAC-3D model is forced by the Fraser River flow at the upstream river boundary, and by tidal water levels from the main eight tidal constituents at the Port Renfrew and Ballenas Islands boundaries (see Fig. 1). Tidal levels at the open boundaries were obtained from the

WebTide tidal prediction model of DFO. The Fraser River flows were obtained from an implementation of the MIKE11 numerical model developed for the Fraser River by NHC. At the water surface, the model is forced by wind stress computed from hourly wind data measured at nine different local stations.

The initial model salinity distribution was estimated from salinity values measured by DFO, at locations near the model open boundaries, during three seasonal water properties surveys (April, June, and September 2012). A salinity of zero is prescribed for the Fraser River inflow. Water temperature is kept constant in the model.

The horizontal eddy viscosity follows a Smagorinsky formulation with a coefficient of 1 m^2/s. The vertical eddy viscosity and diffusivity uses a Prandtl formulation with a background value set at $1x10^{-6}$ m^2/s. The spatially varying Nikuradse bottom friction values appear reasonable, varying from 0.001 m in the deeper basin to 0.005 m in the shallow vegetation areas.

The model was run initially for a two week spin up period in order to allow the model salinity to adjust to the boundary forcing. The Proponent states that this period was considered to be of sufficient duration to ensure that salinity and water levels had reached a state of statistical equilibrium. However, no evidence of such equilibrium state is presented.

The TOMAWAC wave model uses 25 exponentially-spaced frequencies (0.125 Hz to 1 Hz), and 12 evenly spaced directions. It is implemented as a non-stationary model, allowing growth and decay of the wind waves. The model is forced by the wind used to force the TELEMAC-3D model. Wave dissipation by whitecapping is also included in the simulations. Although the model does allow the inclusion of incident waves at the open boundaries, this option was not used in their simulations. Incoming swell at the Juan de Fuca boundary should not affect wave conditions on Roberts Bank, but neglecting waves entering the domain from the northern Strait of Georgia could underestimate the local wave energy from a northwest wind. However, as demonstrated by the Proponent (Vancouver Fraser Port Authority, 2016), the resulting shorter fetch should not generally lead to an important difference in wave height at the site because, in most conditions, the wave development would be time limited and not fetch limited.

Currents and waves were simulated for the three-month “summer” (MJJ) and “winter” (OND) period of 2012. The morphodynamic model was run for 1440 days, repeating the winter three-month period in order to simulate a longer term integration period. This means that the results of the sediment modelling are relevant to winter conditions only. Winter is typically the period of the year with stronger storms.

Three modeling approaches were used to evaluate the potential impact of the project:

1. Hydrodynamic (TELEMAC-3D) and wave (TOMAWAC) models run in a coupled mode to evaluate changes in currents.
2. Hydrodynamic (TELEMAC-3D) model run, without waves, to evaluate the impact on salinity.
3. Morphodynamic model (SISYPHE) run to evaluate sediment transport and changes in the surface of the tidal flats. This was done without including the potentially important effect of waves on sediment (except for the extreme storm simulation reviewed in Section 3.2.4 below).

Each of these three modeling approaches was repeated under the three scenarios:

1. Existing conditions
2. Expected (future) conditions, without the project (including sea level rise)
3. Future conditions, (as in 2), with the project

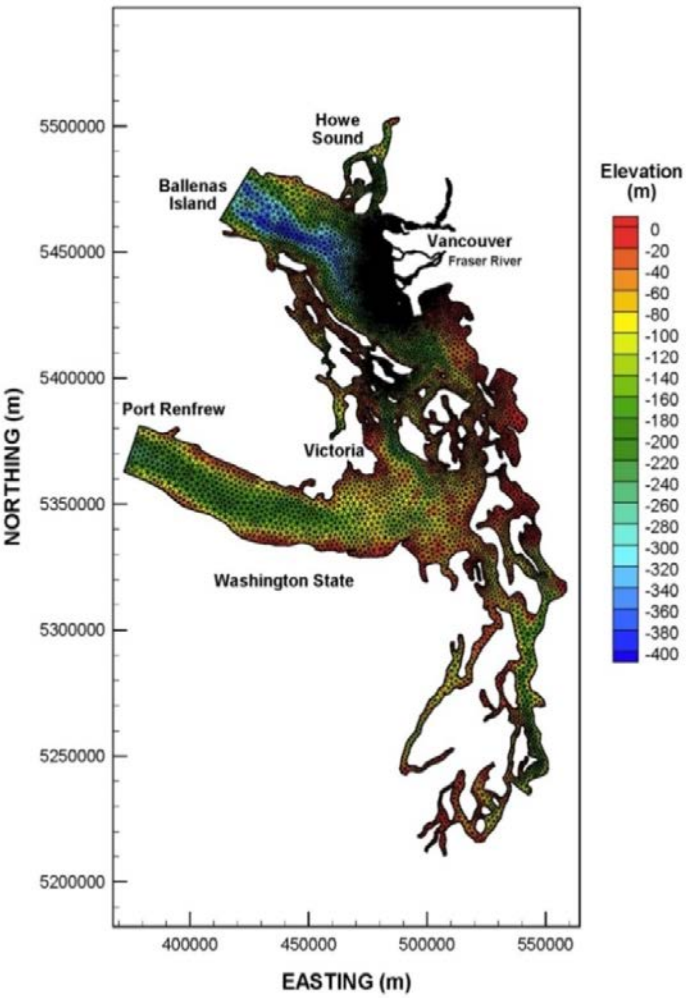

Figure 1: TELEMAC-3D model domain (Port Metro Vancouver Environmental Impact Statement, Appendix 9.5-A, Figure 2. Used with permission).

3.1.2 Comparison of model results with observations

The output of the coupled hydrodynamic-wave model is compared with data collected during August 2012. More specifically, the Proponent makes use of: water levels at Point Atkinson and Canoe Passage, flow at Canoe Passage, salinity at Canoe Passage and Roberts Bank, currents on Roberts Banks (Acoustic Wave and Current Profiler [AWAC] station), and wave height on Roberts Bank and Halibut Bank.

Water levels: the Root Mean Square (RMS) difference between model and observed water level is 0.3 m and 0.23 m for Point Atkinson and Canoe Passage, respectively. These values are somewhat higher than could be expected from a state-of-the-art coastal circulation model, and the Proponent claims that it is due to the fact that the model does not include the effect of atmospheric conditions on sea level. It is recommended that this statement be verified by applying a simple correction to account for the effect of atmospheric pressure on sea level (inverse barometer effect). This type of correction is routinely applied in similar analysis. By including this correction, the comparison between observed and modeled water level would provide a more adequate validation of the model response to tidal forcing.

River flow: The hydrodynamic model simulates the tidal phase of the river flow relatively well, but presents a general negative bias (smaller outflow, larger inflow). There is an error in the EIS Appendix 9.5-A section 4.2, where the statement is made that “The model generally overestimated the outflow and underestimated the inflow”, which is in opposition to the actual bias. Such a bias in the river discharge could possibly result in a positive bias in model salinity around Roberts Bank (not enough freshwater from the river) which, in turn, could have a possible impact on the local hydrodynamics.

Currents: Currents measured by an AWAC, located 1.7 km west of the Roberts Bank terminal in 6.3 m depth, are compared with model results at elevations of 4.4 and 2.4 m off the bottom. Minimal information is given on the current comparison. However, it is evident from Figs 11-12 (EIS Appendix 9.5-B) that, although the observations clearly show stronger currents closer to the surface, the model currents do not appear to change with depth. Given that additional datasets are available (both ADCP (Acoustic Doppler Current Profiler) and AWAC, and data collected in winter), a more complete validation of the model currents is recommended to increase confidence in model results.

Waves: The comparison of measured and modeled waves at two sites (Halibut Bank and Roberts Bank) indicates a reasonably good agreement over the comparison period, with a slight underestimation of the wave height by the model. However, no large storms were included in the validation period (Aug 2012). Therefore, the ability of the model to accurately simulate large storm waves has not been demonstrated by this simulation.

Salinity: At Canoe Passage, the model inflow was found to be larger than observed, and this is consistent with model salinity intrusions being generally too strong. However, the occasionally strong measured salt intrusions are missed by the model. On Roberts Bank, salinity profiles are compared for Aug. 2 and Aug. 29, at three locations (T1, T10, and T16). Very few salinity profiles are presented, and the modelled and measured profiles are given on separate figures, which make the comparison difficult. Many of the features of the spatial salinity distribution are captured by the model (e.g. vertically mixed conditions at T16), but some are missed (stratified conditions at T1, on Aug. 2). The Proponent identifies the uncertainty of salinity at the model’s open boundaries as an important source of model salinity uncertainty on Roberts Bank, and states that “The model results can be improved if additional field salinity profiles…were available” (p.22 of EIS Appendix 9.5-B). We estimate that it is very unlikely that changes in salinity at the relatively distant open boundaries would have an important impact on model salinity at Roberts Bank. Consequently, it is our opinion that the inability of the model to accurately represent the complex hydrodynamics of the Fraser River plume is a more likely reason for the model inaccuracies. A sensitivity test of the model, where the open boundary salinity values would vary, is recommended to provide greater clarity regarding the source of the salinity uncertainty in the model results.

3.1.3 Model results

The hydrodynamic model results are used to estimate the impact of the project on ocean circulation, salinity, and wave climate, as well as changes from climate change (sea level rise of 0.5 m) on nearshore wave climate.

Ocean circulation: Changes in ocean currents due to the Project were estimated by comparing output from the hydrodynamic-wave model for existing conditions and future conditions with the Project. The results are well summarized in Figs 65-66 (Appendix 9.5-A) which give the change in 50th percentile current velocities associated with the Project, for the summer and the winter period. The results indicate increased velocities (+0.1 m/s) in a relatively large area west of the proposed structure, and decreased velocities along the offshore face of the structure (-0.05 m/s) and in the two elbow regions at the junction of the old and new structures (-0.3 m/s).

Salinity: The results presented by the Proponent are limited to vertically averaged salinity values, without any information on the vertical salinity structure. The hydrodynamic model was used in this section, without the coupling with waves. Figs 78-79 (EIS Appendix 9.5-A) illustrate changes in 50th percentile salinity due to the project, for the summer and winter period. The results indicate an increase in salinity (up to +4 psu) in the shallow area to the north west of the proposed structure, and a decrease in salinity (up to -8 psu) along the north side of the causeway. This is caused by the relatively salty water brought onto the tidal flat by the flood currents being diverted to the northwest by the new structure.

Wave climate: Figs 93-94 (EIS Appendix 9.5-A) show the reduction of the 50th percentile wave height due to the project, in summer and winter. A large shadow zone of reduced wave energy is present on the north and west side of the proposed structure. In this area, a reduction of 50% to 100% of the wave energy would result in less frequent sediment mobilization and suspension. In addition, not represented by the model results, but mentioned in the report (p.149, EIS Appendix 9.5-A), an increase in wave energy on the east face of the proposed structure is likely, due to the reflection of the incoming waves from the southeast and south direction. This could result in additional local sediment scour.

Climate change and wave climate: It is shown that increased sea level will result in increased wave energy in the shallow region of the upper tidal flats, with and without the proposed structure. However, the bathymetry changes due to expected localized slope profile adjustments have not been included in this analysis.

3.2 Sediment Transport and Morphodynamic Modelling

3.2.1 Appropriateness of Model

SISYPHE is a well-established process-based (deterministic) coastal morphological model that has proven capable of simulating morphologic change (Amoudry and Souza, 2011). The Proponent indicates that SISYPHE was both driven by and provided feedback to the TELEMAC-3D model, in matching time steps. For the simulations presented in the validation exercise (EIS Appendix 9.5-B), the wave module TOMAWAC was also coupled to SISYPHE. However, the waves were not included in the subsequent morphodynamic model runs.

Amoudry and Souza (2011) have evaluated TELEMAC/SISYPHE and other coastal models, and concluded that all such models include important uncertainties. They state that "even the most advanced model to date can only predict sediment transport within a factor of two at best and that higher uncertainties are not uncommon. These are due in part to the strong amplification of any small errors in the hydrodynamics, which is easily explained by the power dependence of the sediment transport rates on the flow velocities (power three for the bed load transport rate and a power higher than three for the suspended load)". Amoudry and Souza (2011) recommend that modelling studies include a sensitivity analysis and assessment of their particular uncertainty.

Of particular concern in the Roberts Bank study is the use of a single grain size (175 microns; fine sand) to characterize the sediments in the study area. Whereas the grain size data sourced from McLaren and Ren (1995) and Hemmera (2014) in Figure 14 of EIS Appendix 9.5-A indicate that this grain size would be a reasonable average for the whole study area, detailed examination of the samples would indicate spatial variability, particularly in the vicinity of the Deltaport where some samples contain >50% silt and clay. Following Amoudry and Souza (2011), it is recommended that explicit tests and explanation of the model sensitivity to grain size and other assumed values be presented.

3.2.2 Model Validation

Validation of morphodynamic models at the process level is inherently difficult to achieve because techniques for measuring bedload and/or suspended load sediment transport are extremely equipment- and time-intensive and, in the case of bedload transport, arguably near impossible. The Proponent has taken the reasonable approach of comparing final (net) model results to long-term observations by running the coupled hydrodynamic-wave-morphodynamic model for 1,440 model days using 2012 winter season conditions, and comparing the results to observed morphological changes between 2002 and 2011 from bathymetric and LiDAR data. Whereas the overall net changes are quite small, the modeling results reproduce quite well most details of the observed changes, for example along the edge of the bank, in the small tidal creek just east of Canoe Passage and near the southwest corner of the Deltaport.

Ideally, a validation with stronger observed changes would have been preferred, but in the circumstances where little change has been observed over nine years, the validation exercise used in this study is acceptable.

3.2.3 Model Simulations

The morphodynamic modelling is based on average storm conditions from a single year (2012). Because there is a threshold condition for grain sediment transport and the relationship between wave height and sediment transport for a particular grain size is non-linear, extreme waves are usually a key factor in causing coastal structure damage and scour. In general terms, the sediment transport caused by extreme storms can be markedly greater than that produced by average storms. Experience in coastal engineering suggests that large storms can have large and irreversible effects on coastal geomorphology. In coastal engineering, it is therefore standard practice to base design on extreme wave conditions.

Similarly, for an environmental assessment, the extreme-case scenario should be modelled because the potential for morphological change under extreme storms could be orders of magnitude greater than for the moderate conditions modelled in the study. It is not evident that an extreme wave analysis has been completed for Roberts Bank and, if one has not occurred, it is recommended that the Proponent conducts wave hindcasts to simulate extreme wave conditions appropriate to the design life of the structures (e.g. 100 year storm). Note that this concern has been partially addressed by the supplemental sediment modelling work (see next section for more information). An analysis of storm surge associated with the extreme wave condition would also be appropriate. It is recognized that Roberts Bank lies in a fetch-limited location, so it is possible that extreme waves may not be notabtly greater than the modeled waves. However, this should be explicitly demonstrated. If the extreme wave heights are found to be greater than those that were modelled, the higher wave conditions should be used as input to the morphodynamic modelling.

Note that the interpretation that “it is reasonable to exclude waves from the long-term morphodynamic modelling” (EIS Appendix 9.5-A, p.162) may only be applicable under moderate wave conditions such as derived from the 2012 data. When model simulations with more extreme waves are considered as recommended, the fully combined wave and current modelling should be carried out.

3.2.4 CEAR Document #547, Appendix 1.6: Supplemental sediment transport modelling

This supplementary report provides additional information to EIS “Appendix 9.5-A, Roberts Bank Terminal 2 Technical Report Coastal Geomorphology Study” (March 2014), following informal discussion with the Proponent and its contractors. Several of the issues raised above in NRCan’s review of EIS Appendix 9.5-A have been addressed as follows.

1. An analysis of extreme wave conditions in the Strait of Georgia was presented for a northwesterly wind, indicating a 100-year return wave height of 3.1 m. It is not indicated if this is the significant wave height, and the wave period is not specified. However, the analysis confirms that local wave heights are generally limited by fetch and the results seem reasonable.
2. The TELEMAC-MASCARET modelling system was run for a 100-year storm, with northwesterly winds, and using a reasonable scenario for storm duration. The results are presented as maps of sediment transport rate for various stages of the tide and morphodynamic evolution for the existing conditions and for future conditions with the new structure. Sediment transport rates are projected to be maximal during a mid-stage tide rather than at high tide or at low tide (when the tidal flats are above water). Net bed level changes in the area of the proposed structure under both existing conditions and future conditions with the new structure are evaluated at less than 10 cm. This is reasonably interpreted to be because the wave energy is rapidly dissipated across the tidal flats, which is consistent with previous studies in the area (Houser and Hill, 2010). One point of detail is that the net bed level change presented in the results does not necessarily reflect the maximum depth of bed disturbance during the extreme storm. The fact that large volumes of sediment are thrown into suspension during periods of high sediment transport, implies that the bed is generally scoured to a greater depth during a storm event than would be indicated by the final (net) bed level at the end of the storm event. This would be the case under both existing and future conditions. An underestimation of the bed disturbance may also result in an underestimation of the amount of habitat that will potentially be negatively affected by the Project.
3. The results of the 100-year storm simulations clearly indicate the importance of including the effect of waves for both sediment transport and morphodynamic evolution in such simulations. Without sediment re-suspension induced by waves, it is shown that modelled sediment transport rate is one to two orders of magnitude lower (Figs 8-9) and the modelled morphodynamic evolution (Figs 12-13) is reduced. This confirms the concern raised in section 3.2.3 above regarding the exclusion of waves in the morphodynamic modeling study.
4. The results of the 100-year storm simulation indicate large morphodynamic changes in the inter-causeway and in the vicinity of the BC Ferries causeway (Figs. 12 and 13). The importance of these results is dismissed by the Proponent on the basis of the lack of adequate grid resolution in these areas. To adequately resolve this issue, and clarify the importance of the large morphodynamic changes indicated by the 100 year storm simulation, it is recommended that the storm simulations be repeated with improved grid resolution in the inter-causeway and around the BC Ferries terminal.
5. Model simulations were run to assess the sensitivity of the results to the grain size value used in the modelling work for existing conditions only. As would be expected, use of slightly finer grain sizes results in higher rates of sediment transport and greater bed level change, notably at the edge of the bank, in front of the proposed structure location. Assuming that the scale used in the map presentation includes the entire range of bed level change values, the changes are still in the order of 10 cm. However, this sensitivity analysis confirms that the accuracy of the model predictions is sensitive to grain size (and numerous other assumptions), the model is not (and cannot be) calibrated to the local conditions, and the results of the model should be viewed as guide not a prescription. For example; the assumption of a single grain size is a simplification. Natural sediments exhibit a distribution of grain sizes and will be spatially variable. The modelling results using different grain sizes therefore reveal a more realistic range of possible scenarios than a single model result.

6. Model simulations were also run using different sediment transport formulations. The calculation of sediment transport rate (and therefore geomorphological change) requires the choice of an equation from four options in the TELEMAC-MASCARET modelling system. Different equations include different concepts of sediment transport theory (e.g. different assumptions about the vertical profile of sediment concentration) and will therefore generate different results. The previous simulations and those presented in EIS Appendix 9.5-A use the Bijker (1992) formulation. In this set of simulations, only two of the four equations (Bijker, 1992, and Dibajnia and Watanabe, 1992) gave stable results. The Dibajnia and Watanabe formulation simulated lower rates of bed level change than the Bijker formulation. This exercise provides another indication of how sensitive numerical models are to assumptions.

4.0 Conclusions

This review has identified inadequacies in the modelling procedures and assumptions, as well as in the assessment of uncertainties. Therefore, some results and conclusions presented in the Proponent's analysis, as well as the associated uncertainties, are not fully substantiated. The following are the main observations and conclusions of this review:

1. The use of the TELEMAC-MASCARET model suite (i.e. TELEMAC-3D, TOMAWAC and SISYPHE) is appropriate for this study.
2. The observational data used to evaluate the hydrodynamic model was limited to those data collected during the month of August 2012 when most field observations on physical parameters were collected: use was not made of all of the available field data. It is recommended that a more extensive model validation be completed, using the complete field dataset available. This would include existing ADCP data as well as data collected during winter months. Owing to the importance of large storms in local sediment dynamics, it would be important to extend the model validation to include winter conditions, including large storms.
3. In order to clarify which particular model runs were actually done, it is recommended that a complete listing or table summarizing the model runs be provided. This should include the simulation period, model components, and specific model forcings.
4. Given the importance of waves as an agent in stirring and uplifting sediment, especially during storms, it is recommended that the morphodynamic modeling work be fully coupled with the wave model.
5. The storm simulations of the supplementary modelling work indicate a potentially strong impact on the sediment in the inter-causeway region and in the vicinity of the BC Ferries terminal. The Proponent expresses serious doubts regarding the validity of these results due to a lack of adequate grid resolution in this area of the model domain. In order for the model results to be considered defensible, it is recommended that the storm simulations be repeated using a grid that has adequate spatial resolution in the area of concern.
6. The supplementary report strengthens the modelling study of EIS Appendix 9.5-A and addresses concerns raised by DFO/NRCan with respect to the model response to large storms and on the sensitivity of the morphodynamic model to various assumptions, such as sediment grain size. The results support the general conclusions of EIS Appendix 9.5-A and the Environmental Impact Statement; however it should be acknowledged that numerical model results are highly dependent on the assumptions and simplifications incorporated in the model formulation and the input parameters. Given that the results of the morphodynamic model are used to inform the ecosystem models (Ecopath with Ecosim and Ecospace), these uncertainties should be taken into account in their assessment.

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September 7, 2016

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This Report is Available from the

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ISSN 1919-3769

Correct Citation for this Publication:

DFO. 2016. Technical Review of Roberts Bank Terminal 2 Environmental Assessment: Section 9.5 – Coastal Geomorphology. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/045.

Aussi disponible en français :

MPO. 2016. Examen technique de l'évaluation environnementale du terminal 2 à Roberts Bank : section 9.5 – géomorphologie côtière. Secr. can. de consult. sci. du MPO, Rép. des Sci. 2016/045.