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Information Request Package 2 from the Review Panel for the Roberts Bank Terminal 2 Project Environmental Assessment: Responses

List of Responses

IR2-18 Coastal Geomorphology – Clarification

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Package 2 Preamble

1.0 Introduction

The Vancouver Fraser Port Authority (VFPA) has responded to each of the Panel's information requests (IRs) provided in Package 2 on December 16, 2016 in this document. The VFPA has updated their responses to Panel IR Package 2 as requested by the Panel in their letter dated March 31, 2017. To provide context and clarity in support of the VFPA's responses, additional background information is summarised below.

2.0 Design Mitigation

Mitigation measures (measures to eliminate, reduce, or control; *Canadian Environmental Assessment Act, 2012*) are incorporated into the environmental assessment of the Project to mitigate adverse effects of the Project. Avoidance of potential environmental effects were considered during preliminary design of the Roberts Bank Terminal 2 (RBT2 or Project) terminal. The location and orientation of the proposed terminal footprint in subtidal waters six kilometers from the shoreline was deliberately chosen to avoid many direct effects to the intertidal area at Roberts Bank (see Environmental Impact Statement (EIS) Section 5.0). Engagement with regulators (Fisheries and Oceans Canada (DFO) and Canadian Wildlife Service) and experience gained through adaptive management monitoring for the Deltaport Third Berth Project confirmed the presence of more productive marine habitat in the intertidal areas relative to habitat in deeper subtidal waters. As a result, although a terminal in the intertidal area had been the focus of preliminary consideration, the VFPA refocused its consideration on a terminal in the subtidal area. This meant that the main changes of the Project on coastal geomorphology would be localised to the RBT2 terminal footprint—a point acknowledged by the Coastal Geomorphology Technical Advisory Group (TAG) (described in more detail below) and verified by analyses conducted to predict changes in coastal geomorphology presented in the EIS.

The design of the proposed terminal was further modified in response to the predicted increased scouring at the northwest corner of the terminal based on hydrodynamic modelling. The design of the terminal was optimised to include rounding at the northwest corner to reduce scouring and the aerial extent of footprint-related effects (see EIS Section 5.4.1.3).

3.0 Additional Information - Coastal Geomorphology, Seismic Hazard and Geotechnical Stability, and Consideration of Climate Change

Several information sources and documents informed and supplemented the analyses of changes to coastal geomorphology, and how climate change was considered in the environmental assessment of the Project and informed the VFPA's responses to the Panel's IRs (Package 2), including the following:

- Coastal Geomorphology TAG process (engagement conducted in 2012 to 2013, pre-EIS submission); and
- Agency Engagement (post-EIS submission);
    - Follow-up questions on ecosystem modelling from DFO, Natural Resources Canada (NRC), and Environment and Climate Change Canada (ECCC) during the Environmental Assessment Completeness Phase (CEAR Document #547[1]); and
    - DFO's Canadian Science Advisory Secretariat (CSAS) review (CEAR Document #893[2]).

The relevance of each of these information sources to providing the background and context for the scope of the assessment of Project-related changes to coastal geomorphology and the VFPA's responses to the Panel's IR Package 2 is provided below.

3.1 Coastal Geomorphology Technical Advisory Group Process

The TAG process, which is described in EIS Section 7.1, was initiated in 2012, during the development of the EIS Guidelines and prior to the preparation and submission of the EIS, to engage and consult with leaders in the technical and scientific community to provide guidance on key topic areas, including coastal geomorphology and climate change.

EIS Section 7.4 provides an overview of the TAG process through which the VFPA sought guidance to ensure an appropriate and scientifically defensible assessment of potential Project-related effects and develop effective, technically and economically feasible mitigation strategies. The Project may introduce changes in coastal geomorphology (i.e., physical features and processes at Roberts Bank in the vicinity of the Project area), which can influence marine biological and ecological conditions. The VFPA recognised the merit of entering into dialogue with technical experts early in the environmental assessment process to determine how best to describe and interpret changes in coastal geomorphology in the Roberts Bank area. Participants of the Coastal Geomorphology TAG met on three occasions: November 15, 2012, January 31, 2013, and March 8, 2013.

Input provided by TAG process participants was compiled into a Coastal Geomorphology TAG Summary Report (the Summary). The Summary was made available on the VFPA's Project website[3] and is appended to this Package 2 submission (**Appendix IR2-A**). The report documents meeting dates, topics of discussion, existing information, the rationale and

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[1] CEAR Document #547 From the 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 (NOTE: Updated September 28th, 2016)

[2] CEAR Document #893 From the Review Panel Secretariat to the Review Panel re: Technical Review of the Roberts Bank Terminal 2 Environmental Assessment: Section 9.5 - Coastal Geomorphology by Fisheries and Oceans Canada

[3] http://www.robertsbankterminal2.com/wp-content/uploads/RBT2-TAG-Summary-Report-Coastal-Geomorphology-November-2013.pdf

foundation for the topic-specific effects assessment, priority information requirements, and field study work plans relative to each topic.

As described in the Summary, the TAG focused on the following topics:

- Underlying understandings and assumptions about the coastal geomorphology of Roberts Bank;
- How climate change is integrated into an impact assessment, including how sea level rise is factored into analyses;
- Factors affecting the formation of new tidal channels in mudflats, and the effectiveness of mitigation;
- Detailed issues with respect to modeling and interpretive geomorphology methods; and
- How cumulative effects may impact Roberts Bank coastal geomorphology, including consideration of environmental effects and the effects of other human projects could be considered in the analyses.

The VFPA proposed a "three-pronged" approach to assessing coastal geomorphology, which was presented to the TAG and included the following methods:

1. Interpretive geomorphic studies using historical data, site observations, and measurements;
2. Analytical methods; and
3. Numerical modelling of waves, tidal currents, and sediment transport.

The three-pronged approach sought to provide increased confidence in the study results that may not be possible using a single study method. Teeter et al. (2001) concluded that available numerical modelling techniques were limited by present computational power as well as an understanding of the interactions between sediment and vegetation (such as eelgrass), bed sheltering and wave damping effects in very shallow water, sediment re-suspension, and the mechanisms controlling drainage channel formation on tidal flats. There have been significant advances since this paper was published, both in the availability of affordable powerful computational resources as well as in the level of sophistication of numerical models. However, there continue to be limitations to the predictive ability of numerical techniques.

The major processes that shape the Fraser River estuary and Roberts Bank tidal flat are reflected in the morphology. Morphological conditions can be qualitatively and quantitatively assessed using a range of interpretive methods, including historical mapping, field observations, as well as other analytical computations. The inclusion of such geomorphic investigations strengthens the assessment to overcome any limitations associated with numerical modelling. The three-pronged approach integrates hydrodynamics, sedimentation, and geomorphic processes to focus on developing an understanding of the long-term physical processes that drive morphological change in the Project area.

The Summary states that, "In general, the TAG agreed with the "three-pronged" approach for assessing potential effects of the Project on coastal geomorphology." The TAG also agreed with underlying understandings and assumptions that formed the basis of the analytical approach including the following (see Summary Section 3.1.2 provided in **Appendix IR2-A**):

- Contribution of sediment input from the main arm of the Fraser River to Roberts Bank is relatively small;
- Sediment transport to and from the tidal flats is low compared to volume of sand stored in the mudflats;
- Sediment in the lower tidal flats is primarily comprised of sand and silt, which is non-cohesive. Methods available to predict changes in non-cohesive sediments are well described and accepted. No need to consider transport of cohesive sediment (i.e., clay) in assessments;
- Main changes to coastal geomorphology at Roberts Bank will be localised changes in erosion and deposition; and
- Models will be used to identify potential locations where tidal channels might form, and interpretive geomorphology, based on examining past trends in tidal channel formation at Roberts Bank to assess potential small scale changes in tidal channels that might form at Roberts Bank.

The TAG discussed the following factors regarding climate change that should be considered in the environmental assessment (see Summary Section 3.3 provided in **Appendix IR2-A**):

- The magnitude and rate of sea level rise that can be expected at Roberts Bank;
- The extent to which storms that send waves towards Roberts Bank might change;
- The extent of changes of Fraser River outputs (such as volume of flow and sediment load) at the river mouth; and
- The degree to which the tidal flats might change over the long-term due to the above factors.

The TAG process provided an opportunity for the VFPA to present their understanding of coastal geomorphology in the Fraser River estuary, including Roberts Bank, the influence of past disturbances in the area, and solicit feedback on appropriate methods to assess potential effects of the Project on coastal geomorphology at Roberts Bank. The VFPA considered and implemented many of the recommendations proposed during the TAG process in the assessment of changes to coastal geomorphology of the Project. Based on the review of information provided during the TAG process, and as stated in the Summary:

> *Overall, the Coastal Geomorphology TAG endorsed NHC's[4] planned approach and methods.*

3.2 Agency Engagement Post-EIS Submission

Following submission of the EIS in March 2015, engagement with agencies continued during the completeness review of the environmental assessment process.

[4] NHC (Northwest Hydraulic Consultants Ltd.) is a specialist engineering and geoscience consulting firm engaged by the VFPA to undertake the coastal geomorphology studies.

Follow-up Questions on Coastal Geomorphology and Ecosystem Modelling (CEAR Document #547)

DFO and NRC provided written questions to the VFPA based on a preliminary review of the EIS on November 19, 2015, ahead of an in-person meeting on November 23, 2015. The meeting included representatives from the VFPA, NRC, DFO, ECCC, and other federal agencies. Following the meeting, ECCC provided clarification questions on December 1, 2015 and January 20, 2016. This meeting was followed by a focused meeting between the VFPA, NRC, and DFO on December 11, 2015 and between the VFPA, ECCC, and DFO on February 28, 2016 to clarify hydrology, sediment modelling, and ecosystem modelling questions.

The VFPA provided responses to the agencies in March and May 2016, and these responses were posted to the Agency's registry on September 28, 2016 (CEAR Document #547). In the response, and of relevance to responses to IR Package 2, the VFPA provided further clarity regarding coastal geomorphology modelling assumptions on wind, salinity, seasonal variability, water temperature, atmospheric pressure, and sediment dynamics.

The VFPA also conducted supplemental modelling analyses to evaluate the following:

- Changes from an extreme storm event on sediment transport and bed level changes in the intertidal area of Roberts Bank;
- Varying sediment grain size to evaluate the sensitivity of the model results to fine grained sediment; and
- Applying various alternative sediment transport equations to evaluate the sensitivity of the model results.

Information from CEAR Document #547 has been extracted to support responses in this IR package.

Canadian Science Advisory Secretariat Review (CEAR Document #893)

In October 2016, the CSAS, DFO's Science Branch, published a technical review of the numerical modelling of potential changes to coastal geomorphology and salinity related to the Project. The technical review was a joint effort by DFO and NRC. This information contributed to DFO's submission as part of the Panel's sufficiency review of the Project. The CSAS review has been posted to the Agency's Registry (CEAR Document #893). DFO and NRC considered the information provided in the EIS, specifically Section 9.5, Appendix 9.5-A, and Appendix 9.5-B, as well as in CEAR Document #547 in their technical review. They concluded that some of their issues raised during their review of EIS Appendix 9.5-A had been addressed by supplemental information provided in CEAR Document #547.

The CSAS review concluded that "the use of the TELEMAC-MASCARET model suite (TELEMAC-3D, TOMAWAC and SISYPHE) is appropriate for the study". The review identified the need for additional information that in the opinion of the report authors, was required to further substantiate or supplement some of the findings of the models and analyses, assumptions made, and uncertainties in predictions. Further information was gathered in response to the CSAS review and this additional information is reflected in the VFPA's responses contained in this IR package.

4.0 Overview of Topics in Panel Information Request Package 2

Since submission of the EIS, a number of common topics have emerged regarding questions posed during the completeness phase of the environmental assessment process and now during sufficiency review regarding the assessment of coastal geomorphology (**Table IR2-2**). The table also summarises additional clarification and analyses that have been undertaken since submission of the EIS to address these questions. Additional analyses requested and conducted have confirmed the findings reported in the EIS, strengthening the confidence in the conclusions of the assessment. For context, the key topics and findings are summarised below.

Uncertainty

The coastal geomorphology study followed a multiple lines of evidence "three-pronged" approach. Numerical modelling, analytical computations, and interpretive geomorphology contributed to the conclusions of the coastal geomorphology study, to provide increased confidence in the study results that may not be possible using a single study method. This approach was adopted, recognising the inherent uncertainty of any single approach.

Uncertainty was further managed in the valued component effects assessments where outputs of the coastal geomorphology and water quality studies were tested through sensitivity analyses. For example, salinity outputs from the hydrodynamic model were varied by ±20% in the Roberts Bank ecosystem model, as described in EIS Appendix 10-D and section 2.11 of CEAR Document #547.

Waves, Tidal Currents, Sediment Transport, and Storms

One of the simplifying assumptions that was incorporated into the sediment transport modelling reported in the EIS is that tidal currents, not waves, are the dominant process driving bed level changes in the local study area (LSA). This conclusion was supported by field data and historical analysis of bed levels which have shown that bed levels in the LSA have remained relatively stable for a 40 year period based on available records (1967 to 2011), despite the occurrence of a number of large storm events during this time period. This analysis of measured long-term bed level changes reinforces the validity of the numerical model outputs that rely on tidal currents, not waves, as the dominant factor driving sediment transport in the LSA. This is reflected in one of the key findings of the coastal geomorphology study that the main changes to sediment transport are localised to the area around the RBT2 terminal footprint, a consequence of the terminal siting in deep water.

A 1 in 100-year simulated northwest storm event was modelled to understand the effect of an extreme storm on a) sediment transport, and b) bed level changes (morphodynamics) in the intertidal area of Roberts Bank. Sensitivity analyses on sediment grain size and the sediment transport equation were also performed. The study concluded that the Project will not magnify the effects of waves during a large storm event and the specified model grain size is consistent with the geomorphic understanding of the Roberts Bank system, which has evolved to its present form in response to long-term processes that include periodic large storm events.

Inter-causeway Area

Changes to the inter-causeway area and area south of the B.C. Ferries Terminal related to the Project components situated to the north of the causeway are not anticipated. The area to the north of the Roberts Bank causeway is hydrodynamically isolated from these areas by deep water and the presence of the existing Roberts Bank causeway and the B.C. Ferries causeway. As a result, Project components that are proposed to be constructed on the north side of the Roberts Bank causeway, including the terminal, will not influence coastal geomorphology or hydrodynamics on the south side of the causeway, including the inter-causeway and the area south of the B.C. Ferries Terminal (as shown on EIS Figure 9.5-34 and further described in IR2-02). The only Project component that will influence coastal geomorphology or hydrodynamics in the inter-causeway area is the expanded tug basin, which is expected to result in localised changes to the existing coastal landforms in that area (see Table 9.5-6 and Figure 9.5-34 in the EIS).

Table IR2-1 Clarification and Analyses Undertaken Since Submission of the EIS

Reference	Details		Related Information Request Package 2 Response
CEAR Document #547 questions 1.1 to 1.11	1.1 Numerical Model Spin Up	Clarification provided on the model spin up period	IR2-14
	1.2 TOMAWAC Wave Usage	Clarification on how incoming waves were accounted for at the open boundary	IR2-01
	1.3 Wind Statistics	Clarification provided on how large storm events in 2012 were considered in the wave climate study	IR2-06, IR2-10, IR2-11
	1.4 Morphodynamic Seasonal Forcing	Clarification provided on how summer and winter wave and tidal conditions were considered in the morphodynamic study	IR2-06, IR2-10,
	1.5 Salinity Uncertainty	Clarification provided on how uncertainty in relation to salinity values at the open boundary was managed	IR2-13
	1.6 Sediment Dynamics	Clarification provided on why tides not waves are the dominant factor driving sediment dynamics in the local study area	IR2-06
	1.7 Model Sensitivity	Clarification provided on how sensitivity analyses were factored into the model development phase.	IR2-10, IR2-13
	1.8 Wind Vectors	Clarification on how wind vectors were interpolated onto the model grid	Not applicable (N/A)

Reference	Details		Related Information Request Package 2 Response
	1.9 Water Temperature	Clarification on how water temperature was factored into the numerical simulation	N/A
	1.10 Atmospheric Pressure	Clarification on how atmospheric pressure was considered in the numerical simulation	IR2-03
	1.11 Spatial Resolution	Clarification on the spatial resolution of the model	IR2-10
	3.5 Salinity Description Choice	Clarification on the applicability of the 50^{th} versus the 95^{th} salinity percentiles as inputs into the ecosystem model	IR2-02
CEAR Document #547 appendix 1.6	Clarification on the effects of a 1 in 100-year simulated north-west storm event to understand the effect of an extreme storm on a) sediment transport, and b) bed level changes (morphodynamics) in the intertidal region of Roberts Bank. In addition, sensitivity analyses on sediment grain size and the sediment transport equation were also performed.		IR2-05, IR2-06, IR2-10

5.0 Conclusions

To provide context and clarity in support of the VFPA's responses to the Panel's IR Package 2, additional background information is summarised in this Preamble, which includes engagement on approach to the assessment, and supplemental analyses provided during the completeness phase. The VFPA sought feedback on the approach used to assess potential Project-related changes to coastal geomorphology specifically through the Coastal Geomorphology TAG, in addition to engagement and consultation with regulatory agencies, technical experts, Aboriginal groups, local government, non-governmental organisations, and the public through engagement and consultation, which included the TAG process, early in the environmental assessment process as described in Section 7.0 of the EIS. Information obtained during these sessions were considered and incorporated into the assessment, as appropriate.

The VFPA continued to engage with regulatory agencies during the completeness phase, providing further clarification as well as conducting additional analyses as requested to address questions raised (CEAR Document #547). The scientific review conducted by the CSAS supported the modelling approach, but raised some concerns regarding the model uncertainties (CEAR Document #893). These questions were forwarded through this recent IR Package 2 provided to the VFPA by the Panel. The VFPA has responded to these IRs in this submission. Additional analyses provided also re-iterate the key findings presented in the EIS and summarised above.

References

Teeter, A. M., B. H. Johnson, C. Berger, G. Stelling, N. W. Scheffner, M. H. Garcia, and T. M. Parchure. 2001. Hydrodynamic and sediment transport modeling with emphasis on shallow-water, vegetated areas (lakes, reservoirs, estuaries and lagoons). Hydrobiologia 444:1–23.

Appendices

Appendix IR2-A Coastal Geomorphology Technical Advisory Group Summary Report

APPENDIX IR2-A

COASTAL GEOMORPHOLOGY TECHNICAL ADVISORY GROUP SUMMARY REPORT

Proposed Roberts Bank Terminal 2 Project

Coastal Geomorphology Technical Advisory Group

Summary Report

Prepared for

Port Metro Vancouver

Prepared on behalf of TAG Participants by

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Date

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Contents

Acronyms

CCIP	Container Capacity Improvement Program
Compass	Compass Resource Management
DoD	depth of disturbance
DTRRIP	Deltaport Terminal Road and Rail Improvement Project
EA	Environmental Assessment
IPCC	Intergovernmental Panel on Climate Change
LIDAR	Light Detection and Ranging
NHC	Northwest Hydraulic Consultants Ltd.
PMV	Port Metro Vancouver
PPRFFA&Ss	past, present, and reasonably foreseeable future actions and stresses
RBT2	Roberts Bank Terminal 2
SRKW	Southern Resident Killer Whales
TAG	Technical Advisory Group
TEU	Twenty-Foot Equivalent Units
YVR	Vancouver International Airport

1 Introduction

1.1 Purpose and Background

The Roberts Bank Terminal 2 (RBT2) project is a proposed new three-berth container terminal in Delta, BC that would expand existing port facilities by 2.4 million twenty-foot equivalent units (TEUs) of container capacity. The project is part of Port Metro Vancouver's (PMV) Container Capacity Improvement Program (CCIP), a long-term strategy to meet anticipated growth in demand for container capacity. The proposed RBT2 project entails the construction of a new three-berth marine terminal and associated road and rail infrastructure alongside the existing Westshore and Deltaport terminals at Roberts Bank. PMV has a mandate to support the growth of Canadian trade with other countries, and current demand forecasts anticipate container traffic to triple by 2030. Subject to regulatory approvals, the RBT2 project could be operational by the mid-2020s. Further information on the proposed RBT2 project can be found on the project's website, www.robertsbankterminal.com.

Figure 1. Artist's rendering of the proposed RBT2.

Image courtesy of PMV.

The proposed RBT2 project is subject to environmental assessment (EA) under federal and BC provincial laws. EA is a process whereby the potential effects of proposed projects on the environment are examined through a public process. While the scope and nature of the EA for RBT2 has not yet been determined by regulators, PMV expects the EA to be some form of joint review process. The proposed RBT2 project could potentially cause a variety of environmental effects, some of which are reasonably well understood, and some of which are less well understood due to their complexity and based on the current state of scientific knowledge.

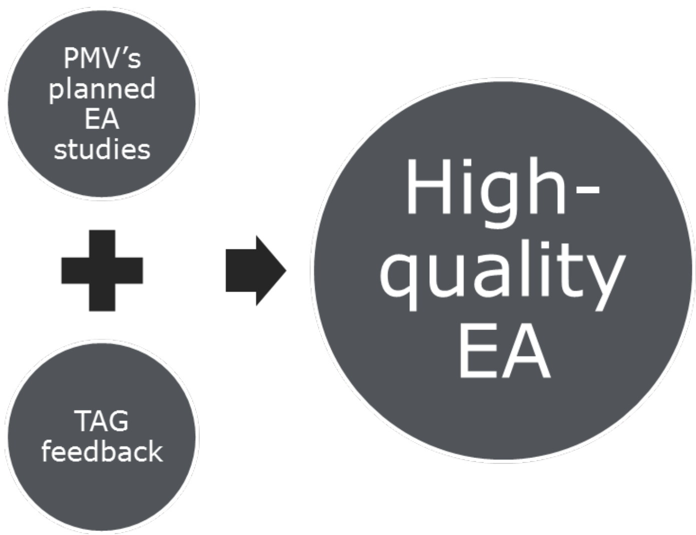
PMV has contracted Hemmera, a consulting firm specializing in EA, to conduct the EA studies for the proposed RBT2 project. Some of these studies, such as baseline studies that characterize the environment pre-construction, are currently underway. As part of its pre-EA work, PMV initiated a Technical Advisory Group (TAG) process to gather input from outside experts on four separate topics.

This report is written by Compass on behalf of the Coastal Geomorphology TAG and summarizes the proceedings and recommendations of that TAG.

1.2 Overview of the Technical Advisory Group Process

The purpose of the TAG process was to pro-actively gather input from scientific and technical experts prior to the formal initiation of the EA for RBT2 so as to enhance the relevance, quality, and rigour of EA studies for the project (Figure 2). Experts were invited from regulatory agencies, academia, First Nations and key non-government organizations based on their ability to contribute to technical discussions pertaining to the identified EA studies.

Figure 2. Role of TAG process in ensuring high-quality EA of the proposed RBT2 project.



The TAG process involved four separate TAGs:

1. Biofilm and Shorebirds;
2. Southern Resident Killer Whales (SRKW);
3. Coastal Geomorphology; and
4. Productive Capacity of Roberts Bank habitat.

The four TAGs each addressed topics that were considered by PMV and its consultants to require additional preliminary scoping in order to satisfy EA requirements.

Biofilm, shorebirds, and SRKW are likely to be recognized in the forthcoming EA as topics of particular importance to stakeholders and thus of the forthcoming EA process. These topics are discussed in companion reports on each of the individual TAGs.

Coastal geomorphology—the physical features and processes in the vicinity of the proposed project area at Roberts Bank—was chosen because any project-related geomorphic and physical oceanographic changes are expected to be the primary driver for marine biological and ecological changes. RBT2 infrastructure may cause changes to tidal currents and water movement associated with wind-generated waves, which could affect sediment settling and re-suspension, and which in turn could cause changes to local marine habitats, such as biofilm and eelgrass beds.

Similarly, the ability of habitat to support species of particular interest to stakeholders is critical to the health of those species. PMV sees merit in entering into technical dialogue on how the productive capacity of habitat is most appropriately defined at Roberts Bank. This topic is explored in a companion report on the Productive Capacity TAG.

Despite the different topic matter of each of the four TAGs, all four had a similar set of objectives:

- build a common understanding of the potential effects of RBT2 based on the best available information;
- provide input on appropriate methods for assessing potential adverse effects and their significance;
- identify priority information needs and related studies; and
- identify opportunities for collaboration.

Each TAG met face to face three or four times between November 2012 and May 2013. Meetings were held in Vancouver over full day periods. Each individual TAG process was designed and led by Compass, who acted as an external facilitator. In each meeting Compass and PMV consultants led discussions with TAG members. In addition, for all TAGs except Coastal Geomorphology, focus groups were created to investigate particular topics in greater depth with an additional set of experts relevant to each field.

1.3 Participants and Roles in the TAG Process

There were five main parties identified as potential participants in the TAG process: technical experts from government agencies, academia, non-governmental organizations, PMV and PMV consultants, and First Nations. First Nations did not participate in the TAG process, however PMV has committed to share TAG information and obtain input through a separate process.

TAG members were tasked with:

- providing input on current and planned EA studies;
- providing input on potential effects of the project on the environment;
- providing input on impact assessment methods;
- helping prioritize and scope key issues; and
- providing input from their organization.

PMV consultants – which for geomorphology included Hemmera and Northwest Hydraulic Consultants (NHC) – were tasked with:

- preparing material for TAG meetings, such as pre-reading packages, presentation slides, and discussion materials;
- managing schedules, scope, and budget for the TAG process;
- explaining current study plans to the TAGs;
- ensuring integration of people and discussions across TAGs where relevant;
- organizing meeting logistics; and
- where relevant, having representatives participate as TAG members in TAG meeting discussions.

PMV was tasked with:

- providing resources and meeting logistics;
- providing communications with TAG participants and the public;
- providing information about the proposed RBT2 project; and
- observing TAG meetings and considering input from each TAG.

The TAG process was *advisory* in nature, and so PMV sought to gather advice through the process in terms of how best it and its consultants conduct specific EA studies for RBT2.

Compass was tasked with:

- designing the TAG process and advising on implementation;
- facilitating TAG meetings;
- advising on how discussions and outputs of individual TAGs might be used by other TAGs;
- summarizing input, including areas of agreement and disagreement, in meeting notes; and
- producing a record of the process in this summary report.

1.4 About This Report

This report reviews the discussions and outputs of the Coastal Geomorphology TAG. This report does not attempt to follow the chronological order in which items were discussed during the meetings, but rather provides a thematically-organized synthesis of discussions that occurred over the course of the TAG meetings. The next section provides more background information on the Coastal Geomorphology TAG in terms of what meetings were held, who was involved, and what specific topics were explored. Section 3 examines methods of impact assessment related to coastal geomorphology and forms the bulk of the report. Section 4 examines several related issues that were less prominent in the TAG process. The reader is encouraged to review the reports for the other three TAGs to have a complete understanding of the RBT2 TAG process.

2 Background on the Coastal Geomorphology TAG

Coastal geomorphology in the context of RBT2 entails the study of the physical features of the shoreline, the Roberts Bank tidal flats, the Fraser River delta, and the processes that shape these features. The coastal geomorphology of Roberts Bank has a direct influence on the marine ecosystem, including species that are expected to be of particular importance to stakeholders. Therefore, PMV has chosen to better understand coastal geomorphological processes to help inform other studies in the environmental assessment for RBT2.

2.1 TAG Meeting Summary

The Coastal Geomorphology TAG met three times between November 2012 and March 2013 to discuss a variety of topics (Table 1). The Coastal Geomorphology TAG discussed how the proposed RBT2 project might affect the coastal geomorphology of Roberts Bank, how these effects might best be assessed, and what mitigation measures could potentially reduce the effects of RBT2 on the environment.

Table 1: Dates and key topics of Coastal Geomorphology TAG meetings.

Meeting Number	Meeting Date	Key Topics Covered
1	November 15, 2012	• overview of the TAG process • overview of the RBT2 project • how coastal geomorphology influences some marine species • overview of Roberts Bank geomorphology • potential ways in which RBT2 may affect the environment (i.e., key effect pathways) • current field studies and planned methods of EA • key questions for the TAG from PMV consultants • work plan for the TAG
2	January 31, 2013	• NHC's 'working conjectures' about the coastal geomorphology at Roberts Bank • how climate change is integrated into impact assessment

Meeting Number	Meeting Date	Key Topics Covered
		• factors affecting the formation of new tidal channels in mudflats
3	March 8, 2013	• methods of interpretive geomorphology • modeling methods for assessing the potential effects of RBT2 on coastal geomorphology • factors affecting the formation of tidal channels, and possible mitigation measures • cumulative effects baselines, including past, present, and reasonably foreseeable projects to be considered • wrap-up of TAG process and confirmation of key messages

2.2 TAG Participants

TAG participants included a variety of TAG members, observers, support staff, and facilitators, as summarized in Table 2.

Table 2: Participants in the Coastal Geomorphology TAG.

Name	Affiliation	Role	Participation
Juergen Baumann	Baumann Environmental Services Ltd	TAG member	Meetings 1,2, and 3
Dr. Doug Bright	Hemmera	TAG member	Meetings 1,2, and 3
Dr. Michael Church	University of British Columbia	TAG member	Meetings 2 and 3
Dr. John Clague	Simon Fraser University	TAG member	Meetings 1 and 2
Dr. Philip Hill	Pacific Geoscience Centre, Natural Resources Canada	TAG member	Meetings 1,2, and 3
Dr. Diane Masson	Department of Fisheries and Oceans	TAG member	Meetings 2 and 3
Dr. William McDougal	University of Florida	TAG member	Meetings 1 and 3
Dr. David McLean	Northwest Hydraulic Consultants	TAG member	Meetings 1,2, and 3
Derek Ray	Northwest Hydraulic Consultants	TAG member	Meetings 1,2, and 3
Dr. Terri Sutherland	Department of Fisheries and Oceans	TAG member	Meeting 2
Dr. José (Pepe) Vasquez	Northwest Hydraulic Consultants	TAG member	Meeting 3
Dr. Jeremy Venditti	Simon Fraser University	TAG member	Meetings 1,2, and 3
Edwin Wang	Northwest Hydraulic Consultants	TAG member	Meeting 3
Dr. André Zimmerman	Northwest Hydraulic Consultants	TAG member	Meetings 1 and 2
Jody Addah	PMV	Observer	Meetings 2 and 3
Rhona Hunter	PMV	Observer	Meeting 1
John Parker-Jervis	PMV	Observer	Meeting 1
Andrew Robinson	Canadian Wildlife Service	Observer	Meeting 3
Eriko Arai	Hemmera	Support	Meetings 1,2, and 3
Ben Wheeler	Hemmera	Support	Meetings 1 and 2
Marina Winterbottom	Hemmera	Support	Meeting 1
Mike Harstone	Compass	Facilitator	Meetings 1, 2, and 3
Chris Joseph	Compass	Facilitator	Meetings 1, 2, and 3

2.3 Selection of TAG Topics and Priorities

At the beginning of the TAG process, Hemmera and NHC identified a number of questions on which they asked the TAG to provide advice and input:

1. What are the most important pathways of potential effects on coastal geomorphic processes at the project site? What are the key uncertainties associated with these pathways?
2. Are the proposed studies appropriate and sufficient with respect to understanding the coastal geomorphology processes at the project site?
   a. What is an appropriate modeling methodology?
   b. In what ways can any weaknesses be addressed?
   c. How should the wave regime be characterized and measured?
   d. How should the potential effects of climate change on coastal geomorphic processes be incorporated into the modeling?
3. Are current data sufficient to support robust analyses on coastal geomorphic processes at the project site?
   a. What are the limitations of using historic data on morphological changes on Roberts Bank to forecast future project-related changes? Are there alternatives to using this historic data for the purposes of developing forecasts?
   b. What is the best approach to quantifying and describing changes to Roberts Bank tidal flats from projected climate change?
   c. Are there additional data available that should be considered?

These questions served to guide the development of initial agendas for the three TAG meetings.

In early discussions in the meetings, the TAG reviewed potential pathways of effects between the proposed project and specific marine species. In other words, the TAG discussed how the project's construction and operations might translate through cause-effect relationships into effects on the environment. The TAG identified numerous pathways, such as how the project may alter tidal currents which in turn might cause erosion or deposition of sediment, and how climate change may alter Fraser River water flows which in turn might compound with the effects of RBT2 on the tidal flats. TAG discussions highlighted the difficulty of disentangling the inter-related effects of development on tidal flat geomorphology. The TAG noted that coastal geomorphology science is associated with high uncertainty, and that viewing individual effects in isolation is problematic.

In the end, the TAG focused on the following topics during the process:

- underlying understandings and assumptions about the coastal geomorphology at Roberts Bank (what came to be known as NHC's 'working conjectures'); [1]
- how climate change is integrated into an impact assessment, including how sea level rise is factored into analyses;
- factors affecting the formation of new tidal channels in mudflats, and the effectiveness of mitigation;
- detailed issues with respect to modeling and interpretive geomorphology methods; and

[1] Note that despite being called 'working conjectures' NHC had come to these sets of understandings and assumptions based upon their considerable knowledge and experience.

- how cumulative effects on Roberts Bank coastal geomorphology, including consideration of environmental effects and the effects of other human projects should be considered in the analysis.

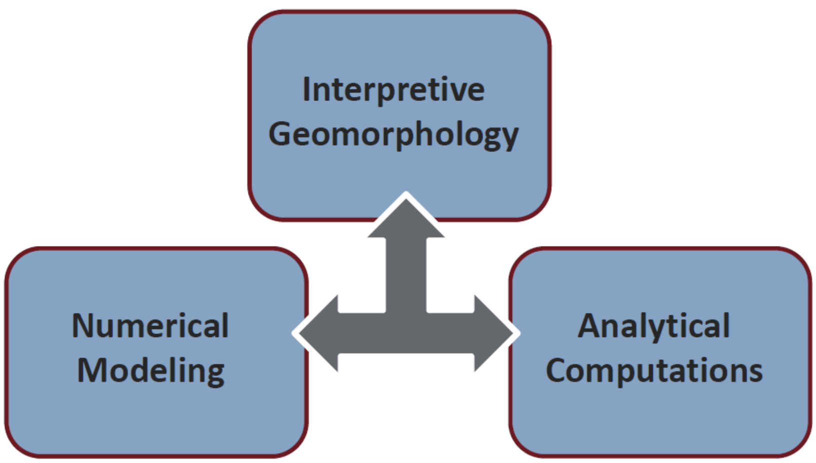
3 Assessing Effects on Coastal Geomorphology

An important part of Coastal Geomorphology TAG discussions was the review of possible methods for predicting the potential effects of RBT2 on coastal geomorphology. This section of the report explores these discussions. The first sub-section reviews the overall approach to impact assessment planned by NHC. The second sub-section examines methods related to assessing tidal channel initiation and propagation. The third sub-section examines TAG discussions pertaining to how to integrate climate change into the assessment.

3.1 Methodological Approach

NHC has proposed to use three inter-related sets of methods in its EA studies for RBT2 including (1) numerical modeling, (2) interpretive geomorphology, and (3) analytical computations (Figure 3). This 'three pronged' approach is expected to provide for a robust effect assessment study as the different methods are complementary and address the weaknesses of any single method used on their own.

Figure 3. NHC's proposed 'three-pronged' approach for EA of the potential effects of the proposed RBT2 project on coastal geomorphology.



Numerical modeling is the use of computer-based programs to solve the equations that describe the primary processes that shape coastal geomorphology. These processes – for instance, waves, tidal currents, sediments, etc. – can be described spatially and temporally and it is possible to relate the various processes using mathematical equations. Once the existing geomorphology conditions are represented in the model, such as tidal current velocity, it is possible to vary one or more parameters to allow for prediction of future conditions. For example, a numerical model could be used to estimate changes to wave heights in the vicinity of the proposed RBT2 project.

NHC is planning on using the TELEMAC model suite (composed of the TELEMAC hydrodynamic module, the TOMOWAC wave module, and the SISYPHE sediment transport module) in an integrated fashion to simulate interactions between water currents, waves, and sediments at Roberts Bank.

Analytical computational methods use empirical or theoretical relationships that describe processes in the natural system. For example, sediment transport, erosion and deposition processes can be described in general terms as a check on the numerical modeling approach. Analytical computational methods rely on the larger body of scientific knowledge regarding mathematical relationships between various system components (for example, between water velocities and the sediment particle sizes that can settle or become re-suspended).

Interpretive geomorphology is the analysis of existing coastal processes and landforms, both locally and around the globe. The patterns evident in coastal zones reflect the cumulative forces and dynamics of water, sediment, wind, and waves. An understanding of existing geomorphic processes and patterns both locally and globally provides the foundation for interpreting the processes underlying the geomorphology at Roberts Bank.

There are at least three reasons for using interpretive geomorphology methods. First, interpretive methods are often used to parameterize models and computations, e.g., data on river flow velocities can be input into models that predict future river flow velocities. Second, interpretative geomorphology helps to validate numerical modeling approaches by critically evaluating the degree of alignment between the current geomorphic state and what would be predicted from modeling. Third, interpretive methods can provide perspective on particular study sites by indicating what has happened, or is happening, elsewhere.

Some of the interpretive methods that NHC plans to use include:

- conducting inspections to observe processes in the field;
- analysing historical air photos for long-term changes and response to past disturbance;
- measuring sediment movement using instruments and monitoring stations in Canoe Passage and across Roberts Bank;
- assessing erosion and deposition on the tidal flats using depth of disturbance rods that show, over time, how much sediment in a location has been removed or collected (Figure 4);
- examining existing and historic tidal channels on Roberts Bank;
- measuring waves using sensors anchored temporarily on the seabed;
- analyzing data on sediment grain size; and
- reviewing and synthesizing experience from previous projects on the Fraser Delta and from similar environments in other regions relating to geomorphic impacts, methods of prediction, and methods of mitigation.

The following sub-sections describe the key issues, findings, and recommendations discussed by the TAG with respect to NHC's planned methods.

Figure 4. Schematic of a depth of disturbance rod (a) during placement, (b) with subsequent deposition of sediment over washer, and (c) following erosion (at which point washer drops down rod) and then subsequent deposition.

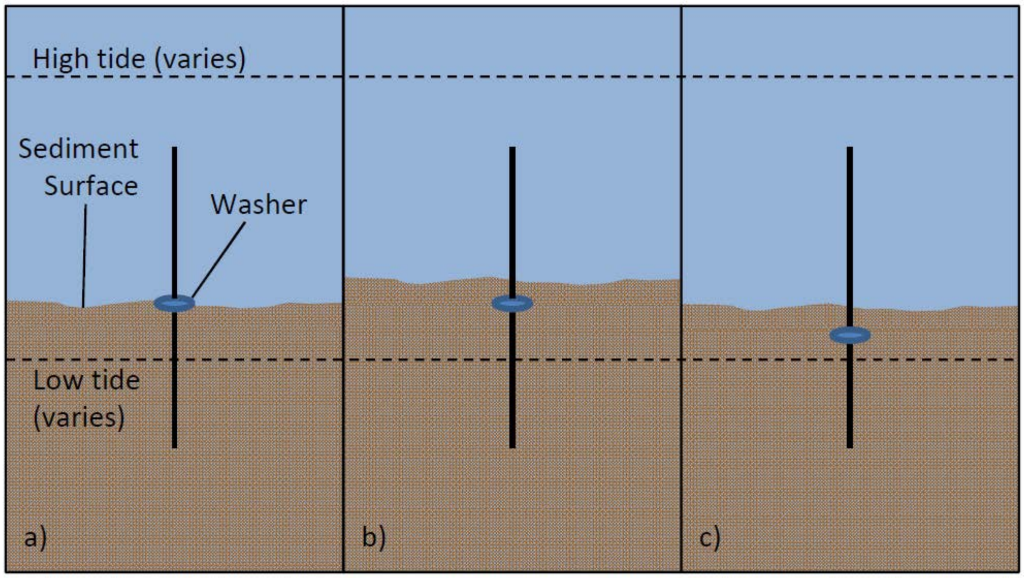


Diagram courtesy of Derek Ray, Northwest Hydraulic Consultants.

3.1.1 Key Issues

The key issues discussed in relation to NHC's proposed methods for predicting project-related effects included the following:

- underlying understandings and assumptions about Roberts Bank geomorphology (i.e., 'working conjectures');
- selection and limitations of models, and how to make the most effective use of available computing power; and
- the use of interpretative geomorphology methods to predict the future wave climate regime and evolution of the tidal flats at Roberts Bank.

3.1.2 Key Findings

In general, the TAG agreed with NHC's proposed three-pronged approach for assessing possible effects of RBT2 on coastal geomorphology. This section explores aspects of these discussions, including NHC's main working conjectures and their approach to numerical modeling and interpretative geomorphology. Section 3.1.3 reviews the TAG's recommendations in response to identified issues.

Working Conjectures

The TAG examined five 'working conjectures', or underlying understandings and assumptions, that NHC is using to form the basis of the EA work at Roberts Bank. These conjectures are based on existing scientific research and NHC's current understanding of the Fraser River delta. In general, the TAG agreed with the substance of the conjectures.

Conjecture #1: The contribution of sand from the main arm of the Fraser River to Roberts Bank is relatively small. Consequently, relatively little additional work is necessary to study sediment contributions from the main arm.

Sandy sediments carried by water flowing through the main arm of the Fraser River tend to remain in the channel and get deposited in the deeper waters of the delta front immediately off the river mouth. The historical pattern of deposition back and forth across the delta has changed as a result of the stability of the main channel imposed by human-made training structures that cause sediment entrainment and dredging. The tidal flats at Roberts Bank are primarily a relict feature that formed during previous stages of delta building and receive no sandy sediments from the main arm. At present, inputs of sandy sediments are limited to those delivered from Canoe Passage, which is a small distributary branch of the Fraser River that carries approximately 5% to 10% of the flow and sand load. Suspended sediments carried in the Fraser River plume are broadcast over Roberts Bank. However, in comparison to the historical sand load deposits, little material is delivered to Roberts Bank on an annual basis.

Conjecture #2: The amount of sediment that is transported to and from the tidal flats is low in comparison to the volume of sand stored in the flats.

The available evidence suggests that there is little change in sediment volumes in the study area.

First, a review of the historical data on the tidal flats (in combination with data gathered from an aerial (LIDAR) survey carried out in 2001 and 2011) indicates that while there has been deposition and erosion of sediment on the tidal flats, these changes are minor. In fact, except for the vicinity of Canoe Pass, where some channel migration is noted, the observed changes are within the accuracy of the survey measurement technique, and so observed 'changes' may not actually be real.

Second, data gathered from NHC's depth of disturbance (DoD) rods that have been placed in various locations across the tidal flats support the notion that there is little net erosion or accumulation of sediment on the tidal flats.

Third, the construction of the original PMV causeway did not trigger obvious drastic change in tidal flat morphology on either side of the causeway. In other words, by placing the original causeway along the tidal flats, the tidal flats on either side did not rapidly grow or diminish appreciably because of any sort of inhibition of sediment transport along the tidal flats.

The TAG discussed two consequences of all of this. One, this evidence lends credence to the notion that the tidal flats are in an approximate state of equilibrium over annual to inter-annual time scales. Two, any erosion caused by the project might become essentially permanent because of the lack of 'nourishment' from new sediment.

The TAG did note, though, that any movement and deposition of finer-grained (silt-clay) fractions (such as silt and clay) may affect species inhabiting Roberts Bank.

Conjecture #3: The majority of the lower Roberts Bank tidal flats consist of non-cohesive sediment, and the methods available for predicting the transport of non-cohesive sediments are well-described and accepted. Consequently, there is no need to consider transport, deposition, or erosion of cohesive sediment.

As the tidal flats are mostly composed of non-cohesive sediments, such as sand and silt, methods to assess how the project may affect sediment transport can be chosen accordingly. NHC plans to conduct sediment transport modeling using equations for non-cohesive sediments, and plans to ignore geomorphic processes related to sediment cohesion. This methodological strategy is conservative given that non-cohesive sediment is more vulnerable to erosion and re-suspension than cohesive sediment (such as clay), and because cohesive sediment settles more rapidly than non-cohesive sediment. In other words, by assuming that sediment on the tidal flats is non-cohesive, the worst-case scenario effects of RBT2 on coastal geomorphology will be predicted.

The TAG discussed how some portions of the upper flats are composed of cohesive mud, and that this mud is important biologically. There is also a shoreward band of elevated mud that wraps around the northern side of the Deltaport causeway. This band of mud appears to be an artefact from the construction activities. This mud supports biofilm, shorebirds, and fish, and it is therefore important for NHC to consider how not just sand and silt fractions may be affected by RBT2 but also the clay fraction. The TAG also discussed how RBT2 might lead to the formation of a new C-shaped mud beach behind the new terminal footprint but it was recognised that this could be assessed using an interpretive, rather than numerical, approach.

Conjecture #4: The primary morphologic changes induced by RBT2 will mainly be local erosion and deposition.

NHC has conducted preliminary modeling of changes that RBT2 may cause to the tidal flats. This preliminary modeling indicated that the proposed RBT2 project may cause some localized erosion of the seabed at the northwest corner of the new RBT2 terminal, and that this erosion may induce other changes on the tidal flats, such as the initiation of a new tidal channel (or the re-activation of a historical channel). While this modeling was only 'preliminary', the TAG agreed with the notion that this modeling work provides a sound basis for understanding the basic nature and scale of effects on tidal flat morphology from RBT2.

Conjecture #5: Mathematical models that examine how the shape of landforms may change over time are not very practical for examining whether or not small-scale tidal channels might form at Roberts Bank. Instead, an interpretive geomorphology approach is more effective for assessing whether such tidal channels might initiate or propagate, and how effective different mitigation measures may be for preventing initiation or curtailing expansion of channels.

NHC's preliminary modeling of changes that RBT2 may cause to the tidal flats is limited in its ability to predict what may eventually transpire at small spatial scales. As NHC pointed out to the TAG, the modeling that has been conducted to date is only preliminary in that it did not take into account the variety of grains sizes of sediment, amongst other issues. Consequently, as the TAG discussed, the results of such modeling cannot be viewed with sufficient confidence to base EA conclusions upon, and while NHC may be able to enhance the sophistication of subsequent modeling efforts, existing models still lack the capacity to consider channel initiation. Therefore, the TAG agreed that a complementary approach was to assess the project's potential to create new tidal channels using interpretative geomorphic methods.

NHC has begun using interpretive geomorphological methods to examine tidal channel initiation and propagation. This work has included examination of the historical depth of the portion of Canoe Passage crossing the tidal flats, and examination of this channel's response during the 2012 spring freshet. The data show that the position and shape of the channel has remained unchanged, despite the fact that the 2012 freshet was a large flood event. The TAG discussed how one implication of this finding is that storm events may be the principal influence on coastal landforms on Roberts Bank. This latter conclusion is supported by water turbidity data that suggest that the majority of sediment movement over the tidal flats occurs during larger wave events at lower tides.

Modeling

The TAG was generally supportive of NHC's proposed approach to modeling which includes the use of the TELEMAC model suite to assess wave – tidal current – sediment interactions. The TAG highlighted that what matters is not the specific model that is used, but whether the underlying physics of the chosen model are sound and appropriate in a given context, and whether the model is properly applied.

NHC's modeling approach is broken down into two parts: a coarse-grid model of the entire Strait of Georgia, and (ii) a fine-grid model providing more detail of Roberts Bank. The purpose of the coarse-grid model is to estimate the waves and currents at the outer boundary of the fine-grid model so that more detailed modeling (using the fine-grid model) is reflective of broader conditions in the Strait of Georgia.

One issue that arose in discussions was how the boundary conditions for the finer-grid, two dimensional (2D) model would be set, and whether the coarser-grid model could adequately capture the complex flow patterns in 2D or whether a 3D model would be required. In particular, the discussion explored the issue of horizontal layering in the water flowing through the Strait of Georgia and the potential for a 2D model to oversimplify the complex flow patterns that exist in the strait. One TAG member, for example, suggested that it is important to consider near-bottom currents when assessing sediment transport, and thus advocated 3D modeling. NHC agreed that they would explore both the 2D and 3D options for the large-area model to examine whether the improvements in terms of more accurate boundary conditions for the finer-scale model was worth the increased computational demands (and consequent limitations on what can be modeled) of the 3D large-area model.

Interpretive Geomorphology

NHC indicated that their interpretive geomorphology methods will involve examining landforms and processes at Roberts Bank, and analysing such things as turbidity levels of water, wave heights, and sediment grain size. The TAG supported these efforts and noted the dual role that these methods could take in terms of gathering data for use on its own but also to support modeling and analytical computations.

The TAG also discussed how best to characterize the wave climate at Roberts Bank (for instance the statistical patterns of wave heights during winter storms) so that waves and their effects on the tidal flats could be investigated while considering the overall regime of waves rather than the simpler approach that looks at the effects of a certain wave height at a certain tide height. NHC is gathering data on waves from sensors at monitoring stations around Roberts Bank, but sought advice from the TAG on whether this approach would be the most effective. In response, the TAG recommended several approaches (see below in s.3.1.3), but also considered how different species might be sensitive to waves – some vegetation may be limited by the long-term average characteristics of waves, whereas other vegetation might be limited by the characteristics of extreme wave events.

Sediment Dynamics and Evolution of the Tidal Flats

A key element of NHC's work is to understand how the tidal flats may change over time – both in response to the existing natural systems but also in response to future changes such as the RBT2 project and climate change. This topic is important because some species may be sensitive to seemingly minor changes in the shape, sediment characteristics, and/or depth of coastal landforms. Key to this topic, then, is how sediment, including fine sediment, may build up or erode over time on the tidal flats due to the erosion, transport, and deposition effects of tidal currents and waves. In the course of the TAG meetings NHC reviewed preliminary conclusions about how the project might affect the wave climate and sediment dynamics, and what this might mean for the evolution of the tidal flats over the long term. In response, the TAG discussed several interpretive geomorphology methods that might help fortify NHC's assessment as relayed in section 3.1.3 below.

3.1.3 Recommended Data Sources and/or Studies

The discussions highlighted above led to a variety of recommendations from the TAG:

- To complement modeling of the potential effects of RBT2 on the tidal flats, given the limitations of existing models, and to improve upon the interpretive geomorphology methods that NHC has planned, the TAG recommended that:
    - NHC draw inferences from development on Roberts Bank, Sturgeon Bank, and around the world (for instance the Bay of Fundy, the US west coast including San Francisco, and Brisbane (Australia) and Indonesia); and
    - PMV incorporate adaptive management strategies for RBT2, i.e., that PMV develop plans to address unforeseen consequences of development ahead of time in case such things do occur in the future.

- Given that modeling relies upon computer technology that has limitations in terms of computational power (i.e., the need to balance level of detail in the model against how long it takes for the model to run), the TAG recommended that NHC:
    - model conditions for summer and winter separately;
    - do short simulations if there is independence in geomorphological responses from year to year;
    - remove periods of calm weather to focus the wave modeling on storms and periods in which geomorphic processes are more likely to affect the tidal flats; and
    - 'leap frog' the modeling over time, i.e., time-stepping the models if there is evidence that year-to-year changes are small.

- To help understand the potential influence of waves on the tidal flats, the TAG recommended that NHC:
    - develop probability distributions of wave characteristics to build an understanding of the frequency with which waves capable of mobilising sediments on the tidal flats might occur; and
    - use scenario analysis to examine the potential effects of different types of storms on Roberts Bank (in lieu of forecasting the probability with which high energy storms might occur).

- Given that the response time for the tidal flats may be many decades, and the effects from human-made structures may only now, or may yet, be coming fully evident, the TAG recommended that NHC take core samples of sediment in the tidal flats and analyse tracers such as ^{210}Pb (lead 210) and silver to try and establish historical sedimentation rates.

- To help ensure that models are based upon accurate reflections of current conditions, and to help NHC determine whether 2D or 3D large-scale models are necessary to set boundary conditions for finer-scale modeling, the TAG suggested that NHC gather data from the Venus coastal network (a project of the Ocean Networks Canada Observatory at the University of Victoria).

3.2 Initiation and Propagation of Tidal Channels

Tidal channel initiation and propagation was an important topic for the Coastal Geomorphology TAG. This topic was discussed in all three meetings and concerned the state of science on the topic, methods of assessment, and mitigation measures.

Tidal channels were discussed under two broad categories: salt marsh tidal channels, and mud flat tidal channels.

Salt marsh tidal channels occur in the upper intertidal zone and are often associated with protected embayments where channels form within areas of vegetation growth. Channels emanating from a salt marsh do not necessarily persist across the tidal flats; such channels often become indistinct within a short distance of the marsh edge. Examples of this type of channel at Roberts Bank exist at Brunswick Point and throughout the upper intertidal zone northwest of the Deltaport causeway. Much of the existing research around the world on tidal channels has been carried out on this type of channel (but not at Roberts Bank).

Mud flat tidal channels are the more prevalent type of channels that have occurred at Roberts Bank in the area between the Deltaport and BC Ferries causeways (Figure 5). This type of channel occurs further down in the middle to lower inter-tidal zone and entails a distinct channel across the tidal flats that extend as far seaward as the low tide zone. The width and depth of mud flat channels tend to reflect the amount of water moving through them.

Figure 5. Aerial view from the northeast of the tidal channel that has formed between the BC Ferries terminal to the east (out of view) and Deltaport (in background).

Photo courtesy Derek Ray, Northwest Hydraulic Consultants.

The channels that have formed in the inter-causeway area are examples of what could potentially develop with the construction of RBT2. This type of channel will be a focus of the

RBT2 EA because of the proximity of the proposed project to an existing channel, the potential for the project re-initiate this channel, and the consequent changes that might occur to existing habitat on Roberts Bank. NHC has identified several alternative footprint designs for RBT2 and is examining those designs that are expected to be least likely to cause new tidal channel formation as occurred in the inter-causeway area.

3.2.1 Key Issues

In the 1950s, prior to construction of the Deltaport and BC Ferries causeways and terminals, there were almost no mud flat tidal channels on Roberts Bank. However, since construction of this infrastructure on Roberts Bank, tidal channels have formed, primarily in response to creation of a turning basin through dredging. This observation then raises the question of whether the mechanisms that triggered channel formation in the inter-causeway could occur in relation to the proposed RBT2 project.

As part of the TAG's exploration of this issue, the TAG discussed the current science on tidal channel formation. According to NHC, the three principal triggers of tidal channels seem to be:

1. head-cutting, where excavation of the tidal flats above the low tide mark leads to channel initiation upslope on the tidal flats, which leads to the channel extending landward through erosion;
2. water draining off uplands during a dropping tide in which seaward-advancing channels are produced by local drainage (from a stream or some other form of a reservoir) onto exposed tidal flats; and
3. a temporary storage of water upland of the tidal flats allows a flow of water to drain across the exposed tidal flats during a dropping tide.

Highlighting the uncertainties that exist with respect to understanding the mechanisms of tidal channel initiation at Roberts Bank, NHC presented the following lessons gathered through a review of the experience at Roberts Bank as well as the international experience of development and tidal flats:

- avoid excavation or eroding portions of the tidal flats that become exposed at low tide levels;
- avoid relying on crest protection structures, or other 'hard' engineering approaches, to control head cutting as they have not been demonstrated to work;
- head-cut channels are not expected to extend landward indefinitely and but are expected to ultimately reach equilibrium, though this equilibrium state may still affect some marine species (some positively, others negatively); and
- avoid increasing drainage onto exposed tidal flats as this may trigger seaward-advancing channels.

In short, NHC suggested that prevention is a key strategy to employ when developing in tidal flats.

3.2.2 Key Findings

The TAG noted that prediction of tidal channel formation is challenging since (i) the processes of interest are inherently non-linear, and (ii) much of the recent scientific research and model development is based on salt marsh channels in sheltered embayments as opposed to more exposed, lower elevation tide flats (i.e., the conditions at Roberts Bank). The overarching conclusion, therefore, was that developers should minimize disturbance of tidal flats.

In the course of discussions the TAG also identified a potential consequence of the proposed RBT2 project. NHC has begun to examine the potential for RBT2 to initiate tidal channel formation through preliminary modeling of sediment erosion and deposition around the new terminal. The results of this preliminary modeling suggest that the project may cause erosion at its northwest corner. The TAG discussed how this 'scour hole', if it should actually occur, might reactivate a relict tidal channel south of Canoe Passage, and if this happened, this relict channel might widen, deepen, and propagate upstream. An important question, then, is whether the channel would reach the wetland north of the existing relict channel at Brunswick Point (given the ecological importance of the salt marsh there) or link up with Canoe Passage. The TAG discussed how tidal channels can erode through eelgrass beds as they have in the inter-causeway area, a concern given the recognised ecological value of eelgrass. The TAG discussed that a tidal channel might not be initiated from the scour hole on the northwest corner if erosional forces could be limited to a narrow, deep area solely within the sub-tidal zone.

The TAG also discussed how numerical models have limitations in terms of predicting tidal channel impacts of development on tidal flats, partly because channel initiation occurs at a smaller scale than what can be modeled. The TAG mentioned that while modeling is not useful at predicting tidal channel formation, models can be used to give insight into where erosion might occur and where new channels might be triggered. This finding is consistent with NHC's planned approach to use models to identify potential locations for channel initiation, and then to rely on interpretive geomorphology methods, such as examining the historical experiences at Roberts and Sturgeon Banks, to estimate the potential scale of channels should they actually develop.

3.2.3 Recommended Data Sources and/or Studies

The TAG agreed with NHC that models should be used to help identify areas where erosion might occur and thus where tidal channels might be initiated, but that interpretive geomorphology methods should be used to help characterize the potential extent of tidal channels if they are initiated.

3.3 Characterizing Future Climate Change Scenarios

3.3.1 Key Issues

The potential effects of future climate change will need to be considered in the EA of the proposed RBT2 project. In a coastal context, this means that the assessment may consider the potential effects of climate change in terms of:

- the magnitude and rate of sea level rise that can be expected at Roberts Bank,
- the extent to which storms that send waves towards Roberts Bank might change,
- the extent of changes of Fraser River outputs (such as volume of flow and sediment load) at the river mouth, and
- the degree to which the tidal flats might change over the long-term to the above factors.

In addition, completion of the effects assessment will require the identification of an appropriate time horizon for analysis, i.e., the appropriate length of time over which EA forecasts are generated, given the long-term nature of climate change and the project. The TAG explored each of these five topics.

3.3.2 Key Findings

Sea Level Rise

There is considerable uncertainty and debate in the scientific community with respect to how high and how quickly sea levels will rise in the future from climate change. This topic was discussed by the TAG in terms of identifying what an appropriate range of sea level rise should be considered in NHC's analyses, given that sea level has an effect on the coastal geomorphology at Roberts Bank (for example, based on wave heights, which are in part a function of water depth).

A starting point was reviewing three scenarios for sea level rise proposed by NHC:

- a lower bound of 0.5m in 100yrs,
- a medium projection of 1m in 100 years (based on a BC Ministry of Environment guidance document (Ausenco-Sandwell 2011)), and
- an upper bound of 2.2 m in 100yrs (a value that is expected to be included in the next Intergovernmental Panel on Climate Change's (IPCC) report).

The TAG agreed that NHC should consider three scenarios consisting of lower and upper bounds and some middle, perhaps more probable, case. By examining the effects of each degree of sea level rise on coastal geomorphology, it may be concluded that, for example, there is little difference in the effect of lower levels of rise and that NHC can focus its efforts on understanding the effects of higher levels of rise.

The TAG further discussed how existing projections may underestimate actual rise. While the TAG noted that any upper bound for sea level rise should be grounded in rational argument, results of international studies on sea level rise continue to be refined, and recent publications suggest that existing projections do not sufficiently take into account some factors, such as melting of the Greenland ice cap and the volumetric expansion of the ocean relating to increased water temperature.

Second, the TAG discussed how there is local variation from the global-wide predictions reported by the IPCC's current projections for global sea level rise. The TAG discussed how sea level rise at Roberts Bank should be about 0.2 m lower than the average sea level rise across the globe predicted by the IPCC as a result of natural variation in sea surface elevation.

Third, the TAG discussed how NHC needs to factor in local changes in the elevation of the land surface relative to sea level caused by subsidence – i.e., lowering of the elevation of the sediments that form Roberts Bank due to settling and compaction. Available data that describe this effect provide poor spatial resolution with respect to the rate of subsidence that occurs at Roberts Bank, but it is known that subsidence in the immediate vicinity of existing structures such as Deltaport is higher than other areas.

Storminess

Climate change could result in changes in the frequency, magnitude, and/or duration of wind storm events which generate large waves at Roberts Bank. Both on its own and in relation to sea level rise, a change in the wave regime may have important implications for coastal geomorphology at Roberts Bank.

NHC reviewed the available scientific literature on the topic with the TAG. NHC explained that a report by Ausenco-Sandwell commissioned by the BC Ministry of Environment concluded that there is no evidence to suggest that future storms would be more frequent or more severe than existing storms. The TAG discussed whether this was a reasonable conclusion for NHC to follow in their EA work. One TAG member noted that there is general consensus in the literature towards more powerful storms with climate change, and therefore it's hard to support Ausenco-Sandwell's conclusion. A more conservative approach, according to this TAG member, would be to assume an increase in 'storminess'. Other TAG members noted that this effect may be less applicable to the temperate latitudes of the southern British Columbia coastal region and that an increase in storminess may be much less pronounced than in lower latitudes.

The TAG discussed how NHC might incorporate the assumption of increased storminess in their work. The TAG noted that it will be important for NHC to consider the frequency, duration, and severity of future 'extreme' storms, as these types of storms are the driving force for geomorphic change, though there is uncertainty of the extent to which Roberts Bank geomorphology depends upon extreme storms because their relative infrequency provides few examples to study. The TAG discussed how the tidal flats themselves might mitigate storm effects, as will the existing causeways. As well, the fetch for waves – i.e., the distance over which winds can blow and waves can form – limits wave heights within the Strait of Georgia, though wind speed is a key factor in determining wave height. The TAG also noted that it will be important to consider the effect of climate change on synoptic storms – storms on the order of 1,000 kilometres in size and commonly associated with weather fronts and intense low pressure centres – as storms of this scale may be the most important from the perspective of winds and waves at Roberts Bank.

The TAG also discussed how making overly conservative assumptions about future increases in storminess from climate change could actually result in an approach that downplays the predictions about the incremental effects of the project on the environment because the relative effect from the natural system is then assumed to be so great. For example, adopting an extreme 2.2m sea level rise over the next 100 years will mean that effects of RBT2 will be miniscule in comparison. Therefore, any use of extreme assumptions about climate change has to be done with caution.

Fraser River Outputs

Another potential effect of climate change is that the volumes of water flowing in the Fraser River and the amount of sediment carried in those flows might change, with consequent effects on the geomorphology at Roberts Bank. These types of changes can also be caused by more local human activities upstream, such as has occurred with the Nechako River diversion west of Prince George. A key question is whether either type of effect might be large enough to warrant consideration in the RBT2 EA – these effects may be so small that they are negligible relative to the potential effects of RBT2 on Roberts Bank's coastal geomorphology.

The TAG discussed how future Fraser River flows will likely be different than today with climate change. A likely scenario is that winter flows will probably be somewhat higher, but summer flows will probably be somewhat lower, while the magnitude of the largest floods will probably remain about the same.

The TAG generally agreed that there will likely be little change in sediment output to the project area with climate change. The TAG also discussed how it was unlikely that changes in land-use upstream of the project (such as pine beetle effects on forests) would substantially affect sediment production on a scale important for this EA. However, human-induced changes in closer proximity to the proposed project in Canoe Passage, such as dredging and channel deepening, or the removal of the George Massey Tunnel, are likely to be more important to Roberts Bank geomorphology than the effects of climate change.

Tidal Flat Adjustment

Adjustments to the cross-profile shape of the Roberts Bank tidal flats have previously been investigated. Hill et al. (2012) find that the tidal flats are likely to adjust due to a rise in sea level, increase in storminess (and consequent increase in wave energy), and changes in Fraser River outputs. These changes are expected to steepen the profile of the tidal flats, and as the TAG discussed, this steepening of slope might have substantial effects on some marine species. For example, many species and habitats (e.g., marshes) occupy a defined elevation range of the tidal flats, and so if the slope steepens the horizontal extent of the elevation band will be narrowed. This is a similar, though distinct, effect to the issue of 'coastal squeeze' that is expected to occur in conjunction with rising sea levels alone. The TAG discussed how the rate of sea level rise could outmatch the ability of the tidal flats to adapt.

Time Horizon for Analysis

All EA studies have a temporal boundary – the EA attempts to forecast the effects of a project on the environment over a given period of time, typically extended at least out to when a project is expected to be decommissioned. With RBT2, given that it may be used for many decades, and given that climate change may occur over centuries, a question arises as to the appropriate time horizon for EA studies. NHC proposed to conduct its assessment work over two time horizons: 50 and 100 years. In discussion the TAG did not contest these horizons, but noted that the further in time one attempts to forecast, the more uncertainty there is related to both a) the projected future conditions that are assumed (for example sea level rise), and b) the inherent uncertainty in making predictions in a complex natural system.

3.3.3 Recommended Data Sources and/or Studies

The TAG discussed a variety of ways in which NHC could improve its methods with respect to addressing climate change.

Sea Level Rise

NHC will need to complete their EA work before the next IPCC report will come out (2014). Since evidence suggests that sea level will rise further than projected in the last IPCC report (2007), the TAG recommended that NHC should adopt a high scenario that is at least as high as what might be forecast in the forthcoming IPCC report.

To help address the uncertainty in the degree to which sea level will rise, the TAG discussed two strategies that NHC could consider employing in its work. NHC could simply assume that the sea level will rise to certain levels (such as 0.5 m or 1 m) at some undetermined time and then to focus on the effects of these levels of rise on geomorphology. This approach focuses analytical efforts on understanding the potential effects of such a rise, and less on the challenging task of forecasting likelihood. Another approach is to gather 'probability of exceedance' of various degrees of sea level rise from experts, and to develop projections of sea level rise accordingly.

Storminess

The TAG identified three ways in which NHC could improve its methods with respect to addressing potential storms and waves under climate change:

1. increase the severity of storms, or their frequency (i.e., total number of storms in a year) to simulate increased storminess;
2. create a 'typical representative' winter season of storms and then model wind and waves from different storm directions; and

3. examine the sensitivity of Roberts Bank coastal geomorphology by altering variables or suites of variables in scenarios, and then adjust future studies if the results of these scenario analyses warrant.

Fraser River Outputs

The TAG did not make any specific recommendations with respect to potential changes to Fraser River outputs.

Tidal Flat Adjustment

The TAG suggested that NHC account for any climate change adaptation activities undertaken in the area as part of its forecasting of any tidal flat adjustment that might occur as a result of climate change, such as changes to coastal defence structures. The TAG also discussed how NHC might use equilibrium profile and wave field approaches to assess potential tidal flat changes.

Time Horizon for Analysis

Given the uncertainty around climate change, the TAG noted that it might be more useful to assess the potential effects of RBT2 under certain climatic conditions (such as particular sea level rise predictions) than to worry about when such conditions might occur. The TAG discussed how government policy may dictate the appropriate timeline for analysis.

4 Other Topics Explored by the Coastal Geomorphology TAG

4.1 Mitigation Options

The TAG did not discuss mitigation options at much length, though several ideas arose during meetings:

- The TAG discussed the tidal channel that formed in the area between the Deltaport and BC Ferries causeways in the past and the failure of attempts that have been made to prevent that channel's propagation. The TAG discussed how the best mitigation measure with respect to tidal channels is prevention.
- NHC explained that it is examining four potential design options for the proposed RBT2 project to minimize adverse geomorphology effects and address potential scouring issues.
- One TAG member wondered why NHC is not considering armouring the seabed where scouring is anticipated, such as through the use of a scour blanket. NHC explained that at this stage NHC is assessing different footprint options and will then look at possible other mitigation measures such armouring, if required.

4.2 Cumulative Effects

On numerous occasions the TAG discussed how other current and planned future human activities, such as future projects in the Fraser River, may have on the coastal geomorphology of Roberts Bank. Consideration of the cumulative effects of past, present, and reasonably foreseeable future actions and stresses (PPRFFA&Ss) on some important marine species is likely to be an important part of the RBT2 EA. Actions include such things as new port terminals, but also ongoing human activities such as routine dredging. Stresses include such things as climate change. A sound EA will forecast the effects of a project on important marine species in light of the pressures that PPRFFA&Ss will already be putting on the species. To assist NHC in such a cumulative effects assessment, the TAG discussed what PPRFFA&Ss might exist and be considered.

Tables 3 and 4 summarize the results of this discussion. The tables present a preliminary list of possible PPRFFA&Ss to include in a cumulative effects assessment for the proposed RBT2 project. The lists were reviewed and added to during the final TAG meeting and are considered a starting point. The TAG questioned the need to consider past and present actions and stresses; the TAG felt that what is likely most important to consider are future actions and stresses.

Table 3: Past and present actions and stresses for possible inclusion in the RBT2 EA.

Past or Present Action or Stress
Existing PMV terminal and causeway (including Westshore, Deltaport, dredging for Deltaport, dredged sediment disposal (at sea) for Deltaport and 3rd Berth, Deltaport expansion, Deltaport 3rd Berth, and Deltaport Terminal Road and Rail Improvement Project (DTRRIP))
BC Ferries (including original terminal and causeway, expansions, and habitat compensation projects)
shipping
Marine cables on south side of ferry terminal, including Vancouver Island Transmission Reinforcement Project
Lulu Jetty
Steveston bend training wall and jetty
Iona wastewater/sewage
Dredging programs of main arm, including Steveston 2013 major dredging project
Existing dykes, and dyke construction, Tsawwassen and Ladner
Port Mann bridge expansion including demolition of existing bridge
South Fraser Perimeter Road
Tsawwassen Gateway Logistics Centre
Tsawwassen First Nation Mixed Use Project
Fraser Surrey Docks Direct Transfer Coal Facility (Piles)
Southern Strait National Marine Conservation Area
Boundary Bay Airport Expansion
Existing sea dykes

Table 4: Future actions and stresses for possible inclusion in the RBT2 EA.

Future Action or Stress	Comments from the TAG
Massey Tunnel decommissioning/replacement	(none)
Vancouver Airport (YVR) fuel delivery project (including berths, dredging, and potential other activities in the water)	(none)
Steveston Harbour dredging project	• do not include: small effect on coastal geomorphology, and far away from Roberts Bank
Deepening of main channel of south arm of Fraser River	• some likelihood • may have an important effect on coastal geomorphology
Future BC Ferries projects	• no known projects planned
Artificial islands (e.g., Richmond) for habitat compensation	• no firm plans known • effects on coastal geomorphology will be location-dependent • potentially important
Ladner Harbour Redevelopment and side channel dredging per December 2012 funding announcement	• dredging might affect water flows into Canoe Passage • would have to be considered
Vancouver International Plaza on Duck Island	• vague plans at this point • unlikely to affect Roberts Bank coastal landforms
Climate change	(none)
Airport expansion of main runway onto Sturgeon Bank	• little effect on Roberts Bank, though depends how big/far it sticks out
Coastal defences against climate change	• highly likely • their form is uncertain, but various

Future Action or Stress	Comments from the TAG
	options are commonly used
Iona wastewater expansion	• unlikely to affect Roberts Bank coastal landforms

In the course of brainstorming PPRFFA&Ss the TAG identified several criteria that NHC and other PMV consultants might use in identifying PPRFFA&Ss:

- spatial proximity to RBT2 and Roberts Bank;
- likelihood of future actions and stresses happening (one needs to be reasonably certain that the action or stress will occur);
- the strength of effect(s) that the action or stress is expected to have;
- whether the action or stress will affect components of the environment of interest in the EA (such as marine species of particular importance to stakeholders); and
- whether the effects of the action or stress will occur over the time frame of the project.

The TAG discussed how Table 4 did not include future PMV projects. The TAG suggested that NHC maintain dialogue with PMV around what other projects are planned or might be envisioned in the foreseeable future, especially in the near vicinity of RBT2 such as Canoe Passage. The TAG discussed how it will be important that PMV understand any possible linkages between routine dredging actions and possible implications for Roberts Bank geomorphic changes.

4.3 Linkages to Other EA work

As noted in s.4.1 of this report, an understanding how the proposed RBT2 project may affect marine species rests upon a solid understanding of how the proposed project might affect the coastal geomorphology of Roberts Bank. Given this, on several occasions the TAG discussed how coastal geomorphology methods must have the spatial resolution – i.e., level of detail – to identify geomorphic changes that are of the scale of which some marine species are sensitive. In other words, from an EA perspective, it is not useful if coastal geomorphology studies cannot detect changes that matter to species. It was in this vein that there was interaction across TAGs during the TAG process. For example, Derek Ray of NHC presented at one of the Biofilm and Shorebird TAG meetings.

5 Conclusion

The Coastal Geomorphology TAG met three times over 2012 and 2013 to provide PMV and its consultants with feedback on appropriate methods to assess the potential effects of the proposed RBT2 project on the coastal geomorphology of Roberts Bank. This report catalogues this TAG process and the key findings and outputs of the process. Overall, the Coastal Geomorphology TAG endorsed NHC's planned approach and methods. At this point, PMV and its consultants are continuing their EA studies with the Coastal Geomorphology TAG's guidance in mind. Looking forward, PMV and its consultants will complete their EA studies, engage the provincial and federal governments in the formal EA process, and continue to consult with stakeholders and First Nations.

References

Hill, P. R., R. W. Butler, et al. (2012). Impacts of sea level rise on Roberts Bank (Fraser Delta, British Columbia). 57pp.

Ausenco-Sandwell (2011). Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use: Guidelines for Management of Coastal Flood Hazard Land Use. 45pp.

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IR2-01 Coastal Geomorphology – Hydrodynamics: Hydrodynamic Modelling

Information Source(s)

EIS Volume 2: Section 9.5; Appendix 9.5-A, Appendix A, Appendix B and Appendix C

Context

The Proponent reported that the observational data used to validate the hydrodynamic model was specifically limited to those data collected during the month of August 2012 because data for all four physical parameters (water levels, waves, currents and salinities) were collected in that month. The EIS, Appendix 9.5-A, Appendix A identified that other data sources were available, including data for winter months.

Fisheries and Oceans Canada reported that large storms may influence local sediment dynamics.

Information Request

Complete a more extensive model validation for the hydrodynamic model, using the complete field dataset available including the existing Acoustic Doppler Current Profiler (ADCP) and Acoustic Wave and Current Profiler (AWAC) data as well as the data collected during winter months as indicated in the EIS, Appendix 9.5-A, Appendix A.

Describe how results from the field data collection program provided in Appendix C of Appendix 9.5-A were utilized to validate the Telemac - 3D, Tomawac and Sisyphe models.

Identify discrepancies between the field data results and modelled predictions.

Report the results of simulations for winter conditions, including large storms.

VFPA Clarification

The context for this information request confirmed statements made in Section 4 of EIS Appendix 9.5-A: Appendix B, which states "Data from August 2012 were used to validate the model". However, it is not the case that *only* data from August 2012 were used to validate the model during model development; to the contrary, data from other periods were also used to validate model results. August 2012 validation was presented in the EIS for the following reasons:

- A month long period was selected for ease of presentation to explain the representativeness of model results to measured data; and
- This period had data available for all four physical parameters (water level elevations, wave heights, current speeds, and salinity levels), so this period provided a comprehensive dataset to illustrate the model's capability to reproduce observed conditions in 2012.

In addition to the model validation for summer (August) 2012 presented in Section 4 of EIS Appendix 9.5-A: Appendix B, model validation information using measured or predicted data for other months representing spring, fall, and winter is provided below.

VFPA Response

Responses to the four requests for information above, including 1) undertaking more extensive model validation using available dataset, 2) explaining the use of field data collection program information in model validation, 3) identifying any discrepancies between measured data and modelled results, and 4) reporting the results of model validation for winter conditions (including large storms) are discussed together below by four categories: water levels and flows, current speeds, wave heights, and salinity.

Model Validation – General Information

The entire field dataset collected in 2012 was used in the model validation phase, except where noted and summarised in **Table IR2-01-1**. The dataset includes the existing Acoustic Doppler Current Profiler (ADCP) and Acoustic Wave and Current Profiler (AWAC) data, as well as the data collected during winter months. As noted above, EIS Appendix 9.5-A: Appendix B presents validation only for the August 2012 period because data for all four physical parameters (water levels, waves, currents, and salinity) were collected in this month. Additional data collected prior to and after 2012 (the period for which the model was run) were considered but not used for model validation for the reasons summarised in **Table IR2-01-1**.

The coastal geomorphology assessment adopted a "three-pronged" approach for assessing potential effects of the Project on coastal geomorphology, as described in EIS Section 9.5.5.3 and Section 1.3 of EIS Appendix 9.5-A, that includes 1) numerical modelling, 2) analytical computational methods, and 3) interpretive geomorphological analyses. The three-pronged approach was used to account for the inherent uncertainty that is acknowledged in the EIS when applying models to predict future changes of the Project. This approach was endorsed through the Technical Advisory Group (TAG) process (refer to Appendix IR2-A of the Preamble at the beginning of this response package) and confirmed in the Canadian Science Advisory Secretariat (CSAS) review on coastal geomorphology (CEAR Document #893).

The potential changes of the Project on tidal currents (hydrodynamics), wave climate, and local seabed scour and deposition (morphodynamics) were investigated within the local study area using the TELEMAC-MASCARET numerical modelling system (TELEMAC). Three TELEMAC models were applied to compute the physical processes of tidal currents (TELEMAC-3D), wind-generated waves (TOMAWAC), and sediment transport (SISYPHE). For the coastal geomorphology assessment, the models were internally coupled to simulate tidal currents, wave climate, and local bed scour and deposition, as described in Section 2 and shown in

Figure 1 of EIS Appendix 9.5-A: Appendix B. Model results were validated using measured or predicted data from the local and regional study areas[1].

The hydrodynamic model results were compared to water level data, salinity level and profile data, current data, and wave height data obtained from within the coastal geomorphology local and regional study areas (study areas are described in EIS Section 9.5.5.2 and shown in EIS Figures 9.5-1 and 9.5-2, respectively). Table 3 of EIS Appendix 9.5-A: Appendix A lists the current and wave data available from the local and regional study areas. **Table IR2-01-1** expands upon this list by incorporating data collected in the field by Northwest Hydraulic Consultants (NHC) from April 2012 to August 2013 (described in Appendix C of EIS Appendix 9.5-A). **Table IR2-01-1** also outlines which datasets were used in hydrodynamic model validation, and provides the rationale for omission of a dataset from the validation analyses, if relevant. **Figure IR2-01-1** shows the locations where field observation data were collected in the local and regional study areas. As shown, the datasets used in model validation included ADCP, AWAC, wave buoy, and water quality instrument data obtained from ASL Environmental, Environment Canada, or NHC, and also considered data obtained during winter months.

[1] Field data referred to for model validation comparisons in the EIS and in this information request refer to measured data collected in the field, predictions from Fisheries and Oceans Canada (DFO) (e.g., tide or water levels), or predictions by Northwest Hydraulic Consultants (NHC) based on measured data (e.g., development of a stage-discharge rating curve to quantify flow through Canoe Passage).

Table IR2-01-1 Field Datasets Considered for Use in Hydrodynamic Model Validation

Data Provider	Location	Data Type				Instrument	Data Acquisition Period	Used in Model Validation	Rationale for Omission
		Currents	Waves	Water Levels	Salinity				
WorleyParsons	Tidal flat, NW of terminal	√				ADV	Summer Jul 6-14, 2011	No	a
	Shelf slope near terminal	√	√			AWAC (16 m depth)	Winter Jan 18-Mar 7, 2011	No	a
	Shelf slope near terminal	√	√			AWAC (16 m depth)	Summer Jul 7-Aug 4, 2011	No	a
	PMV #15474		√			TWR-2050	Spring Mar 6-May 25, 2011	No	a
	Close to Canoe Passage	√				ADCP (5 m depth)	Summer Jul 8-22, 2011	No	a
	George Massey Tunnel, Westham Island Bridge			√ (discharge, flow)		ADCP (from boat)	Summer Jul 7-9, 2011	No	a
ASL Environmental	Shelf slope near terminal	√	√			AWAC and ADCP	Summer Aug 8-Sep 9, 2012	Yes, AWAC only	b
	Shelf slope near terminal	√	√			AWAC and ADCP	Winter Dec 17, 2012-Feb 20, 2013	Yes, AWAC only	b
VENUS	Westshore coal terminal	√				CODAR	All Seasons Jan 1, 2012-Jan 1, 2013	No	c

Data Provider	Location	Data Type				Instrument	Data Acquisition Period	Used in Model Validation	Rationale for Omission
		Currents	Waves	Water Levels	Salinity				
Environment Canada	Halibut Bank, Strait of Georgia		√			Wave Buoy	All Seasons Mar 13, 1992-Apr 30, 2013	Yes	N/A
NOAA	New Dungeness, Juan de Fuca Strait	√				3 m discus data buoy	All Seasons Jan 2011-Dec 2012	No	d
NHC	Canoe Passage Currents and Discharge	√		√		ADCP	May 8 to Dec 31, 2012	Yes	N/A
	Canoe Passage Salinity				√	C4E-15 Digisens	May 8 to Dec 31, 2012	Yes	N/A
	Roberts Bank Salinity and Turbidity				√	Manta2	Various dates between June 12-August 29, 2012	Yes	N/A
	Roberts Bank Waves		√			RBR Virtuoso Wave Recorder	July 4, 2012-April 4, 2013	No	e

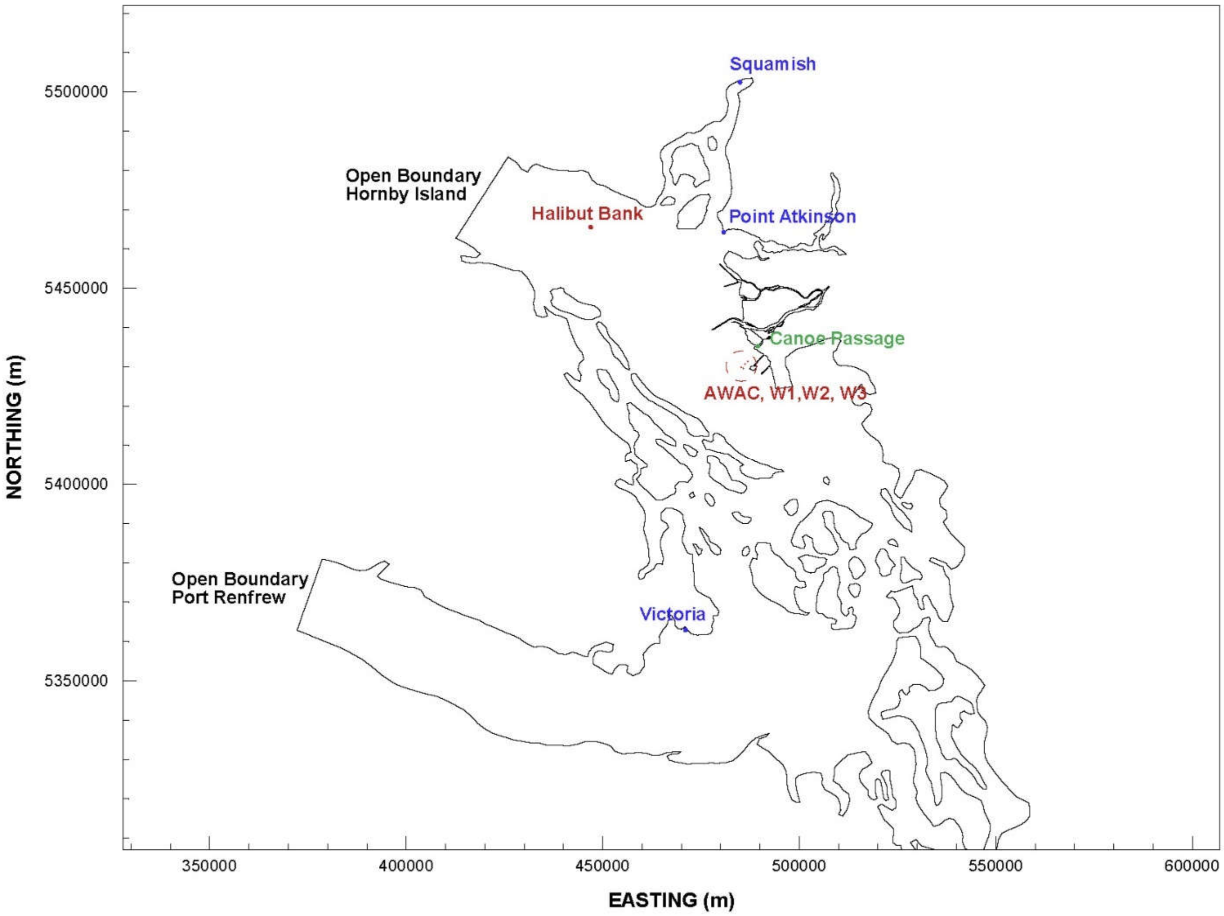
Notes: NOAA = National Oceanic and Atmospheric Administration; VENUS = Victoria Experimental Network Under the Sea; ADV = Acoustic Doppler Velocitymeter; AWAC = Acoustic Wave and Current Profiler; TWR-2050 = type of tide and wave data logger; ADCP = Acoustic Doppler Current Profiler; CODAR = Coastal Ocean Dynamics Applications Radar system;

Rationale for omission from model validation:

a. Not coincident with 2012 modelled period.
b. ADCP station located in close proximity to AWAC station and measurements were not significantly different; as the instruments at these stations measured the same conditions, only AWAC station data was used in validation analyses.
c. CODAR was reviewed but not directly compared to the model results because the CODAR grid spacing is not directly aligned with the TELEMAC grid spacing.
d. Distance from Project and presence of islands between station and Project.
e. Data was examined visually but not directly compared to model output.

N/A = rationale not applicable as dataset used in model validation.

Figure IR2-01-1 Location of Field Data Stations Used in Model Validation



Model Validation – Water Levels

Modelled water levels were validated against water level data collected by NHC, observed water levels at Fisheries and Oceans Canada (DFO) Canadian Hydrographic Service stations, or DFO predicted water level data at four stations in the regional study area: Squamish, Point Atkinson, Victoria, and Canoe Passage (see **Figure IR2-01-1** for locations). As background, the hydrodynamic model was 'forced'[2] using predicted tides (not measured tides) published by DFO. Comparisons of model-predicted water levels to observed water levels are provided for Point Atkinson and Canoe Passage stations for August 2012 in Appendix B of EIS Appendix 9.5-A. The validation of model predictions (provided below) for May 1 to December 31, 2012 at the three marine stations (Squamish, Point Atkinson, and Victoria) is

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[2] As articulated in the response to IR2-14, boundary forcing is the a priori selection of hydrodynamic conditions at the open boundaries of the TELEMAC-3D model, which subsequently drives future hydrodynamic conditions in the rest of the model domain over a specified period of time. The most important boundary forcing is tide height (i.e., from DFO predicted tidal conditions), followed by wind forcing and Fraser River discharge.

based on DFO predicted water levels, since water levels are driven by predicted tides at the open boundaries at Port Renfrew and Ballenas Island, just south of Hornby Island[3] (for locations, refer to **Figure IR2-01-1**).

Comparisons of modelled (blue line) and DFO predicted (black line) hourly water levels for May 1 to December 31, 2012 at Squamish, Point Atkinson, and Victoria are provided in **Figures IR2-01-2** to **IR2-01-4**, respectively. Water levels in the figures below are expressed as water surface elevation in metres from geodetic datum[4] (WSE [m GD]), with a positive value expressing an elevation above and a negative value expressing an elevation below this reference level. Refer to IR2-03 for more information on the comparison of modelled water levels to both DFO observed and predicted water levels at Point Atkinson for the two periods.

For Canoe Passage, water levels measured by NHC during the field data collection program are used as a comparison, as water levels for this Fraser River station are a function of both the tides and the river discharge (i.e., water levels at this station are not influenced solely by DFO predicted tides). **Figure IR2-01-5** shows modelled (blue line) and DFO observed (black line) hourly water levels at the Canoe Passage station for May 1 to December 31, 2012. Refer to IR2-03 for more information on the comparison of modelled water levels to observed water levels at Canoe Passage for the two periods.

[3] Artificial boundaries were selected for the hydrodynamic model to limit the model domain. An open boundary refers to an artificial boundary which consists of open water, where inflow and outflow occurs. The prescription of open boundary conditions requires extensive information for physical parameters such as water level elevations and salinity levels at specific points in time and space. Once boundary conditions were prescribed for the open boundaries at Port Renfrew in Juan de Fuca Strait and Ballenas Island, just south of Hornby Island in the Strait of Georgia, the hydrodynamic model was used to simulate conditions in the local study area.

[4] A geodetic datum (GD) is a reference point for various coordinate systems used in mapping the earth. The geodetic datum used at Roberts Bank was North American Datum 1983 (NAD 83), the official horizontal datum for use in the North and Central American geodetic networks. Elevations in the numerical model are referenced to GD because the model extends across numerous Chart Datum (CD) boundaries.

Figure IR2-01-2 Modelled (blue line) and Predicted (black line) Water Levels at Squamish from May 1 to December 31, 2012

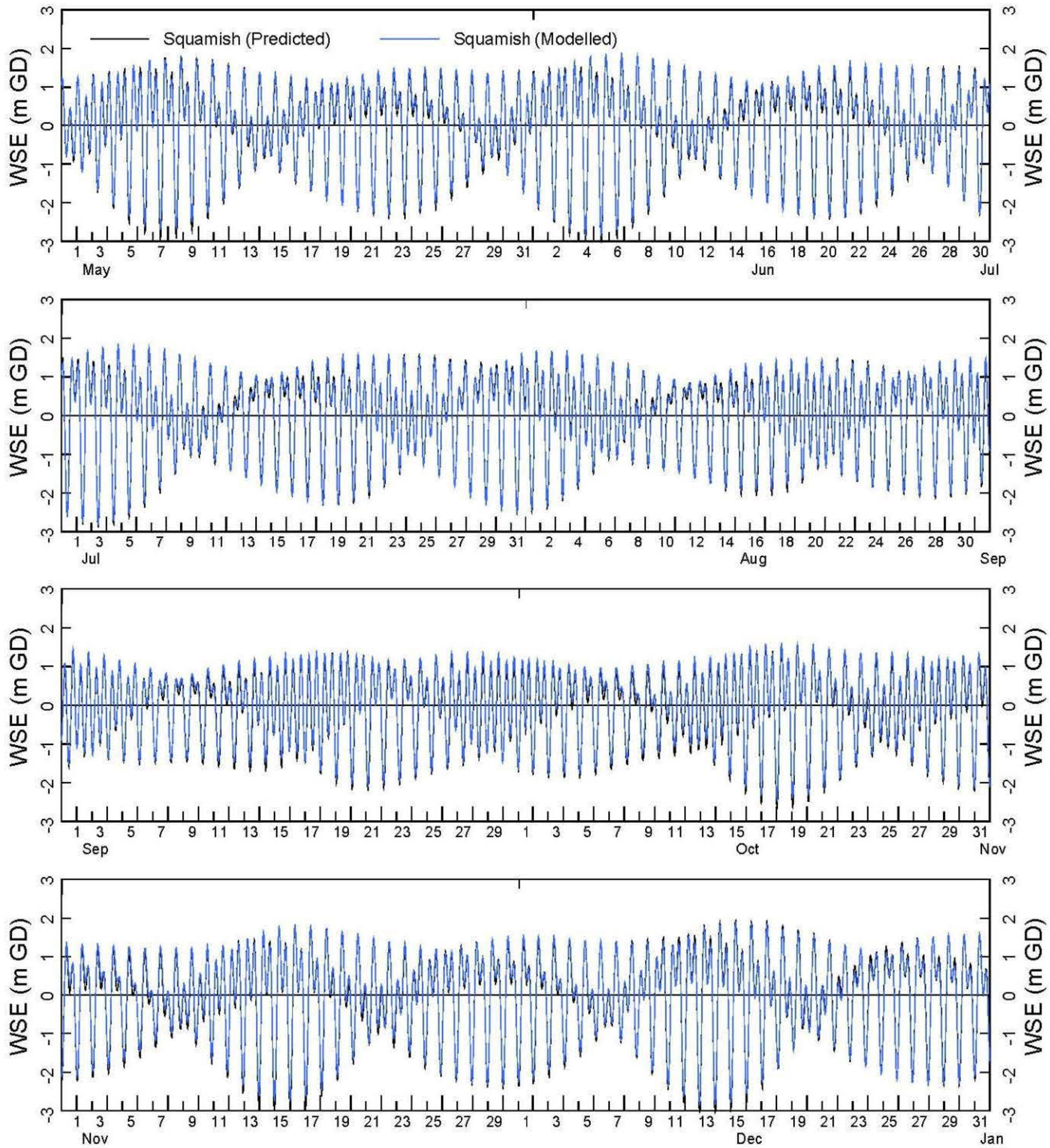


Figure IR2-01-3 Modelled (blue line) and Predicted (black line) Water Levels at Point Atkinson from May 1 to December 31, 2012

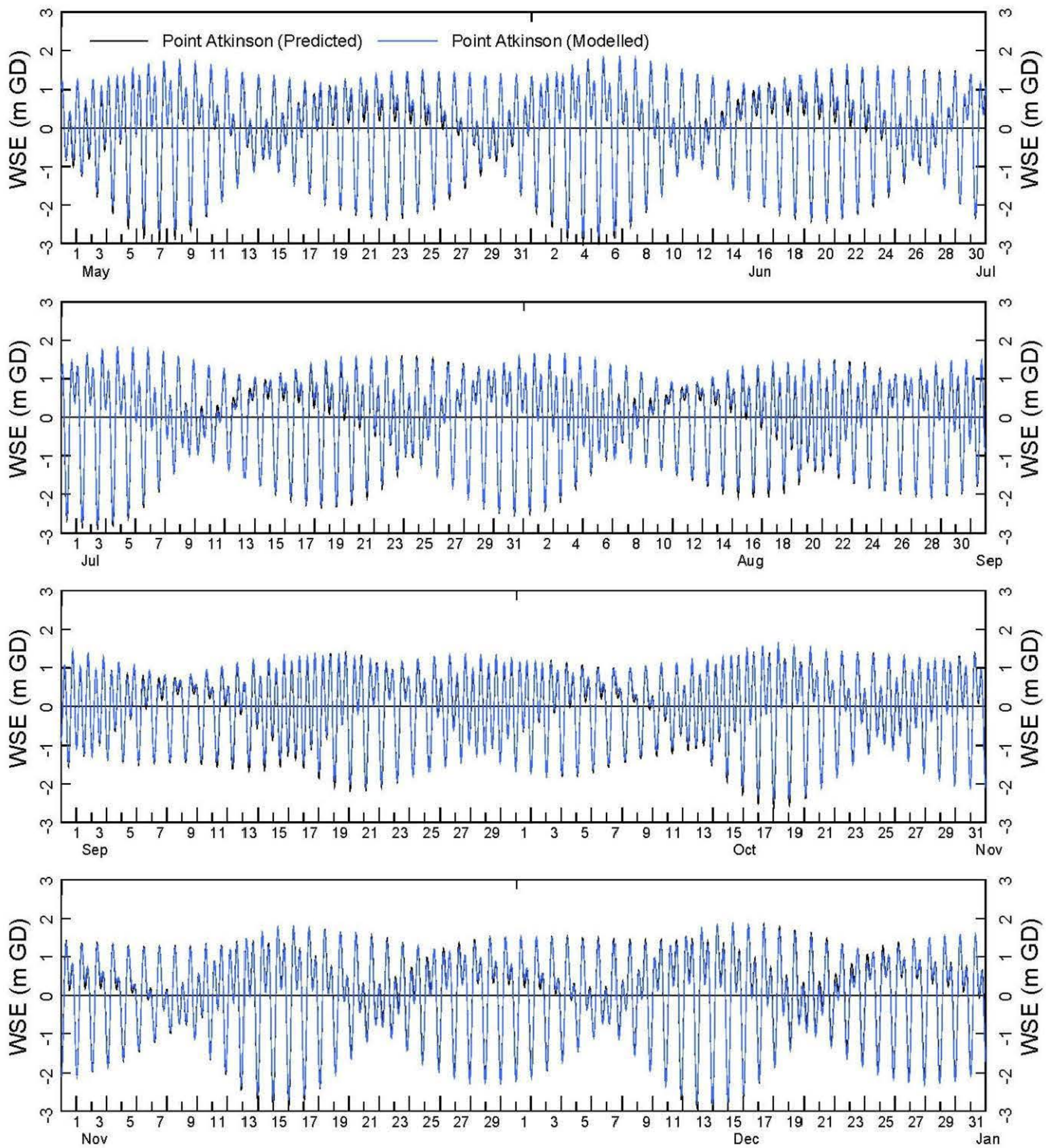


Figure IR2-01-4 Modelled (blue line) and Predicted (black line) Water Levels at Victoria from May 1 to December 31, 2012

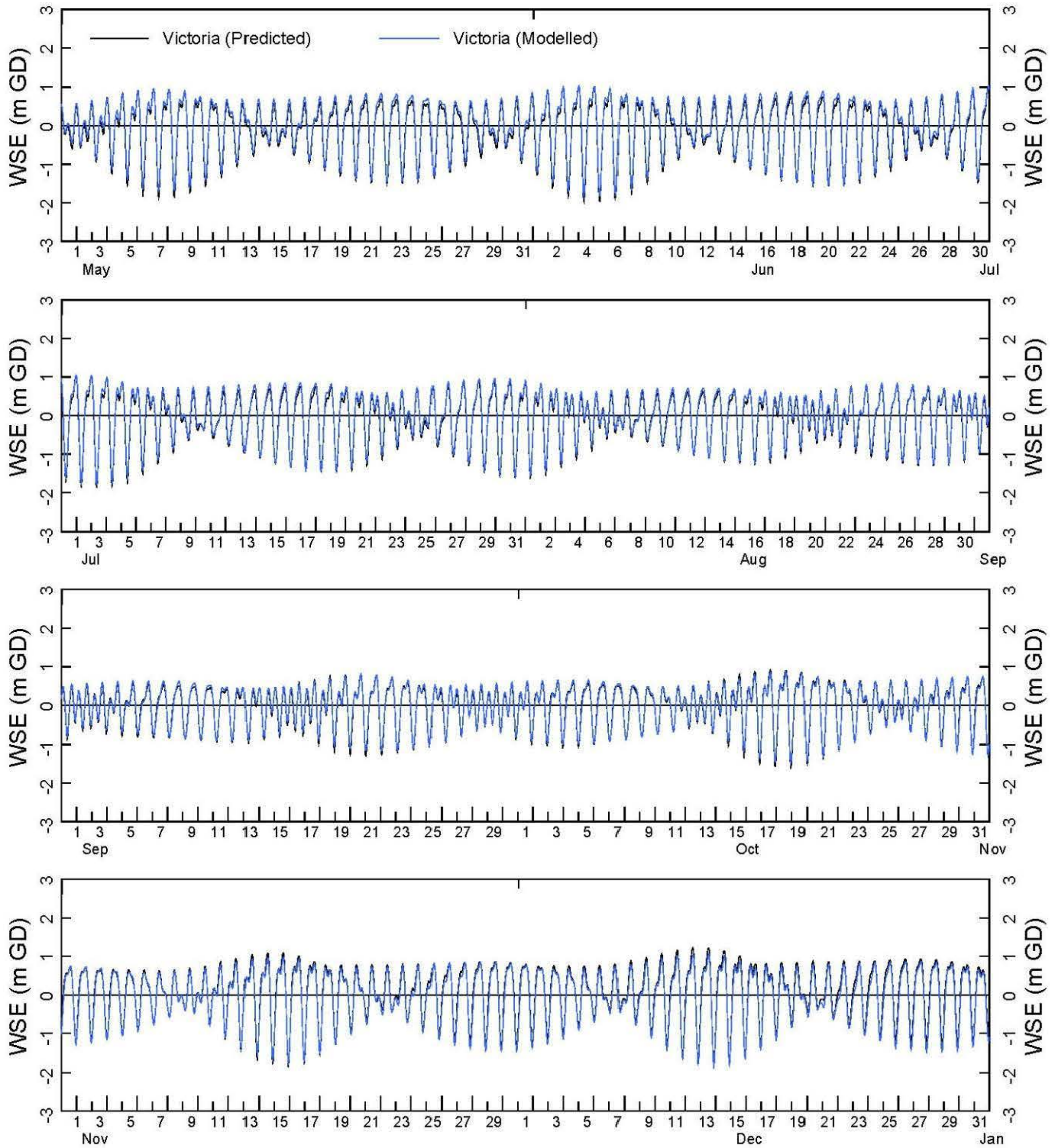
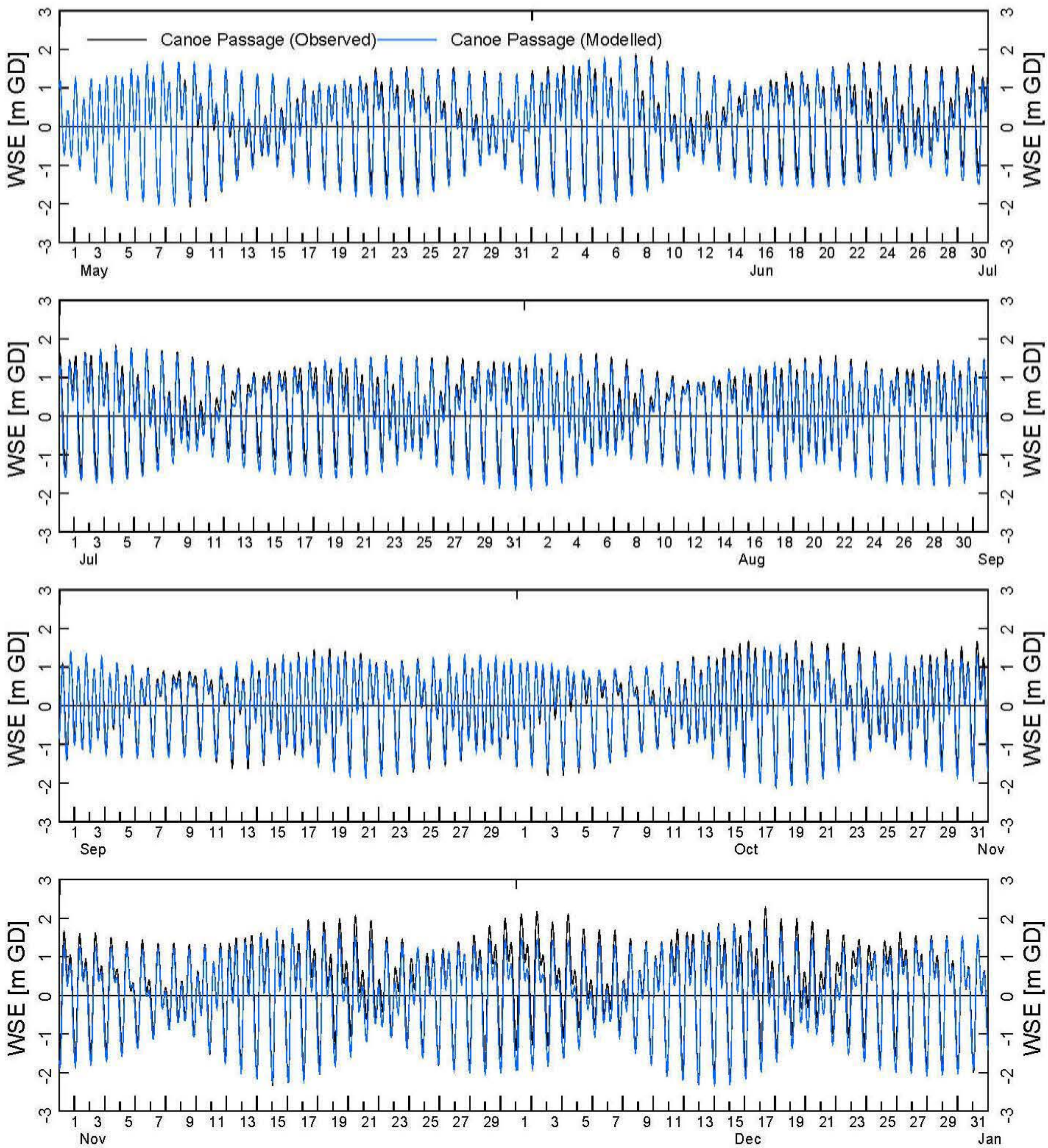


Figure IR2-01-5 Modelled (blue line) and Observed (black line) Water Levels at Canoe Passage from May 1 to December 31, 2012



The results indicate good agreement between DFO predicted water levels and modelled water levels at the three marine stations and between measured and modelled water levels at the Canoe Passage station. The tidal range variability from spring to neap tidal cycles and the daily high and low water level elevations are well reproduced, as shown by the alignment of water levels shown in blue and black lines. The root-mean-squared error (RMS) value between predicted and modelled water levels at Point Atkinson is 0.10 m, and compared to a mean tidal range of 3.1 m, this error is within 4%. The RMS value between predicted and modelled water levels at Squamish is 0.11 m (within 4% of mean tidal range) and at Victoria is 0.09 m (within 5% of mean tidal range).

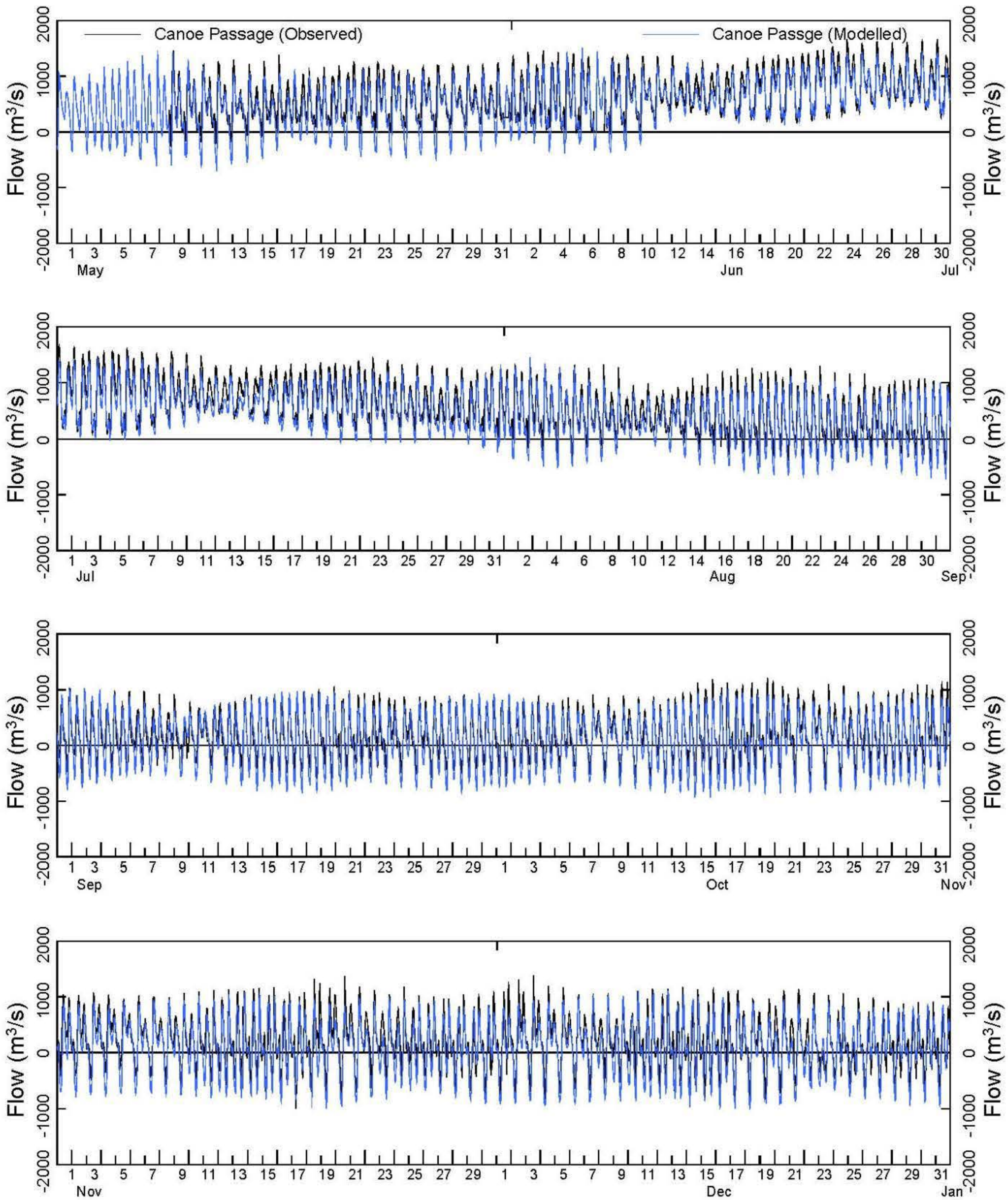
The RMS value between measured and modelled water levels at Canoe Passage is 0.25 m for the May 1 to December 31, 2012 period, which is similar to the RMS value of 0.23 m for the August 2012 period that was reported in Appendix B of EIS Appendix 9.5-A. Since Fraser River flow rates are not measured at the model's upstream boundary at New Westminster (i.e., they are measured at Hope), the hydrodynamic model inflow was obtained from predictions using the Fraser River Mike11 model, as described in Sections 3.2 and 4.2 of EIS Appendix 9.5-A: Appendix B. This model was optimised for higher Fraser River discharges, so may be less accurate during mean flows and lower flows; in addition, there are uncertainties associated with estimating the tributary flows entering the Fraser River between Hope and New Westminster. Despite these limitations, however, modelled water levels at Canoe Passage are generally aligned with observed levels.

Model Validation – Canoe Passage Flow

Modelled discharges in Canoe Passage were compared to the results of the Canoe Passage flow study conducted by NHC, which was undertaken to determine the amount, character, and timing of water delivery to Roberts Bank during various tidal stages and during a wide range of Fraser River flows. Section 2.1 of EIS Appendix 9.5-A: Appendix C describes the methods and results related to this field program and the development of a stage-discharge rating curve to quantify flow through Canoe Passage. Model predictions of Canoe Passage flows were compared to the flows derived from the stage-discharge curve, which are referred to as 'observed flow' in the discussion and figures that follow.

The modelled flows (blue line) and the observed flows (black line) across Canoe Passage for May 1 to December 31, 2012 are shown in **Figure IR2-01-6**. Positive discharge values represent downstream outflow associated with an ebbing tide and negative discharges represent upstream flow associated with a flooding tide.

Figure IR2-01-6 Modelled Flows (blue line) and Observed Flows (black line) at Canoe Passage Station from May 1 to December 31, 2012



The results show that the timing of the flow reversal and flow range (i.e., between maximum outflow and maximum inflow) predicted by the model are consistent with the observed flow data. As shown by the differences in the ‘peaks’ for the maximum inflows and outflows, and as per the clarification provided in IR2-18, the model generally underestimated the outflow and overestimated the inflow at Canoe Passage compared to the stage-discharge relationship developed for this location from field data. The RMS difference between hourly modelled and observed Canoe Passage flows is 241 cubic metres per second (m^3/s), a difference that is within the natural variability of Canoe Passage flows (which ranges from -390 m^3/s to 1,280 m^3/s) and uncertainties associated with the observed flow values that were interpolated from the stage-discharge curve. The mouth of Canoe Passage is strongly influenced by ocean conditions, and water levels and flow vary rapidly as the tide rises and falls. Thus, the ADCP flow measurements, upon which the stage-discharge curve (and observed flows) are based, are sensitive to the time they were collected. The RMS difference between observed flow derived from the stage-discharge curve and field flow measurements is 106 m^3/s, which is within the range of natural variability observed in this system. The differences are unlikely to affect the predicted local hydrodynamics around Roberts Bank as the Canoe Passage monitoring station is relatively removed from the area of primary interest.

Model Validation – Current Speed

Currents and waves were measured at two locations immediately west of Westshore Terminals using AWAC and ADCP instruments, as described in Section 2.7 of EIS Appendix 9.5-A: Appendix C (see Figure 44 for station locations). Based on detailed statistical analysis of the near-bed currents measured from both instruments, there was an insignificant difference in measured currents at the two sites, which are located in close proximity to each other. Based on this analysis, only data from the AWAC instrument was used in the model validation included in Appendix B of EIS Appendix 9.5-A for August (summer) 2012 and below for both August and December (winter) 2012.

It is necessary to understand how an AWAC instrument works in order to interpret the validation results presented below. An AWAC instrument measures waves and currents using sound energy. Sound energy is transmitted into the water column and the Doppler shift is measured from the energy returned to the instrument that is reflected by particles at various locations in the water column. These measurements are then resolved into a three-dimensional velocity vector that describes the motion of each ‘bin’ or section of the water column. The water column is divided into bins (or cells) having a vertical height that is dependent on the resolution of the instrument and the total depth of water. In the results presented below, model and measured current speeds are presented according to the bin position (in metres) relative to geodetic datum (GD).

AWAC data from the -4.5 m and -3.5 m GD bins were averaged to generate a time series of currents at -4.0 m GD. Similarly, the data from the -2.5 m GD and -1.5 m GD bins were averaged to generate currents at -2.0 m GD. A principal component analysis was conducted to resolve currents into first principal component (direction of maximum variance) and second principal component (90 degrees to the first principal component axis). This approach takes into consideration local geometry and provides more information than comparing north-south and east-west velocities. Modelled currents and measured currents at -2.0 m and -4.0 m GD are shown in **Figures IR2-01-7** and **IR2-01-8**, respectively, with the first and second panels of each figure displaying August (summer) data for the first and second principal components and the third and fourth panels of each figure displaying December (winter) results for the first and second principal components.

The RMS difference between measured and modelled current speeds varied between 0.16 metres per second (m/s) and 0.23 m/s in August and 0.15 m/s and 0.16 m/s in December. These results indicate that the model reproduced the magnitude and phase (i.e., the timing of flood and ebb tides) of the first principal component well at -2.0 m GD in both August 2012 and December 2012, but for -4.0 m GD the model tended to overestimate the magnitude of the first principal component. The model results show that the timing of the tides are not aligned for the second principal component. The deviation is smaller in December than in August, suggesting that the difference between measured and modelled data are likely attributed to differences in freshwater input to the system. Nevertheless, the magnitude of current speed in the second principal component is small (as shown by the differences in the height of the peak maximum currents in the first and third panels to the peaks in the second and fourth panels on each figure), which is reflective of the fact that the secondary principal component is not the main current direction at the AWAC location.

Figure IR2-01-7 Modelled (blue line) and Observed (black line) Current Speeds at -2.0 m GD at the AWAC station for August and December 2012

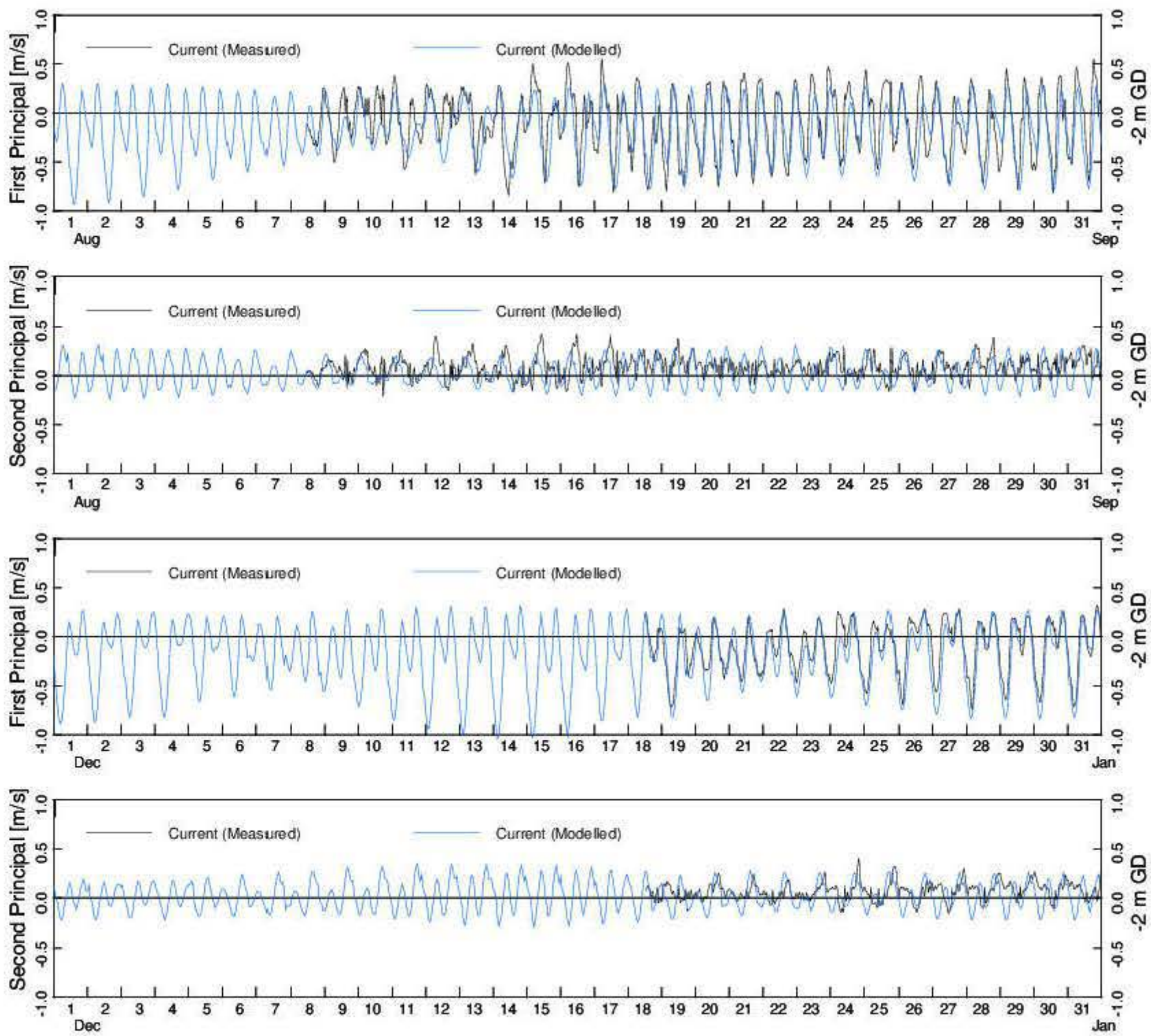
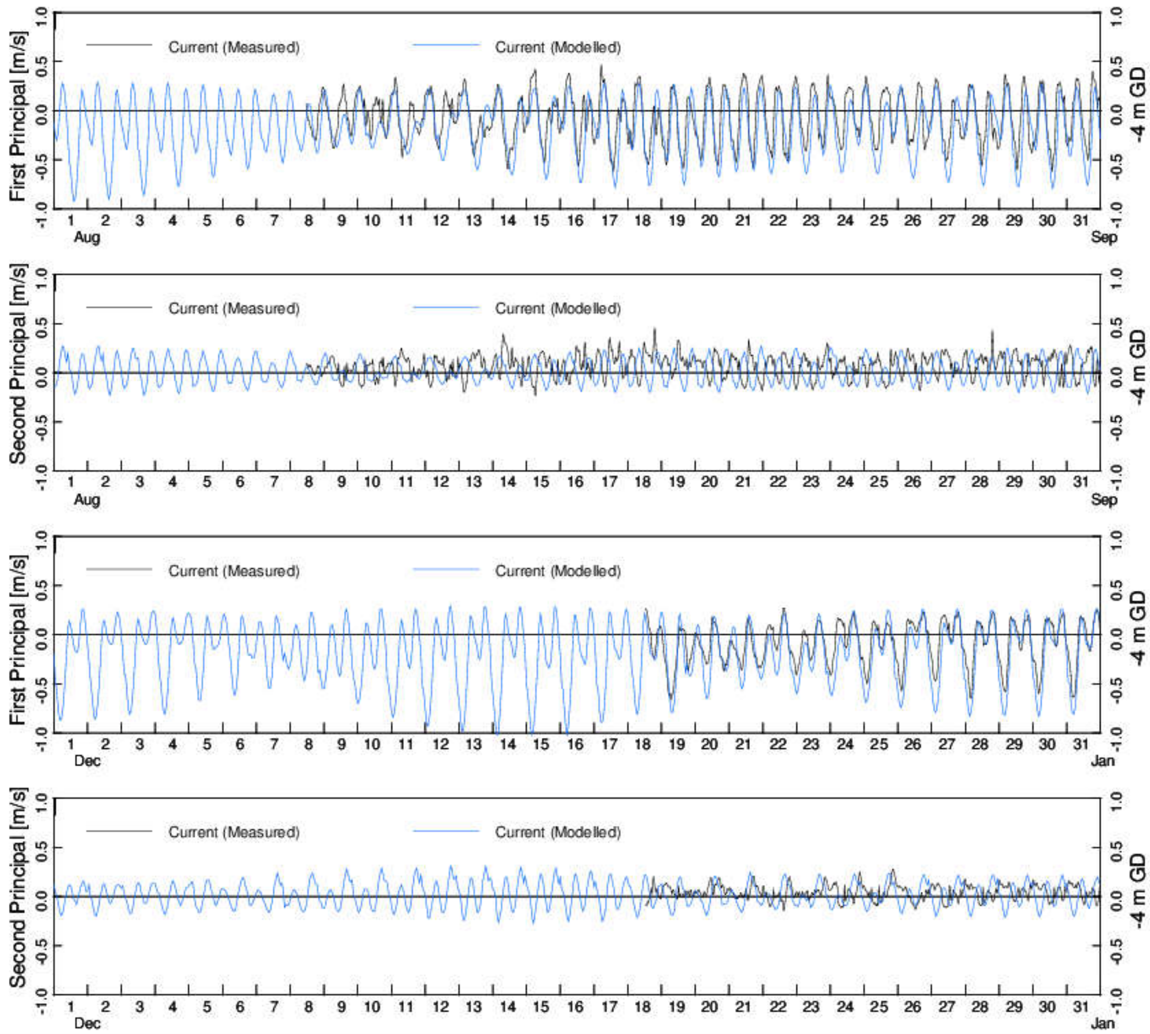


Figure IR2-01-8 Modelled (blue line) and Observed (black line) Current Speeds at -4.0 m at the AWAC station for August and December 2012



Model Validation - Wave Heights

As wind-generated waves are one of the geomorphic mechanisms that form and maintain the tidal flats as well as influence sediment grain size, waves heights were measured at various locations within the Strait of Georgia, including at Halibut Bank (see **Figure IR2-01-1**), at the AWAC and ADCP stations at Roberts Bank (see Figure 44 of EIS Appendix 9.5-A: Appendix C for station locations), and at three wave recorder stations (W1, W2, and W3) in shallow subtidal to intertidal waters at Roberts Bank (for locations, see Figure 38 of EIS Appendix 9.5-A: Appendix C). Refer to Section 2.7 of Appendix 9.5-A: Appendix C for more information pertaining to the field programs to measure waves and currents.

Figures IR2-01-9 to **IR2-01-13** show the modelled wave heights (blue line) and measured wave heights (black line) at the Halibut Bank wave buoy, AWAC, and wave recorder W1, W2, and W3 stations, respectively. Wave heights (or Hs) in the figures are expressed in metres (m).

Figure IR2-01-9 Modelled (blue line) and Observed (black line) Wave Heights at Halibut Bank Station from January 1 to December 31, 2012

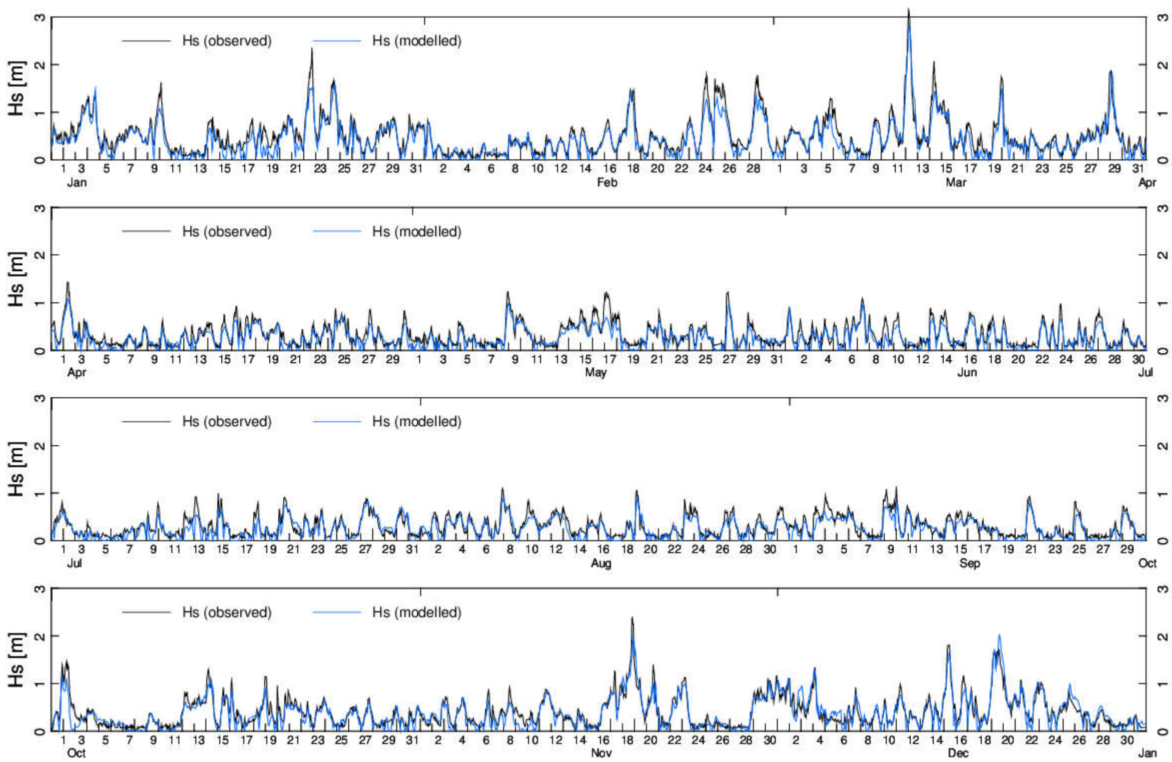


Figure IR2-01-10 Modelled (blue line) and Observed (black line) Wave Heights at AWAC Station from July 1 to December 31, 2012

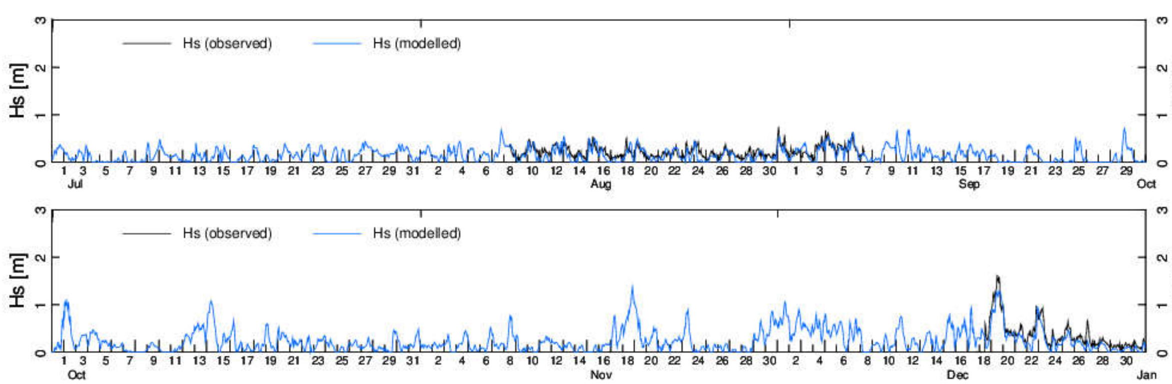


Figure IR2-01-11 Modelled (blue line) and Observed (black line) Wave Heights at W1 Wave Recorder Station from July 1 to December 31, 2012

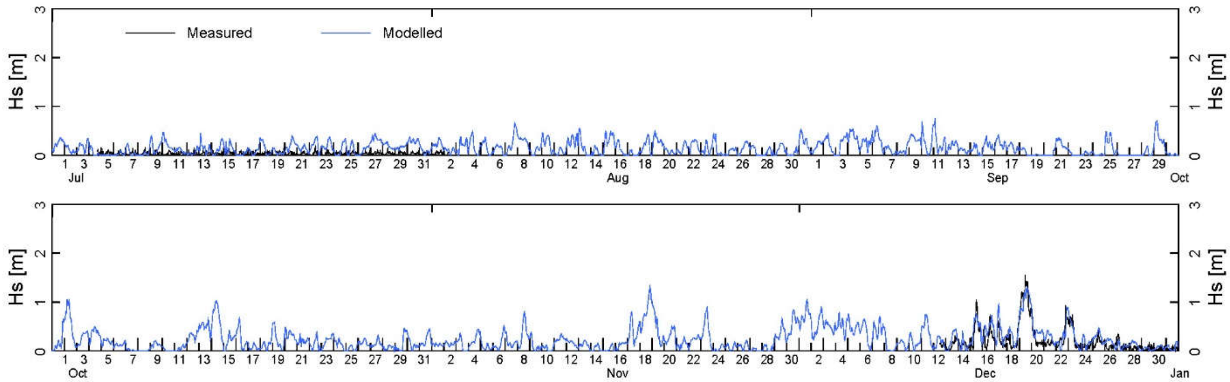


Figure IR2-01-12 Modelled (blue line) and Observed (black line) Wave Height at W2 Wave Recorder Station from July 1 to December 31, 2012

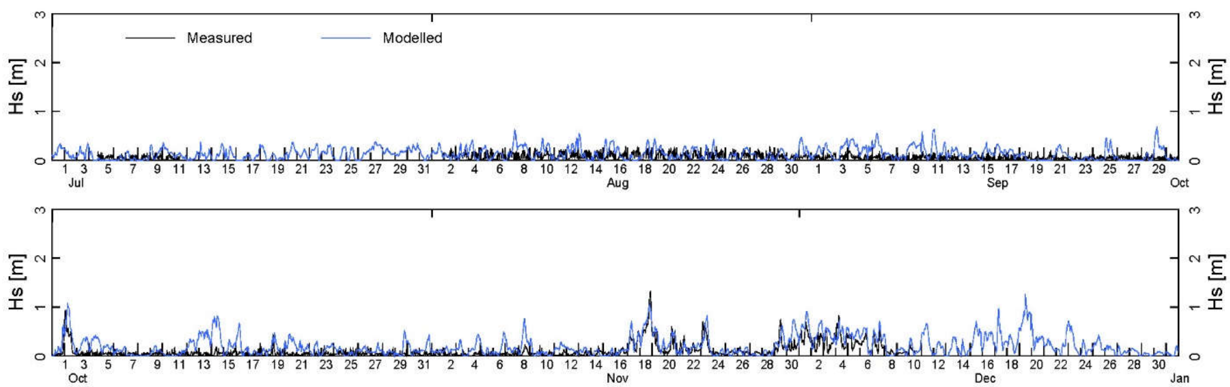
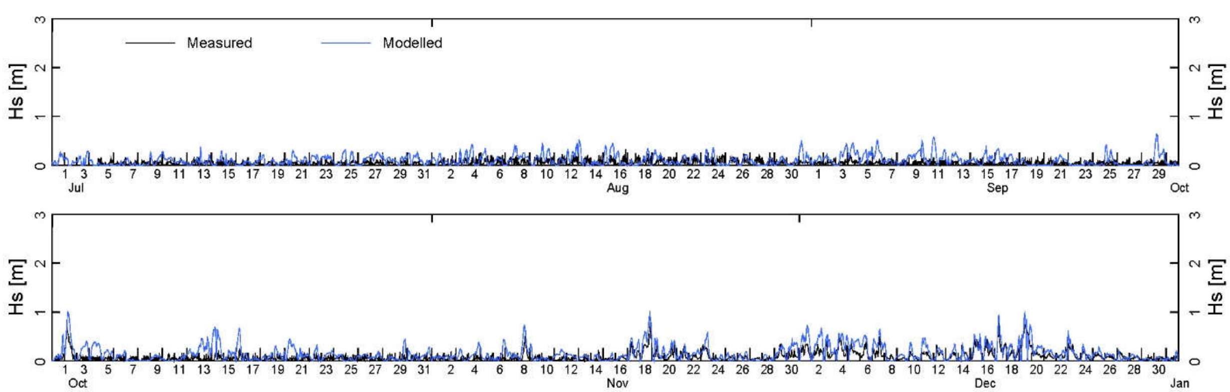


Figure IR2-01-13 Modelled (blue line) and observed (black line) wave height at Wave Recorder Station W3 from July 1 to December 31, 2012.



The results show that the model reproduced the storm events at all locations well, as RMS differences in modelled and predicted wave heights are between 0.13 m and 0.16 m. At times, the model underpredicted the waves at Halibut Bank, but this is a result of wave spectrum information not being prescribed at the open boundary. Since the Strait of Georgia consists of such a highly fetch- and duration-limited wave generation regime[5], this underprediction of wave heights does not have a major influence on the wave climate at Roberts Bank, which is 80 km southeast of the open boundary.

Three notable storm events were recorded over the course of the wave recorder July 1 to December 31, 2012 monitoring period: October 2 (northwesterly storm), December 15 (southeasterly storm), and December 19 (southerly storm). Modelled and measured wave heights at Roberts Bank stations (i.e., AWAC, W1, W2, and W3) during each of these events are summarised in **Table IR2-01-2**.

Table IR2-01-2 Modelled and Measured Wave Heights at Roberts Bank Stations During Storm Events

Roberts Bank Station	Measured Wave Heights (m)	Modelled Wave Heights (m)
October 2, 2012 – Northwesterly Wind Event		
AWAC	n/a	1.1
W1	n/a	1.1
W2	0.5	1.1
W3	0.6	1.0
December 15, 2012 – Southeasterly Wind Event		
AWAC	n/a	0.7
W1	0.6	0.7
W2	n/a	0.5
W3	0.4	0.5
December 19, 2012 – Southerly Wind Event		
AWAC	1.6	1.2
W1	1.6	1.2
W2	n/a	1.2
W3	0.7	0.9

n/a = no measured data available due to issues with interference of the recorders (suspected to be by commercial fishers, as described in Section 2.7.1 in Appendix C of EIS Appendix 9.5-A).

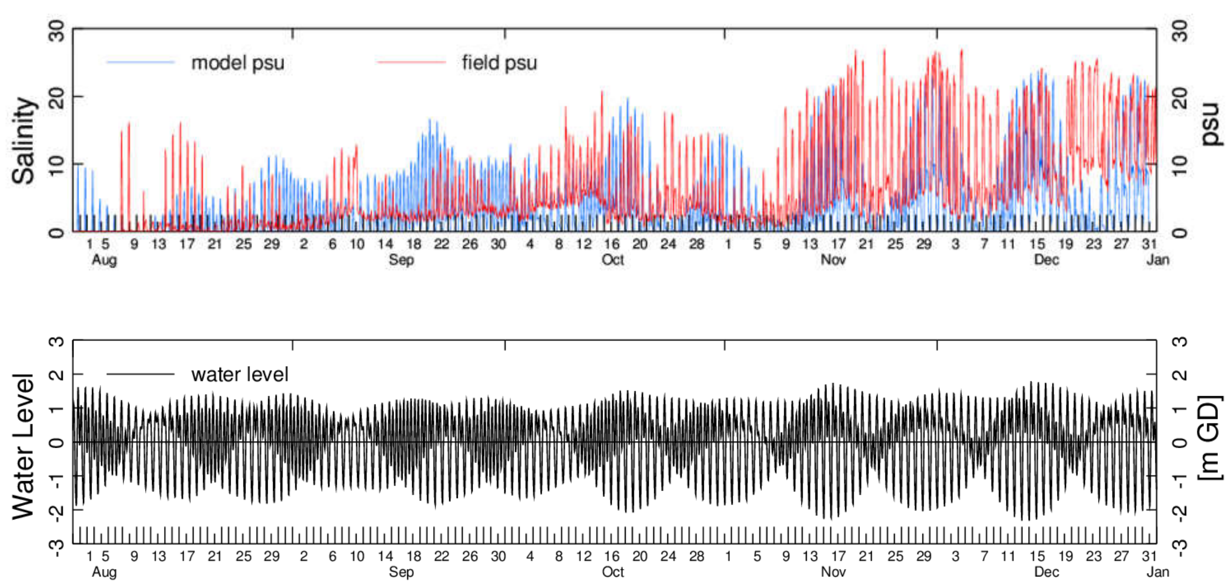
[5] The height of waves propagated in deep water and arriving at an area is a function of wind speed, duration of time that the wind has blown, and the distance over which the wind acts on the water (fetch), as described in Section 4.3 of EIS Appendix 9.5-A. A *fetch-limited system* is one in which the fetch length is too short and the wind is not in contact with the waves over a distance sufficient to impart the maximum energy to the waves (i.e., the ranges of frequencies and wave heights are limited as the process of wave generation required for waves to become fully developed has not been met). A *duration-limited system* is one in which the wind has not been in contact with the waves long enough to impart the maximum energy to the waves (i.e., the growth of the frequency range and wave heights ceases before waves have become fully developed).

Based on the two measurements available for the December 15, 2012 southeasterly storm at W1 and W3 wave recorder stations, modelled wave height during this storm event are in good agreement with observed wave heights. Wave heights were overestimated during the October 2, 2012 northwesterly storm for stations W2 and W3 and the December 19, 2012 southerly storm at station W3, and were underestimated at AWAC and W1 stations during the December 18, 2012 southerly storm by the model compared to observed wave heights. The comparisons show that the model reproduces the wave climate pattern in the Strait of Georgia and at Roberts Bank well. Part of the reason for the wave height discrepancies is the limited number of meteorological stations available in the Strait of Georgia to generate time-varying and spatial-varying two-dimensional wind fields (that were used to drive the wave field in the model).

Model Validation – Salinity at Canoe Passage

Continuous salinity data was collected at the Canoe Passage station from May 8, 2012 to December 31, 2012. **Figure IR2-01-14** shows hourly modelled salinity (blue line) and measured salinity (red line) levels (in practical salinity units, or PSU) at the station between August and December 2012. The bottom panel on **Figure IR2-01-14** shows the corresponding water level elevation (in m GD) The data between May and July are not presented in either figure because few salinity readings were recorded at the station during this period of high Fraser River discharges (i.e., mainly freshwater conditions).

Figure IR2-01-14 Modelled and Observed Salinity at the Canoe Passage Station August 1 to December 31, 2012



The results indicate that the model reproduced the timing of the salt intrusion (i.e., increases in salinity) relatively accurately during spring tides with the large tidal currents, but not as accurately during the neap tides with relatively weak tidal currents. Since the position of the salt wedge is a function of river discharge, tides, as well as the channel geometry, discrepancies between the model and observed salinity levels may be due to inaccuracies associated with the flow output from the Mike11 model at New Westminster (the upstream boundary of the model) as well as the 2004 bathymetry data for Canoe Passage. Refer to Section 4.2 of EIS Appendix 9.5-A: Appendix B for additional information pertaining to Mike11 output data and bathymetric surveys in the Canoe Passage.

Model Validation – Salinity at Roberts Bank

Modelled salinity profiles were also compared to salinity profiles measured at seven stations at Roberts Bank (T1, T5, T6, T10, T12, T16, and T17 station locations are shown in Figure 17 of EIS Appendix 9.5-A: Appendix C).

Section 4.5 of EIS Appendix 9.5-A: Appendix B presents comparisons for summer 2012 (based on August 2 and 29, 2012) at three locations (T1, T10, and T16). For salinity stations T1, T5, T6, T10, T12, T16, and T17, measured and modelled salinity profiles are provided in **Figures IR2-01-15** and **IR2-01-16** for spring 2012 (based on June 20, 2012), respectively. Measured and modelled salinity profiles at these seven stations are also provided in **Figures IR2-01-17** and **IR2-01-18** for late spring freshet conditions in 2012 (based on July 11, 2012), respectively.

Figure IR2-01-15 Measured Salinity Profiles for June 20, 2012

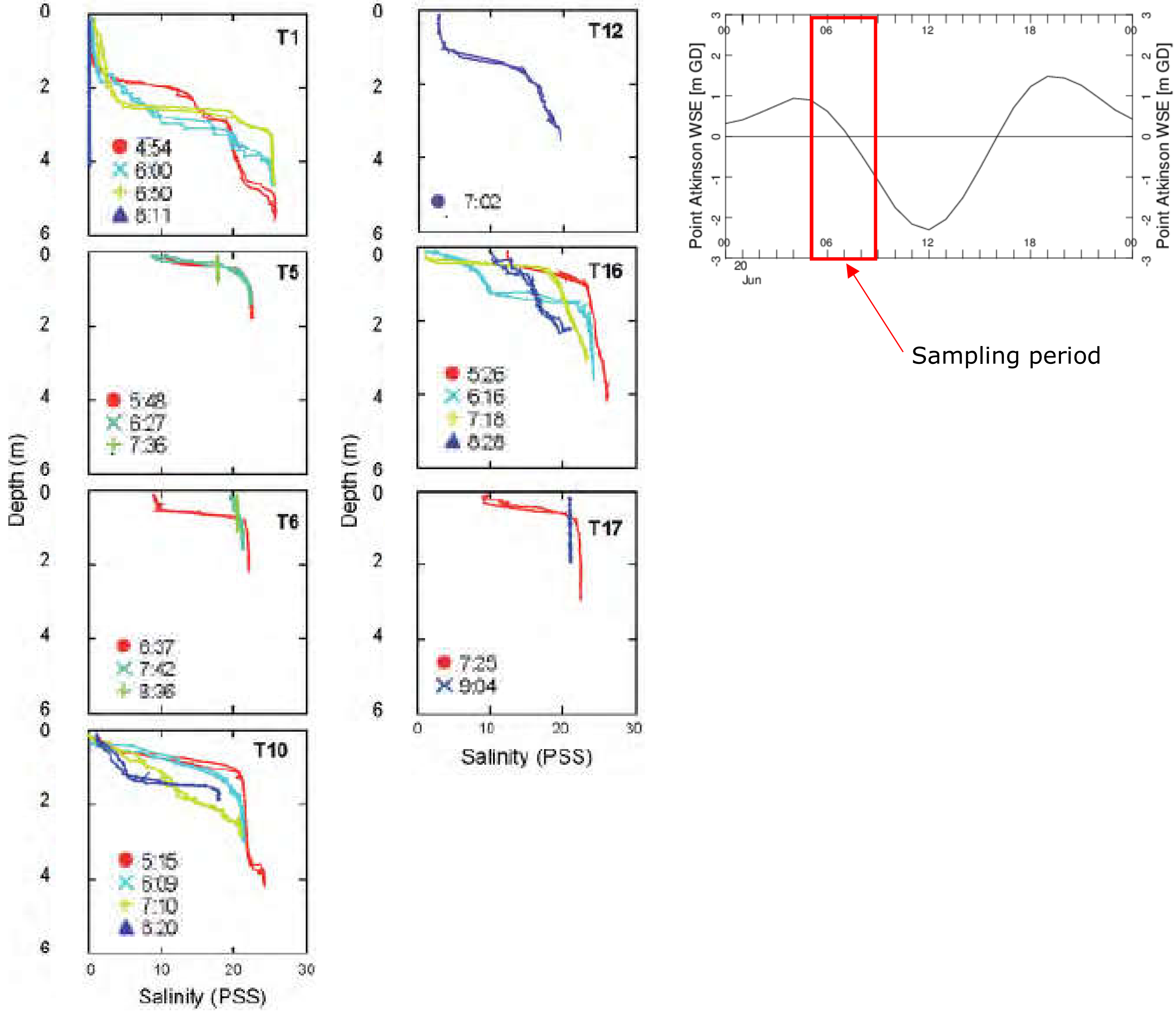


Figure IR2-01-16 Modelled Salinity Profiles for June 20, 2012

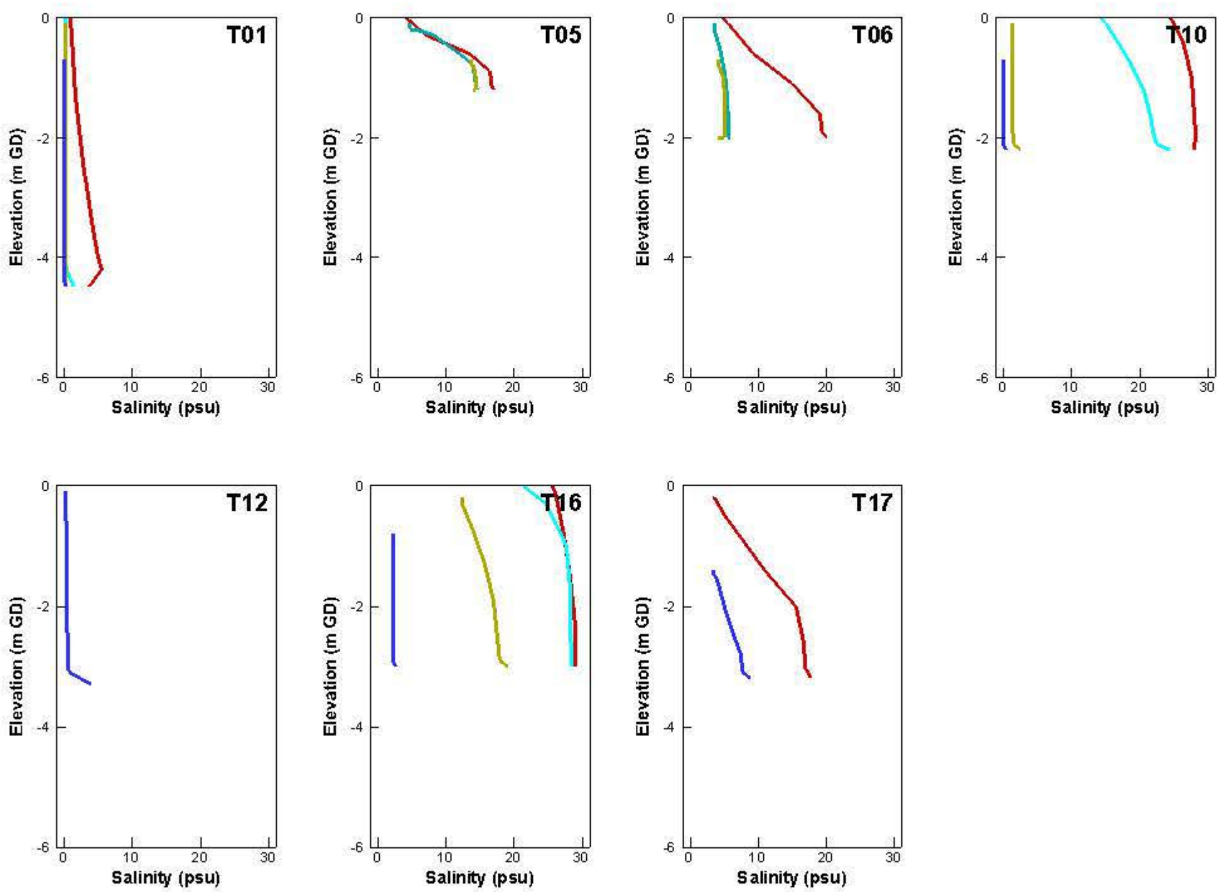


Figure IR2-01-17 Measured Salinity Profiles for July 11, 2012

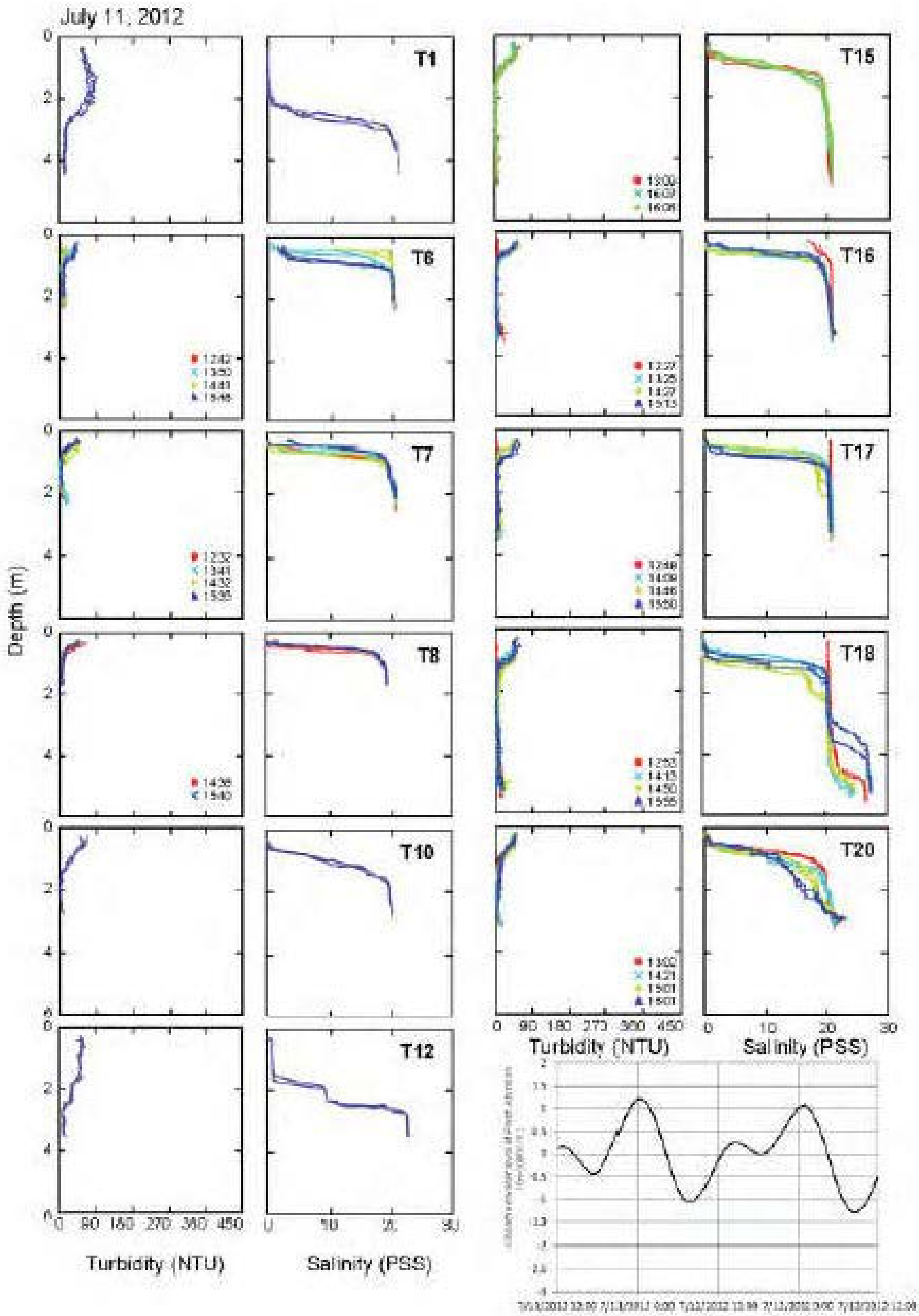
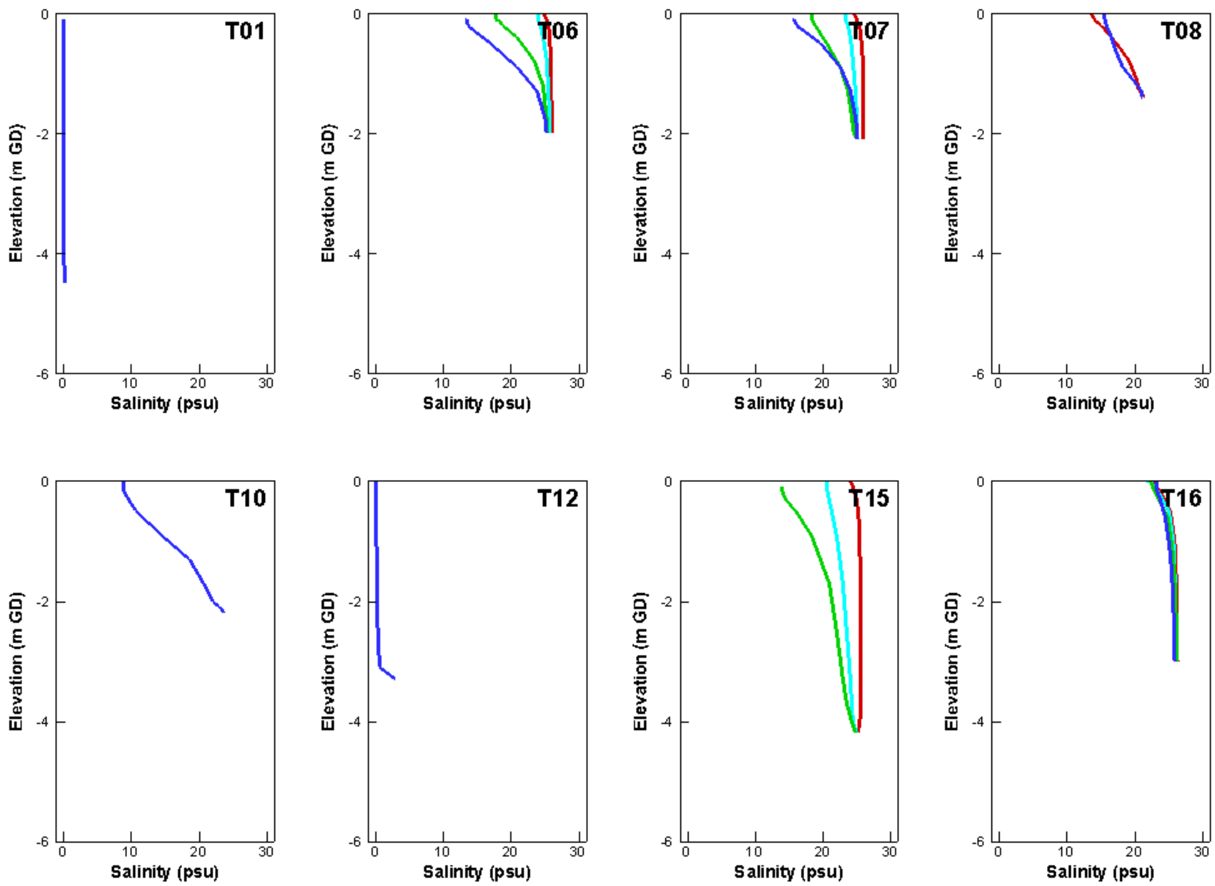


Figure IR2-01-18 Modelled Salinity Profiles for July 11, 2012



For the August comparisons presented in Section 4.5 of Appendix 9.5-A: Appendix B, the modelled profiles had weaker stratification and a more diffuse halocline[6] compared to profile measurements taken at the three locations at Roberts Bank (T1, T10, and T16). For the comparisons presented above, similar comparisons were noted. As per conclusions stated in IR2-13, the limited availability of salinity data collected by DFO at the model's open boundaries (Port Renfrew and Hornby Island) are unlikely to influence model salinity predictions at Roberts Bank or explain these discrepancies. The model is able to represent relative changes in the salinity distribution expected in the future with the Project as the model reproduced the spatial and vertical distribution of the Fraser River plume well during various stages of tidal conditions in the intertidal region. Despite observed differences, the model captured the spatial and vertical distribution of the Fraser River plume well during various stages of tidal conditions in the intertidal region. Thus, the model is able to represent relative changes in the salinity distribution expected in the future with the Project.

[6] A halocline is a vertical zone in a water column in which salinity changes rapidly with depth.

Model Validation - Conclusion

Overall, the TELEMAC-MASCARET model suite is able to reproduce observed conditions in 2012 for physical parameters, including water level elevations, wave heights, current speeds, and salinity levels during a range of tidal and seasonal conditions. The "use of TELEMAC-MASCARET model suite is appropriate for this study", as identified by CSAS in CEAR Document #893, to evaluate future changes both with and without the Project.

IR2-01a Coastal Geomorphology – Hydrodynamics, Modelling Data

Information Source(s)

Proponent Response to IR2-01 (CEAR Doc#961): Figures IR2-01-02 to IR2-01-06, Figure IR2-01-14

Context

Figures IR2-01-02 to IR2-01-06 of the Proponent's response to Review Panel information request IR2-01 clearly showed that the hydrodynamic model output matches the phase of measured tidal dependence of water levels, but because of the way the variables were plotted, it is impossible to determine visually if tidal amplitude has been correctly modelled.

Similarly, Figure IR2-01-14 shows that the model matches the phase of measured tidal dependence of salinity, but it is impossible to visually determine the salinity magnitude at Canoe Passage.

Information Request

Prepare scatter plots of modelled and measured maxima (high high and low high) and minima (high low and low low) of water levels from Figures IR2-01-02 to IR2-01-05. Use colour coding to distinguish maxima from minima. Calculate root mean square deviation and mean bias error for each plot.

Prepare scatter plot of modelled and measured maxima (high high and low high) and minima (high low and low low) of volume flow rate from Figure IR2-01-06 Use colour coding to distinguish maxima from minima. Calculate root mean square deviation and mean bias error for each plot.

Prepare a scatter plot of modelled and measured maxima and minima of salinity from Figure IR2-01-14 (top panel). Use colour coding to distinguish maxima from minima. Calculate root mean square deviation and mean bias error for each plot.

Provide an assessment of the model ability to capture the magnitude of flow variables. If this ability is inadequate in any way, discuss how this will influence the predictions of effects on environmental components that are influenced by salinity and flow.

VFPA Response

Prepare scatter plots of modelled and measured maxima (high high and low high) and minima (high low and low low) of water levels from Figures IR2-01-02 to IR2-01-05. Use colour coding to distinguish maxima from minima. Calculate root mean square deviation and mean bias error for each plot.

For reference, Figure IR2-01-1 showed the location of the various field data stations that were referenced in the response to IR2-01 (CEAR Document #961[1]). Figures IR2-01-2 to IR2-01-4 showed modelled and predicted water levels for Squamish, Point Atkinson, and Victoria, respectively, and Figure IR2-01-5 showed modelled and observed water levels for Canoe Passage. These figures demonstrated that the model reproduced the tide phase very well, but the format of the plots made comparison of the amplitude of the tides more difficult to discern. Per the information request, these data have been reprocessed to display only the maxima (magnitude of the higher high water and lower high water) and minima (magnitude of the higher low water and lower low water) levels to more clearly demonstrate that the model was able to predict the magnitude of the daily tides.

Comparisons of modelled and DFO predicted maxima (red dot) and minima (blue dot) water levels for May 1 to December 31, 2012 at Squamish, Point Atkinson, and Victoria are provided in **Figures IR2-01a-1** to **IR2-01a-3**, respectively. Water levels in the figures below are expressed as water surface elevation in metres from geodetic datum[2] (WSE [m GD]), with a positive value expressing an elevation above and a negative value expressing an elevation below this reference level.

Figure IR2-01a-4 shows modelled and measured maxima (red dot) and minima (blue dot) water levels at the Canoe Passage station for May 1 to December 31, 2012. Water levels recorded in Canoe Passage by Northwest Hydraulic Consultants (NHC) during the 2012 field data collection program are used as a comparison, as water levels for this Fraser River station are a function of both the tides and the river discharge (i.e., water levels at this station are not influenced solely by DFO predicted tides).

[1] CEAR Document #961 From the Vancouver Fraser Port Authority to the Review Panel re: Revised Responses to Information Request Package 2 (See Reference Documents #946 and #908).

[2] A geodetic datum (GD) is a reference point for various coordinate systems used in mapping the earth. The geodetic datum used at Roberts Bank was North American Datum 1983 (NAD 83), the official horizontal datum for use in the North and Central American geodetic networks. Elevations in the numerical model are referenced to GD because the model extends across numerous chart datum (CD) boundaries.

Figure IR2-01a-1 Modelled and Predicted Maxima (Red) and Minima (Blue) Water Levels at Squamish from May 1 to December 31, 2012

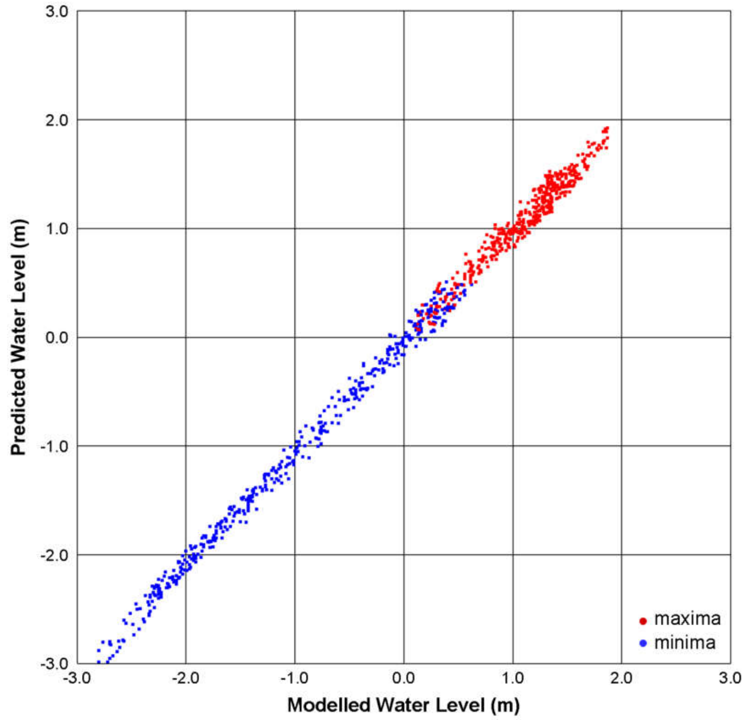


Figure IR2-01a-2 Modelled and Predicted Maxima (Red) and Minima (Blue) Water Levels at Point Atkinson from May 1 to December 31, 2012

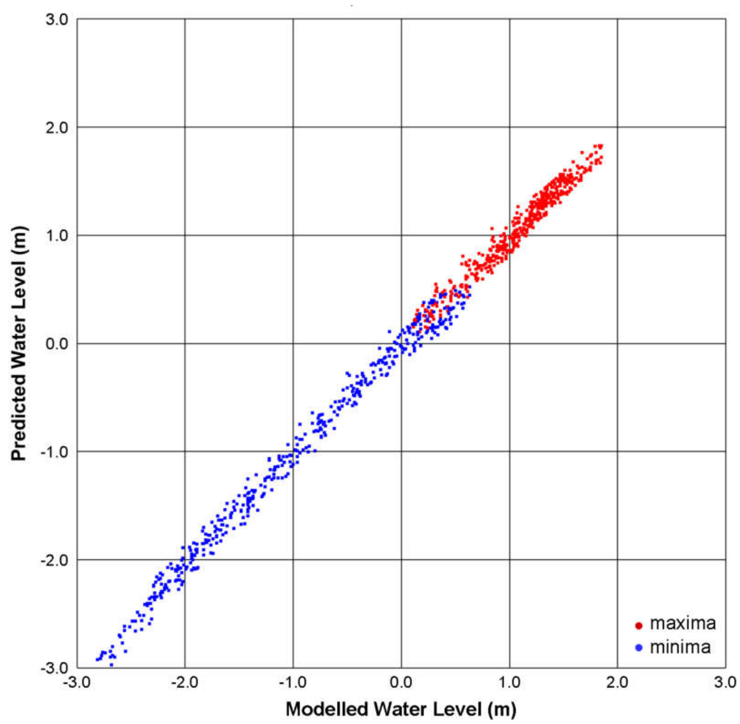


Figure IR2-01a-3 Modelled and Predicted Maxima (Red) and Minima (Blue) Water Levels at Victoria from May 1 to December 31, 2012

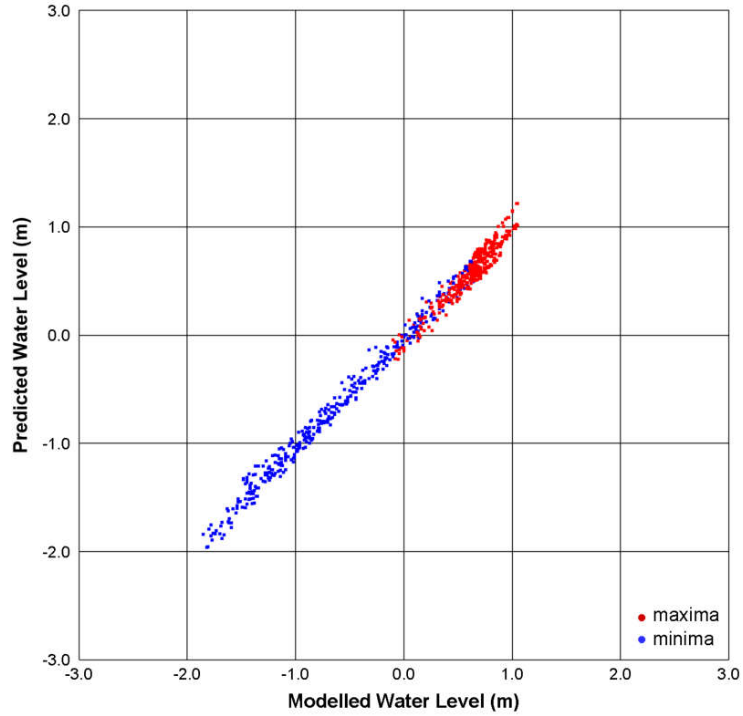
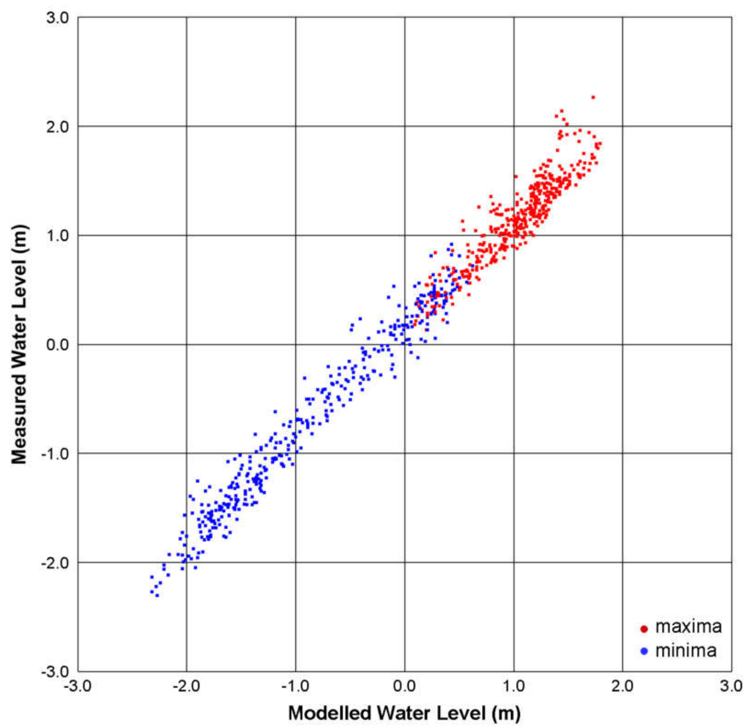


Figure IR2-01a-4 Modelled and Measured Maxima (Red) and Minima (Blue) Water Levels at Canoe Passage from May 1 to December 31, 2012



The root-mean-squared error (RMS) value and mean bias error (MBE) for the four stations are summarised in **Table IR2-01a-1**. The maximum RMS value between predicted and modelled water levels at the three marine stations is 0.10 m. Compared to mean tidal ranges at each station, these errors are within 5%. The MBE values are similar to the RMS values and are within 3% of the mean tidal ranges. The MBE describes the direction of the error bias and its value is related to magnitude of the values under investigation. A negative MBE occurs when the modelled values are smaller in value than the predicted water levels.

The RMS value between measured and modelled maxima and minima water levels at Canoe Passage is 0.22 m for the May 1 to December 31, 2012 period, which is similar to the RMS value of 0.23 m derived by comparing modelled and measured hourly data for the August 2012 period that was reported in Appendix B of EIS Appendix 9.5-A[3]. The MBE is -0.15, indicating a slight underestimation of the water levels in the model, which cannot be compared to the mean tidal range at this station[4]. As reported in IR2-01, since Fraser River flow rates are not measured at the model's upstream boundary at New Westminster (i.e., they are measured at Hope), the hydrodynamic model inflow was obtained from predictions using the Fraser River Mike11 model, as described in Sections 3.2 and 4.2 in Appendix B of EIS Appendix 9.5-A. This model was optimised for higher Fraser River discharges, so may be less accurate during mean flows and lower flows. In addition, there are uncertainties associated with estimating the tributary flows entering the Fraser River between Hope and New Westminster. Despite these limitations, modelled water levels at Canoe Passage are generally aligned with measured levels. The differences are unlikely to affect the predicted local hydrodynamics around Roberts Bank as the Canoe Passage monitoring station is relatively removed from the area of primary interest.

Table IR2-01a-1 RMS and MBE Values for Squamish, Point Atkinson, Victoria, and Canoe Passage Water Level Comparisons

	Mean Tidal Range (m)	RMS	% of mean tidal range	MBE (m)	% of mean tidal range
Squamish	3.3	0.10	2.9%	0.05	1.5%
Point Atkinson	3.2	0.10	3.0%	0.03	0.9%
Victoria	1.8	0.09	5.0%	0.04	2.2%
Canoe Passage	n/a[a]	0.22	n/a	-0.15	n/a

Notes: n/a = not applicable

a. Water level at Canoe Passage is affected by both the river flow and tide, thus a mean tidal range is not computed. For comparison, the mean tidal range at the nearby Tsawwassen tide gauge is 3.0 m.

[3] In the response to IR2-01, the RMS value for the May 1 to December 31, 2012 period was reported as 0.25. The difference in reported RMS values for the same period is because the RMS value was calculated on all data points in IR2-01, while only maxima and minima are considered in this response.

[4] Water level at Canoe Passage is affected by both the river flow and tide, thus a mean tidal range is not computed. For comparison, the mean tidal range at the nearby Tsawwassen tide gauge is 3.0 m.

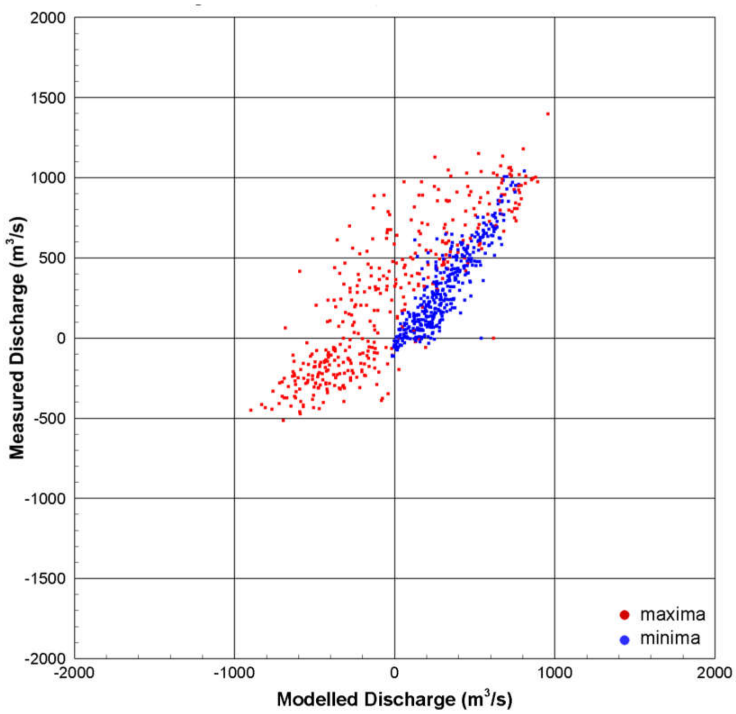
Prepare scatter plot of modelled and measured maxima (high high and low high) and minima (high low and low low) of volume flow rate from Figure IR2-01-06 Use colour coding to distinguish maxima from minima. Calculate root mean square deviation and mean bias error for each plot.

For reference, Figure IR2-01-6 that was included in the response to IR2-01 showed modelled and measured flows in Canoe Passage for the period May 1 to December 31, 2012. The data from this figure were reprocessed to show only the maxima (flows associated with the higher high water and lower high water tide conditions) and minima (flows associated with the higher low water and lower low water tide conditions).

As reported in IR2-01, modelled discharges in Canoe Passage were compared to the results of the Canoe Passage flow study conducted by NHC, which was undertaken to determine the amount, character, and timing of water delivery to Roberts Bank during various tidal stages and during a wide range of Fraser River flows. Section 2.1 in Appendix C of EIS Appendix 9.5-A described the methods and results related to this field program and the development of a stage-discharge rating curve to quantify flow through Canoe Passage. Model predictions of Canoe Passage flows were compared to the flows derived from the stage-discharge curve, which are referred to as 'observed flow' in the discussion and figures that follow, although it should be noted that stage (water height) and velocity are the observed values, while discharge is a derived value.

Comparisons of modelled and measured flows across Canoe Passage at maxima (red dot) and minima (blue dot) water levels for May 1 to December 31, 2012 is shown in **Figure IR2-01a-5**. Positive discharge values represent downstream outflow associated with an ebbing tide and negative discharges represent upstream flow associated with a flooding tide.

Figure IR2-01a-5 Modelled and Measured Maxima (Red) and Minima (Blue) Discharges at Canoe Passage from May 1 to December 31, 2012



The results show that the timing of the flow reversal and flow range (i.e., between maximum outflow and maximum inflow) predicted by the model are consistent with the measured flow data. As per the clarification provided in IR2-18 of CEAR Document #961, the model generally underestimated the outflow and overestimated the inflow at Canoe Passage compared to the stage-discharge relationship developed for this location from field data. The RMS difference and MBE, respectively, between hourly modelled and measured Canoe Passage flows are 277 m^3/s and -146 m^3/s. These differences are within the natural variability of Canoe Passage flows (which ranges from -1,118 m^3/s to 1,666 m^3/s over the observation period) and uncertainties associated with the 'observed flow' values that were interpolated from the stage-discharge curve. The mouth of Canoe Passage is strongly influenced by ocean conditions, and water levels and flow vary rapidly as the tide rises and falls. Thus, the ADCP flow measurements, upon which the stage-discharge curve (and observed flows) are based, are sensitive to the time they were collected. The RMS difference between observed flow derived from the stage-discharge curve and field flow measurements is 106 m^3/s, which is within the range of natural variability observed in this system. The differences are unlikely to affect the predicted local hydrodynamics around Roberts Bank as the Canoe Passage monitoring station is relatively removed from the area of primary interest (i.e., the station is over 4 km upstream of Brunswick Point, which is over 4 km from the nearest edge of the Project terminal).

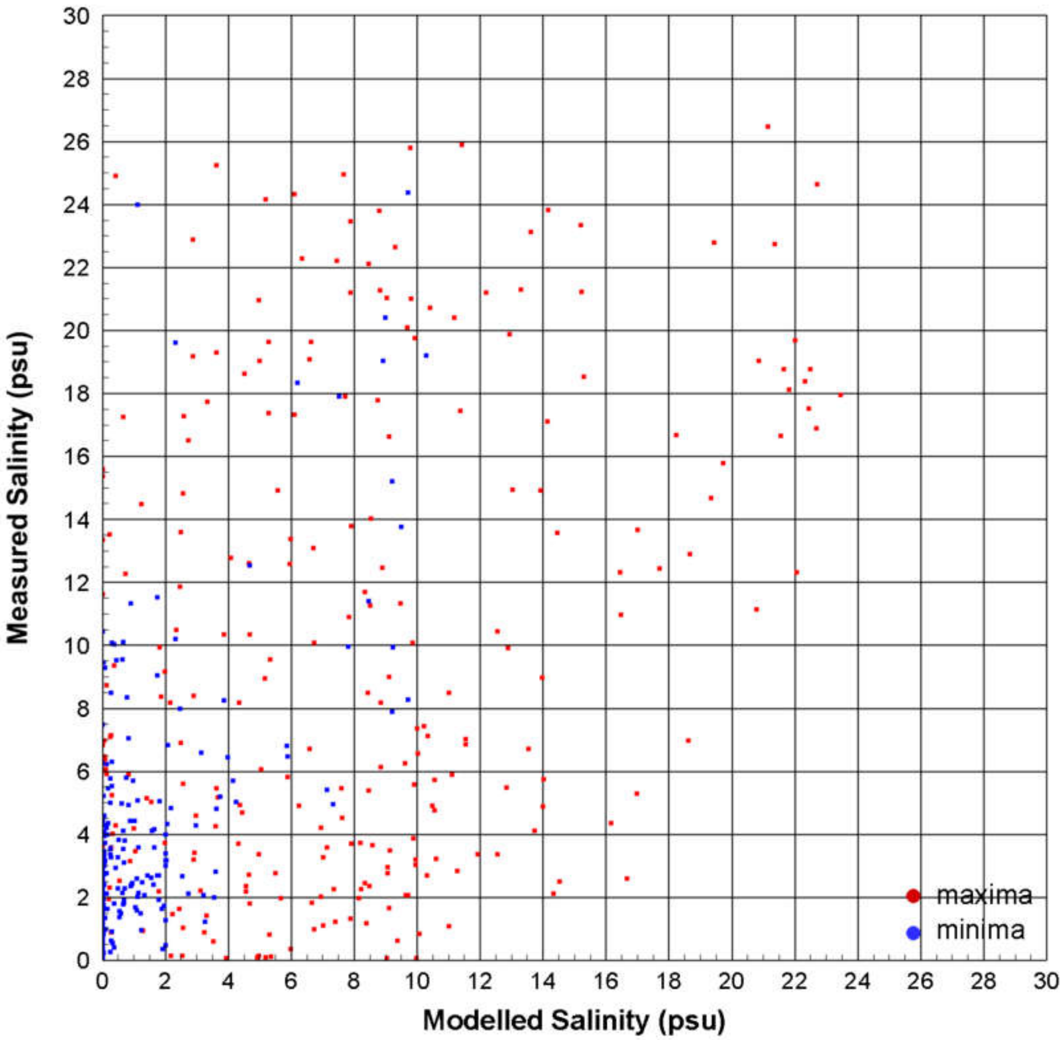
Prepare a scatter plot of modelled and measured maxima and minima of salinity from Figure IR2-01-14 (top panel). Use colour coding to distinguish maxima from minima. Calculate root mean square deviation and mean bias error for each plot.

For reference, Figure IR2-01-14 that was included in the response to IR2-01 showed modelled and measured salinity in Canoe Passage for the period August 1 to December 31, 2012. The data from this figure were reprocessed to show only the maxima and minima.

Continuous salinity data were collected at the Canoe Passage station from May 8 to December 31, 2012. Figure IR2-01-14 showed hourly modelled salinity (blue line) and measured salinity (red line) levels (in practical salinity units, or PSU) at the station between August and December 2012. The bottom panel on Figure IR2-01-14 showed the corresponding water level elevation (in m GD). The data between May and July were not presented in either figure because few salinity readings were recorded at the station during this period of high Fraser River discharges (i.e., mainly freshwater conditions).

Comparisons of modelled and measured salinities at the Canoe Passage monitoring station at maxima (red dot) and minima (blue dot) water levels for August 1 to December 31, 2012 is shown in **Figure IR2-01a-6**. These values were extracted from the record based on the timing of the high and low tide in order to relate the two measurements in the plot. The RMS error and MBE are 6.2 and 2.1 respectively.

Figure IR2-01a-6 Modelled and Measured Maxima and Minima Salinity at the Canoe Passage Station August 1 to December 31, 2012



Unlike the good comparisons of water level and discharge shown in **Figure IR2-01a-1** to **Figure IR2-01a-5**, modelled and measured salinity at maxima and minima water levels are not aligned (**Figure IR2-01a-6**). The time series comparisons indicate that the model reproduced the timing of the salt intrusion (i.e., increases in salinity) relatively accurately during spring tides with the large tidal currents, but not as accurately during the neap tides with relatively weak tidal currents. Since the position of the salt wedge is a function of river discharge and tides, as well as the channel geometry, discrepancies between the model and observed salinity levels may be due to inaccuracies associated with the flow output from the Mike11 model at New Westminster (the upstream boundary of the model) as well as the 2004 bathymetry data for Canoe Passage. Furthermore, the time series plots of modelled versus measured salinity at the Canoe Passage station (shown in Figure IR2-01-14) showed that there is a greater phase difference with regards to salinity than for currents and tides. As a result, relating salinity at maxima and minima water levels exaggerates the poor performance of the salinity model at this location, and is therefore not a good measure of overall model performance. Refer to Section 4.2 in Appendix B of EIS Appendix 9.5-A for additional information pertaining to Mike11 output data and bathymetric surveys in Canoe Passage. As noted above, the differences are unlikely to affect the predicted local hydrodynamics around Roberts Bank as the Canoe Passage monitoring station is relatively removed from the area of primary interest. Good performance of the salinity model over the Roberts Bank area has previously been demonstrated in EIS Section 9.5 and in the response to IR2-01.

Provide an assessment of the model ability to capture the magnitude of flow variables. If this ability is inadequate in any way, discuss how this will influence the predictions of effects on environmental components that are influenced by salinity and flow.

As demonstrated above, the model reproduces the magnitude of the tidal maxima and minima very well. The tidal processes drive currents, which are one of the dominant processes controlling the physical environment at Roberts Bank. The model represents channel discharge and salinity at the Canoe Passage station less well. As described above, there are a number of reasons for the discrepancies between observed values and modelled values of salinity and discharge in Canoe Passage, but these discrepancies that are noted at a station that is relatively removed from Roberts Bank do not indicate that the model is inadequate for the purposes of predicting the effects of the Project on environmental components that are influenced by salinity and flow. Information presented in the response to IR2-01 showed that salinity patterns within the main area of interest at Roberts Bank were well represented by the model as compared to field measurements, and that the model adequately captures the magnitude of flow variables in the local assessment area for the purposes of assessing changes to coastal geomorphology related to the proposed Project.

IR2-02 Coastal Geomorphology – Salinity

Information Source(s)

EIS Volume 2: Section 9.5.6.2; Figures in Section 9.7; Appendix 9.5-A

CEAR Doc #547

Context

Salinity is a key component of the water quality predictions for the proposed Project, and is used as an input for the coastal geomorphology model and the Roberts Bank ecosystem model (EwE model).

Figures 9.7-3, 9.7-4, 9.7-9 and 9.7-10 in Section 9.7 of the EIS showed salinity predictions for the area north and south of the causeway. However, according to Figure 26 of Appendix 9.5-A, salinity monitoring stations were only located north of the causeway. It is unclear how baseline salinity estimates were derived for areas south of the causeway in the absence of monitoring stations in this location.

The Proponent predicted changes to salinity by using the TELEMAC model to assess variations in salinity for the proposed Project due to mixing of saline water from the Strait of Georgia with freshwater from the Fraser River. As identified in section 9.5.6.2 of the EIS, changes to salinity as a result of the proposed Project were based only on 2012 freshet data, which was an abnormally high freshet year. Data from other years should be used to evaluate the changes in salinity that are predicted to occur with the proposed Project.

The local change from the proposed terminal on salinity was assessed by comparing the hydrodynamic model simulations of Existing and Future with the Project scenarios.

Three analyses of the model output were conducted:

1. spatial analysis of salinity distribution at selected tide stages during a spring tide cycle;
2. station specific hourly variation in salinity; and
3. spatial and temporal statistical analysis using 50^{th} percentile salinity, displayed on a map.

Current salinity and predicted changes to salinity as a result of the Project were presented only as 50^{th} percentile data, as indicated in Figures 9.7-3, 9.7-4, 9.7-9 and 9.7-10 in Section 9.7 of the EIS.

Information Request

Clarify how baseline salinity was estimated for areas without monitoring stations.

Re-run the TELEMAC model to predict changes in salinity conditions from average and below average freshet years and compare the outputs with Figures 9.7-3, 9.7-4, 9.7-9 and 9.7-10.

Using the data from average and below average freshet years in addition to 2012, carry out statistical analyses (mean, median, minimum, maximum, standard deviation, 90th percentile, 95 Upper Confidence Limits for Means (UCLM)) to derive the range of current salinity concentrations and the predicted changes with the proposed Project for the area shown in Figures 9.7-3, 9.7-4, 9.7-9 and 9.7-10.

VFPA Clarification

To clarify the statement in the context from the Panel, salinity was not used as an input to the "coastal geomorphology model"; rather, salinity was defined at the open boundaries[1], and the TELEMAC-3D model calculated the physical interactions between freshwater and ocean water in the model domain (domain shown in Figure 50 in EIS Appendix 9.5-A). The resultant salinity predictions from the TELEMAC-3D model were used as one of many abiotic inputs to the Roberts Bank ecosystem model to predict changes of the Project to productivity (see Section 2 of EIS Appendix 10-B). Similarly, salinity outputs from the TELEMAC-3D model were used as inputs to the shorebird foraging opportunity model, which was used to predict changes of the Project on the availability of food for western sandpipers (see Section 3.4.2.3 in EIS Appendix 15-B).

The information request refers to "conditions from average and below average freshet years". The VFPA has assumed in this response that this is referring to the magnitude of the maximum Fraser River *discharge* during the freshet as its measure of 'average' and 'below average' conditions. Discharge is the typical metric that is used to describe the freshet.

VFPA Response

Clarify how baseline salinity was estimated for areas without monitoring stations.

Existing (baseline) conditions for salinity were predicted for the *entire* model study area (Figure 50 of EIS Appendix 9.5-A), regardless of whether there were field (monitoring) stations. Confidence in predictions was strengthened with the dominant processes controlling the hydrodynamics of the Fraser River plume coded into the model and field-based data at select monitoring locations to test the accuracy of model predictions. The field data collection program is one aspect of a suite of tools that are used to ensure confidence in predictions.

The field program was targeted in the area that was predicted to have the biggest change to salinity as a result of the Project and was, therefore, focused in the area north of the causeway (salinity sampling locations shown in Figure 16 of EIS Appendix 9.5-A: Appendix B). By focusing on this area, the field program was able to capture the dominant processes in the system, particularly the Fraser River plume. This data was then used to calibrate and validate the model to test how well model outputs compare with actual conditions. Validation results, which are presented in Section 4 of EIS Appendix 9.5-A: Appendix B and IR2-01, show that the model, grounded in locally derived field data, provides a good representation of the dominant hydrodynamic processes in the local study area.

[1] See IR2-01 for definition of open boundary.

It was not necessary to collect field data in the area south of the causeway, because of the following:

a) There is little influence of the Fraser River plume in the inter-causeway area. For instance, EIS Figure 9.5-9 (reproduced below as **Figure IR2-02-1**) shows the distribution of the Fraser River plume during a summer ebbing tide, which is diverted from the inter-causeway area by the Roberts Bank causeway. Field observations made during quarterly field visits between 2007 and 2012 for the Deltaport Third Berth (DP3) Adaptive Management Strategy (AMS) program confirm that the Fraser River plume has very little influence in the inter-causeway area; and

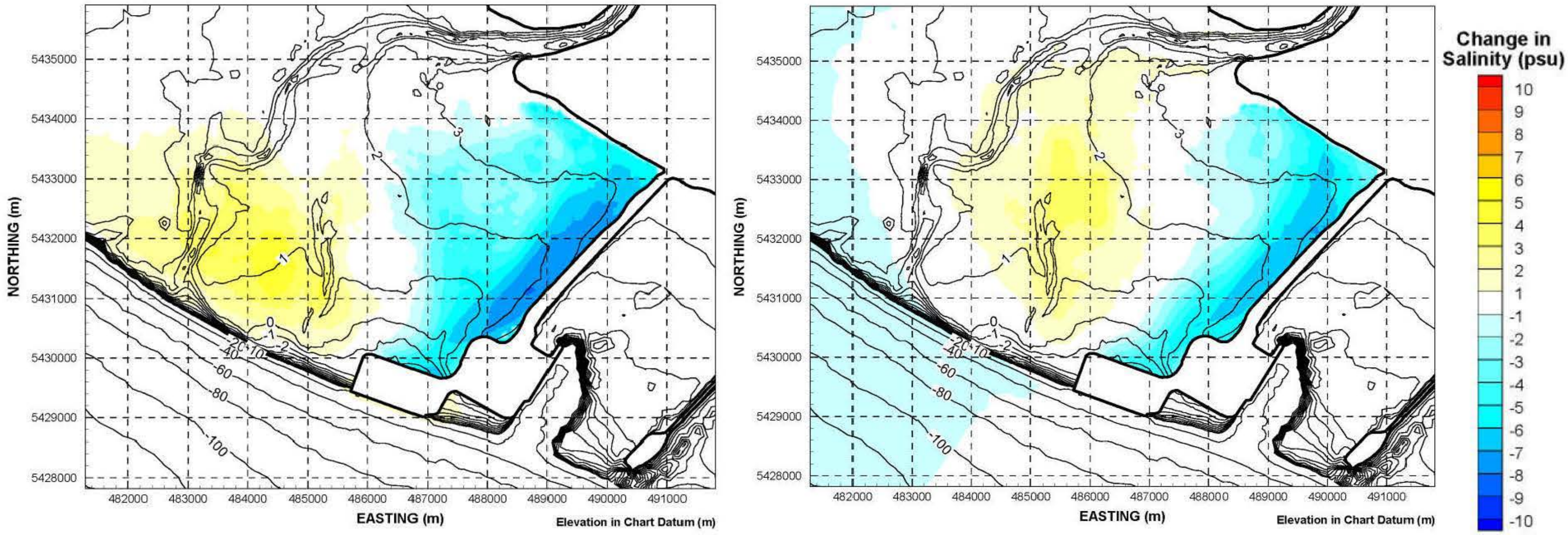
b) The inter-causeway area is hydrodynamically separate from the area to the north of the Roberts Bank causeway; therefore, any changes to ocean currents, waves, sediment transport, or salinity related to the Project will not extend into this area. This determination is because the Roberts Bank terminals and causeway extend from shore to deep water and so the hydrodynamic influence of the Project components located on the north side of the causeway will be either physically blocked by the existing infrastructure, or the influence will be dissipated by the presence of deep water where current velocities become very small in comparison to those in shallower waters.

The model predictions consistently support this conclusion that when conditions with and without the Project are compared, the model shows no change in the inter-causeway area in salinity (see EIS Figures 9.7-9 and 9.7-10, reproduced as **Figure IR2-02-2**). These predictions are also consistent with predicted changes to the other processes, including currents (see EIS Figures 9.5-28 and 9.5-29) and waves (see EIS Figures 9.5-30 and 9.5-31).

To increase confidence in the results, these model outputs were tested against known patterns of salinity distribution. For example, although there were no field based measurements that were taken in the inter-causeway area, salinity data from other RBT2 studies (as described in EIS Appendix 9.6-A) and data from the DP3 AMS program were used to compare model outputs. These studies confirmed that the inter-causeway area is much more saline than waters north of the causeway and nearly identical to the salinity in the rest of the Strait of Georgia, due principally to the presence of the existing causeway, which has blocked the Fraser River plume.

Figure IR2-02-1 **Portion of 1999 Landsat Image of the Strait of Georgia Showing Distribution of the Fraser River Plume During a Summer Ebbing Tide** (originally presented as EIS Figure 9.5-9)

Figure IR2-02-2 Predicted Changes in 50th Percentile Salinity Associated with the Project Footprint (Existing Conditions Compared to the Future with Project) – Freshet Period (May to July) Shown on the Left and Non-freshet Period (October to December) Shown on the Right (originally included as EIS Figure 9.7-9 and EIS Figure 9.7-10, respectively)



Re-run the TELEMAC model to predict changes in salinity conditions from average and below average freshet years and compare the outputs with Figures 9.7-3, 9.7-4, 9.7-9 and 9.7-10

Above average and well below average freshet discharge were captured and considered in the effects assessment. The EIS has captured a range of freshet flow scenarios and their influence on salinity and a re-running of the TELEMAC-3D model is unnecessary for the reasons outlined below.

In the EIS, modelled salinity conditions for two time periods in 2012 were presented; freshet (May to July) and non-freshet (October to December). These time periods were chosen because they had similar tidal cycles (**Figure IR2-02-3**) but were differentiated by a large range in discharge from the Fraser River. This is important, as the general processes that drive salinity patterns at Roberts Bank are the tidal mixing of saline water with freshwater from the Fraser River. If tidal conditions are similar between periods, then the influence of variable Fraser River flow can be tested within the same freshet year.

To help illustrate this, **Figure IR2-02-4** shows the annual hydrograph of the Fraser River at Hope, including discharge for 2012, as well as the mean, minimum, and maximum flow for each calendar day for the period of record (1913 to 2012). These data show that discharge during May to July 2012 ranged between 5,080 cubic metres per second (m^3/s) and 11,700 m^3/s, which was mostly above the historical average for the freshet period. In contrast, discharge during October to December 2012 ranged between 800 m^3/s and 2,080 m^3/s and was similar to the historical winter average flow for each day. These winter flows were well below the historical average for the freshet period, and only slightly lower than the lowest recorded historical freshet flow. Therefore, salinity conditions for above average and well below average historic freshet flows fall between these 'end points' and are considered in the effects assessment.

When these two periods are used to assess the changes to salinity conditions related to the Project, the comparison is a *de facto* assessment of the effects that variations in Fraser River flow have on the resultant changes related to the Project. For ease of reference, **Table IR2-02-1** provides a summary of the figures that were presented in the EIS together with their corresponding freshet flow scenario. To help illustrate the point, **Figure IR2-02-2** shows the predicted change in 50^{th} percentile salinity related to the Project for May to July 2012 and October to December 2012. For both periods, salinity is predicted to decrease adjacent to the Roberts Bank causeway and in the area extending northwest across the tidal flats, and salinity is predicted to increase in the area of Roberts Bank between the Project and Canoe Passage. The difference in predictions between seasons can be summarised as a difference in the magnitude of the change, as well as the extent of the area that is changed, while the overall pattern remains very similar. Since the main process that is different between seasons is the volume of freshwater emanating from the Fraser River, it can be concluded that the results from modelling a smaller freshet would lie between these two 'end points'. The EIS has therefore captured a range of saline conditions from an above average to a well below average freshet year.

Table IR2-02-1 Summary of Figures Presented in the EIS and their Corresponding Freshet Discharge Scenario

EIS Figure Number	Title of Figure	Flow Compared to Freshet Scenario
9.7-3	Existing conditions salinity (freshet period)	Above average
9.7-4	Existing conditions salinity (non-freshet period)	Well below average
9.7-9	Future conditions with Project salinity (freshet period)	Above average
9.7-10	Future conditions with Project salinity (non-freshet period)	Well below average

Figure IR2-02-3 Predicted Water Level at Point Atkinson for May to July 2012 (top panel) and October to December 2012 (bottom panel) (originally presented as Figure 5 in CEAR Document #547)

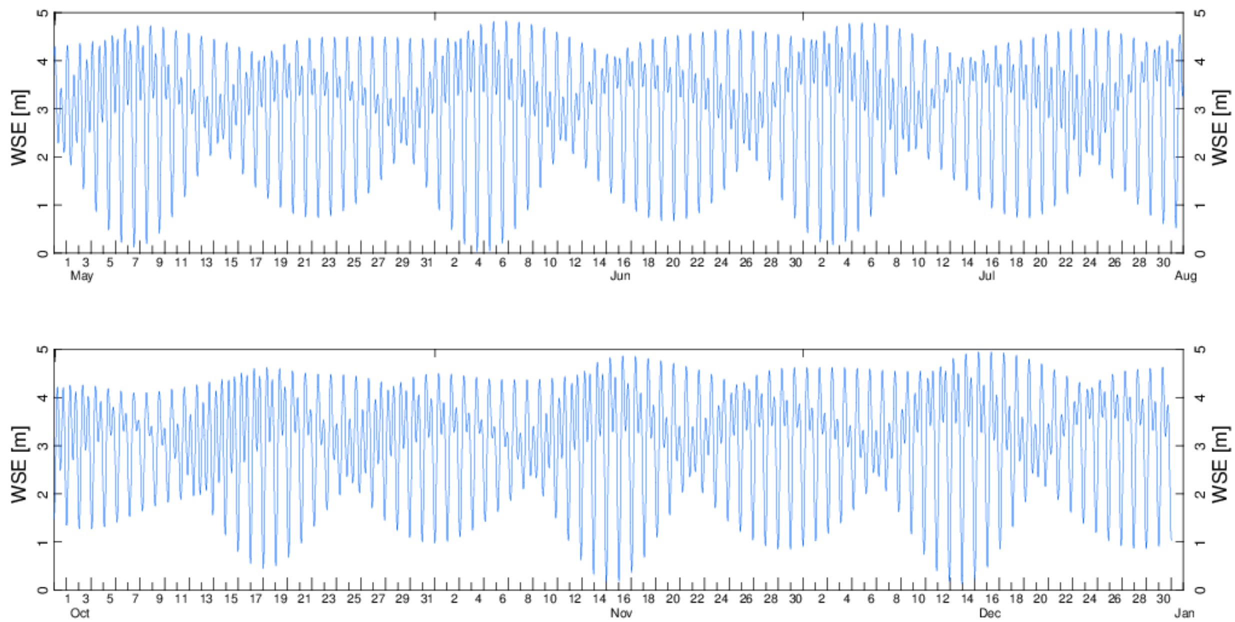
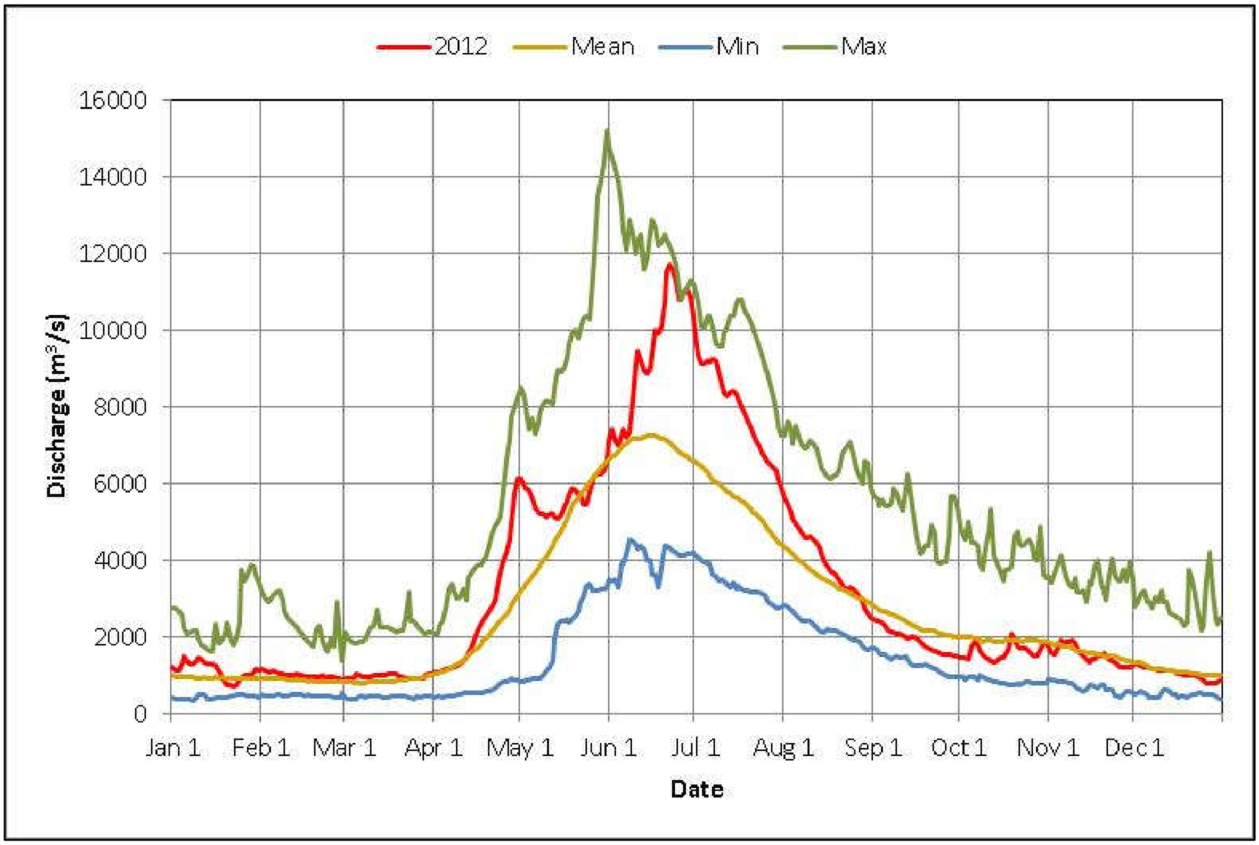


Figure IR2-02-4 Average Annual Hydrographs of Fraser River at Hope for 1913 to 2012 (originally included as EIS Figure 9.5-7)



Source: Data from Water Survey of Canada 2013

Using the data from average and below average freshet years in addition to 2012, carry out statistical analyses (mean, median, minimum, maximum, standard deviation, 90th percentile, 95 Upper Confidence Limits for Means (UCLM)) to derive the range of current salinity concentrations and the predicted changes with the proposed Project for the area shown in Figures 9.7-3, 9.7-4, 9.7-9 and 9.7-10.

Statistical data for 2012 freshet and non-freshet flow conditions that bracket average and below average freshet discharges are provided in **Figures IR2-2-5** to **IR2-2-10**. For ease of comparison, these figures show the same extents as has previously been presented in EIS Appendix 9.5-A.

The information request is asking for additional statistical representations of salinity at Roberts Bank. In order to respond to this request, it is helpful to understand the underlying structure of the dataset that is generated by the TELEMAC-3D model, as well as the mathematics of the statistics that are being requested, both of which are described below.

TELEMAC-3D Model Salinity Output

The TELEMAC-3D model calculates conditions within the model domain on a 30-second time step and archives the results of the ongoing model run every hour. This contributes to a dataset of ever-changing salinity at every node in the model domain. The sample size (n) of each node-specific dataset is dependent on the length of time over which the model is run (in this case, three months) as well as average depth of water at the node, noting that zero values that represent dry conditions are excluded from the dataset. For example, a node in subtidal waters would archive approximately 2,160 values (24 hours times 90 days), but a node located at approximately mean sea level (3 m Chart Datum) would have approximately half that number since, on average, the cell is dry half the time.

Explanation of Statistical Calculations

A statistical representation of the dataset[2] is made for each node in the area of interest to collapse the thousands of salinity values to a single number at each node, and the results are plotted spatially. Values between points are interpolated to create a smooth map. The theoretical maximum range in the values is from zero practical salinity units (PSU) (i.e., freshwater) to 34 (maximum salinity measured near the mouth of Juan de Fuca Strait in June and September 2012). **Table IR2-02-2** explains each of the statistical representations of the salinity data that are requested, as well as the 50th percentile value that has previously been presented in the EIS.

Table IR2-02-2 Summary of Statistical Expressions of Model Salinity Output

Statistic	Explanation
Mean	The average of all values, calculated by summing all values and dividing by the number of values
Median	When all values are ranked, the median value lies in middle of the population such that 50% of the values are greater and 50% of the values are smaller. The median value is the same as the 50th percentile value.
Minimum	The lowest value in the dataset
Maximum	The highest value in the dataset
Standard Deviation	The square root of the variance of the values in the dataset. This statistic describes how much the values vary from the central mean. Two assumptions are made: 1) each value in the dataset is independent of the others (which is not true in the case of salinity values), and 2) the population fits a normal distribution (which is an untested assumption). The standard deviation is a measure of variability. In areas where salinity is more variable (e.g., the upper intertidal), the standard deviation will be larger relative to areas which are less variable (e.g., the Straight of Georgia).
50th Percentile	The same as the median value (see above)
90th Percentile	When all values are ranked, the 90th percentile value describes the value for which 10% of salinity values are greater and 90% are smaller.
95 Upper Confidence Limits for Means (UCLM)	This is a statistical expression of the confidence with which the mean is estimated for a sample of the population. It is not reasonably applicable to the salinity data output from the TELEMAC-3D model because the statistics previously calculated are applied to the entire population of salinity values and not a subset (sample) of the values.

[2] The entire dataset is analysed, so in statistical terms, the sample and the population are the same.

Requested Statistical Expression of Salinity Model Output

Table IR2-02-3 summarises the statistical expressions of salinity for the various conditions and periods provided in **Figures IR2-02-5** to **IR2-02-10.** Each of the eight statistics is presented as a panel in each figure.

Table IR2-02-3 Summary of Model Runs for which Statistics are Presented

Statistic	Freshet Period (above average freshet year)		Non-Freshet Period (well below average freshet year)		Existing Conditions minus Future Conditions	
	Existing Conditions	Future Conditions	Existing Conditions	Future Conditions	Freshet Period (average freshet year)	Non-Freshet Period (average freshet year)
Mean Median Minimum Maximum Standard Deviation 50th Percentile 90th Percentile 95 Upper Confidence Limits for Means (UCLM)	Figure IR2-02-5	Figure IR2-02-6	Figure IR2-02-7	Figure IR2-02-8	Figure IR2-02-9	Figure IR2-02-10

The mean, median, and 50th percentile panels in **Figures IR2-02-5** to **IR2-02-8** and the delta mean, delta median, and delta 50th percentile panels in **Figures IR2-02-9** to **IR2-02-10** show essentially the same pattern. The minimum is the lower bound in the range for any given point in the model, while the maximum and 90th percentile show the upper bound and close to the upper bound in the range, respectively.

Standard deviation is a measure of the variability of the value around the mean. Those areas in the Strait of Georgia and in the Fraser River have a very small standard deviation because variability in those areas have a narrow range (freshwater in the river and saline conditions in the strait), while standard deviation in the local study area is higher because of the variable salinity regime experienced there.

Rationale for Selection of 50th Percentile in the Valued Components Assessment

The rationale for why the 50th percentile is the most appropriate statistic to use in the valued components effects assessment was provided in response to question 3.5 in CEAR Document #547, and is reproduced partly in this response for context.

Salinity, like almost all environmental and physical variables at Robert Bank, is naturally variable (on hourly, daily, monthly, seasonally, and annual bases), especially in the intertidal area where numerous species occur. Daily salinity changes are most pronounced in the upper intertidal at Roberts Bank, fluctuating from nearly fresh to 32 PSU. The intertidal community is characterised by the ability to withstand large regular fluctuations in salinity from completely freshwater conditions to marine conditions with every tidal cycle. The 5th and 95th percentile of salinity values in this intertidal area represent the extreme range in salinities. However, while the intertidal area undergoes extreme fluctuations in salinity regularly, most time is spent by marine organisms at some moderate salinity level and the 50th percentile salinity statistic represents the most common salinity condition across Roberts Bank, most consistently. This feature is well portrayed in Figure 14 of question 3.5 in CEAR Document #547, where the 50th percentile statistic is represented across a sample salinity profile at Roberts Bank.

In addition, statistical analyses associated with the shorebird foraging opportunity model, which also used the 50th percentile salinity statistic, found that the 50th percentile salinity values showed the strongest and most consistent correlation with shorebird prey (biofilm, meiofauna, and macrofauna) abundance measurements (as compared to 5th and 90th percentile salinity values). This finding supports the general ecological premise that intertidal organisms are adapted to tolerate extreme conditions but function best at average conditions (common condition), and that use of the 50th percentile salinity statistic was appropriate for ecological modelling.

Figure IR2-02-5 Various Statistical Expressions of Salinity During the Freshet Period (Above Average Freshet Year) Under Existing Conditions

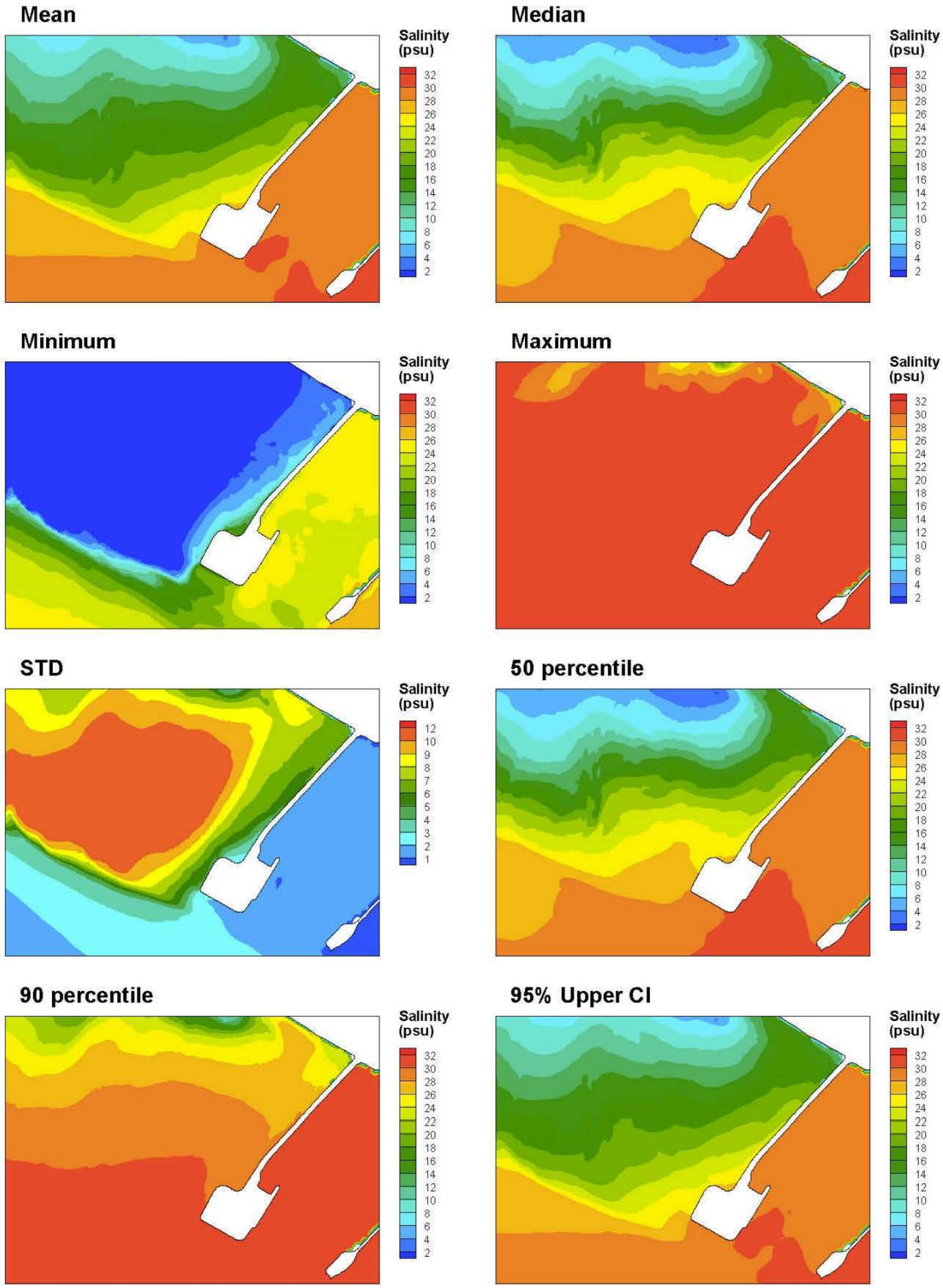


Figure IR2-02-6 Various Statistical Expressions of Salinity During the Freshet Period (Above Average Freshet Year) Under Future Conditions with Project

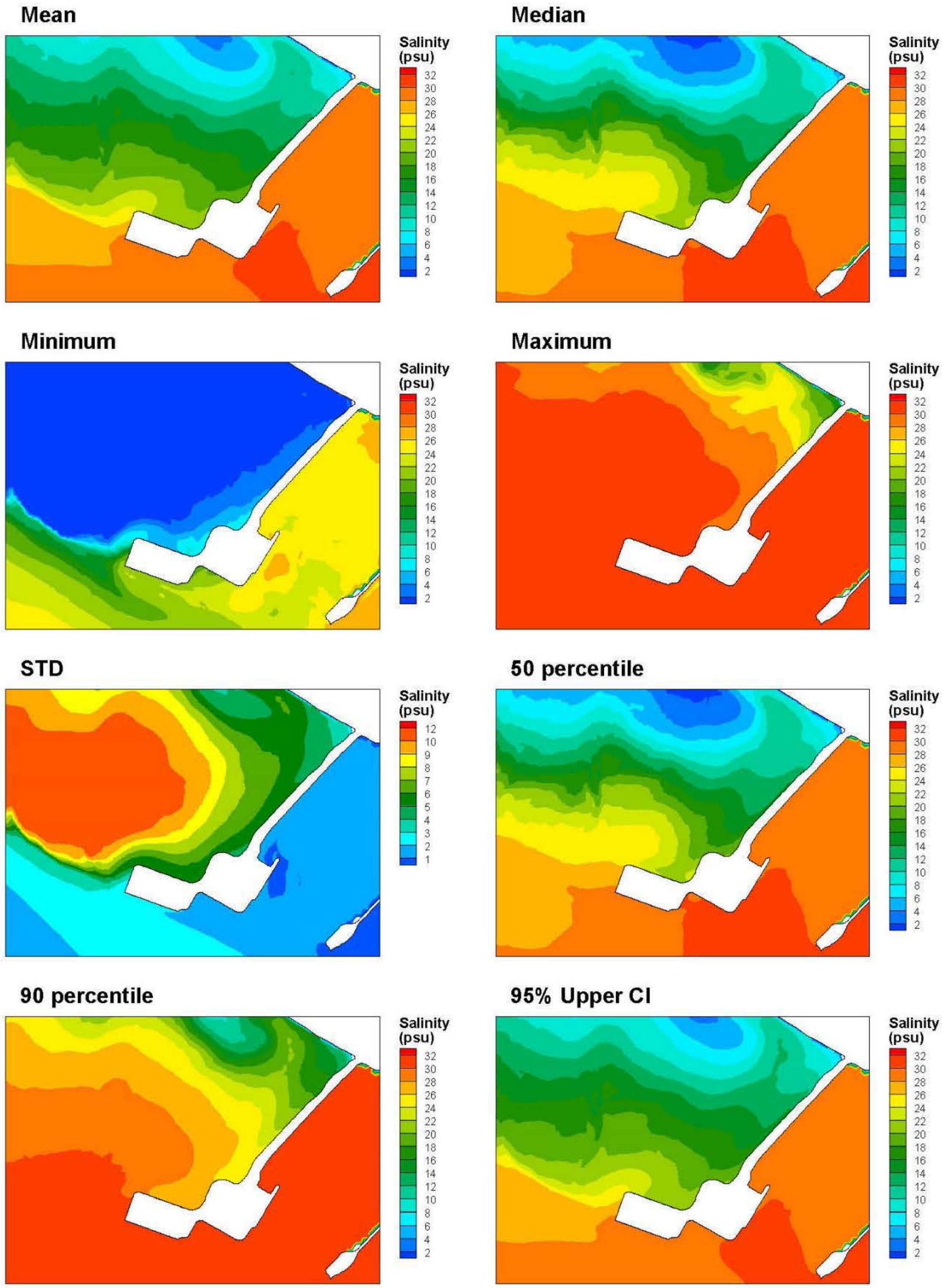


Figure IR2-02-7 Various Statistical Expressions of Salinity During the Non-freshet (Well Below Average Freshet Year) Period Under Existing Conditions

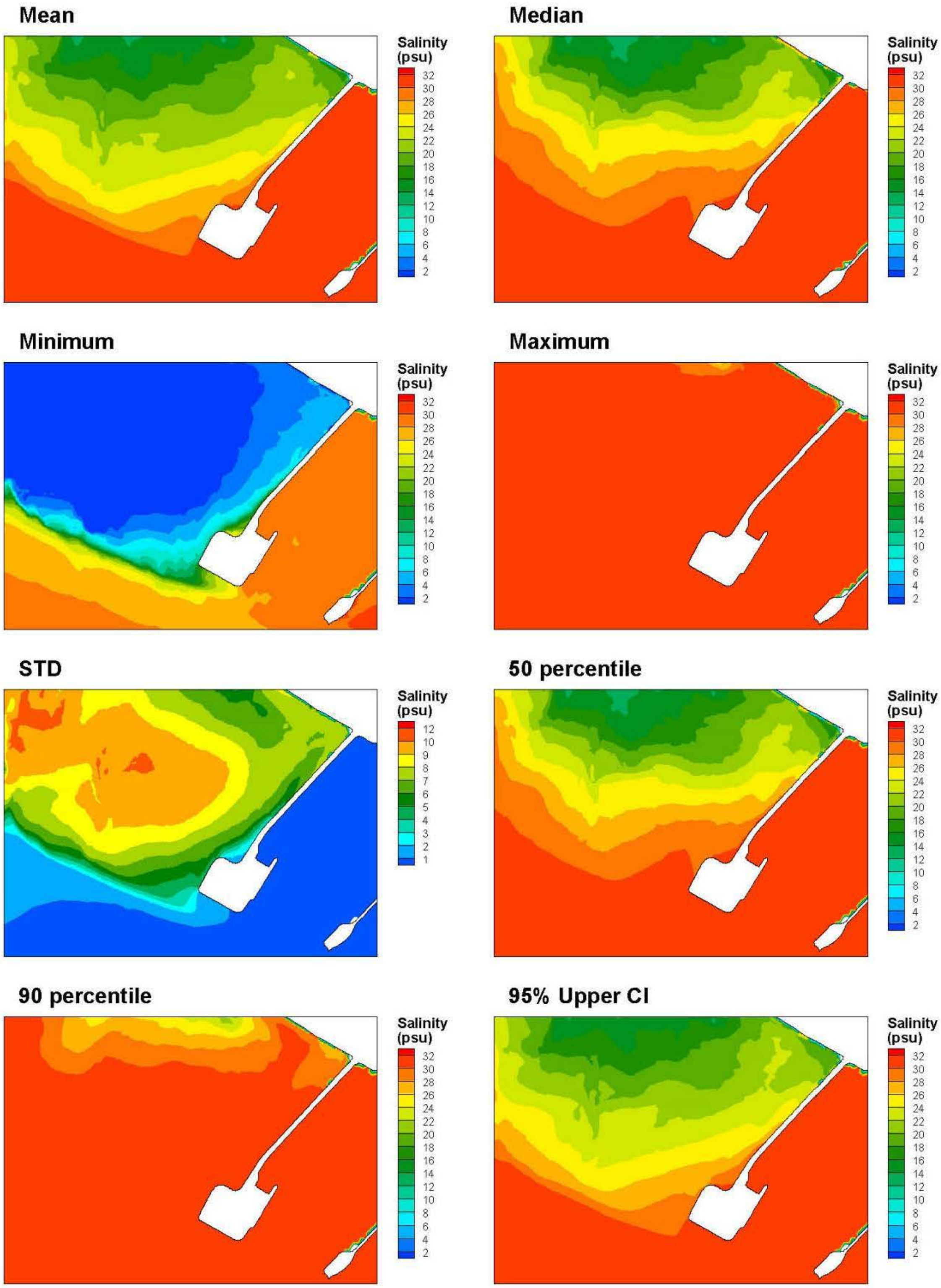


Figure IR2-02-8 Various Statistical Expressions of Salinity During the Non-freshet (Well Below Average Freshet Year) Period Under Future Conditions with Project

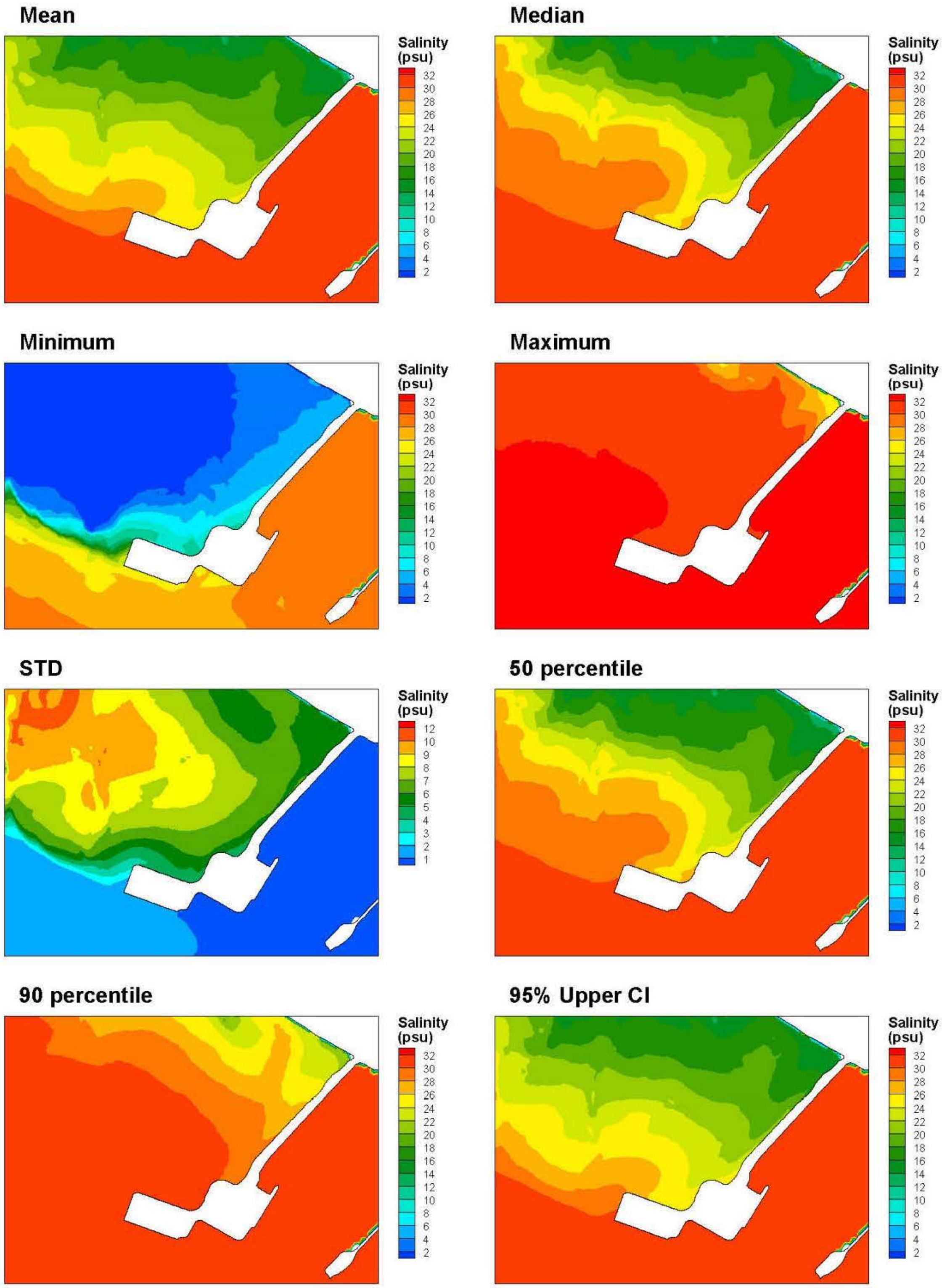


Figure IR2-02-9 Various Statistical Expressions of Salinity During the Freshet Period (Above Average Freshet Year) – Existing Conditions Minus Future Conditions with Project

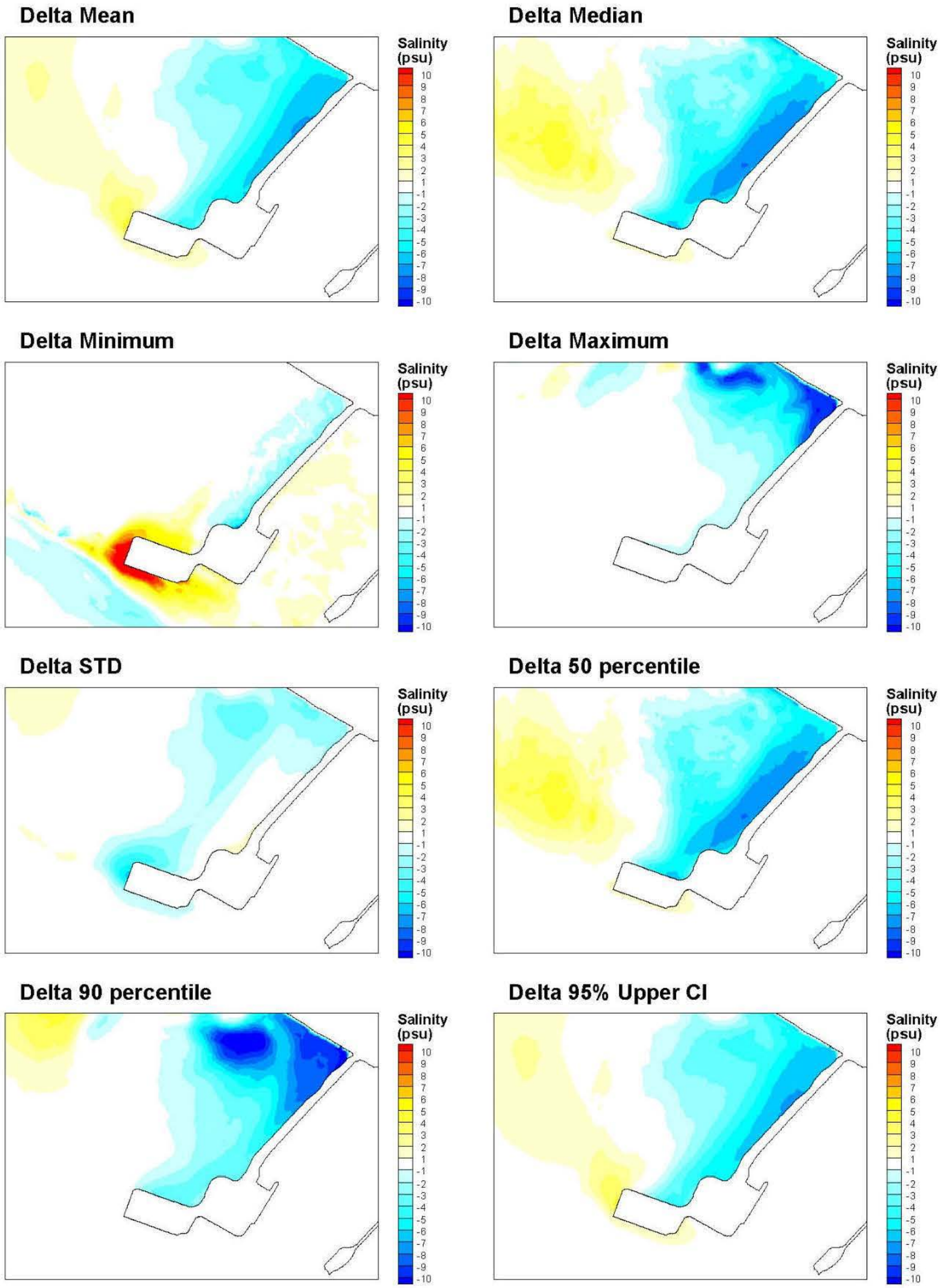
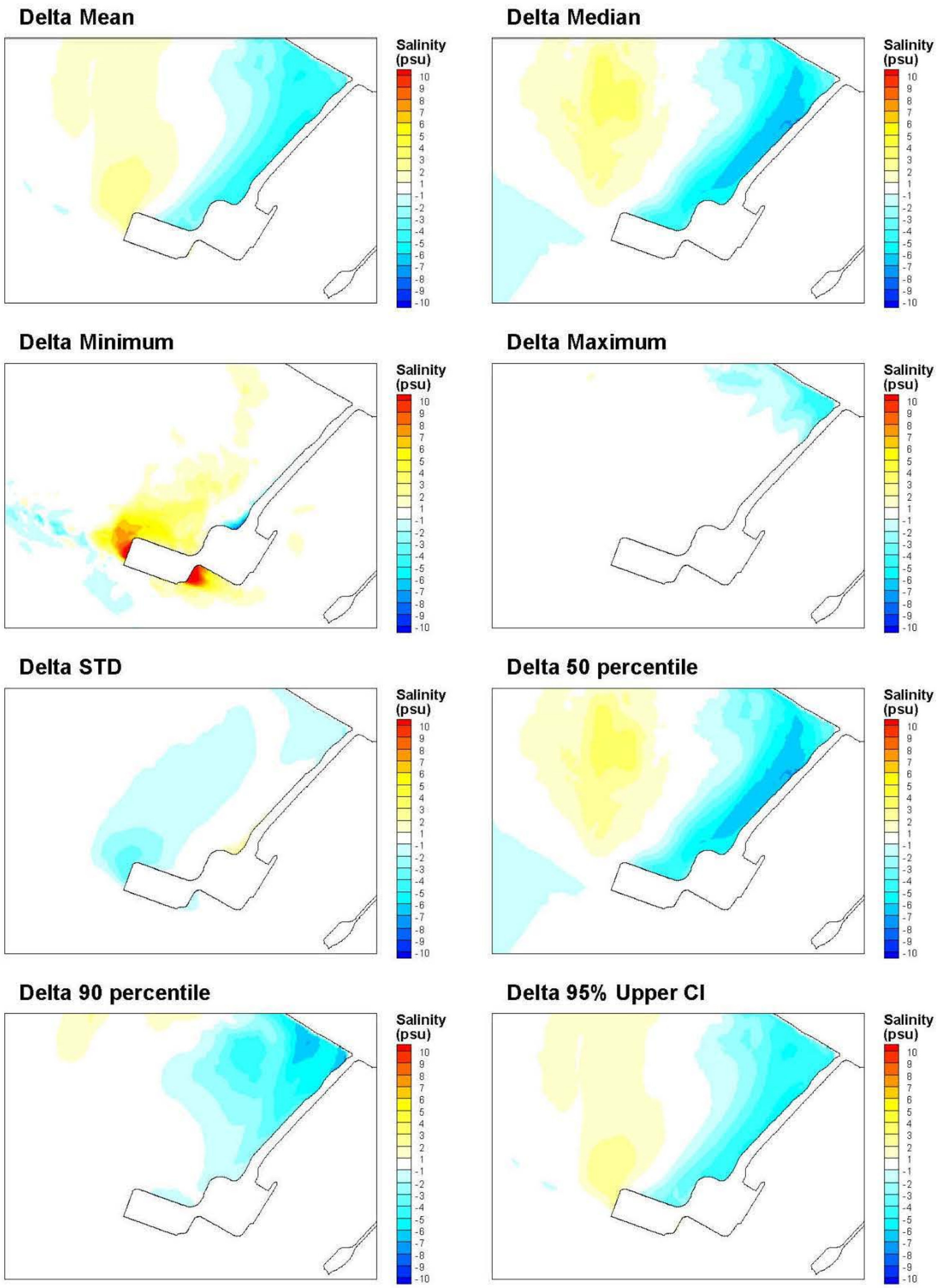


Figure IR2-02-10 Various Statistical Expressions of Salinity During the Non-freshet (Well Below Average Freshet Year) Period – Existing Conditions Minus Future Conditions with Project



IR2-03 Coastal Geomorphology – Hydrodynamics: Atmospheric Pressure

Information Source(s)

EIS Volume 2: Section 9.5; Appendix 9.5-A

Context

In the coupled hydrodynamic wave model validation of sea level height, the Root Mean Square (RMS) difference between modeled and observed water level was reported as 0.3 metres and 0.23 metres for Point Atkinson and Canoe Passage, respectively. The Proponent claimed that this difference is due to the fact that the model did not include the effect of atmospheric conditions at sea level. Fisheries and Oceans Canada reported that these values were higher than expected from a coastal circulation model. By including a correction to account for the effect of atmospheric pressure on sea level, the comparison between observed and modelled water level would provide additional validation of the coupled hydrodynamic wave model response to tidal forcing.

Information Request

Apply a correction to the measured water levels for Point Atkinson and Canoe Pass to account for the effect of atmospheric pressure on sea level (inverse barometer effect) and analyze the effects of this correction on the coupled hydrodynamic wave model output.

VFPA Response

The purpose of the coastal geomorphology assessment was, in part, to assess changes to coastal processes and conditions related to the Project. Applying the atmospheric correction in the hydrodynamic model would not measurably affect predicted Project-related changes, as outlined below. As background, the hydrodynamic model was 'forced'[1] using *predicted* water level elevations (not *observed* water level elevations) published by Fisheries and Oceans Canada (DFO). A small difference between predicted water levels and actual water level observations is expected due to climatic variability (wind and atmospheric pressure), storm surges, and the small inconsistencies inherent in the tidal predictions, the latter of which is explained further in Forrester (1983). The statement in Section 4.1 of EIS Appendix 9.5-A: Appendix B regarding the influence of atmospheric conditions on water levels incorrectly articulated the discrepancy between observed versus modelled water levels. Differences due to atmospheric pressure are typically very small except in the case of large climatic events,

[1] As articulated in the response to IR2-14, boundary forcing is the *a priori* selection of hydrodynamic conditions at the open boundaries of the TELEMAC-3D model, which subsequently drives future hydrodynamic conditions in the rest of the model domain over a specified period of time. The most important boundary forcing is tide height (i.e., from DFO predicted tidal conditions), followed by wind forcing and Fraser River discharge. Atmospheric forcing is a relatively minor process.

and hence an atmospheric correction can be omitted for longer-term model analyses, such as the modelling undertaken for the assessment of Project-related changes.

The approach taken for the coastal geomorphology assessment is appropriate to inform the comparison between predicted future conditions (without the Project) and predicted future conditions with the Project for the following reasons:

- Atmospheric forcing is not considered to be one of the dominant processes affecting the hydraulic and sedimentation process, as previously described in the response to question 1.10 in CEAR Document #547;
- Atmospheric forcing is a constant for future conditions with and without the Project. Atmospheric forcing will not be influenced by the Project, and therefore, its inclusion in the model will not affect the evaluation of Project-related changes; and
- Introducing an atmospheric correction in the model could introduce additional uncertainty because tides are affected by pressure changes outside the model boundaries as well as within them.

The results of model validation indicate good agreement between *observed* and modelled water levels at Point Atkinson and Canoe Passage stations (i.e., observed water level elevations are reproduced well by the model) during August 2012, as shown in Figures 5 and 6 in Appendix B of EIS Appendix 9.5-A, respectively. Model validation results for Point Atkinson and Canoe Passage for the periods of August 2012 as well as May 1 to December 31, 2012 are provided below to further illustrate that the model's capability with respect to representing existing tidal conditions, and conditions in the future with the Project.

Model Validation Results at Point Atkinson

Modelled hourly water level results at Point Atkinson (location is shown in Figure IR2-01-1 in IR2-01) were validated by comparing the following data:

- DFO *observed* hourly water levels from the Canadian Hydrographic Service Point Atkinson station during August 2012; and
- DFO *predicted* hourly water levels at Point Atkinson for the period of August 1 to December 31, 2012.

For August 2012, *observed* water levels generally align with modelled water levels, as shown in Figure 5 of EIS Appendix 9.5-A: Appendix B. The observed water level range was 4.0 m in August 2012, and the Root Mean Square (RMS) difference between modelled and observed water levels is 0.3 m.

A comparison of modelled water levels to DFO *predicted* water levels provides a better validation of model performance than to DFO *observed* water levels, because the hydrodynamic model was forced using DFO predicted tides at the open boundaries of the model domain (i.e., Port Renfrew and Ballenas Island)[2]. Comparisons of DFO predicted hourly

[2] Artificial boundaries were selected for the hydrodynamic model to limit the model domain. An open boundary refers to an artificial boundary which consists of open water, where inflow and outflow occurs. The prescription of open boundary conditions requires extensive information for physical parameters

water levels to modelled hourly water levels for Point Atkinson for the period of May 1 to December 31, 2012 are shown in Figure IR2-01-3 in IR2-01. The RMS difference between DFO predicted and modelled water levels is 0.10 m at Point Atkinson, a deviation of only 4% of the mean tidal range of 3.1 m. Considering the large observed water level ranges at this location (i.e., over 3 m), the RMS differences indicate good model performance.

Model Validation Results at Canoe Passage

To validate modelled hourly water levels at Canoe Passage (for location see Figure IR2-01-1 in IR2-01), observed hourly water levels were used in comparisons over two periods (August 2012 and May 1 to December 31, 2012), as water levels for this Fraser River station are a function of both the tides and the river discharge (i.e., water levels at this station are not influenced solely by tides).

The modelled and observed water levels during August 2012, as described in EIS Appendix 9.5-A: Appendix B, Section 4.1, are generally aligned as shown in Figure 6 in Appendix B. The observed water level range was 3.3 m over August 2012 and the RMS difference between modelled and observed hourly water levels is 0.23 m. Based on comparisons of modelled and observed water levels for the period of May 1 to December 31, 2012, the RMS difference is 0.25 m (see IR2-01 and Figure IR2-01-5 in that response for more information).

The RMS differences for these two periods are similar (i.e., 0.23 m for August 2012 and 0.25 m for May 1 to December 31, 2012) and indicate good model performance.

Validation of Modelled Water Levels – Summary

For model validation comparisons at Point Atkinson and Canoe Passage, the tidal range variability from spring to neap tidal cycles and the daily high and low waters level elevations are reproduced well by the model. Additional comparisons are provided in IR2-01 for DFO marine stations at Squamish and Victoria (i.e., RMS values for DFO predicted to model predicted water levels are 4% and 5% of the mean tidal range for stations located at Squamish and Victoria, respectively).

In summary, based on validations undertaken using both observed and predicted water levels, the hydrodynamic wave model reproduced water level elevations well, as shown in Figures 5 and 6 of EIS Appendix 9.5-A: Appendix B and IR2-01, Figures IR2-01-3 and IR2-01-5. Applying an atmospheric correction in the hydrodynamic model will not measurably affect predicted Project-related changes.

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such as water level elevations and salinity levels at specific points in time and space. Once boundary conditions were prescribed for the open boundaries at Port Renfrew in Juan de Fuca Strait and Ballenas Island, just south of Hornby Island in the Strait of Georgia (for locations, refer to Figure IR2-01-1 in IR2-01), the hydrodynamic model was used to simulate conditions in the LSA.

References

Forrester, W. D. 1983. Canadian Tidal Manual. Department of Fisheries and Oceans, Canadian Hydrographic Service, Ottawa, ON. 138 pp.

IR2-04 Coastal Geomorphology – Morphodynamics: Ridge and Runnel Complex

Information Source(s)

EIS Volume 2: Section 9.5, Appendix 9.5-A

Context

There is uncertainty about the evolution of the ridge and runnel complex at Roberts Bank. The Proponent stated in Appendix 9.5-A that a "…recent reference to this feature as being a relict marsh surface…is inconsistent with field observations of geomorphic processes and existing conceptual models of delta formation. A variety of observations, field measurements and analysis of sediment cores that are presented below indicates that the ridge and runnel complex is an accreting sedimentary feature that has shown significant vertical and horizontal expansion in recent decades. This model of mudflat building has very different implications for the overall health of the various ecosystems on the tidal flats as opposed to general loss of elevation on the upper tidal flats that would be implicit if it were in fact a relict marsh surface. It is therefore very important to determine which of these models more accurately represents the evolution."

The reference in question provided an alternate and contrary hypothesis for the erosion/deposition state of the ridge and runnel complex - a critical zone where biofilm is present.

An evaluation of this alternative hypothesis is necessary in order to assess the Proponent's interpretation of the evolution ridge and runnel complex at Roberts Bank.

Information Request

Provide additional information to support the statement that the ridge and runnel complex at Roberts Bank is an accreting sedimentary feature and not a relict marsh surface.

VFPA Response

The VFPA has referenced relevant sections of the EIS and provided additional information to the EIS to support the statement that the ridge and runnel complex at Roberts Bank is an accreting sedimentary feature. As described in Section 5.3.3 of EIS Appendix 9.5-A, a variety of observations, field measurements, and analysis of sediment cores indicate that the ridge and runnel complex or the 'mumblies' is an accreting sedimentary feature, rather than a relict marsh feature. This conclusion is supported by the following evidence (as reported in EIS Appendix 9.5-A: Sections 5.3.3 and 5.3.4):

- The presence of biomat, on the ridge surfaces of the mumblies, through its higher hydraulic roughness, traps fine sediments, and the extracellular polymeric substances it produces binds sediment particles, which leads to more rapid accretion as compared to other areas of the mudflat where biomat has not established. This is evidenced by higher surface elevations of the ridges where biomat is present relative to adjacent surface depressions on ridges, and runnels, which have no biomat;

- Six depth of disturbance rods located in the mumblies showed more accretion than areas outside of the mumblies. In addition, rods located on the tops of ridges showed a seasonal growth of the biomat, wherein the biomat grew up as much as a half-centimetre around the washer (see Figures 27 and 28 of Appendix C of EIS Appendix 9.5-A);
- Soil pits, collection of cores, and subsequent radiometric dating of sediments (using ^{137}Cs and ^{210}Pb) indicate that the mud comprising the ridges was deposited since the construction of the causeway and at a relatively constant rate. The rate of sedimentation in the mumblies north of the causeway is about 6.4 mm per year, again providing supporting evidence that the ridges of the mumblies are a net accretionary sedimentary feature; and
- The longitudinal elevation profile for the tidal flats north of the causeway (see Figure 46 in EIS Appendix 9.5-A) shows that the ridge and runnel complex is a raised form rising above the background tidal flat profile by up to 30 cm, with the bottoms of the runnels sitting on the background tidal flat profile.

In addition, although not referred to in EIS Appendix 9.5-A: Sections 5.3.3 and 5.3.4, information collected by Hemmera (2014)[1] supports the conclusion that the ridge and runnel complex is not a relict marsh feature. As part of this study, sediment cores were sampled in the mumblies and tested for fatty acids which are biomarkers or indicators of the origin of organic matter. The relative abundances of fatty acids within the sediment underneath the biomat were used to determine whether the biomat was an erosional (relict marsh) or an accreting feature. The results concluded that samples taken at deeper depths did not have fatty acid signatures consistent with plants of an intertidal marsh origin. Rather, the fatty acid composition was consistent with a cyanobacterial and algal origin in both the surface samples and down-core samples, suggesting a progressive upward growth of the biomat surface, which is consistent with the statement in the EIS that the ridge and runnel complex at Roberts Bank is an accreting sedimentary feature.

With the above information taken into account for the ridge and runnel complex to have previously been a marsh surface, the following conditions would need to exist:

1) The surface of the ridges would have had to be higher at some point in the past to support marsh plants. Presently the elevation of the tops of the runnels is a maximum of 3.5 m Chart Datum (CD), while the adjacent marshes north of the causeway reside in an elevation band just below 4.0 m and up to 4.8 m CD;

2) Marsh plants would have to have been present on higher surfaces, before eroding to the present day surface elevation before airphotos were taken of the site in the early 1950s. (No marsh plants are visible in any of the photos shown in Figures 35 to 37 in EIS Appendix 9.5-A); and

[1] CEAR Document #388 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements Follow-Up (See Reference Document # 345) including 22 Technical Data Reports

3) There would need to be a fatty acid signature consistent with the roots of marsh plants within the sediments.

These conditions are inconsistent with the field data and observations, which show that the sediment comprising the mumblies was deposited subsequent to causeway construction (i.e., within the period of time captured by the available airphoto record) and does not contain a fatty acid signature that is consistent with colonisation by marsh plants. Therefore, all the evidence that has been collected and presented in the EIS is consistent with the hypothesis that the ridge and runnel zone is an accreting feature that has not previously supported marsh plants.

The alternate and contrary hypothesis referred to in the context of this information request is cited in the following referenced document: Vancouver Airport Fuel Delivery Project EA Certificate Application document *Supplement 5: Fraser River Delta Biofilm: Sensitivity to Jet A Fuel Spills - Summary Report* (VAFFC 2012). In section 1.2 of the report the following is stated:

> *Older marsh surfaces—the biomat units (also referred to as "mumblies")—are relic marsh surfaces elevated above the existing flats and suggest that recent deposits in this portion of Roberts Bank are thin*.

In addition, section 4.1 of the report states the following:

> *Rusty brown "diatom" mats associated with relict relief on the flats ("mumblies" area of the flat) are not consumed by Western Sandpiper (Elner 2012, pers. comm.).*

There is no reference provided in the report for the first statement, and it is unclear whether the personal communication attributed to the second statement concerns the feeding by western sandpiper or the idea that diatom mats are associated with relict relief. Irrespective of this, based on the review of this document, no accompanying evidence was provided to support the interpretation that the ridge and runnel complex (the "mumblies") are a relict marsh feature. In contrast, based on the field study program described in EIS Appendix 9.5-A and Hemmera (2014)[1] the information summarised above, there is strong evidence to support the view that the ridge and runnel complex is an accreting sedimentary feature.

References

Vancouver Airport Fuel Facilities Corporation (VAFFC). 2012. Fraser River Delta Biofilm: Sensitivity to Jet A Fuel Spills - Summary Report. Report submitted by Vancouver Airport Fuel Delivery Project in support of Environmental Assessment Certificate Application, Vancouver, B.C. 21.

Hemmera. 2014. Roberts Bank Terminal 2 Technical Data Report. Marine Vegetation: Intertidal Marsh, Foreshore Habitat and Invertebrate, Eelgrass, Ulva and Biomat Survey results (submitted to Panel Registry February 19, 2016 in response to Additional Information Request #10 (AIR-12.04.15-10), Appendix AIR10-C, TDR MVB-1, CEAR Document #388).

<u>IR2-05 Coastal Geomorphology – Morphodynamics: Maximum Bed Disturbance</u>

Information Source(s)

EIS Volume 2: Section 9.5; Appendix 9.5-A

CEAR Doc. #547, Appendix 1.6

Context

As identified by Natural Resources Canada, the net bed level change presented in the supplementary sediment transport model in Appendix 1.6 of CEAR Doc #547 did not necessarily reflect the maximum depth of bed disturbance during the sediment transport events. 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 Conditions and Future Conditions with the Project.

The estimation of the bed disturbance during and after a 100 year storm event is relevant to understanding the potential effects of the proposed Project on marine habitat.

Information Request

Provide maps of maximum bed disturbance (erosion) from Canoe Pass to the United States (US) border for sediment transport modeling simulations, including during and after a 100 year storm event, under both Existing Conditions and Future Conditions with the Project.

VFPA Response

The requested maps of maximum bed disturbance based on the sediment transport modelling simulations would not reflect realistic conditions. This is because the intermediate bed level conditions calculated from the sediment transport model, which was run on a one-minute time step, were archived at 12-hour intervals. The maximum bed disturbance is highly unlikely to be represented in this archived dataset since bed level changes that would occur in response to waves, including the 100-year modelled storm, would occur over much shorter time periods. Intermediate bed level changes were not archived more frequently because of a) the limitations on file size storage and processing, and b) the study was focused on the net bed level changes over time, as outlined below.

To respond to the Panel's request, the VFPA has provided an explanation of the approach of the study, how modelling was used to determine the effects of storm events on bed disturbance in the future with and without the Project, and how this substantive piece of work addresses the concerns of Natural Resources Canada referenced by the Panel in the "context" section in ways the requested maps would not.

A description of existing coastal conditions, the extent of changes on the tidal flats expected to occur in the future with ongoing coastal processes, and the potential changes under the future conditions with the Project are provided in EIS Sections 9.5.6.3, 9.5.7.2, and 9.5.8.2, respectively. Supplemental analyses on morphological changes in combination with an extreme storm event have also been completed (provided in appendix 1.6 of CEAR Document #547), as stated in the context from the Panel. The Project is not expected to intensify storm-event conditions.

The purpose of the coastal geomorphology study was, in part, to quantify the morphological changes (i.e., changes in bed levels on the tidal flats) within the local study area (LSA, as shown in EIS Figure 9.5-1) that may be caused by the Project and compare those changes to the ongoing evolution of the environment that is likely to occur in the absence of the Project (expected conditions). The rationale for the boundary of the LSA used to determine the potential changes due to the Project on coastal geomorphology is described in EIS Section 9.5.5.2. This area represents "the maximum extent of the likely zone of influence of the Project based on alterations in physical processes that are key determinants of geomorphology. The LSA also incorporates the existing natural boundaries (e.g., shoreline, Canoe Passage channel, intertidal, subtidal zones) and human-made boundaries (i.e., causeways and terminal) influencing the transfer of sediment and freshwater across Roberts Bank by various processes, including waves, river currents, and ocean currents." The identified changes were then considered by the various disciplines assessing Project-related effects on the existing biophysical and human environments.

A discussion of the approach taken to assess bed level changes and the subsequent assessment of potential effects on marine habitat is provided below.

Assessment of Morphological Changes on the Tidal Flats

Existing maximum bed level changes were evaluated within the LSA as part of a field data collection program using depth of disturbance (DoD) rods, and modelling was used to quantify the magnitude and extent of future changes on the tidal flats from ongoing processes and the Project. DoD rods were deployed in three separate regions of the tidal flats on the north side of the causeway (as shown in Figure 27 in Appendix C of EIS Appendix 9.5-A). Measured changes were on the order of -5 cm to +4 cm for the lower tidal flats, -2 cm to +3 cm for the middle tidal flats, and -1 cm to +2 cm for the upper tidal flats (EIS Section 9.5.6.3). The DoD rod deployment between June 2012 and May 2013 spans a time period that experienced at least five large storms and these storms were incorporated into the sediment transport modelling. **Table IR2-05-1** summarises the characteristics of these storm events. For comparison, a synthetic 100-year storm was considered in CEAR Document #547, appendix 1.6, with a wind speed of 23.8 m/s (86 km/hour) sustained for 24 hours, which is a conservative assumption. A description of the existing morphology, the extent of changes on the tidal flats expected to occur in the future, and the potential changes under the future conditions with the Project are provided in EIS Sections 9.5.6.3, 9.5.7.2, and 9.5.8.2, respectively.

Table IR2-05-1 Summary of Large Wind Events in 2012 Measured at the Sand Heads Station

Date	Wind Direction	Wind Speed in m/s (km/h)	Return Period
October 2, 2012	NW	17.5 (63)	1:2
October 19, 2012	SE	12.8 (46)	<1:1
November 20, 2012	SE	13.9 (50)	<1:1
December 7, 2012	NW	13.3 (48)	<1:1
December 15, 2012	SE	15.6 (56)	<1:1

For the purposes of modelling future changes in sediment transport, the LSA was represented by a computational mesh divided into cells. Net sediment transport—that is, the difference between sediment entering and leaving each cell—governs whether the seabed elevation will increase, decrease, or remain stable[1]. The net, or 'resultant' bed elevation has been presented in Figures 9.5-26 and 9.5-32 of the EIS to show the evolution of the bed under expected conditions and future conditions with the Project, respectively, after 1,440 model days. EIS Figure 9.5-33, which shows the difference between the two cases, indicates that the changes to the bed elevation of Roberts Bank that are related to the Project generally fall within a zone of influence that is approximately 100 hectares (ha), and that these changes are generally relatively small in the medium- to long-term (summarised in EIS Table 9.5-6). As an example, scour immediately adjacent to the terminal is expected to be up to 1.6 m below the existing bed level in an area approximately 5.8 ha. Over the wider area of the tidal flats, bed level changes generally fall within the range of ±0.6 m, which are of a similar magnitude to those predicted to occur under expected conditions (as shown in EIS Figure 9.5-26). It is probable that some areas within the model were higher or lower at some earlier time increment, but the resultant change at the end of the simulation was deemed most applicable to representing changes to coastal geomorphology resulting from the Project. For the upper to lower tidal flats where the DoD rods were deployed (Figure 27 in Appendix C of EIS Appendix 9.5-A), the model predicts net bed level changes in the same order of magnitude (i.e., less than ±5 cm) as the existing maximum level of disturbance measured by the DoD rods from June 2012 and May 2013.

Supplemental analyses on the morphological changes (described above) in combination with an extreme storm event have also been completed. During the completeness phase of the environmental review of the Project, Fisheries and Oceans Canada (DFO), Natural Resources Canada (NRC), and Environment and Climate Change Canada, submitted a series of preliminary technical questions to the VFPA. In response, the VFPA submitted responses that included the results of supplemental sediment transport modelling analysis (CEAR Document #547, appendix 1.6). The objectives of the supplemental analyses were to 1) assess changes from an extreme storm event (i.e., 100-year northwesterly storm with winds of 86 km/h) on sediment transport and bed level changes in the intertidal region of Roberts Bank, and 2)

[1] Net sediment transport is not governed by the sediment transport rate, which is the total amount of sediment passing through a model grid cell.

evaluate the sensitivity of the model to finer sediment grain size as well as alternative sediment transport equations. The results of this work confirmed that predicted changes attributed to a 100-year storm event were similar in the future with and without the Project (see figure 15 in CEAR Document #547, appendix 1.6). The Canadian Science Advisory Secretariat reviewed the supplemental storm event analysis report (CEAR Document #893) and concluded that "The supplementary report strengthens the modelling study of EIS Appendix 9.5-A and addresses concerns raised by DFO/NRCan [NRC] 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…". The conclusions of the assessment of coastal geomorphology are illustrated in EIS Figure 9.5-35 and summarised in EIS Table 9.5-26.

Additional analyses presented in IR2-06 further supports the conclusions of the EIS and CEAR Document #547, appendix 1.6—the influence of waves for both sediment transport and morphodynamic evolution are not as important as the influence of tidal currents (i.e., tidal currents, not storm-induced waves, are the dominant process driving bed level changes at Roberts Bank).

Based on the conclusions of the analyses and the coastal geomorphology objective to determine Project-related morphological changes, the VFPA considers the assessment to be complete.

Relevance of Bed Level Changes on Marine Habitat

As stated above, the Project is not expected to intensify storm-event conditions. Marine habitat will continue to support aquatic species in the future with the Project through the range of storm conditions currently experienced at Robert Bank, as storm conditions are not expected to change in the future as a result of climate change (as described in IR2-11).

A description of how marine habitat at Roberts Bank has been influenced by physical changes from past and present projects and activities, including changes to coastal geomorphic processes, was provided in Additional Information Request #13 (AIR-12.04.15-13), Appendix AIR13-A (CEAR Document #388[2]). Schedules 13-1, 13-2, 13-3, and 13-5 of CEAR Document #388 describe the collective effects of past and present projects and activities in the Fraser River estuary, including changes to coastal geomorphic processes and biophysical habitats, on marine vegetation, marine invertebrates, marine fish, and coastal birds, respectively, and effects of Project-related changes on coastal geomorphic processes and biophysical habitats. Therefore, existing conditions have been characterised and Project-related changes have been assessed for aquatic species that depend on marine habitat at Roberts Bank.

[2] CEAR Document #388 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements Follow-Up (See Reference Document # 345) including 22 Technical Data Reports

IR2-06 Coastal Geomorphology – Morphodynamics: Wave Effects

Information Source(s)

EIS Volume 2: Section 9.5; Appendix 9.5-A

CEAR Doc. #547, Appendix 1.6, Figures 8, 9, 12 and 13

Context

In the supplementary sediment transport model the Proponent evaluated the following:

1. The effect of an extreme storm on:
   a. sediment transport; and
   b. bed level changes (morphodynamics) in the intertidal region of Roberts Bank.

   This model run included changes from a non-linear extreme storm event on sediment transport;

2. The effect of varying the median sediment grain size to evaluate the sensitivity of the model results to finer sediment sizes; and
3. The effect of specifying various alternative sediment transport equations to evaluate the sensitivity of the model results to the specific equation.

According to Fisheries and Oceans Canada and Natural Resources Canada, there is a threshold condition for grain sediment mobilization and transport, and the relationship between wave height and sediment transport for a particular grain size in non-linear, extreme waves is usually a key factor in causing coastal structure damage and scour.

In Appendix 1.6 of CEAR Doc #547, both federal departments reported that the results of the Proponent's extreme 100-year storm simulations 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 was shown that modelled sediment transport rate is one to two orders of magnitude lower (Figures 8 and 9) and the modelled morphodynamic evolution (Figures 12 and 13) is greatly reduced.

Due to the importance of waves as agents in stirring and uplifting sediment, especially during storms, it is necessary to couple the wave model with the morphodynamic model to evaluate the effect of waves on local sediment dynamics.

Information Request

Re-run the morphodynamic model fully coupled with the wave model, and provide an analysis of the influence of including wave effects on local sediment dynamics.

VFPA Clarification

The morphodynamic model was re-run with both waves and tidal currents and the results are presented below. The VFPA first provides a summary of the modelling approach taken to assess the potential changes in sediment transport as a result of waves and tidal currents and the rationale for focusing on tidal currents. The model results for the analysis that incorporated tidal currents are consistent with the interpretive geomorphic analysis that suggests that tidal flats in the local study area (LSA) are in a state of dynamic equilibrium (i.e., little historical change in bed levels) with sediment dynamics driven largely by tidal currents, not waves (see Section 7.1 of EIS Appendix 9.5-A). Based on the model results for the analysis that incorporated both waves and tidal currents that are presented below, the findings support the results presented in Section 7.1, that tidal currents are the dominant process driving sediment dynamics at Roberts Bank.

Morphodynamic Modelling Approach

A detailed description of the methods and results of the morphodynamic study (a component study of the broader coastal geomorphology study), which considered changes to sediment transport and sedimentation patterns on the tidal flats under expected conditions and future conditions with the Project, is provided in Section 7.1 of EIS Appendix 9.5-A. In line with the overall approach to the assessment of coastal geomorphology, the morphodynamic study followed a "three-pronged" approach for predicting change associated with the Project on sediment transport and sedimentation patterns in the LSA and included 1) numerical modelling, 2) analytical computational methods, and 3) interpretive geomorphological analyses (described further in EIS Section 9.5.5.3 and Section 1.3 of EIS Appendix 9.5-A). The three-pronged approach was used to account for the inherent uncertainty that is acknowledged in the EIS when applying models to predict future changes. This approach was presented to the Coastal Geomorphology Technical Advisory Group (TAG). Section 3.1.2 of the TAG summary report (Appendix IR2-A of the Preamble at the beginning of this response package) summarises the feedback on the approach:

> *In general, the TAG agreed with NHC's proposed three-pronged approach for assessing possible effects of RBT2 on coastal geomorphology.*

Appendix IR2-A of the Preamble at the beginning of this response package provides more information on the TAG process and discussions.

In this case, numerical models were used to predict the effects of tidal currents and waves on the bed morphology in the LSA under expected conditions and under future conditions with the Project, acknowledging that Roberts Bank will continue to evolve regardless of the Project. These results were then compared to existing processes using interpretive geomorphological methods such as historic bed level analyses and known sedimentation rates. Therefore, all model outputs are scrutinised against an existing understanding of the system, which was also the case for the supplementary sediment transport modelling study, described further in the next section.

In addition, and of relevance to this information request are two working conjectures of the TAG (refer to Appendix IR2-A of the Preamble at the beginning of this response package). 'Conjecture 2' established that the amount of sediment that is transported to and from the tidal flats is low in comparison to the volume of sand stored in the flats, indicating that there has been little change in sediment volumes in the study area. The evidence presented to the TAG and in EIS Section 9.5.6.3 on bed level changes from 2002 to 2011 and sedimentation rates is summarised in the next section. In response to this, the TAG acknowledged the following:

> *…this evidence lends credence to the notion that the tidal flats are in an approximate state of equilibrium over annual to inter-annual time scales.* (see Section 3.1.2 in Appendix IR2-A)

Although not directly discussed by the TAG, but discussed in question 1.6 and Appendix 1.6 of CEAR Document #547, this ten year period, which generally saw bed level changes of 25 cm or less over much of the tidal flats, encompassed a number of large storm events (see **Table IR2-06-1**), indicating that the tidal flats are a resilient geomorphic feature, a finding corroborated by the findings in the EIS. Comparisons with bed level data from the late 1960s confirm the view that the tidal flats have remained relatively stable for the past 40 years (see IR2-09 for more information).

'Conjecture 4' established that the primary morphologic changes induced by RBT2 will mainly be local erosion and deposition. This working assumption was confirmed by analyses presented in EIS Section 9.5.10 that the principal changes to the wave and tidal current environment related to the Project would result in localised erosion-deposition patterns around the proposed terminal footprint.

Table IR2-06-1 Large Storm Events recorded at Sand Heads 2002 - 2011

Date	Wind Direction	Wind Speed in m/s (km/h)	Return Period*
April 27, 2004	NW	18.1 (65)	1 in 3
March 8, 2010	NW	17.5 (63)	1 in 2
March 28, 2009	NW	16.4 (59)	1 in 1
January 10, 2010	NW	16.4 (59)	1 in 1
November 12, 2007	SE	21.7 (78)	1 in 6
November 18, 2009	SE	21.7 (78)	1 in 6
January 18, 2010	SE	21.7 (78)	1 in 6
April 2, 2010	SE	21.7 (78)	1 in 6
November 15, 2006	SE	20.6 (74)	1 in 2
December 11, 2006	SE	20.6 (74)	1 in 2

*Note: Return periods and wind speeds for northwest and southeast storms differ because they represent two independent populations of events.

Background to the Supplementary Sediment Transport Study

As described in EIS Appendix 9.5-A: Section 7.1, waves and tidal currents were modelled together for the three-month winter period (October to December) and then compared to a model run that included only tidal currents. The results for expected conditions showed that although the intensity of change was slightly greater, the patterns of sediment deposition and erosion were the same when tidal currents and waves were modelled and when only tidal currents were modelled (EIS Appendix 9.5-A: Figures 99 and 100, respectively). Similarly, in the future with the Project, a similar pattern was shown regardless of the inclusion of waves in the model, confirming that the Project is not expected to induce greater changes to bed elevations when waves are present (EIS Appendix 9.5-A: Figures 101 and 102). Based on these findings, tidal currents were identified as the dominant process that determines sediment erosion and deposition patterns in the LSA. As a result, waves were excluded from the long-term (1,440 model days) morphodynamic runs to achieve considerable computational efficiencies.

In line with the three-pronged approach, the morphodynamic model outputs were placed into context using interpretive geomorphology, comparing model outputs with historic bed level changes as described in the previous section. Question 1.6 in CEAR Document #547 provides a comparison between the longer-term (1,440 model days) morphodynamic runs for existing conditions with actual topographic changes calculated from LiDAR and bathymetric surveys collected in 2002 and 2011. The long-term morphodynamic simulations of existing conditions compare well with actual bed level changes that occurred during this period, providing further assurance that the morphodynamic model is incorporating the dominant sediment transport processes.

Depth of Disturbance (DoD) rods, which measure erosion-deposition rates, were placed in various locations across the tidal flats over an 18-month period between June 2012 and May 2013, also showed only very small changes to bed levels (see IR2-05 for more information). At least five storms occurred during the DoD rod deployment period, the largest of which was a 63 km/h northwesterly 1 in 2 year event (see Table IR2-05-1), yet the measured changes to bed levels were very small. These observations support the view that the tidal flats are a resilient geomorphic feature that is in dynamic equilibrium with the long-term storm driven wave environment, which appears to play a relatively minor role in changing the bed morphology at Roberts Bank.

Also of relevance, and discussed by the TAG, is that the construction of the original Roberts Bank causeway has not triggered large changes in the tidal flat morphology on either side of the causeway. In respect to Project-related effects, this same pattern was confirmed through storm simulations as reported in appendix 1.6 of CEAR Document #547, which showed very little difference in morphodynamic response related to the Project.

VFPA Response

The morphodynamic model was run fully coupled with the wave model to incorporate the effects of both currents and waves in the sediment transport calculations. As with the previous model run that was reported in EIS Section 9.5 that incorporated currents, the three-month winter period was repeated for 1,440 model days. The three-month winter period included the storms listed in table 2 of CEAR Document #547.

The morphodynamic model results from 1,440 simulated days that incorporated waves and tidal currents are presented in **Figures IR2-06-3** and **IR2-06-4**. For context, EIS Figures 9.5-26 and 9.5-32 have also been reproduced to aid comparison with the new results. For clarity, **Table IR2-06-2** lists the figures included in this response.

Table IR2-06-2 Summary of Figures Presented in IR2-06

Figure Number	Figure Title	EIS Figure reference
Figure IR2-06-1	Expected conditions – Morphodynamic evolution of the tidal flats – Tidal currents only	EIS Figure 9.5-26
Figure IR2-06-2	Future conditions with the Project – Morphodynamic evolution of the tidal flats – Tidal currents only	EIS Figure 9.5-32
Figure IR2-06-3	Expected conditions – Morphodynamic evolution of the tidal flats – Tidal currents and waves	Figures not previously presented in EIS
Figure IR2-06-4	Future conditions with the Project – Morphodynamic evolution of the tidal flats – Tidal currents and waves	

The influence of waves on sediment dynamics in the long-term model simulations are as follows:

a) A comparison of **Figure IR2-06-1** (Expected conditions – tidal currents only) to **Figure IR2-06-3** (Expected conditions – tidal currents and waves) shows that the patterns of erosion-deposition are aligned, confirming that sediment dynamics are dominated by tidal currents and that the influence of waves is to smooth out the relative changes.
b) A comparison of **Figure IR2-06-2** (Future conditions with the Project – tidal currents only) to **Figure IR2-06-4** (Future conditions with the Project – tidal currents and waves) shows that the influence of waves on modelled bed elevations for future conditions with the Project is similar to the bed elevations predicted for expected conditions. Minor differences are observed on the foreslope where waves reduced the magnitude of erosion along the -10 m to -30 m Chart Datum (CD) contour and the zone of deposition along the -30 m to -40 m CD contour. The sediment dynamics along the foreslope are discussed in more detail in IR2-08.

The results of modelling that incorporate both waves and tidal currents confirm key conclusions provided in Section 7.1 of EIS Appendix 9.5-A that a similar pattern in erosion and deposition occurs with the 1) tidal currents only scenario and 2) tidal currents with waves scenario for both expected conditions and future conditions with the Project, confirming that the Project does not induce greater changes to the bed when waves are present.

Figure IR2-06-1 Morphodynamic Evolution from Tidal Currents After 1,440 Simulated Days – Expected Conditions Scenario (Originally presented as EIS Figure 9.5-26 and Figure 106 in EIS Appendix 9.5-A)

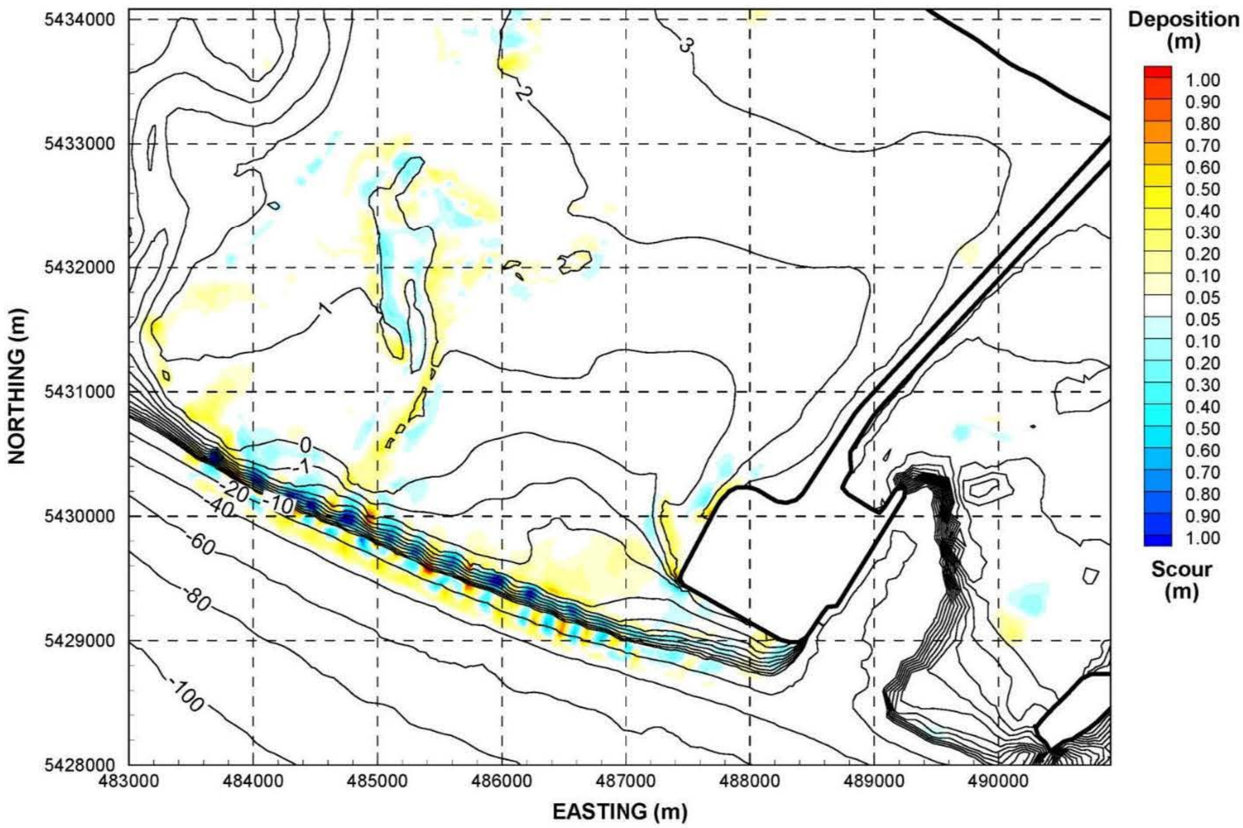


Figure IR2-06-2 Morphodynamic Evolution from Tidal Currents After 1,440 Simulated Days – Future Conditions (Originally presented as EIS Figure 9.5-32 and Figure 103 in EIS Appendix 9.5-A)

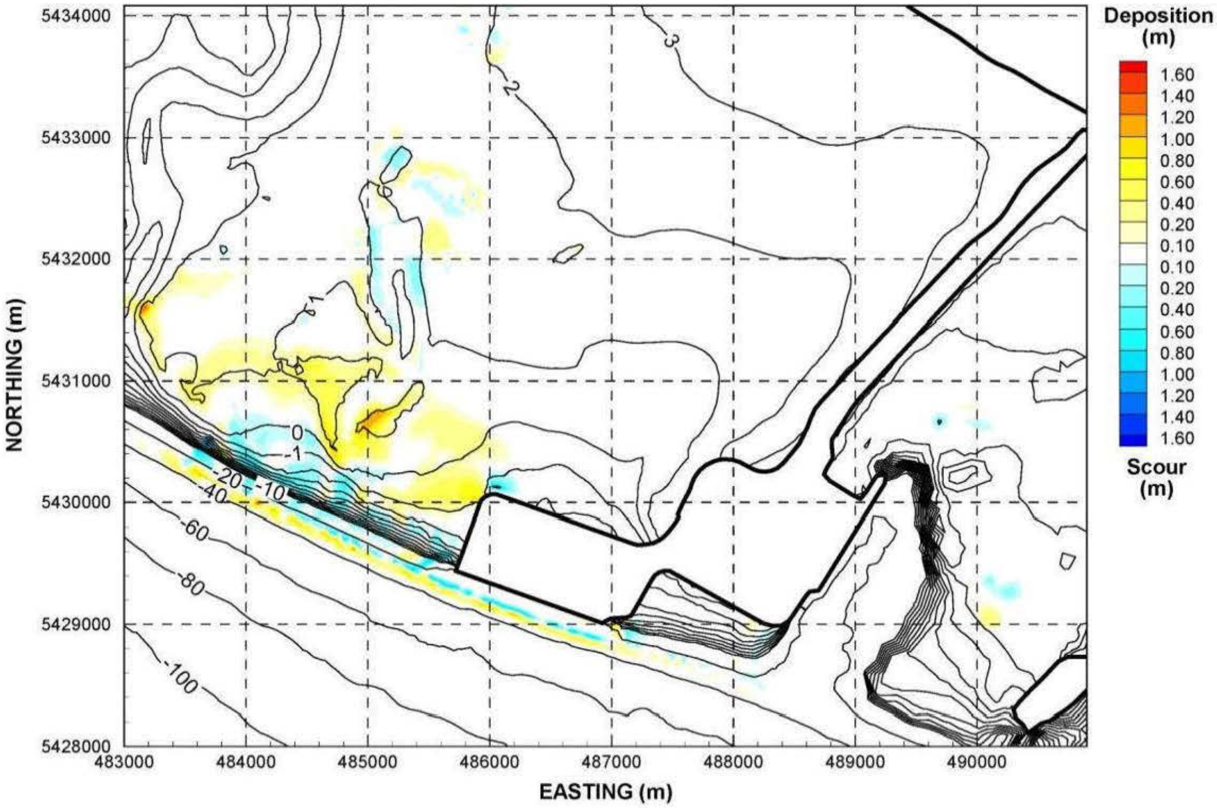


Figure IR2-06-3 Morphodynamic Evolution from Tidal Currents and Waves After 1,440 Simulated Days – Expected Conditions (Not previously presented)

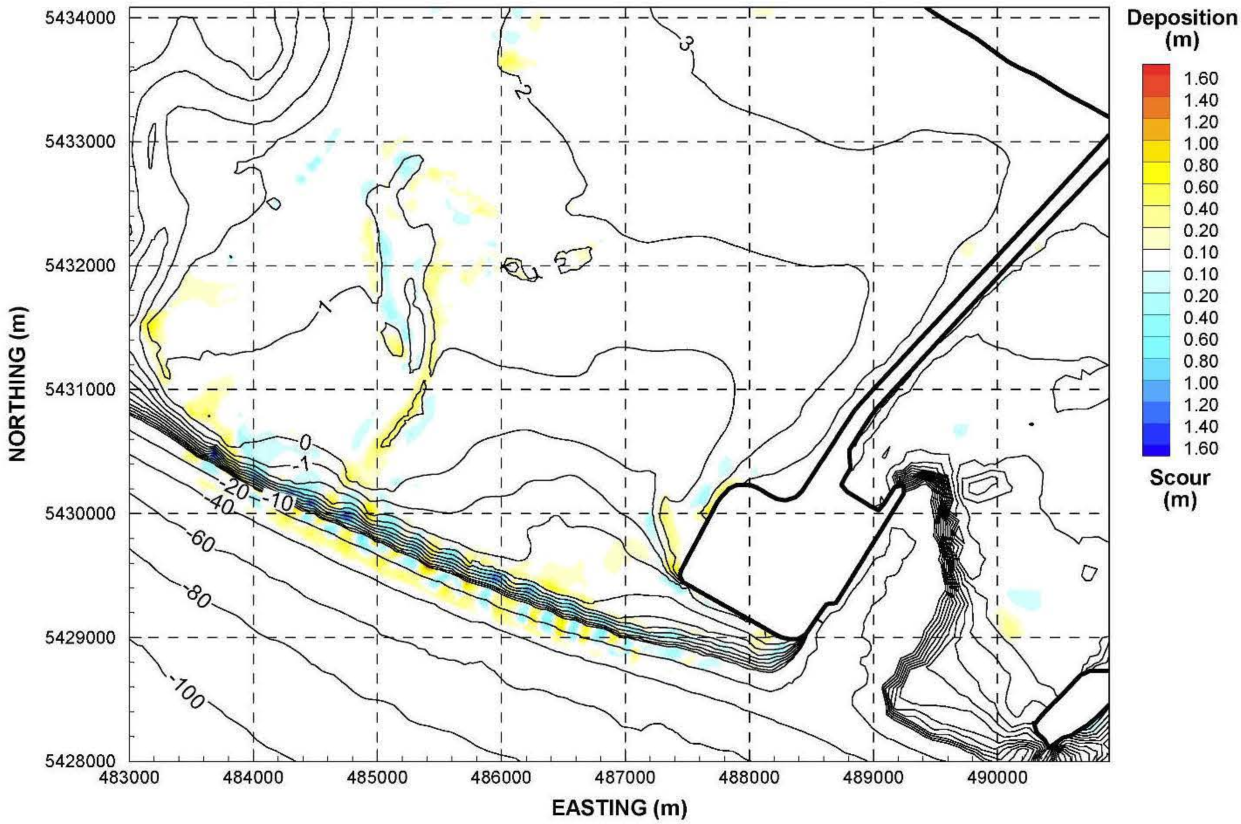
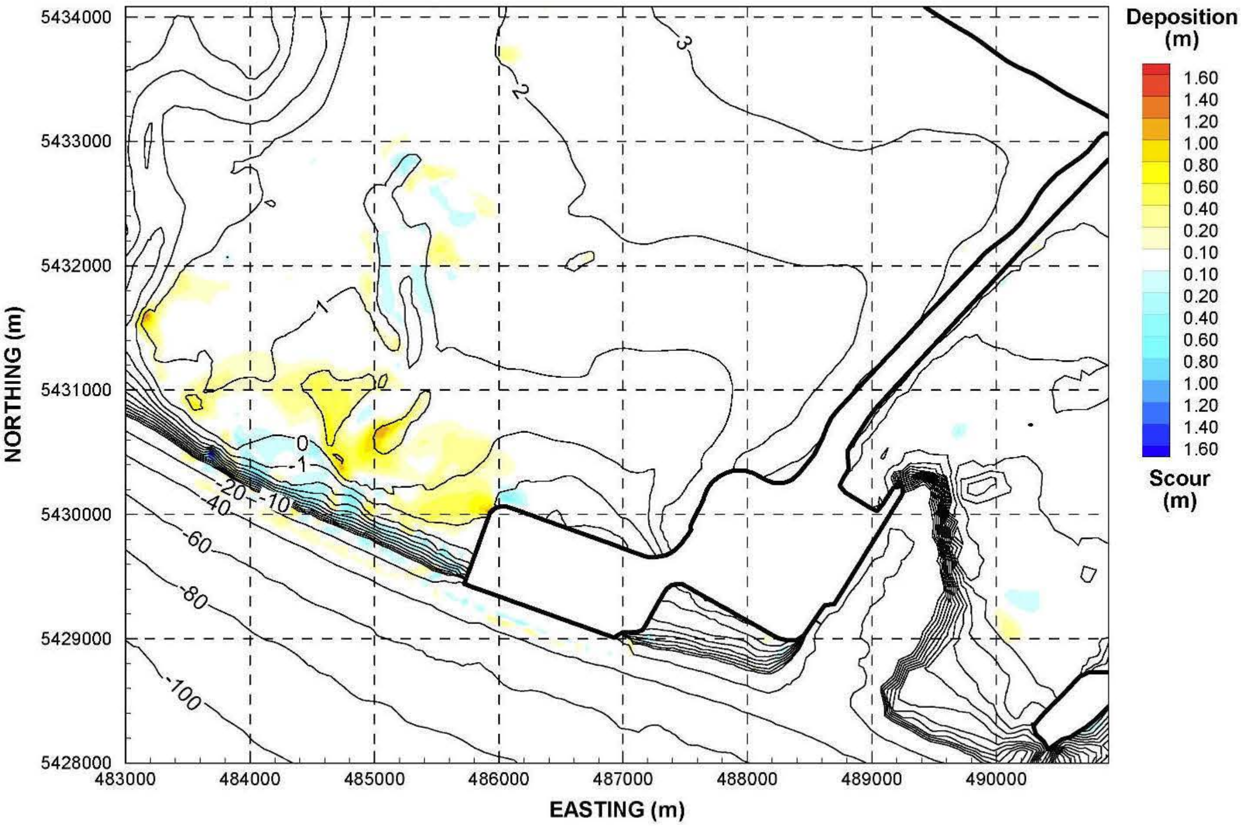


Figure IR2-06-4 Morphodynamic Evolution from Tidal Currents and Waves After 1,440 Simulated Days – Future Conditions (Not previously presented)



IR2-07 Coastal Geomorphology – Morphodynamics: Potential for Enhanced Current Velocities and Erosion

Information Source(s)

EIS Volume 2: Section 9.5; Appendix 9.5-A, Figures 5, 55, 56, 107 and 108

Context

In Appendix 9.5-A, the Proponent stated that water flow might be enhanced in the relict tidal channel further to the west of the proposed Roberts Bank terminal footprint, but there is no reference to the zone of enhanced flow in the broad embayment nearer to the northwest corner of the proposed terminal (Figure 5 of Appendix 9.5-A). Air photos of the tidal flats (e.g., Figure 108 of Appendix 9.5-A) show an incipient channel system linking the ridge and runnel area to this broad embayment of the contours that will be partially blocked by the proposed terminal.

A reduction of the width across which water could drain from this system would lead to higher current speeds, the establishment of new and potentially more focused drainage pathways, and the potential for erosion of a more pronounced tidal creek network. Figure 56 in Appendix 9.5-A showed enhanced flow in the embayment, during an ebb tide on May 7, 2012 under Future Conditions with Project. This enhanced flow seems incompatible with the morphodynamic evolution results presented in Figure 107 of Appendix 9.5-A, where net deposition was simulated in the area of predicted enhanced velocities.

According to Natural Resources Canada, it is important to verify if enhanced flows occur across all tidal conditions to better assess the potential for formation of erosional dendritic channels.

Information Request

Provide confirmation that the simulations in Figures 55 and 56 of Appendix 9-5A correspond to the maximum tidal current velocities during ebb and flood tidal conditions on May 7, 2012.

Conduct hydrodynamic-wave model simulations for maximum tidal current velocity during flood tidal conditions on May 7, 2012 in the area between the proposed Project and Canoe Pass under Future conditions with Project. Compare these results with the hydrodynamic-wave model simulations for maximum tidal current velocity during ebb tidal conditions that were obtained with May 7, 2012 data.

Assess the potential for enhanced current velocities and erosion during maximum ebb and flood tidal flow conditions in the area northwest of the causeway and evaluate the potential for formation of a modified tidal channel network between the proposed widened Causeway and Canoe Pass.

Reconcile the results with the morphodynamic evolution simulations (Figure 107 of Appendix 9.5-A) that show little or no change in net deposition of sediment.

VFPA Response

Provide confirmation that the simulations in Figures 55 and 56 of Appendix 9-5A correspond to the maximum tidal current velocities during ebb and flood tidal conditions on May 7, 2012.

To clarify, Figures 55 and 56 of EIS Appendix 9.5-A show current velocities and current patterns during ebb tide conditions only (not flood tide conditions) on May 7, 2012 at a lower-tide stage for existing conditions and future conditions with the Project, respectively. For flood tide conditions, Figures 53 and 54 of EIS Appendix 9.5-A show the spatial distribution of ocean currents on May 7, 2012 at an above mean tide stage for existing conditions and future conditions with the Project, respectively. The purpose of these figures is to show Project-related changes for current velocities and patterns during ebb and flood tide conditions. May 7, 2012, a day on which a typical large tidal swing occurred (approximately 4.5 m, as shown in Figure 52 of EIS Appendix 9.5-A), was selected for illustrative purposes (i.e., a snapshot in time) to explain the general interactions of tidal current velocities and patterns related to the Project. These four figures do not represent the maximum tidal current velocities during ebb and flood conditions, noting that during the ebb tide condition displayed on Figures 55 and 56 most of the tidal flat area is not covered with water (as shown by the white zone in the mid to upper intertidal region). Statistics on the temporal variations of velocities during the model simulation period were compiled at selected locations. Information on the magnitude and frequency of maximum velocities are summarised below.

A map showing the aggregation of maximum tidal current velocities in the local study area (LSA) would be unrepresentative of tidal flat conditions, as it would represent a condition that never exists in the LSA during ebb or flood conditions at a single point in time (i.e., the maximum velocity would occur at different times for each location within the area).

Conduct hydrodynamic-wave model simulations for maximum tidal current velocity during flood tidal conditions on May 7, 2012 in the area between the proposed Project and Canoe Pass under Future conditions with Project. Compare these results with the hydrodynamic-wave model simulations for maximum tidal current velocity during ebb tidal conditions that were obtained with May 7, 2012 data.

Hydrodynamic-wave model simulations were conducted using tidal conditions in 2012 to assess future conditions with the Project within the LSA, as previously described in EIS Section 9.5.8.2 and EIS Appendix 9.5-A: Section 6.2.1. As explained in the response above, May 7, 2012 was selected to illustrate conditions at a point in time in 2012 during a typical large tidal exchange to show differences in tidal current velocities and patterns related to the Project. Information from the spatial and temporal analyses of tidal currents during ebb and flood conditions (presented in EIS Appendix 9.5-A: Sections 6.2.1 and 6.2.2, respectively) is summarised below to respond to this question.

Spatial Distribution of Tidal Currents Under Existing Conditions and Future Conditions with the Project

The general pattern of ocean circulation near the Project is similar to that in the deep waters of the Strait of Georgia: tidal currents flood to the northwest and ebb to the southeast. This dominant flow pattern, which is parallel to the delta foreslope, is altered by interaction with the shallower areas of the tidal flats such that flow direction is dominantly onshore and offshore in relation to the rising and falling tide, respectively. Under existing conditions, there is a moderate local acceleration of flow at the southwest corner of the existing Westshore Terminals as the rising tide sweeps onshore and around the structure (Figure 53 of EIS Appendix 9.5-A).

The Project is predicted to extend the existing structural control of Westshore Terminals on ocean currents, diverting both flooding and ebbing water to the west around the end of the Project terminal. Based on a typical large tidal exchange during a flooding tide[1], the Project is expected to interrupt the existing shoreward movement of water on a flooding tide, causing the flow to be deflected further to the northwest and accelerated around the western end of the terminal (Figure 54 of EIS Appendix 9.5-A). This zone of local flow acceleration will occur mainly between the -2.0 m and +0.5 m Chart Datum (CD) contour and overlap with the seaward end of a tidal channel that is presently minimally active. The location of overlap is shown as Zone 3 in EIS Appendix 9.5-A: Figure 110. A zone of flow separation and recirculation is predicted off the northwest corner of the terminal, which is likely to cause sediment to move around the corner and deposit along the north side of the terminal (shown as Zone 2 in Figure 110 of EIS Appendix 9.5-A). The addition of the terminal is also predicted to reduce velocities near the elbow at the connection point with the west face of the existing Westshore Terminals, creating a depositional area for sediment (shown as Zone 4 in Figure 110 of EIS Appendix 9.5-A). A second recirculating back-eddy is predicted in the corner between the south face of the Westshore Terminals and the east side of the terminal face. The seaward extent of the back-eddy is predicted to reach elevation -5.0 m CD. Sediment will likely deposit in this region from the change in velocity, but the deposition will likely be offset by an increase in wave energy (resulting in scour, shown as Zone 6 in Figure 110 of EIS Appendix 9.5-A) related to wave reflection from the terminal side (as described in EIS Appendix 9.5-A: Section 6.4).

Based on the same typical large tidal exchange[2] during ebbing tide conditions, the terminal is predicted to divert the existing seaward movement of water. This will cause the flow to be deflected and locally accelerated around the western face of the terminal. The zone of increased current velocity is predicted to occur mainly between the +0.0 m to -2.0 m CD contour. The westward edge of this zone coincides with the seaward end of the existing tidal channel (i.e., 1949 former Canoe Passage outlet channel) to the west of the terminal (shown as Zone 3 in Figure 110 of EIS Appendix 9.5-A). Sediment mobilisation is more likely to occur in this zone with the Project in place than under existing conditions.

EIS Appendix 9.5-A: Table 6 summarises the sedimentological and morphological changes associated with changes in currents resulting from the Project footprint.

[1] A tide cycle occurring on May 7, 2012 was used to provide a snapshot illustration of conditions during a typical large tidal exchange (tidal range of about 4.5 m, as shown in Figure 52 of EIS Appendix 9.5-A).

Temporal Analyses of Tidal Currents Under Existing Conditions and Future Conditions with the Project

Tidal currents occurring during the January 1 to December 31, 2012 period (inclusive of May 7, 2012, the date on which information is requested) were statistically analysed at four stations (A10, B05, B03, and D01—locations are shown on Figure 56 of EIS Appendix 9.5-A). These locations were selected to represent conditions across the tidal flats from the upper intertidal to subtidal zone near the Project. Based on the analysis, a current rose was produced for each location for existing conditions and for future conditions with the Project, as shown in Figures 57 to 60 of EIS Appendix 9.5-A. The current roses indicate current velocity, frequency of occurrence, and direction (direction toward which the prevailing current flows).

Table IR2-07-1 lists the current velocity statistics previously summarised in Figures 57 to 60 of EIS Appendix 9.5-A for the four locations during ebb and flood tides, including predominant current direction, maximum current velocities, and frequency of occurrence of maximum current velocities. For the three locations in the intertidal zone, the predicted maximum current velocities are the same and the frequency of occurrence of the maximum current velocities decreases in the future with the Project compared to existing conditions. Erosive forces, therefore, are not predicted to increase in the area north of the causeway with the Project.

Table IR2-07-1 Current Velocity Statistics for the January 1 to December 31, 2012 Period for Existing Conditions and Future Conditions with the Project at Four Stations

Station Location	Tidal Condition	Existing Conditions		Future Conditions with Project	
		Predominant Current Direction[a]	Maximum Current Velocity in m/s (frequency[b])	Predominant Current Direction[a]	Maximum Current Velocity in m/s (frequency[b])
A10 Upper intertidal zone	Ebb	S	0.3 to 0.5 (4%)	SW	0.3 to 0.5 (1%)
	Flood	N	0.3 to 0.5 (3%)	NE	0.3 to 0.5 (1%)
B05 Mid intertidal zone at +2 m CD contour	Ebb	S	0.3 to 0.5 (4%)	SW	0.3 to 0.5 (1%)
	Flood	N	0.3 to 0.5 (3%)	NE	0.3 to 0.5 (1%)
B03 On 0.1 m CD contour (north of terminal)	Ebb	S	0.3 to 0.5 (10%)	W	0.3 to 0.5 (1%)
	Flood	N	0.3 to 0.5 (13%)	E	0.3 to 0.5 (2%)
D01 Subtidal zone	Ebb	S	0.9 to 0.11 (1%)	SW	0.7 to 0.9 (1%)
	Flood	NW	0.5 to 0.7 (2%)	N	0.7 to 0.9 (2%)

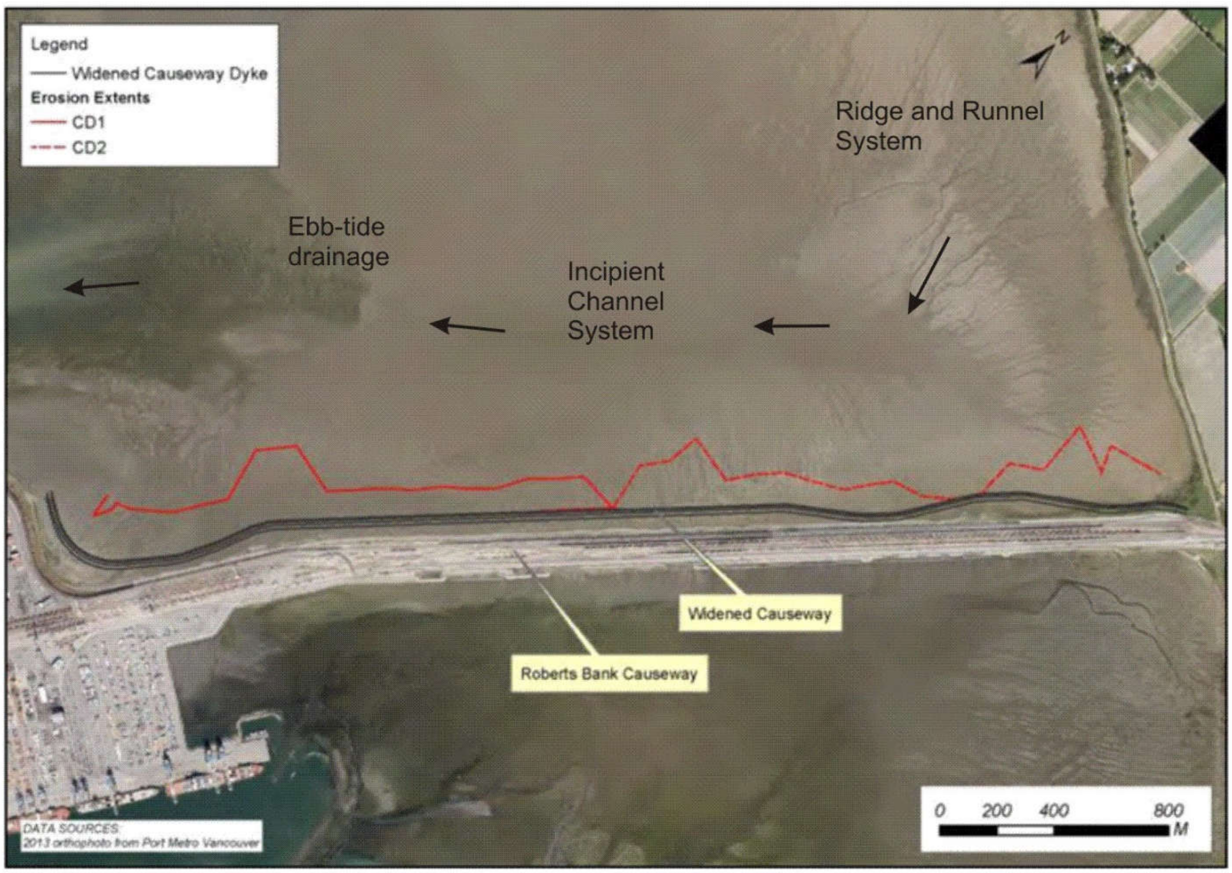
Notes:

a. Direction = the direction towards which the prevailing current flows; N = north; S = south; NW = northwest; SW = southwest; NE = northeast.
b. Frequency = the frequency of occurrence of the maximum current velocity as a percentage of time in 2012 that it occurs, based on current roses presented in Appendix 9.5-A: Figures 57 to 60; m/s = metres per second.

Assess the potential for enhanced current velocities and erosion during maximum ebb and flood tidal flow conditions in the area northwest of the causeway and evaluate the potential for formation of a modified tidal channel network between the proposed widened Causeway and Canoe Pass.

The Panel has provided clarification for the location of 'the area northwest of the causeway' (also referred to in the context from the Panel as 'an incipient channel system' that links the ridge and runnel area to a broad embayment), as indicated in **Figure IR2-07-1**. As a point of clarification, flow velocities associated with maximum ebb and tidal flow conditions in this area *have* been incorporated in the morphodynamic model. The model integrates all of the changes in flow conditions to arrive at the prediction shown in Figure 107 of EIS Appendix 9.5-A, which shows no change in bed evolution in the area identified by the Panel as 'an incipient channel system'.

Figure IR2-07-1 Clarification from Panel on Incipient Channel System Location



Source: Annotation of 'incipient channel system' on Figure 108 of EIS Appendix 9.5-A by Natural Resources Canada (CEAR Document #918[2]).

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[2] CEAR Document #918 From the Review Panel to the Vancouver Fraser Port Authority re: Exchange between Natural Resources Canada to provide clarity on Information Requests in Package #2 (See reference document #908)

Background Information

Tidal channel initiation and propagation was an important topic of discussion during the Coastal Geomorphology Technical Advisory Group (TAG) meetings, as tidal channels that have formed in the inter-causeway area could potentially develop on the north side of the causeway with the construction of the Project. As such, mudflat tidal channels were a focus of the coastal geomorphology assessment presented in EIS Section 9.5 because of the proximity of the proposed Project to a relict (1949) Canoe Passage outlet channel (shown in Figure 33 of EIS Appendix 9.5-A), the potential for the Project to re-initiate this channel, and the consequent changes that might occur to existing habitat on Roberts Bank. As stated in Appendix IR2-A of the Preamble at the beginning of this response package, the TAG discussed "how numerical models have limitations in terms of predicting tidal channel changes from development on the tidal flats, partly because channel initiation occurs at a smaller scale than what can be modelled". The TAG mentioned that "while modelling is not useful at predicting tidal channel formation, models can be used to give insight into where erosion might occur and where new channels might be triggered". Based on this input, a two-pronged approach was adopted to understand the morphodynamic evolution of the tidal flats in the coastal geomorphology assessment, including 1) modelling to identify potential locations for channel initiation (e.g., induced by increases in current velocities) and 2) use of interpretive geomorphology methods to estimate the potential scale of channels should they actually develop (e.g., method such as airphoto interpretation to evaluate historical changes within the LSA). Refer to EIS Section 9.5.5.3 for more information on methodology and Appendix IR2-A of the Preamble at the beginning of this response package for further details pertaining to TAG discussions.

Assessment of the Potential for Enhanced Current Velocities and Erosion During Maximum Ebb and Flood Tidal Flow Conditions in the Area Northwest of the Causeway

As described in the response above, the spatial distribution of current velocities and the temporal evaluation of maximum tidal current velocities and their frequency of occurrence has been assessed for future conditions with the Project in the LSA, inclusive of the area northwest of the causeway shown in **Figure IR2-07-1**.

Based on a comparison of future conditions with the Project to existing conditions, maximum current velocities are predicted to be the same within the area northwest of the causeway and the frequency of occurrence of maximum currents are predicted to decrease (see statistics for locations A10, B01, and B03 in **Table IR2-07-1** above and Figures 58 to 60 of EIS Appendix 9.5-A, respectively).

Evaluation of the Potential for Formation of a Modified Tidal Channel Network Between the Widened Causeway and Canoe Passage

Based on content provided in the context from the Panel, the incipient channel system "will be partially blocked by the proposed terminal", and that "a reduction of the width across which water could drain from this system would lead to higher current speeds". Based on observed morphological changes on the tidal flats over time, as well as interpretive geomorphology investigations (both of which are described in EIS Section 9.5.6.3), Project-related changes in currents or morphology are not predicted in the future with the Project in the area northwest of the causeway. The proposed location of the terminal was selected over five other alternatives as its location in subtidal waters[3] has limited to no potential to induce erosional dendritic channel formation on the tidal flats (see EIS Section 5.6.2). Information is provided below to support this conclusion.

A comparison of bathymetric surveys completed in 1967 and 2011, presented in EIS Figure 9.5-18, shows sediment deposition along the north edge of the Westshore Terminals and along the causeway. Since construction of the Westshore Terminals was completed in 1969, this comparison reflects a combination of both natural and human induced bathymetric changes. Based on airphoto evidence (see Figure 10 of EIS Appendix 9.5-A), methods of construction for the Roberts Bank causeway resulted in significant dispersal of sediment over the tidal flats which persists to the present day in the form of an apron of material that slopes away from the causeway, as previously described in EIS Table 9.5-3 and EIS Appendix 9.5-A: Section 3.4.2. The comparison of bathymetric surveys also shows that tidal flats north of the causeway away from structures and channels (i.e., Canoe Passage) have remained stable over the past 40 years.

A comparison of bathymetric surveys completed in 2002 and 2011 and presented in EIS Figure 9.5-19 also shows that most of the tidal flats are morphologically stable. If an 'incipient channel system' existed in the area north of the causeway, patterns of erosion and deposition would have been observed as the channel shifted its location on the tidal flats over time, as evidenced by the migration of the Canoe Passage channel (and patterns of erosion and deposition) shown in EIS Figures 9.5-18 and 9.5-19.

Based on modelling of morphologic changes under future conditions with the Project, the terminal is predicted to interrupt the seaward movement of water, but the zone of increased current velocity is predicted to occur mainly beyond the intertidal zone (i.e., between the +0.0 m to -2.0 m CD contour, as shown EIS Appendix 9.5-A: Figures 107 and 110). The terminal is expected to deflect and accelerate the ebbing flow around the western face of the terminal. Therefore, the formation of a modified tidal channel network is not expected in the intertidal area northwest of the causeway based on maximum tidal current velocities predicted in the future with the Project, observed sedimentological and morphological changes on the tidal flats over time, and modelling of Project-related changes.

Reconcile the results with the morphodynamic evolution simulations (Figure 107 of Appendix 9.5-A) that show little or no change in net deposition of sediment.

The changes in morphodynamic evolution resulting from the Project presented in Figure 107 of EIS Appendix 9.5-A expresses different information over different time scales than the areas of enhanced flow shown in Figure 56 of EIS Appendix 9.5-A under future conditions with the Project. Figure 107 of EIS Appendix 9.5-A shows the differences between expected conditions and future conditions with the Project (i.e., Project-related changes) from all tidal conditions (including ebb, flood, and slack tide conditions) after 1,440 simulated days. Figure 56 of EIS Appendix 9.5-A is a snapshot of conditions in the future with the Project

[3] Terminal orientation and location W1, with the terminal berth face facing offshore along the -10 m CD contour and parallel to the mainland shoreline, as shown in EIS Figure 5-2.

(includes expected conditions plus changes attributable to the Project) on an ebbing tide at one point in time (using a tide cycle observed on May 7, 2012 to represent conditions at a single point in time during a typical large tidal exchange). Figure 56 should be compared to Figure 55 in EIS Appendix 9.5-A, which illustrates current velocities associated with an ebb tide on May 7, 2012 under existing conditions. For existing conditions and future conditions with the Project, the current velocities within the 'broad embayment' (at the outlet end of the 'incipient channel system') at this specific period in the tide cycle are generally in the range of 0.1 m/s to 0.5 m/s, with some areas showing enhanced velocities while other areas showing decreased velocities, as would be expected for a 'snapshot' illustration in time (see Figures 55 and 56 of EIS Appendix 9.5-A).

In the 'broad embayment' area, maximum current velocities are anticipated to range from 0.3 m/s to 0.5 m/s for both existing conditions and future conditions with the Project, based on temporal statistical analyses at Station B03 (see **Table IR2-07-1** above). Under future conditions with the Project, the predominant current direction is predicted to shift and the frequency of the maximum velocities is predicted to decrease for both ebbing and flooding tides (see **Table IR2-07-1** and EIS Appendix 9.5-A: Figure 58).

Based on the intended content of Figures 56 and 107 of EIS Appendix 9.5-A, therefore, the results of the two figures cannot be reconciled.

IR2-08 Coastal Geomorphology – Morphodynamics: Foreslope Assessment

Information Source(s)

EIS Volume 2: Section 9.5; Appendix 9.5-A, Figure 106

Context

In Section 3.4.6 of Appendix 9.5-A, the Proponent stated that "Sedimentation rates range from less than 1 to 2 cm/year over much of the Sturgeon Bank foreslope and in the Strait of Georgia. However, much higher sedimentation rates have been measured off the mouth of the main channel. Little or no sediment is being deposited today over most of the Roberts Bank slopes. Previous studies reported dunes off Roberts Bank at depths of 20 to 120 metres, with net northwesterly transport. Some researchers claimed that these features were evidence of erosion of the delta front; however, these features were later interpreted to be dredged spoil that had been dumped in deep water."

The EIS implied that the presence of dunes on the foreslope does not indicate erosion of the delta front. As identified by Natural Resources Canada, more recent studies based on multibeam sonar data have shown the presence of active subaqueous dunes on the slope to at least 100 metres water depth. These dunes are likely to have erosional troughs and other features, such as outcropping beds, which suggest that strong tidal flows are eroding the shallow region of the foreslope.

The sediment transport modelling appeared to indicate local zones of erosion and deposition on the foreslope in the present-day scenario (Figure 106 in Appendix 9.5-A) which would be consistent with bedform migration, and a changed pattern of erosion when the proposed widened causeway and terminal structure is in place.

Information Request

Assess the foreslope between the Tsawwassen Ferry Terminal and Canoe Pass to determine whether it is undergoing active erosion or not.

VFPA Response

The VFPA's response to this information request is based on information provided in the EIS as well as new information presented in Carle and Hill (2009) that was not previously considered. EIS Appendix 9.5-A: Section 3.4.6 provides a description of conditions on the Roberts Bank foreslope based on existing information. The information presented in the EIS, particularly the reference to Hay and Company (1996), was not intended to imply that there is no active erosion of the foreslope. There is good evidence to suggest that sections of the foreslope between the B.C. Ferries Terminal and Canoe Passage are undergoing active erosion, which is explained in more detail below. Construction of the RBT2 terminal will include armouring of a 1,700 m long section of the foreslope down to -30 m Chart Datum (CD), and will effectively halt any erosion of the foreslope in that area that may be occurring at present.

The information provided below describes the studies that have been conducted to assess the stability of the foreshore, as described in the EIS, as well as new information presented in Carle and Hill (2009).

The Hay and Company (1996) study was commissioned by the (then) Vancouver Port Corporation and BC Ferry Corporation to undertake a study in response to an earlier GeoSea Consulting (1995) report that had concluded that net erosion was occurring on the delta foreslope of Roberts Bank and that there was potential for port infrastructure to be undermined. Hay and Company (1996) concluded from a review of bathymetric charts that erosion of the "delta slope" had occurred, but in small patches, was not continuous through time, and was of very small magnitude. Hay and Company (1996) also conducted an assessment of delta slope stability and concluded that erosion on the order of 40 m would be needed to make the delta slope unstable. These findings were subsequently presented at an international conference of engineering geologists (Atkins et al. 1998).

EIS Section 9.1.3.6 refers to erosion of the submarine terrain of Roberts Bank (e.g., the steeper parts of the delta from –5 m CD to approximately –150 m CD). EIS Section 9.5 presents a comparison between a 1967 bathymetric survey and a combined LiDAR and bathymetric survey collected in 2011 (EIS Figure 9.5-18), which implies that there was a broad area of deposition of up to 5 m along the top of the foreslope between the existing Roberts Bank terminals and Canoe Passage (the extent of the overlapping surveys); however, the accuracy of the 1967 survey, particularly with respect to horizontal positioning, is not known and so it is challenging to differentiate actual change from apparent change resulting from survey inaccuracies.

A more robust evaluation of change to the foreslope, though over a shorter time span, is made by comparing LiDAR and bathymetric surveys collected in 2002 to those collected in 2011 (EIS Figure 9.5-19). Over the ten-year comparison, there is a pattern of distinct areas of erosion of up to 1.75 m along the foreslope interspersed with areas of deposition of up to 0.75 m. This general pattern of erosion and deposition along the delta foreslope is reproduced in the results of the morphodynamic modelling shown in EIS Figures 9.5-26 and 9.5-32. EIS Figure 9.5-26 presents results of the morphodynamic modelling after 1,440 model days for expected conditions—a model prediction for the future with no Project. Changes along the upper delta foreslope between the Roberts Bank terminals and Canoe Passage show areas of erosion on the order of 0.7 m between areas of deposition on the order of 0.5 m. EIS Figure 9.5-32 shows the results for the same timeframe with the Project. EIS Figure 9.5-33 shows the difference between expected conditions and future conditions with the Project. The magnitude of erosion and deposition along the foreslope are similar, but the pattern is altered from the expected conditions case (shown in EIS Figure 9.5-26). The area of erosion appears as a discontinuous band between the -10 m CD and -20 m CD contours and the area of deposition appears in a similar discontinuous band along the -30 m CD contour. The difference between expected conditions and future conditions with the Project emphasises that the Project appears to disrupt what may be bedform migration, which the model is capable of reproducing. Given that the Project will effectively armour a 1,700 m long section of the foreslope down to -30 m CD in the dredge basin (as described in EIS Section 4.4.1.9 and shown in EIS Figure 4-5 and EIS Appendix 4-B Engineering Drawing 60287593-MA-510), a large area of the existing foreslope will no longer contribute to this system of sediment migration.

The study by Carle and Hill (2009) revealed through analysis of a multibeam survey collected in the summer of 2001 that subaqueous dunes are more abundant and more widely distributed than described previously in the scientific literature. Analysis of the imagery produced from the survey indicates that some portions of the dune field have formed in an environment of high suspended load sediment transport and are active features. The source of the sediment in the dune field is not directly assessed in this paper, but based on the work of others, is thought to originate from past dredging activities (e.g., Hay and Company 1996), from erosion of the delta foreslope (e.g., Hart et al. 1995), or a combination of the two. The authors observe that in the zone of irregularly-spaced dunes, sediment starvation is occurring in that the rate of sediment input is insufficient to maintain the bedform in an environment of high sediment transport capacity driven by high current velocity.

As stated above, there is good evidence to suggest that sections of the foreslope between the B.C. Ferry Terminal and Canoe Passage are undergoing active erosion. Only the section between the Roberts Bank terminals and Canoe Passage can be assessed directly through comparison of a 1967 survey to a more recent 2011 survey and the results of this comparison are partly confounded by unknown inaccuracies in the 1967 survey. The presence of an extensive area of subaqueous dunes in water depths between -10 m CD and over -100 m CD, described by Carle and Hill (2009), demonstrates contemporary active sediment transport, and is strongly suggestive of ongoing erosion of the foreslope without specifying which areas may be contributing sediment to the dune field. Construction of the RBT2 terminal will result in armouring of a 1,700 m long section of the foreslope down to -30 m CD, and will effectively halt any erosion of the foreslope in that area that may be occurring at present.

References

Atkins, R. J., O. Sayao, and D. Hay. 1998. Evaluation of erosion at Roberts Bank, Fraser River, British Columbia, Canada. Engineering Geology: A Global View from the Pacific Rim, Proceedings, 8th Congress of the International Association for Engineering Geology and the Environment, A.A. Balkema, Vancouver, B.C. 3833–3837.

Carle, L., and P. R. Hill. 2009. Subaqueous dunes on the upper slope of the Fraser River delta (British Columbia, Canada). Journal of Coastal Research. 25(2). 448-458.

GeoSea Consulting. 1995. Sediment transport and its environmental implications in the Lower Fraser River and Fraser Delta (DOE-FRAP 1995-03). Report prepared for Environment Canada, Environmental Conservation Branch by GeoSea Consulting (Canada).

Hay and Company. 1996. Erosion at Roberts Bank geophysical evaluation. Report prepared for Vancouver Port Corporation and BC Ferry Corporation.

Hart, B. S., T. S. Hamilton, D. B. Prior, and J. V. Barrie. 1995. Seismostratigraphy and sedimentary framework of a deep Holocene delta: the Fraser Delta, Canada. Geology of Deltas. 167–168.

IR2-09 Coastal Geomorphology – Morphodynamics: Topographic Change on Outer Flats

Information Source(s)

EIS Volume 2: Section 9.5; Appendix 9.5-A, Figures 33 and 39

Context

In Appendix 9.5-A of the EIS, the Proponent stated that the Roberts Bank tidal flats between the north side of the Roberts Bank causeway and Canoe Passage (Brunswick Point) had remained relatively stable over the last decade. Figure 39 in Appendix 9.5-A showed differences of greater than 1 metre in topographical changes within this area; this corresponds to the position of a re-entrant and short tidal creek in the air photo shown in Figure 33 of Appendix 9.5-A.

As reported by Natural Resources Canada, the creek appears to be the conduit for draining the inner part of the tidal flats on the ebbing tide at Roberts Bank and the terminal expansion will infill it, necessitating a re-alignment of the drainage system.

Information Request

Assess the topographic change (erosion > 1 metre) that occurred on the outer flats between the proposed terminal site and Canoe Passage, and the area of Brunswick Point in particular, over the past 75 years corresponding to the air photos referenced in Figure 33 of Appendix 9.5-A.

Evaluate whether the re-entrant and short tidal creek was present before the construction of the coal terminal causeway and the Deltaport terminals or if it formed in response to the construction of these structures and continues to evolve.

VFPA Response

Assess the topographic change (erosion > 1 metre) that occurred on the outer flats between the proposed terminal site and Canoe Passage, and the area of Brunswick Point in particular, over the past 75 years corresponding to the air photos referenced in Figure 33 of Appendix 9.5-A.

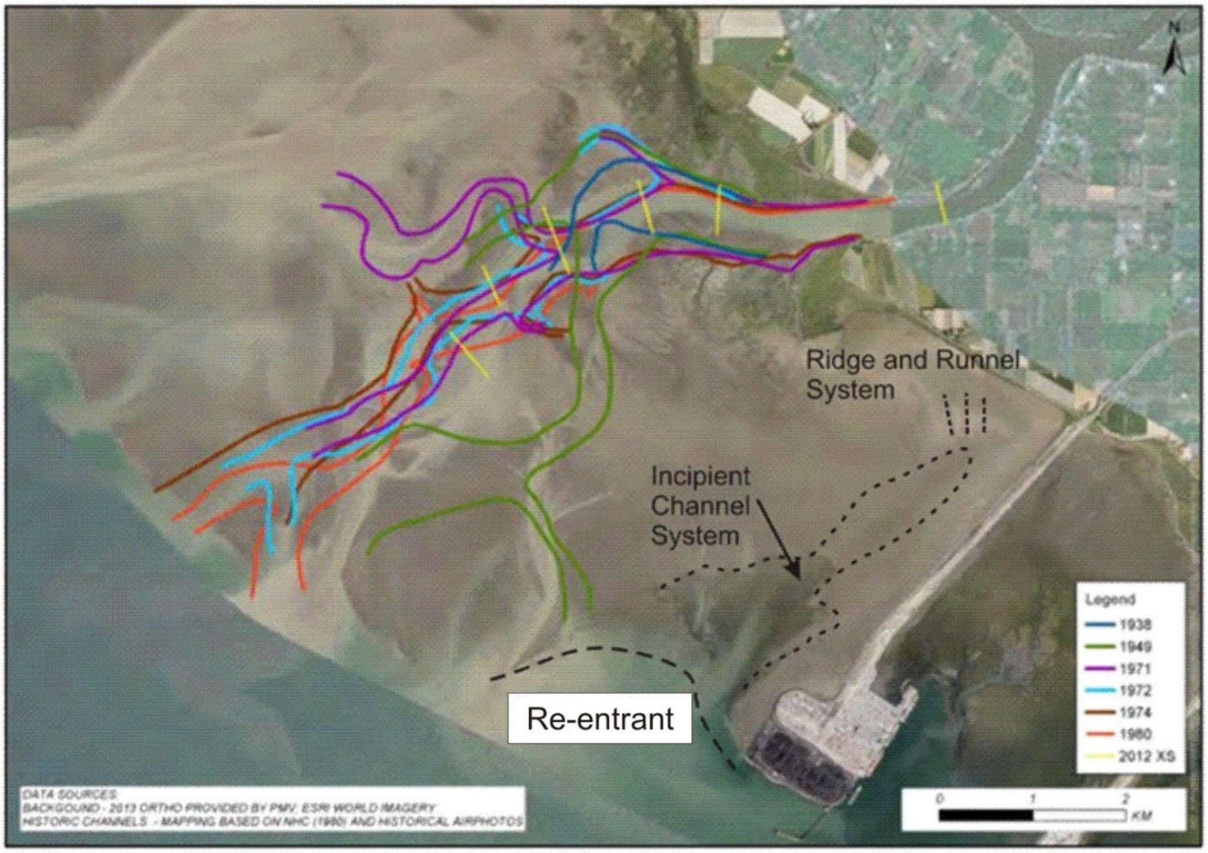
Airphotos from 1932 to 2013 were used as a source of information in the coastal geomorphology assessment to analyse long-term changes at Roberts Bank (summarised in EIS Appendix 9.5-A: Appendix A, Table 2). To clarify, airphotos referenced in Figure 33 of EIS Appendix 9.5-A were not used to compare topographic changes over time (i.e., with respect to changes in depth), as the airphotos provide a good indication of the horizontal location of features, but they do not provide an accurate indication of vertical change (i.e., changes in depth). Therefore, to assess topographic changes such as the >1 m change referred to in the information request, bathymetric charts and surveys (dating back to 1860) were used. Table 1 of EIS Appendix 9.5-A: Appendix A lists the historical bathymetric surveys in the Roberts Bank and lower Fraser River area that were reviewed to describe topographic changes over time, noting that the 1967 and 2011 datasets provide the most comprehensive extent of coverage at Roberts Bank (44 year timespan). Older bathymetric information cannot be relied upon for specific evidence about depths and planform at the time because the survey methods used were subject to inaccuracies (EIS Appendix 9.5-A: Appendix A, Section 1.3).

To evaluate changes over time, the bathymetric surveys were overlain in GIS (geographic information system). The extent of topographic change from 1967 to 2011 shown in EIS Appendix 9.5-A: Figure 39 is believed to be an artifact of differences in survey techniques from 1967 and 2011. Relative horizontal position (e.g., the location of a topographic feature such as a channel to other adjacent features) is often a source of error when comparing older surveys to more recent data because 1) older surveys do not always report the model that was used to represent the curving earth's surface on a planar chart; and 2) older survey techniques were less precise with respect to establishing horizontal positioning in the field. As elevations change with horizontal position, there is the potential for apparent changes to be attributed only to elevation measurements. The comparison between the 1967 and 2011 bathymetric survey implies that there have been changes (both erosion and deposition) of greater than 1 m; however, the accuracy of the 1967 survey, particularly with respect to horizontal positioning, is not known and it is difficult to discern actual change from apparent change resulting from survey inaccuracies. There may have been smaller changes over this period, but it is unlikely to be in the range of 1 m. A more robust evaluation of change to the topography, though over a shorter time span, is made by comparing LiDAR and bathymetric surveys collected in 2002 to those collected in 2011 (Figure 40 in EIS Appendix 9.5-A). Over this ten-year period, vertical changes on the tidal flats, both of accretion and erosion, are less than 0.25 m over much of the area of survey coverage, which is within the survey accuracy of 0.3 m. Based on this comparison, the tidal flats have remained relatively stable over the last decade.

Evaluate whether the re-entrant and short tidal creek was present before the construction of the coal terminal causeway and the Deltaport terminals or if it formed in response to the construction of these structures and continues to evolve.

The Panel has provided clarification for the location of 'the re-entrant and short tidal creek', as indicated in **Figure IR2-09-1** (location has been annotated on Figure 33 of EIS Appendix 9.5-A). This is the same location referred to in IR2-07 as the 'the area northwest of the causeway' or 'incipient channel system'.

Figure IR2-09-1 Clarification from Panel for Location of Re-entrant and Short Tidal Creek



Source: Annotation of 're-entrant', 'incipient channel system' and 'ridge and runnel system' by Natural Resources Canada (CEAR Document #918[1])

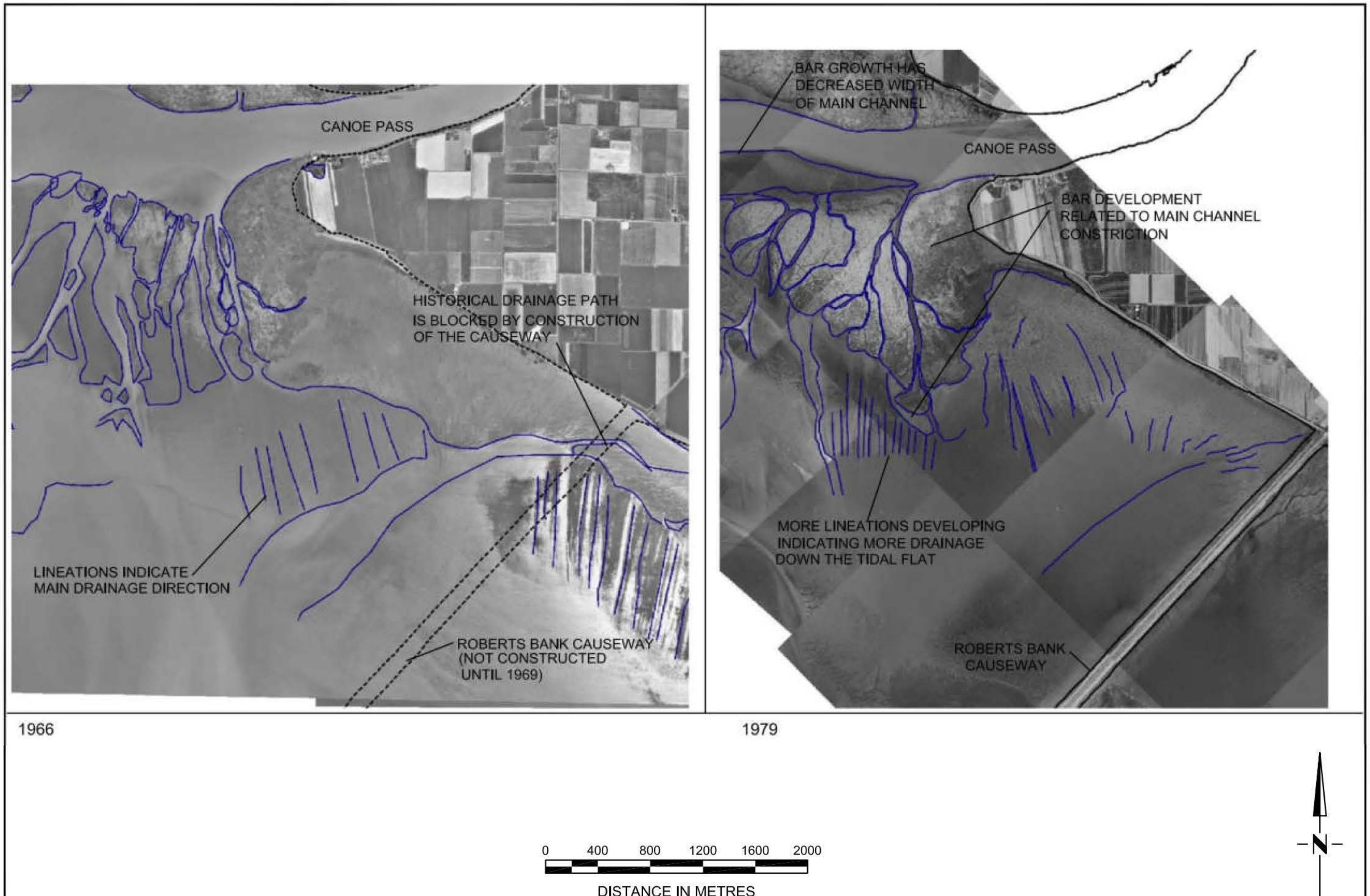
As outlined in IR2-07, the initiation and propagation of tidal channels was an important topic discussed by the Coastal Geomorphology Technical Advisory Group (TAG) and this topic was a focus of the coastal geomorphology assessment presented in EIS Section 9.5. Based on TAG input, interpretive geomorphology methods (e.g., interpretation of historical airphotos) was one of the methods used to examine morphological changes over time at Roberts Bank. Refer to EIS Section 9.5.5.3 for more information on methodology, Appendix IR2-A of the Preamble at the beginning of this response package for further details pertaining to TAG discussions, and EIS Section 9.5.6.2 for information on morphological changes at Roberts Bank.

The channel area indicated in **Figure IR2-09-1** is the same as the drainage channel described by Northwest Hydraulic Consultants (NHC) and Triton (2004) that existed prior to the construction of the causeway. Based on interpretations from historical photos by NHC and Triton (2004), some drainage channel features existed on Roberts Bank before major developments occurred, as shown in the 1966 airphoto in **Figure IR2-09-2**. A few larger

[1] CEAR Document #918 From the Review Panel to the Vancouver Fraser Port Authority re: Exchange between Natural Resources Canada to provide clarity on Information Requests in Package #2 (See reference document #908)

tidal channels were present prior to causeway development that included remnants of former Canoe Passage outlet channels (shown in **Figure IR2-09-1**) and a channel that drained in a predominantly northwest to southeast direction in the area where the Roberts Bank causeway was constructed (see 1966 airphoto in **Figure IR2-09-2**). The presence of the Roberts Bank causeway constructed in 1969 re-directed tidal flows in the area of the causeway (NHC and Triton 2004). Based on airphoto evidence (see Figure 10 of EIS Appendix 9.5-A), methods of construction for the Roberts Bank causeway resulted in dispersal of sediment over the tidal flats which has persisted to the present day in the form of an apron of material that slopes away from the causeway (EIS Table 9.5-3 and EIS Appendix 9.5-A: Section 3.4.2). Modifications to this drainage pathway have shifted the predominant tidal flow to a generally north-south direction, parallel to the causeway (see 1979 airphoto in **Figure IR2-09-2** and 1984 and 2002 airphotos in **Figure IR2-09-3**). This drainage pathway, which aligns with the 'incipient channel system' annotated in **Figure IR2-09-1**, has persisted in this area due to the apron of material along the causeway deposited during causeway construction. Further evidence of this drainage area persisting in the area north of the causeway is supported by comparisons of bathymetric surveys described in EIS Section 9.5.6.3 and IR2-07. Based on comparisons over time from these surveys, the morphology of this area has remained stable since causeway construction in 1969 (i.e., the drainage path has persisted in this area and hence areas of erosion and deposition have not been observed in a comparison of 2002 and 2011 bathymetric surveys provided in Figure 40 of EIS Appendix 9.5-A). This drainage path has not shifted or evolved across the tidal flats over time as would be expected by a tidal channel on a mudflat (as observed with migration of the tidal channel (i.e., relict Canoe Passage outlet channel) to the west side of terminal in **Figure IR2-09-1**). Other smaller channels shown on the airphotos occur either on the outer margins of the tidal flats or on the upper tidal flats, but rarely connect between the two elevation bands, as described in EIS Table 9.5-3. Widening of the causeway and development of the terminal is not predicted to change drainage patterns or the morphology of the tidal flats in this area north of the causeway in the future with the Project, based on the stability of the area shown over time in Figure 40 of EIS Appendix 9.5-A.

Figure IR2-09-2 Aerial Photographs of Canoe Passage to Roberts Bank Causeway 1966 and 1979

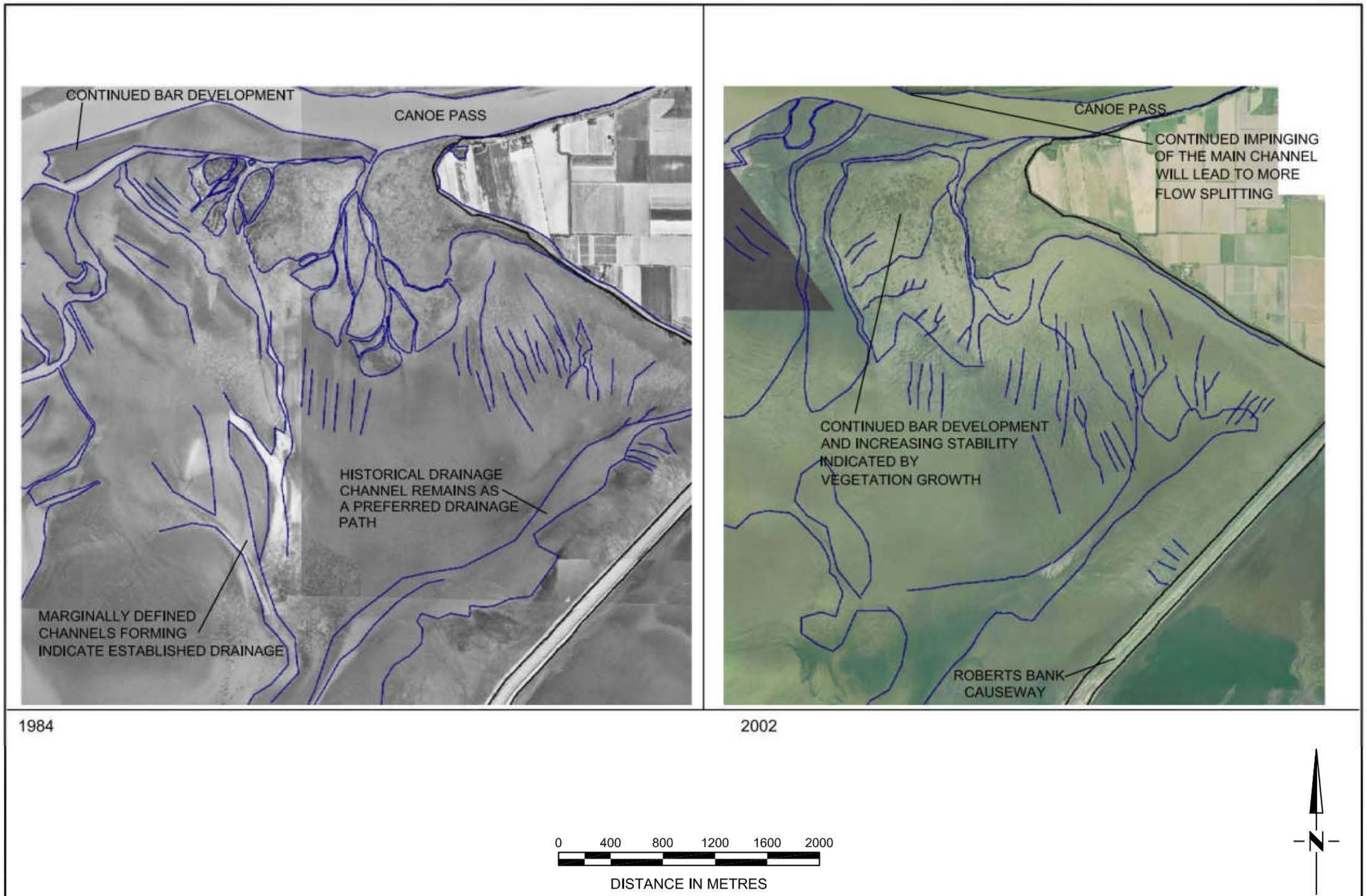


Notes:

1) Orthophotos georeferenced using ArcView GIS.
2) Current Deltaport structures are shown.

Reference: Northwest Hydraulic Consultants Drawing 'FIGURE 3–5.dwg'

Figure IR2-09-3 Aerial Photographs of Canoe Passage to Roberts Bank Causeway 1984 and 2002



Notes:

1) Orthophotos georeferenced using ArcView GIS.
2) Current Deltaport structures are shown.

Reference: Northwest Hydraulic Consultants Drawing 'FIGURE 3–6.dwg'

References

NHC and Triton Consultants Ltd. (Triton). 2004. Roberts Bank Container Expansion Coastal Geomorphology Study. Prepared by Northwest Hydraulic Consultants Ltd. and Triton Consultants Ltd. for Vancouver Port Authority.

IR2-10 Coastal Geomorphology – Morphodynamics: Storm Simulations

Context

According to Fisheries and Oceans Canada, the storm simulations of the supplementary sediment transport modeling (CEAR Reference Doc. #547) indicated a potential for increased sedimentation in the inter-causeway area and in the vicinity of the Tsawwassen Ferry Terminal. The Proponent questioned the validity of these results because of a lack of adequate grid resolution in this area of the model domain. The storm simulations should be repeated using a grid that has adequate spatial resolution in the area of concern in order to make the sediment transport model defensible.

Information Request

Repeat the storm simulations of the supplementary sediment transport modelling work provided in CEAR Doc. #547, Appendix 1.6 using a grid with the spatial resolution necessary to validate the sediment transport analysis for the following areas:

- the inter-causeway;
- the Tsawwassen Ferry Terminal; and
- the area between the expanded causeway and Canoe Passage.

Conduct a sensitivity analysis to evaluate the influence of different grid sizes on the sediment transport simulation results.

VFPA Response

Repeat the storm simulations of the supplementary sediment transport modelling work provided in CEAR Doc. #547, Appendix 1.6 using a grid with the spatial resolution necessary to validate the sediment transport analysis for the following areas:

- ***the inter-causeway;***
- ***the Tsawwassen Ferry Terminal; and***
- ***the area between the expanded causeway and Canoe Passage.***

The context from the Panel states that "The Proponent questioned the validity of these results because of a lack of adequate grid resolution in this area of the model domain." To clarify, the VFPA, in appendix 1.6 of CEAR Document #547 (page 14), stated that the model was not optimised to produce reliable predictions of bed level changes in the inter-causeway and the B.C. Ferries Terminal areas. Optimisation of the model to predict potential changes in bed levels in these areas is not required. The model mesh size for the area where Project changes are predicted (i.e., the area between the expanded causeway and Canoe Passage) is already optimised, as detailed below.

The VFPA has therefore not re-run the storm simulations with a finer model spatial resolution as requested, based on the following rationale:

- The model is already optimised in the area predicted to experience Project-related changes;
- The model does not need to be optimised south of the causeway in the inter-causeway area or in the vicinity of the B.C. Ferries Terminal as Project-related changes are not predicted in these areas; and
- The prediction that the Project will not change areas south of the causeway is supported by interpretive geomorphology lines of evidence.

In addition, the following is noted in CEAR Document #893 section 3.2.2:

> *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.*

Therefore, with respect to validation of the sediment transport model, the VFPA has met this requirement. Further information is provided below.

Rationale for Model Optimisation

Section 6 of EIS Appendix 9.5-A describes the approach and rationale behind the development of the hydrodynamic numerical model, which was also used in the storm simulation for the supplementary sediment transport study (provided in appendix 1.6 of CEAR #547).

The computational grid is one of the fundamental building blocks of the numerical model, defining where conditions in the model domain will be calculated. The grid size is optimised in the area of interest that is predicted to change as a result of the Project, while more distant areas are represented with less detail to achieve computational efficiencies (see Section 6.1 of EIS Appendix 9.5-A for more details). This is a standard and accepted approach in numerical modelling studies to provide detail in the immediate area of interest, while ensuring that the total number of grid cells does not exceed that which can be computed. For example, the TELEMAC model mesh varies in size from 3,000 m in the Strait of Georgia, where no Project changes are predicted, to 25 m in the area north of the existing terminal causeway, where Project changes are anticipated. As Project changes were not anticipated for the inter-causeway area or near the B.C. Ferries Terminal, the model mesh size was optimised with a larger grid spacing of up to 120 m. Project components are in an area that is hydrodynamically isolated from the inter-causeway and B.C. Ferries Terminal areas by deep water and the presence of the causeways themselves.

Similarly, the underlying bathymetric (bed elevation) dataset within the model is also optimised with greater resolution in the area of interest predicted to change as a result of the Project. For this reason, bed levels in the area north of the causeway were represented in the model with higher resolution bed level data, whilst the inter-causeway and B.C. Ferries Terminal areas were represented in the model with a coarser bed level dataset (see Appendix A of EIS Appendix 9.5-A for more information).

This approach was validated by the modelling results summarised in Table 9.5-6 and Figure 9.5-34 in the EIS, which show the main changes in sediment transport occurring in the area north of the causeway, with little to no change in the inter-causeway and B.C. Ferries Terminal areas.

Interpretive Geomorphology

In line with the three-pronged approach (described further in the Appendix IR2-A of the Preamble at the beginning of this package), outputs of the numerical model were compared to existing processes presently affecting the tidal flats in the local study area. For example, monitoring of deposition in the inter-causeway area over a period from 2007 to 2011 as part of the Deltaport Third Berth Adaptive Management Strategy concluded that the magnitude of change in deposition rates during that period was small (generally less than 10 cm over five years) (see Hemmera et al. 2012). During this monitoring period there were a number of large north-westerly storm events (see Table IR2-06-1 in IR2-06) that did not result in significant changes to bed levels in the inter-causeway area, a finding that supports the view that north-westerly storm events do not drive bed level changes in the inter-causeway and B.C. Ferries Terminal areas. This trend is also reflected in elevation data recorded over the past forty years which show relatively little change in bed levels during that period (see IR2-07).

Conduct a sensitivity analysis to evaluate the influence of different grid sizes on the sediment transport simulation results.

Sensitivity analyses of model performance are not typically carried out on the computational mesh because, as mentioned above, this is a fundamental foundation of the model and, as such, is not typically varied except where anomalous results occur within the area of interest. The anomalous results for the 1 in 100-year storm event in the inter-causeway area and the area south of the B.C. Ferries Terminal do not occur within the area of interest, and therefore, do not influence the outcome of the assessment of Project-related changes.

More typical sensitivity analyses were undertaken for the supplementary sediment transport study; namely, the effect of varying sediment grain size and the effect of different sediment transport equations, the results of which are presented and summarised in appendix 1.6 of CEAR Document #547. The sensitivity tests demonstrated that the model performs well with the specified input parameters that were used in the sediment transport model, as discussed in Section 3.5 of EIS Appendix 9.5-A.

References

Hemmera, Northwest Hydraulics Consultants, and Precision Identification Biological Consultants. 2012. Final Report Adaptive Management Strategy 2011 Annual Report Deltaport Third Berth, Delta B.C. Prepared for Vancouver Fraser Port Authority.

IR2-11 Coastal Geomorphology – Climate Change: Future Storm Conditions

Information Source(s)

EIS Volume 2: Section 9.5; Appendix 9.5-A

Context

The Proponent stated in Appendix 9.5-A that although there is an accepted popular assumption that storms will become stronger and more frequent in the future, the analysis conducted in support of the Provincial guidelines for coastal flooding concluded that there was no statistically significant indication that the existing storm population would not provide a reasonable model for the expected storm population in the future.

Information Request

Provide information supporting the assumption reported in the EIS that storm conditions will remain constant under climate change.

Explain the range of uncertainty associated with this assumption by providing the number and nature of projections used in the statistical analysis and the range of projected storm populations.

VFPA Response

The VFPA assessed storms in response to climate change in accordance with provincial documents, as stated by the Updated EIS Guidelines part 2, section 6.2:

> *In planning for a port proposal in coastal British Columbia and in developing the EIS and technical supporting documentation, the proponent is advised to consider the document entitled "Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use: Sea Level Rise Guidelines for the Management of Coastal Flood Hazard Land Use (Process Infrastructure: Ports, Marine, and Offshore)" published by the British Columbia Ministry of Environment in 2011 or any subsequent replacement guidelines.*

The extent to which climate change could result in changes to the statistical probability of strong weather patterns that generate large waves (storminess), including the use of provincial guidelines, was discussed January 31, 2013 at a Coastal Geomorphology Technical Advisory Group (TAG) meeting (refer to EIS Section 7.4 for background information on TAG, EIS Appendix 7.4-A for summaries of TAG meetings, and EIS Appendix 7.4-B for a summary of TAG feedback and endorsements). The key discussion points, summarised in the Coastal Geomorphology TAG Summary Report provided in Appendix IR2-A of the Preamble at the beginning of this response package, informed the approach taken to the assessment of climate change in the coastal geomorphology study.

Three documents related to climate change adaptation guidelines, which were prepared by Ausenco-Sandwell in 2011 for the B.C. Ministry of Environment, were considered or incorporated within the EIS, as summarised in **Table IR2-11-1**. **Table IR2-11-1** also clarifies which Ausenco-Sandwell (2011) documents are relevant to specific topics (i.e., projections of sea level rise, change in storminess, and storm surges) presented in EIS Sections 4.2.1.2, 9.1.2, 9.5.7.2, and 31.2.6.

Table IR2-11-1 Ausenco-Sandwell (2011) Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Documents Considered in the EIS

Document Title	Document Objective	Reference Provided in EIS	Revised Reference
Draft Policy Discussion Paper	Help to bridge the gap between the science and practical application of measures to address climate change factors in British Columbia coastal areas.	Not referenced in EIS.	Ausenco-Sandwell (2011a) for information pertaining to storms in Sections 9.1.2, 9.5.7.2, and 31.2.6, and projections of sea level rise in Sections 9.1.2 and 9.5.7.2
Guidelines for Management of Coastal Flood Hazard Land Use	Guidelines for the management of lands that are exposed to coastal flood hazards arising from their exposure to the sea and to expected sea level rise due to climate change.	Referenced as Ausenco-Sandwell (2011) in Sections 4.2.1.2, 9.5.7.2, and 31.2.6.	Ausenco-Sandwell (2011b) for information pertaining to projections of sea level rise (alternative reference to Ausenco-Sandwell (2011a))
Sea Dike Guidelines	Guidelines for the design of sea dykes to protect low lying lands that are exposed to coastal flood hazards arising from their exposure to the sea and to expected sea level rise due to climate change.	Referenced as Ausenco-Sandwell (2011) in Section 9.1.2.	Ausenco-Sandwell (2011c) for source information pertaining to projections of sea level rise (alternative reference to Ausenco-Sandwell (2011a))

Note: The Ausenco-Sandwell (2011) reference provided in both EIS Sections 31.2.6 and 9.5.7.2 should have cited the draft Policy Document (Ausenco-Sandwell 2011a), as well as the Guidelines for Management of Coastal Flood Hazard Land Use (Ausenco-Sandwell 2011b) referred to in the Updated EIS Guidelines.

Ausenco-Sandwell (2011a), provided in **Appendix IR2-11-A**, describes climate change related considerations and effects for sea level rise, storms, and tides in coastal waters of B.C. This document concludes that although on a global scale, climate change is generally expected to result in increases to the frequency, intensity, and to other characteristics of storms, in the mid-latitude regions (especially in the Pacific Ocean basin between 30 degrees and 60 degrees latitude N) the expected changes that will affect coastal B.C. waters are not well defined in the climate change literature. For the establishment of policy for climate change adaptation in the coastal waters of B.C., Ausenco-Sandwell (2011a) states that “At the present time, scientific information on the expected changes in storms approaching British Columbia coastal waters and their characteristics, specifically on the intensity of the storms, their related wave conditions and the associated storm surges in the future, is only starting to emerge.” The science underlying these assumptions does not appear to be based on a number of studies, but on a lack of such studies, and for this reason, the range of uncertainty as requested in the information request cannot be provided at the present time.

Ausenco-Sandwell (2011a) further states, "Based on the available information it appears reasonable to conclude that no significant change is expected in coastal BC waters; however, further investigations are warranted to fully assess the regional implications and to further assess future trends." This conclusion is substantiated in Ausenco-Sandwell (2011a) (**Appendix IR2-11-A**) with a discussion of the calibration of global and regional atmospheric-oceanographic model results against the last 40 years of available data for ocean weather and waves. In summary, based on the expected trends over the North Pacific and specifically for the mid-latitudes occupied by B.C. coastal waters, the B.C. Ministry of Environment has "assumed that the existing storm population is a reasonable model for the expected storm population in the future" and for the development of guidelines for sea dykes and the management of coastal flood hazard land use for application in B.C.

References

Ausenco-Sandwell. 2011a. See Appendix IR2-11-A

Ausenco-Sandwell. 2011b. Climate Change Adaption [Adaptation] Guidelines for Sea Dikes and Coastal Flood Hazard Land Use: Guidelines for Management of Coastal Flood Hazard Land Use. Prepared for B.C. Ministry of Environment. Available at http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/guidelines_for_mgr_coastal_flood_land_use-2012.pdf. Accessed January 2017.

Ausenco-Sandwell. 2011c. Climate Change Adaption [Adaptation] Guidelines for Sea Dikes and Coastal Flood Hazard Land Use: Sea Dike Guidelines. Prepared for B.C. Ministry of Environment. Available at http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/sea_dike_guidelines.pdf. Accessed January 2017.

Appendices

Appendix IR2-11-A Climate Change Adaption [Adaptation] Guidelines for Sea Dikes and Coastal Flood Hazard Land Use: Draft Policy Discussion Paper

APPENDIX IR2-11-A

CLIMATE CHANGE ADAPTION [ADAPTATION] GUIDELINES FOR SEA DIKES AND COASTAL FLOOD HAZARD LAND USE: DRAFT POLICY DISCUSSION PAPER

Process Infrastructure

Ports, Marine & Offshore

Project No. 143111
Revision Number 0

BC Ministry of Environment

Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use

Draft Policy Discussion Paper

27 January 2011

Revision Status

Revision	Date	Description	Contributors		Reviewer		Approver		Signature
			FirstName LastName	Position Title	FirstName LastName	Position Title	FirstName LastName	Position Title	
A3	31 March 2010	For Internal Information/Discussion	HR/JSR		Client				
A4 – A6	various	For Internal Information/Discussion	HR/JSR/DR/MM		internal				
A7	20 June 2010	For Stakeholder Meeting	HR/JSR/DR/MM		Client				
B	31 October 2010	For Client Use	JSR/DR		JM				
0	27 January 2011	Final Issue	JSR/DR		JM				

Ausenco Sandwell

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Ausenco Sandwell

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Appendix B – Uplift and Subsidence Rates

Appendix C – Quantitative Risk Analysis

Ausenco Sandwell

Executive Summary

Emerging information from scientists and agencies around the world indicates that in the near future and continuing thereafter for some time, anticipated climate change will result in increased rates of sea level rise. Rising sea levels will increase the risk of coastal flooding and the associated consequences.

The purpose of this project is to develop policies and updated guidelines for sea dike design and coastal flood hazard land management to address climate change factors in coastal waters of British Columbia. Specific objectives are to update the sea dike section of the ministry's existing "**Dike Design and Construction Guide**", July 2003, and the coastal section of the current "**Flood Hazard Area Land Use Management Guidelines**" May, 2004.

The incorporation of climate change related sea level rise considerations into existing BC Ministry of Environment documents is structured into three documents:

- **Draft Policy Discussion Paper 2010**
- **Guidelines for Management of Coastal Flood Hazard Land Use 2010**
- **Sea Dike Guidelines 2010**

The intent of this Draft Policy Discussion document is to help to bridge the gap between the science and practical application of measures to address climate change factors in British Columbia coastal areas.

The **Guidelines for Management of Coastal Flood Hazard Land Use 2010** document provides guidelines for the management of lands that are exposed to coastal flood hazards arising from their exposure to the sea and to expected sea level rise due to climate change.

The **Sea Dike Guidelines 2010** document provides guidelines for the design of sea dikes to protect low lying lands that are exposed to coastal flood hazards arising from their exposure to the sea and to expected sea level rise due to climate change.

Based on the investigations and research summarized in this document, and reflected in the companion reports **Guidelines for Management of Coastal Flood Hazard Land Use 2010** and **Sea Dike Guidelines 2010**, the following conclusions regarding the establishment of policy for climate change adaptation in the coastal waters of British Columbia have been drawn:

1. Sea level rise (SLR) in the future is expected to be both faster and higher than previously anticipated. While there is still scientific uncertainty related to the present understanding of the future rates and magnitudes, it seems reasonable to anticipate higher SLR than summarized in the **"BC Sea Level Report 2008"**. A large degree of the related uncertainty can be eliminated by recognizing that it seems likely that sea level will rise but the rate at which it rises, and therefore the particular sea level rise on a given date, carries the most uncertainty.
2. For planning purposes it is recommended that the rates and trends reflected in Figure 1 and Table 3-2 should be used at present.
3. The choice of appropriate response options or adaptation measures is so site specific that their identification and adoption must be the responsibility of local governments, with guidelines and other support provided by the province. Provincial policy should include updating the basic guidelines for sea dikes, FCLs and Setbacks as spelled out in the companion documents and requiring the establishment of SLR Planning Regions, as described in Section 5.2.

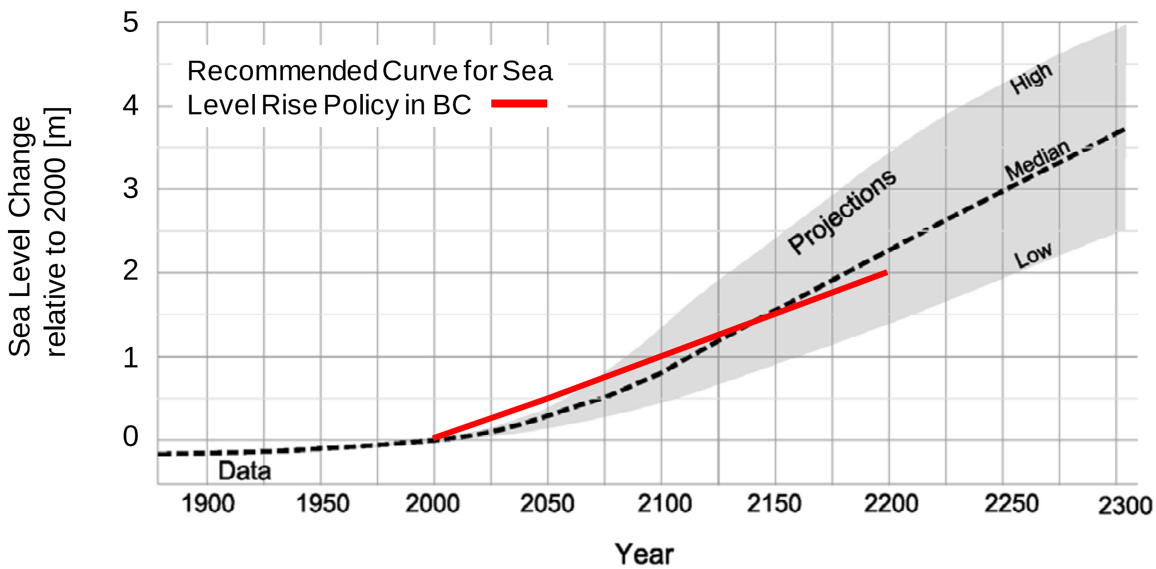

Figure 1: Recommended Global Sea Level Rise Curve for Planning and Design in BC
source: Figure 3-5, this document

Table 1: Sea Level Rise Recommendations and Their Application for BC Sea Dike and Coastal Flooded Land Management Guidelines

Development/ land use timeframe	Global SLR	Regional SLR	Application	Comment
For short to medium term - life of 25 to 50 years	0.5 m	To be developed on a site specific basis. See Appendix B for existing crustal movement rates along coastal BC shorelines.	Evaluation of existing structures (sea dikes)	This estimate is slightly higher than suggested by the present range of SLR estimates and planning curves and anticipates revision in the near future (circa 2014).
For longer term - life of up to 2100	1.0 m		Definition of requirements for permanent structures (sea dikes) that can be expected to be upgraded again in the future as science and knowledge increases	This is consistent with the present "*extreme high*" estimates in **BC Sea Level Report 2008**.
For issues with long life (> 100 years), and as a sensitivity example	2 m		Consideration of long-term land-use and planning issues having very long term implications – especially where decisions may be made that allow or encourage concentration of high value or high population density uses	This value is a balance between the current often stated upper limit of ~ 2 m for updated accounting of ice sheet mass loss by 2100 and potential increases identified by others.

4. At the present time, scientific information on the expected changes in storms approaching British Columbia coastal waters and their characteristics, specifically on the intensity of the storms, their related wave conditions and the associated storm surges in the future, is only starting to emerge. Based on the available information it appears reasonable to conclude that no significant change is expected in coastal BC waters; however, further investigations are warranted to fully assess the regional implications and to further assess future trends.
5. It is clear that the present recommended rates and trends for SLR have significant implications for British Columbia coastal communities. Detailed quantitative risk analysis (QRA) processes may be appropriate for some communities. In the meantime, and in situations where QRA may not be appropriate, the recommendations outlined in this document, and the companion documents, for design standards, design procedures and planning alternatives can provide a basis for initial planning and responses.

Recommendations for the implementation of these updated policies are provided in Section 8 of this document.

Acknowledgements

Preparation of this document and its companion documents was made possible through funding by Natural Resources Canada's Regional Adaptation Collaborative program and administration by the Fraser Basin Council.

1 Introduction

1.1 Purpose

Emerging information from scientists and agencies around the world indicates that in the near future and continuing thereafter for some time, anticipated climate change will result in increased rates of sea level rise. Rising sea levels will increase the risk of coastal flooding and the associated consequences.

The purpose of this project is to develop policies and updated guidelines for sea dike design and coastal flood hazard land management to address climate change factors in coastal waters of British Columbia. Specific objectives are to update the sea dike section of the ministry's existing "**Dike Design and Construction Guide**", July 2003, and the coastal section of the current "**Flood Hazard Area Land Use Management Guidelines**" May, 2004. The existing documents are referenced in more detail in Section 2.1 below.

The intent of this Draft Policy Document is to help to bridge the gap between the science and practical application of measures to address climate change factors in British Columbia coastal areas. While scientific studies discuss factors affecting relative sea level in detail, they do not set definitive guidance that can be readily applied to the many practical problems arising from sea level rise and other climate change impacts. For example, determining the appropriate crest elevation of a sea dike or the habitable building floor elevation in a coastal zone, potentially subject to flooding, must be based on policy guidance and engineering analysis in addition to scientific research findings.

1.1.1 The Policy Discussion Paper

Policy decisions are required to help guide the scientific and technical analyses regarding climate change and the implications for coastal sea dikes and flood construction levels. This document discusses the background for potential policies and the supporting rationale for adaption of the updated Provincial guidelines for sea dike design and coastal flood construction levels (FCL).

It specifically addresses:

- Global sea level rise scenarios – which one to use.
- Anticipated climate change effects on storm intensity factors.
- The appropriate project life or time interval to be used for dike and community planning to account for climate change.
- Design "standards": in terms of an annual probability of exceedance for design or planning of coastal flood protection works.
- Implication for long term community planning – e.g., when or where to defend versus retreat.
- Dike right of way – policy planning: specifically acquiring or setting aside the land needed for future dike expansion and upgrade.

1.2 Areas of Interest

The draft policies outlined in this document are intended to apply to all of coastal British Columbia, but the focus is concentrated into the following areas:

- Fraser River delta: Richmond, Delta and Surrey sea dikes.
- Lower Fraser River dikes where sea dike criteria govern.
- Vancouver Harbour: no dikes but extensive foreshore development.
- Squamish River delta: existing and development plans for sea dikes, downtown Squamish.
- East Vancouver Island: extensive existing coastal development and a few sea dikes (i.e. Cowichan River Estuary).
- West Vancouver Island, Central Coast and North Coast: occasional coastal development and few sea dikes (note: design for tsunami effects may govern building location and design).

Tsunami effects are not specifically addressed as these are independent of climate change and are outside of the scope of this document.

1.3 Consultation Workshop

As part of this program, a consultation workshop was held in Vancouver, to present and discuss the initial conclusions and recommendations described in this report and the companion guidelines. The initial conclusions and recommendations were further developed and refined to reflect the feedback received from the attendees and form the content of this report.

Ausenco Sandwell

2 Reference Documents, Definitions and Terminology

For the purpose of clarity, this draft policy document uses, where possible, definitions and terminology that are either consistent with existing documents or consistent with existing practise worldwide. In some cases existing definitions or terminology may require modification or clarification for application to coastal flooding or sea dike application in a continuing and accelerating climate change driven sea level rise scenario. Existing documents are summarized below followed by a brief summary of the definitions used in this document. Detailed explanation of definitions is provided in Appendix A.

2.1 Existing Documents

"BC Sea Level Report 2008" means the report, "An Examination of the Factors Affecting Relative and Absolute Sea Level in Coastal British Columbia" by R. Thomson, B. Bornhold, and S. Mazzotti, 2008, Fisheries and Oceans Canada, Institute of Ocean Sciences, Sidney, BC, Canadian Technical Report of Hydrography and Ocean Sciences 260, 2008. An unpublished addendum to this report was also provided by BCMOE for this document and is reproduced in part in Appendix B.

The summary report "Projected Sea Level Changes for British Columbia in the 21st Century (B. Bornhold, 2008, British Columbia and Canada) is also used. Copies of these documents can be downloaded from http://www.dfo-mpo.gc.ca/Library/335209.pdf.

"Dike Design and Construction Guide 2003" means the "Dike Design and Construction Guide – Best Management Practices for British Columbia", July 2003, prepared by Golder Associates Ltd. and Associated Engineering (BC) Ltd. for the Ministry of Water, Land and Air Protection. A copy of the document can be downloaded from:
http://www.env.gov.bc.ca/wsd/public_safety/flood/structural.html

"Land Use Guidelines 2004" means the Flood Hazard Area Land Use Management Guidelines, May 2004, prepared by the Ministry of Water, Land and Air Protection. A copy of the document can be downloaded from: http://www.env.gov.bc.ca/wsd/public_safety/flood/landuse_mgmt.html

2.2 Definitions

A summary of definitions and terminology used in this document is provided in Appendix A. Where possible the same terminology and definitions as used in the existing documents such as the **Dike Design and Construction Guide 2003** and **the Land Use Guidelines 2004** are used. However, in some cases existing terminology and definitions need modification, clarification or expansion to be appropriate for coastal conditions. It is recommended that readers of the updated documents familiarize themselves with the updated terminology and definitions in Appendix A as necessary.

3 Climate Change Impacts on Sea Level Rise, Storms and Tides.

3.1 Introduction

In general terms, climate change is expected to result in warmer air and sea temperatures, global, regional and possibly local increases in sea level, changes to ocean storm patterns and characteristics, and changes to precipitation and terrestrial vegetation. The precipitation and vegetation effects will affect rivers and streams that transit coastal areas. While climate change effects may not create new coastal hazards, they will exacerbate existing coastal flooding and erosion problems at many locations, both in areas where coastal flooding is experienced now (2010) or in low lying areas that may become exposed in the future. Commonly quoted impacts include:

- More coastal flooding or inundation, both in areas presently flooded and in areas presently above existing water levels.
- Increased coastal erosion due to exposure of land to higher water levels and wave action.
- Change to coastal ecosystems – potentially leading to coastal erosion and the interaction of storm related effects with the shoreline.
- Saltwater intrusion into coastal wells and aquifers.
- Changes in surface and groundwater quality.
- Changes in coastal sedimentation processes.

Specific changes that will affect shorelines, the land immediately landward of the shoreline and existing coastal defences, through various marine processes, include:

- An increase in mean sea level (MSL), resulting in a rise in the relative elevation of tides, which changes both the frequency of flooding for a given land elevation and exposes new land to a flooding hazard. Depending on the land elevation, flooding may start to occur due to tide alone or due to the combined effects of storms and tide.
- An increase in MSL will lead to a disconnection between the existing correlation between MSL and the vertical reference plane (Canadian Geodetic Datum - CGD) used to define terrestrial elevations[1]. Unless CGD is revised at the same rate as sea level increases a false sense of security may arise.
- Increased water levels will increase the depth of water at existing shorelines and increase the heights of waves that can exist at the present shoreline.
- The frequency and duration of wave action at existing shorelines will increase, leading to more severe design conditions for existing coast defences, or more frequent flooding of low lying unprotected land.
- Wave runup and the volume of water overtopping existing shorelines or coastal structures will increase, which can lead to increased erosion of the area behind the structure, leading to

[1] In 2010 the vertical reference plane in Canada is in the process of being changed from a MSL related datum plane – technically known as CGVD28 – to a geoid based datum plan. The update program is described at http://www.geod.nrcan.gc.ca/hm/index_e.php. For the purpose of this document we use the term CGD to mean the datum as defined in 2010 and approximately equal to MSL.

failure of the defence itself, or increased risk and extent of inundation where low lying land exists behind a coastal defence.

- Larger waves, resulting from sea level rise alone, increases the wave loads on a coastal defence structure and the risk of damage or failure. As an example, the weight of a rock required for stability on a sea dike slope is directly proportional to the cube of the wave height at the toe of the structure. Increased wave heights will require an increase in the size of armour required to achieve the same stability. Increased duration of exposure will also likely require an increase in the size or quantity of armour materials on an existing coastal defence structure. Transitions at places along a dike system where other features such as tidal gates or pump outlet structures are present, will also be more vulnerable to damage or breaching.
- Larger waves also means increased wave energy is reflected from coastal defence structures and may lead to higher wave related currents and increased scouring on the seaward side of a coastal defence structure. This will likely increase the risk of undermining the structure and further increasing the depth of water that needs to be considered.

Harford (2008) notes that in BC:

- A 1 metre rise would inundate more than 4600 ha of farmland and more than 15,000 ha of industrial and residential urban areas in the lower mainland of BC.
- Approximately 220,000 people live near or below sea level, currently protected by 127 km of dykes not built to accommodate rising sea levels resulting from climate change.
- Coastal communities and coastal tourism, and their associated infrastructure and services, are vulnerable to erosion, storm surges, extreme high water events and flooding hazards.

Hanak and Moreno (2008) suggest that low-lying coastal communities will face increasing difficulties draining treated wastewater and stormwater via traditional gravity-based systems, as these systems may ‘back up’ due rising sea levels at their outlets. Streams presently flowing through communities or culverts and discharging into tidewater will also be affected. This will be further exacerbated if more extreme precipitation events also occur as part of climate change.

Saltwater intrusion into the groundwater of coastal lands and lands bordering rivers near the coastline will also impact fresh water supply for agriculture, which may, in turn, change the economics and nature of activity, land use and land values. These effects have an influence on decisions relative to management of coastal lands or the design and construction of sea dikes; however, this additional influence of climate change on coastal areas is not addressed specifically in this document.

This chapter examines three aspects of climate change impacts on coastal areas:

- Change in relative sea level – global and regional.
- Storminess and storm surge.
- Impacts on high tides.

3.2 Relative Sea Level Change

Definition of the potential effects of climate changes on sea level requires consideration of two main factors:

- Projected *global* sea level rise associated with climate change (global SLR); and
- *Regional and local* factors that affect the manifestation of global sea level rise in the project area (regional SLR).

An understanding of sea level rise relative to the land also requires an understanding of the ongoing changes in geological related crustal processes along the coastline of BC. These processes are addressed in the **BC Sea Level Report 2008**, and where necessary incorporated or referenced in this document.

3.2.1 Global Sea Level Rise Projections

The degree of change that can be expected in coastal areas is essentially defined by the expected sea level rise, and in turn, by how far into the future the expected changes are considered. Expected global SLR is well described in the scientific and associated literature, and summaries of these projections are provided in various update documents prepared in 2009 (see References, this document). Expansion on and updates to this literature can be expected for some time to come.

Based on present and expected increases in emissions in the near future, sea levels are expected to rise at accelerating rates into the next century and even if drastic measures are affected to slow down or even stop GHG emissions, to persist for several millennia in the future.

Figure 3-1 provides a recent summary of global SLR projections extending over the next three hundred years. The grey band spans the range of uncertainty that exists in these predictions, including different estimates of future global SLR resulting from the family of scenarios described by the IPCC in its 2007 Assessment Report 4 (AR4), IPCC (2007). These scenarios consider the overlapping effects of future population growth, global economic trends and emissions trends and strategies. The bands and trends in Figure 3-1 also reflect the effects of what is commonly referred to as post IPCC AR4 science. Projections of very long term persistent changes in SLR are provided in Solomon, et al. (2009), which shows that elevated sea and levels will persist for millennia, even in the most optimistic IPCC scenarios.

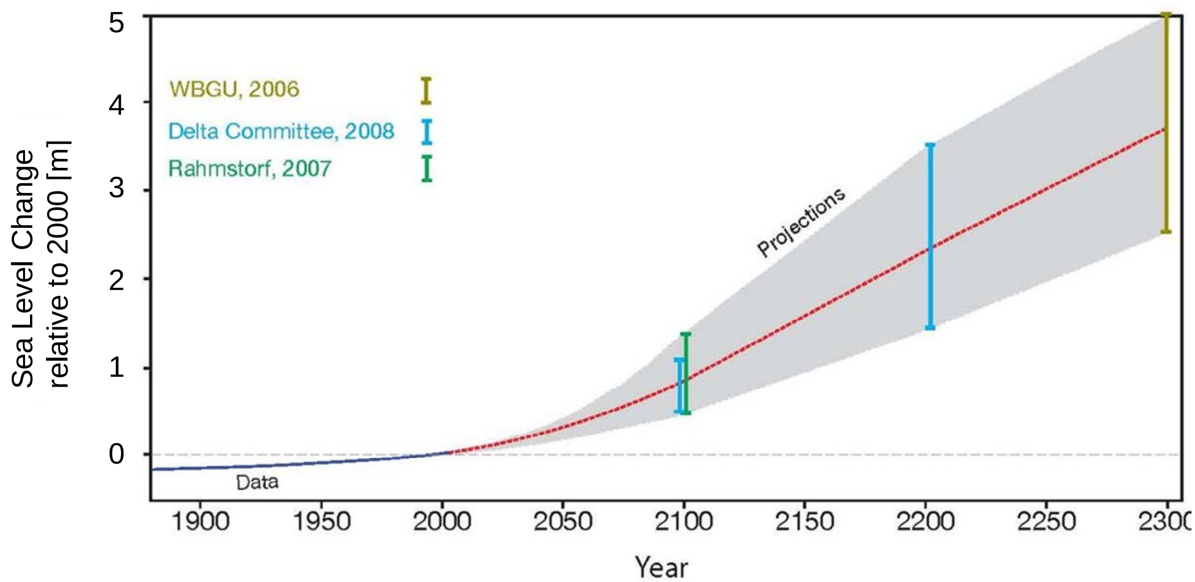

Figure 3-1: Recent Projections of Expected Global Sea Level Rise
Source: Allison *et al.,* 2009

Recent measurements of carbon emissions, Figure 3-2 and sea level rise, Figure 3-3, both suggest that the present trend is close to, or above, the upper envelope of global scenarios. However, the duration of available information, approximately 15 years, may be too short to differentiate between a long term trend versus shorter term fluctuations that exist in the observed data, both in recent times and over the last century. Monitoring and the ongoing assessment of the collected data can be expected to revise these comparisons.

Of the series of greenhouse gas scenarios generated by the IPCC Assessment Report 4 (AR4; IPCC, 2007), the A1FI scenario is often used as the basis for assessing future global SLR. The A1FI scenario predicts a global mean temperature increase of approximately 2° to 6˚C by 2100 to reflect high economic growth with widespread global use of fossil fuels. As actual emissions since 2000 align with or even exceed this IPCC estimate (Figure 3-2) suggests that the A1FI scenario is a realistic basis for assessing potential future effects at this time (Delta Committee, 2008).

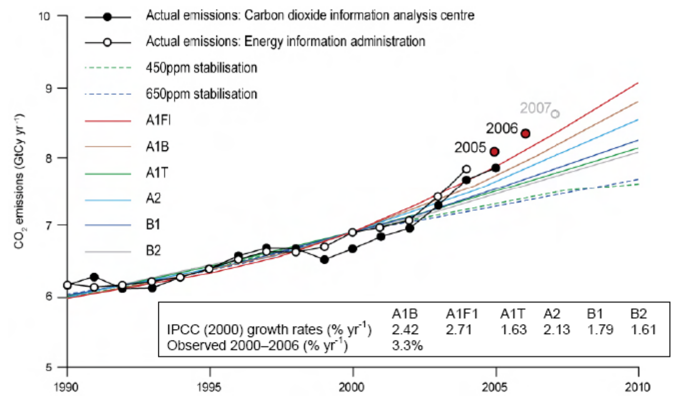

Figure 2 Projected and observed CO_2 emissions. The envelope of IPCC projections are shown for comparison (*Source*: Steffen 2009, Raupach et al. 2007; with additional data points from Canadell et al. 2007 and Global Carbon Project annual carbon budgets; © National Academy of Sciences, USA)

Figure 3-2: Projected and Observed CO_2 Emissions
Source: NSW Government, 2009

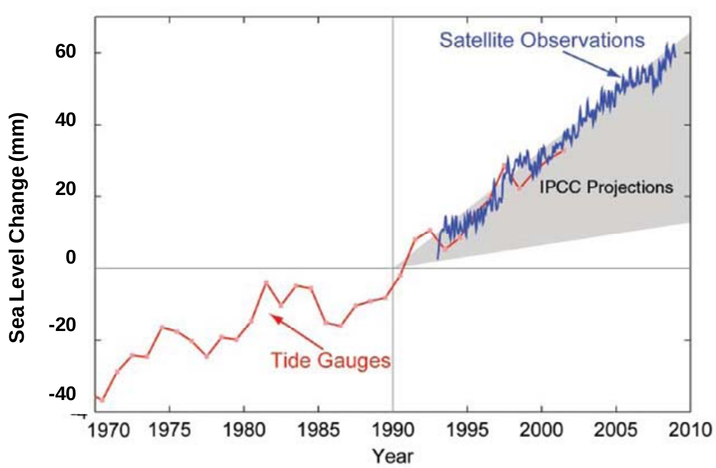

Figure 16. Sea level change during 1970-2010. The tide gauge data are indicated in red (Church and White 2006) and satellite data in blue (Cazenave et al. 2008). The grey band shows the projections of the IPCC Third Assessment report for comparison.

Figure 3-3: Projected and Observed Global Mean Sea Level Changes
Source: Allison *et al.,* 2009

The IPCC A1FI scenario projected a global SLR of 0.25 to 0.76 m by 2100. However, the IPCC estimate does not take into account the effect of melting ice sheets because at the time of the IPCC AR4 report the fate and rate of ice discharge from the ice sheets in Antarctica and Greenland was very uncertain. The occurrence of accelerated ice melt of these ice sheets since IPCC AR4 has led many experts to consider that the IPCC AR4 projections underestimate future global SLR:

- According to Allison *et al*. (2009), satellite and ice measurements now demonstrate that the Greenland and Antarctic ice sheets are losing mass at an increasing rate; glacier melting in other parts of the world has also accelerated since 1990. Satellites also show global average SLR to be 80% above past IPCC predictions; which is consistent with a doubling in contribution from melting of glaciers, ice caps and the Greenland and West-Antarctic ice sheets. Allison *et al.* (2009) predict that by 2100, global sea level is likely to rise at least twice as much as projected by the IPCC AR4; for unmitigated emission it may well exceed 1 meter. The authors note that future sea level rise is still highly uncertain, mainly due to unknowns regarding the rate and extent of response of the big ice sheets to global warming. However, they also note that sea level will continue to rise for centuries after global temperature has been stabilized and several meters of SLR must be expected over the next few centuries.
- In their study for the United Nations Environment Program, McMullen and Jabbour (2009) also indicate that Arctic ice is melting faster than previously assumed, and that plausible values of total global average sea level rise, including all land-ice sources plus thermal expansion, may reach 0.8 to 2 m by 2100.
- Based on their estimates of ice sheet contribution, the Delta Committee (2008) of the Netherlands estimate a global SLR of 0.55 to 1.10 m by 2100, and a *possible* upper limit rise in global SLR of 1.5 to 3.5 m by 2200. This range is indicated in Figure 3-1.
- In December, 2008, the U.S. Climate Change Science Program (USCCSP) released a report to the U.S. President and Congress on expected abrupt climate change. The report specifically addresses the expected effects of an increased contribution to global sea level rise due to dynamic ice mass wasting processes[2] that are not included in the models which underlie the IPCC predictions. The USCCSP report does not predict specific annual rates due to the present lack of detailed predictive tools linking atmosphere – ocean – ice interaction processes. Inclusion of responses from these processes is; however, expected to result in sea-level projections for the 21st century "that substantially exceed the projections in the IPCC Fourth Assessment Report".
- The selection of the A1FI emissions scenario and its impacts on climate change for 2100 and beyond is also recommended by the Pacific Climate Impacts Consortium[3] and is consistent with other Regional Adaptation Collaborative (RAC) projects in BC, currently planning for a timeline of 2100 and beyond.

3.2.2 Regional Sea Level Rise Projections

Global sea level rise expectations must be adjusted to account for regional variations and for crustal movements particular to the area under consideration. Regional variations to be considered include:

[2] In general terms these processes include an accelerated rate of contribution to sea-level rise due to increased rates of ice movement into the sea or sub-sea melting of portions of the Greenland and Antarctica ice sheets currently grounded below present sea-level.
[3] Pers Comm: T. Murdock, 29 July 2010.

- Variations particular to the Pacific Ocean Basin and to the NW Pacific portion;[4]
- Variations particular to coastal British Columbia waters;
- Local variations caused by crustal movement leading to land uprising or subsidence, which may offset or exacerbate the sea level rise.

The **BC Sea Level Report 2008** provides the most recent definition of expected regional or local sea level rise due to climate change effects. The results of this study are summarized below in Table 3-1. The "*mean*" values in Table 3-1 are based on a global SLR of 0.3 m by 2100, which corresponds to the present rate of rising sea level based on recent satellite observations (Figure 3-3). The "*extreme high*" values are based on a global SLR of 1.0 m by 2100.

The ranges expressed for each region in Table 3-1 are due to variations in the underlying data defining the crustal movement in each region along the BC coast (see Appendix B). There is additional variation – not shown in Table 3-1 – attributable to uncertainties in the crustal movement data. As an example, the "extreme high" estimate for the Fraser River Delta has a range of 0.87 to 1.53 m around the quoted 1.2 m mean value.

Table 3-1: Summary of Regional Sea Level Rise Estimates for 2100 for Selected BC Locations

Source: BC Sea Level Report 2008

Location	Sea Level Rise based on *extreme low* estimate of global sea level rise (m)	Sea Level Rise based on *mean* estimate of global sea level rise (m)	Sea Level Rise based on *extreme high* estimate of global sea level rise (m)
Prince Rupert	0.10–0.31	0.25–0.46	0.95–1.16
Nanaimo	–0.04	0.11	0.80
Victoria	0.02–0.04	0.17–0.19	0.89–0.94
Vancouver	0.04–0.18	0.20–0.33	0.89–1.03
Fraser River Delta	0.35	0.50	1.20

Planning or design of appropriate responses to coastal flooding or of sea dike requirements needs more than an estimated height of sea level rise by a given date. It is also necessary to understand the rate at which sea level will rise to the expected height and how the sea level will rise beyond the specific date.

The planning sea level rise curves being used by other jurisdictions are briefly summarized below.

- the New Zealand Ministry for the Environment (2008) recommends the following parameters for planning and decision timeframes out to the 2090s:
    - a base value of SLR of 0.5 m relative to the 1980-1999 average;
    - an assessment of the potential consequences of SLR of <u>at least</u> 0.8 m relative to 1980-99, where impacts are likely to have high consequence or where additional adaptation options are limited;
    - for longer planning and decision-making timeframes, an allowance for SLR of 10 mm per year beyond 2100. By 2200, this would result in a SLR of approximately 1.8 m.

[4] Available satellite measurements of recent sea level rise show considerable variation around the globe compared to the often quoted global means. Information on the global variation during upcoming climate change is not as readily available at this time.

- The US Army Corps of Engineers (2009) directs that planning studies and engineering design consider alternatives for the entire range of possible future rates of sea-level change. Alternatives are to be assessed using "low," "intermediate," and "high" rates of future sea-level change. These rates are indicated in Figure 3-4 and have the following basis:
  - The "Low" rate (Modified NRC-I) [5] is based on historic rates of sea-level change from tide gauge records.
  - The "Intermediate" rate (Modified NRC-II) reflects the IPCC 2007 AR4 projections.
  - The "High" rate (Modified NRC Curve-III), which exceeds the upper bounds of IPCC 2007 estimates, anticipates a potential rapid loss of ice mass from Antarctica and Greenland.

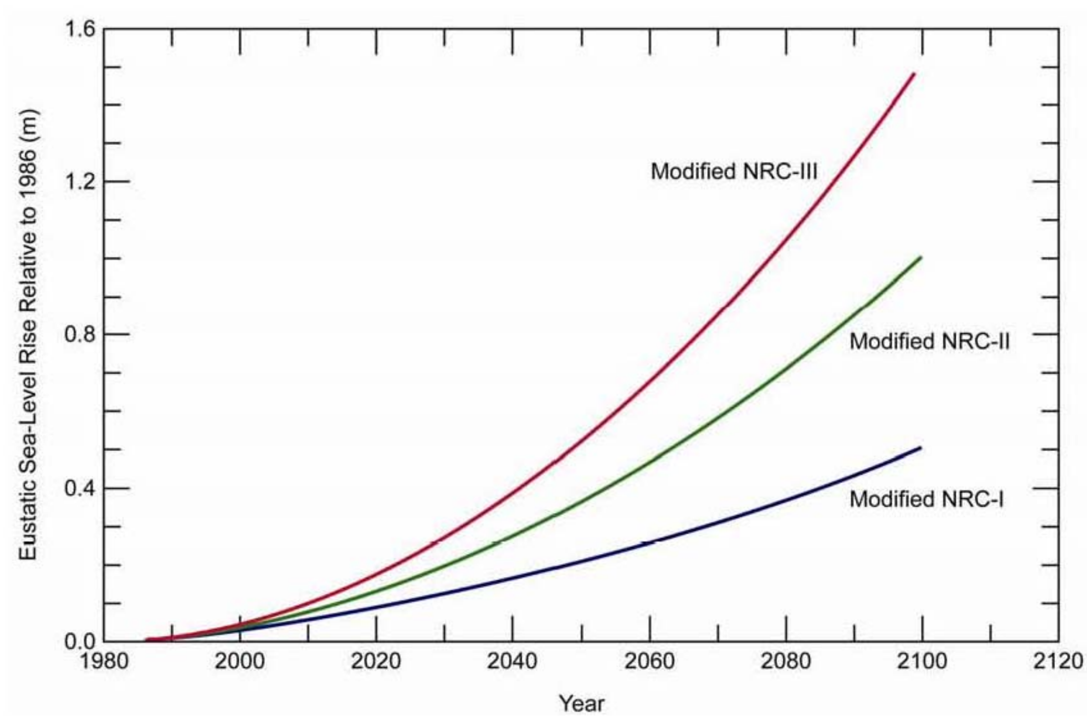

Figure 3-4: US Army Corps of Engineers Planning and Design Curves
Source: (US Army Corp of Engineers, 2009)

- The Delta Committee (2008) of the Netherlands, using the same mean temperature increase of 2 – 6 ^{o}C as the IPCC A1FI scenario but including estimates of ice sheet melting, estimates a local sea level rise along the Dutch coast of 0.55 to 1.20 m by 2100, and 2.0 to 4.0 m by 2200.
- In a recent study for the UK, Lowe, et al., 2009, assembled a standalone overview of climate change related marine effects around the UK coastline, showing key findings and detailing the science used. In response to requests for a high end coastal flooding scenario that lay beyond the likely range for the 21st century, but still remained within the physically plausible range, a High plus plus (H++) scenario was developed. This H++ range is an attempt to quantify the emerging understanding of dynamic ice sheet processess described but not fully quantified in the IPCC AR4 reports. An upper limit of +2.5 m sea level rise was adopted for the 21st century

[5] The NRC curves are from: National Research Council 1987 Responding to Changes in Sea Level: Engineering Implications. National Academy Press: Washington, D.C. http://www.nap.edu/catalog.php?record_id=1006

(from 1990 – 2095). This rise was recognized to be greater than an upper limit of 2 m for the 21st century suggested by Pfeffer, Harper and O'Neel (2008).

It is clear that a range of both planning curves and date specific global SLR estimates are being used worldwide at the present time (2010). These curves and the associated date specific predicted SLR heights can be expected to become similar as more data and analysis becomes available in the future. It also seems clear that the present BC regional SLR estimates for 2100 (Table 3-1) could be low and also that further guidance is warranted for time frames extending beyond 2100.

3.2.3 Recommendation for BC Sea Level Rise Policy and Adaptation Planning

Based on the results summarized above, it is recommended that the sea level rise curve provided below in Figure 3-5 should be used as the basis for defining policy in BC. The envelope of projections shown on Figure 3-5 reflects the ranges described above. The recommended curve is slightly higher than the high projection, for the years from the present, up to approximately 2070, to reflect the present trends of measured CO_2 emissions and sea level rise to be greater than the IPCC projections as discussed above. The recommended curve moves below the current median projection with the recognition that in a planning framework, time remains to revise the recommended curve upwards, if the science or the required response warrants.

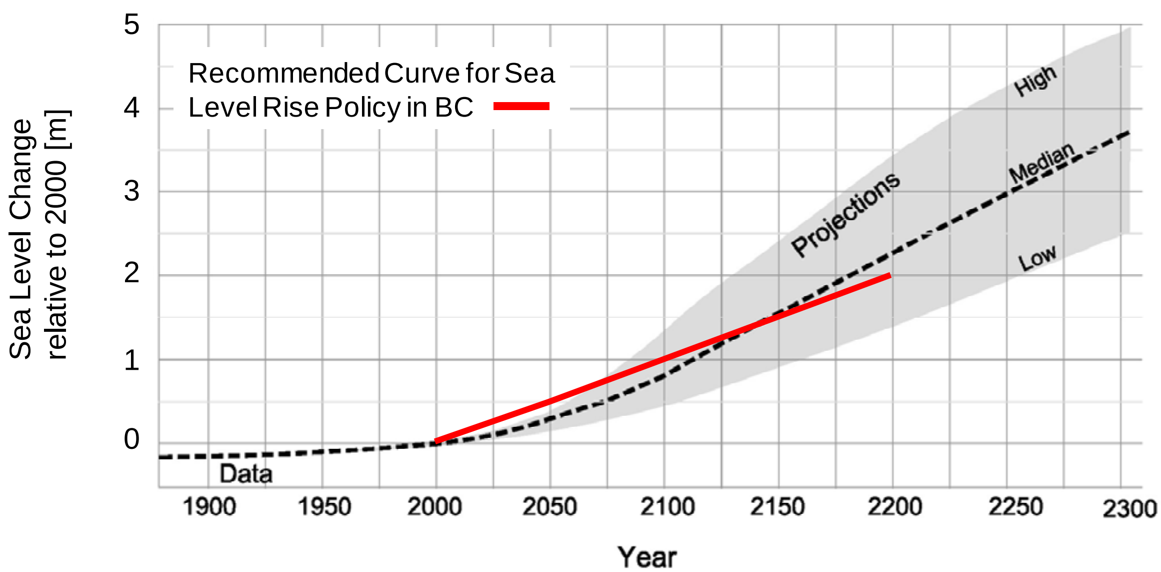

Figure 3-5: Recommended Global Sea Level Rise Curve for Planning and Design in BC

The specific increases for common time frames; their likely application and the underlying rational are summarized in Table 3-2. Specific adjustment of the global SLR defined by Figure 3-5, to account for regional factors along the BC coast, can be made by reference to the **BC Sea Level Report 2008** and Appendix B.

These recommended values represent an initial precautionary approach, given prevailing uncertainties, and will likely undergo review and revision over the near future; as more measurements and observations of related phenomena become available, as the science and the associated modelling assimilate the results, and as the trajectory of global response to climate change issues becomes clearer. It is recognized that considerable social and economic implications may arise; however the early precautionary approach means that implementation of planning measures can be easily adjusted if future data and science confirms a slower rise in global SLR. Based on the envelope curves in Figure 3-5, planning for a global SLR of 0.5 m over the next 25 to 50 years would be appropriate for 2100, if climate change and the related sea level effects follows the low projection curve.

As a further commentary it should be noted that in a 2009 Policy Statement on Sea Level Rise, the New South Wales (NSW) Government of Australia states "The use of the [NSW] benchmarks will be required when undertaking coastal and flood hazard assessments in accordance with the Coastline Management and Floodplain Development Manuals. It is already a statutory requirement that the preparation of local environmental plans gives effect to and be consistent with these Manuals. " (emphasis added).

The NSW government goes on to state "the benchmarks are not intended to be used to preclude development on land that is projected to be affected by SLR. The goal is to ensure that such development recognizes and can appropriately accommodate the projected impacts of SLR…" (emphasis added).

Table 3-2: Sea Level Rise Recommendations and Their Application for BC Sea Dike and Coastal Flooded Land Management Guidelines

Development/ land use timeframe	Global SLR	Regional SLR	Application	Comment
For short to medium term - life of 25 to 50 years	0.5 m	To be developed on a site specific basis. See Appendix B for existing crustal movement rates along coastal BC shorelines.	Evaluation of existing structures (sea dikes)	This estimate is slightly higher than suggested by the present range of SLR estimates and planning curves and anticipates revision in the near future (circa 2014).
For longer term - life of up to 2100	1.0 m		Definition of requirements for permanent structures (sea dikes) that can be expected to be upgraded again in the future as science and knowledge increases	This is consistent with the present "*extreme high*" estimates in Table 3-1.
For issues with long life (> 100 years), and as a sensitivity example	2 m		Consideration of long-term land-use and planning issues having very long term implications – especially where decisions may be made that allow or encourage concentration of high value or high population density uses	This value is a balance between the current often stated upper limit of ~ 2 m for updated accounting of ice sheet mass loss by 2100, (Allison, et al., 2009; USCCSP, 2008) and the median estimate for the year 2200 developed by the Delta Committee (Delta Committee, 2008).

3.3 Storm Effects

On a global scale, climate change is generally expected to result in increases to the frequency, intensity and to other characteristics of storms, especially for hurricanes or tropical cyclones in low latitude and sub-tropical regions. In the mid-latitude regions, especially in the Pacific Ocean basin between 30 degrees and 60 degrees latitude N, the expected changes that will affect coastal BC waters are not well defined in the climate change literature.

Climate change related influences on the overall storm generation processes in the earth's atmosphere and primarily in the troposphere, where storms are created, may result in increased wind speeds, increased durations of strong winds, larger atmospheric pressures differences and corresponding changes to storm tracks, storm surges and the storm wave climate. However, this is largely conjecture and a potential decrease in some or all of these storm characteristics cannot be discounted at this time.

A review of the scientific literature, as of February 2010, indicates that studies of possible changes are on-going and take two typical forms:

- Review and analysis of long records of recorded winds, water levels or waves.
- Review and assessment of the results of ensembles of Global Climate Models (GCMs) and, in some cases, scaled down results from Regional Climate Models (RCMs). Both model classes generally include coupled oceanic and atmospheric physics in their formulation.

A detailed review of the literature is beyond the scope of this assignment; however, based on an initial review, these investigations tend to suggest the following trends:

- A small increase (generally less than 10 per cent) in the mean or in the extreme values, can be seen in some sets of recorded data from the last 30 to 40 years.
- A similar trend is not clear in recorded data sets that extend as far back as 80 to 100 years.
- Global (GCM) and regional (RCM) atmospheric-oceanographic model results, which have been calibrated against the last 40 years of available data for ocean weather and waves, tend to show only a small increase, sometimes a decrease, for all IPCC scenarios into the future, in the mid-latitudes and especially the latitudes (40 degrees - 50 degrees N) where most storms that affect coastal BC waters are generated.

The difference between the recorded data set based studies and the forward looking coupled models may be because the recorded datasets do not tend to be long enough to separate multi-decadal scale variations from any specific climate change related trends over the decades covered by the recorded data sets.

Regional studies, involving a downscaling of GCM results, specifically to the NE portion of the Pacific Ocean basin, have not reported in the technical literature at the time of this review (February 2010); however, Ulbrich, et al., 2009, in a comprehensive review of climatologies of mid-latitude cylcones for both Northern and Southern Hemispheres, for both the present climate and for possible future anthropogenic climate changes, found a range of mixed results.

For existing climate conditions, Ulbrich, et al., 2009 report the following for the North Pacific basin area:

- An overall northward shift of mid-latitude storm tracks.
- A range of results for frequency or intensity of extreme cyclones that is sensitive to the choice of storm identification algorithms and of the representative dataset.

- A significant change in the intensity of mean winter cyclones over the North Pacific, accompanied by the northward shift in storm track.

For future climate change scenarios, Ulbrich, et al., 2009 found that 16 separate available GCM's, all of which had a reasonable ability to reproduce the general structure of existing climate conditions, tended to show the following trends for the future climate in the North Pacific, over a range of different greenhouse gas scenarios:

- The number of extreme cyclones increases in winter, but the total number of cyclones is reduced.
- An increasing number of extreme cyclones is not a general result and several studies found this is only the case for limited defined areas, such as near Great Britain in the North Atlantic and near the Aleutian Islands in the North Pacific.
- The results are very variable from model to model and appear to be sensitive to how an intense or extreme cyclone is defined.

The Delta Committee (2008), of the Netherlands, concluded, based on IPCC AR4 (2007) scenario results, examined specifically for the Dutch coast, that projected future changes in wind and wave conditions will be small relative to natural variability and the inherent uncertainty associated with the use of relatively short data series. The scenarios used by the Committee showed no clear dependence on future greenhouse gas emissions.

In a recent study for the UK , Lowe, et al., 2009, who examined the results of an ensemble of GCM and RCM model results for IPCC AR4 (2007) scenarios for UK waters, found that the physical significance of any trend in the storminess-driven component of extreme sea level – i.e. surges – by the end of the present century (2100) was small. The related trends in wave climate were also small, with a general decrease of the northern waters of the UK and a small increase over southern waters of the UK. The changes were attributed to expected changes in storm tracks over the North Atlantic.

In a just released study (June, 2010) Mori et al (2010) conclude, on the basis of a 20 km by 20 km high resolution GCM model, for the IPCC A1B scenario, that the mean annual signifcant wave height in the North Pacific, adjacent to British Columbia waters, will decrease by approximately 5 to 10 per cent.

It is clear that further study and analysis is required to define the expected trends over the North Pacific and specifically for the mid-latitiudes occupied by BC coastal waters. For the present assignment we have assumed that the existing storm population is a reasonable model for the expected storm population in the future. It may actually tend to overestimate future trends in southern BC coastal waters.

3.4 Tide Range and High Tide Frequency

Tides around the world are predominately generated by the relative motions and gravitational forces of the earth, moon and sun and their collective effect on the ocean, which covers 70 per cent of the earth's surface. Climate change is not expected to change these interactions directly; however, some high level science papers have postulated that melting of the polar ice caps may eventually change the character of the earth's rotation leading to changes in tidal characteristics. For the purpose of this assignment, no change in tidal characteristics in BC coastal waters is anticipated.

At present there is a close and well defined relationship between tide ranges, mean sea level (MSL) and the vertical reference plane normally used in Canada, i.e. Canadian Geodetic Datum (CGD), to define elevations on land. As sea level rises the relationship between the terrestrial datum CGD and MSL will change, unless CGD is continuously revised. For the purpose of this document we refer to the 2010 version of the CGD terrestrial datum and associated elevations as a constant.

MSL will rise in the foreseeable future due to climate change but the tide ranges, which are related to MSL, are not expected to change. Tide ranges will still be centered about MSL but their absolute elevations will rise in relationship to CGD.

For the purpose of this assignment, existing tidal information is superimposed on a mean water level that reflects the sum of existing mean water level plus the appropriate regional SLR.

4 Community/Land Use Planning and Hazard Management Options

Climate change may not create new coastal hazards but it will almost certainly exacerbate existing coastal flooding and erosion problems. The literature on climate change refers frequently to four main land use “strategies” for adapting to the hazards created or increased by climate change:

- Avoid.
- Protect.
- Accommodate.
- Managed Retreat.

Each of these strategies is briefly discussed in this section, as the need to construct or upgrade sea dikes or to define the exposure to coastal flooding, is closely related to which strategy is being considered or adopted.

4.1 Avoid

In simplest terms, avoidance means not developing in areas considered at moderate to high risk to a hazard. Avoidance measures are typically limited in application to future development or redevelopment. Typical avoidance measures include:

- Zoning or designating lands as undevelopable or only suitable for very low density development or for land uses that have relatively low risk with respect to flooding and inundation. “Risk Zoning” is discussed further in Section 4.7.3 of this document.
- Setbacks to place structures beyond the reach of sea level rise, tides, storm surge or the effects of waves.

4.2 Protect

Protection means building protective structures specifically for protecting private and public assets. Protection approaches and designs may be “hard” (e.g. by armouring the coastline with sea dikes, seawalls or riprap revetments) or “soft” (e.g., by constructing or augmenting berms, dunes, beaches and marshes).

There are limits to the extent to which communities can or should rely on structural protection to adapt to climate change effects. On eroding coastlines that have been developed, there is typically high public (and often political) demand for coast protection measures to ‘hold the line’ and protect private property, infrastructure or utilities. Such measures are often viewed by the public as ‘solutions’ to coastal erosion problems; however with a rising sea level the distinction between erosion protection and flooding protection may become blurred. The decision to protect tends to:

- Be reactive.
- Lead to a false sense of future security; many constructed coastal defences are not as permanent as the residents behind them assume.
- Often encourage further development behind the structures.
- Lead to other property and environmental damage and impacts on other coastal values including aesthetics and recreational access.

- Rising sea levels will dictate that sea dikes must be raised periodically and considerable land area behind the dikes will need to be acquired for the dike right of way.
- Create an expectation that defences will be maintained in perpetuity, leading to ever increasing financial commitment to maintain and upgrade such defences.

On coastlines that are retreating, the effectiveness of coastal defences is continually reduced while the potential negative impacts caused by them often increase. This process is likely to be accelerated by climate change.

In the aftermath of storm events where retreat or inundation has occurred, there is a temptation to use coastal protection works as a short-term measure to 'buy some time' to permit more long-term options to be explored and implemented. However, in reality, once defence works are in place, it is extremely difficult to then remove them.

4.3 Accommodate

Accommodating climate change effects means adapting land-based structures and activities to tolerate flooding and inundation. Typical accommodation measures include (Heap, 2007):

- Building above Flood Construction Levels (FCLs) to avoid flooding.
- Flood resilient construction measures - e.g., waterproof resilient materials; situating electrical devices above projected flood level; one-way valves in drainage pipes; moving building contents out of the flood path.
- Liability reduction measures – e.g., covenants indemnifying governments should a hazard occur; certification by a qualified professional that the design and construction will mitigate risks; more stringent design criteria.
- Warning and evacuation protocols based on thresholds such as rainfall amounts or predicted storm events.
- Innovative institutional and regulatory measures – e.g., rolling easements (see discussion under "Managed Retreat").

4.4 Managed Retreat

'Managed retreat' is defined as any strategic decision to withdraw, relocate or abandon private or public assets that are at risk of being impacted by coastal hazards (New Zealand Ministry of Environment, 2008) . Relocation of properties tends to occur on a case-by-case basis, usually at the discretion of a private property owner.

The various scales of managed retreat include:

- Relocation within a property boundary.
- Relocation to another site.
- Large-scale relocation of settlements and infrastructure.

The most likely methods for implementing managed retreat would be a mix of some or all of the following (New Zealand Ministry of Environment, 2008):

- District and regional plan measures that relate to managing existing use rights and limiting or controlling the construction of protection works.
- Property title covenants, to prevent undesirable activities such as construction of coastal defences. Covenants may also specify where and when retreat and/or relocation is required.

- Financial instruments or assistance measures including:
  - Purchase of property.
  - Subsidies for relocation.
  - Taxation of risk or adverse effects.
  - Pre-paid community relocation fund.
  - Transferable development rights.
  - Relocation of infrastructure out of a hazard area.
  - Insurance incentives or disincentives.

For managed retreat to be implemented, Turbott and Stewart (2006) suggest that regulation must also include two key elements:

1. prohibiting hard protection works in the coastal marine area and adjacent land, and
2. specifying control of land-use rights for both new and existing buildings plus the trigger levels that would require relocation.

Significant barriers exist to managed retreat becoming a strategic and more commonly applied mechanism including public perception, existing land use rights, costs, the infrequent use of decision-making tools, particularly cost–benefit analysis, that incorporate non-market valuations.

4.4.1 Managed Re-alignment – A Variation on Retreat

Managed Re-alignment, a favoured term in Europe, involves setting back the line of actively maintained defences to a new line inland of the original – or preferably to rising ground – and promoting the creation of intertidal habitat between the old and new defences (Rupp and Nicholls, 2002). This is accomplished either by the complete removal or by a breach of the defence. The main objectives are:

- Habitat conservation: intertidal habitat conservation and re-instatement. Intertidal habitat also provides recreation and public enjoyment opportunities and acts as pollution sinks.
- Flood defence: salt marshes can be effective dissipaters of wave energy and the first line of defence against tides and waves, reducing the capital and maintenance costs of fixed flood defences.

In the EU, salt marshes are protected under the EU Habitats Directive and as habitat for species protected under the Birds Directive. The United Kingdom’s biodiversity action plan aims to prevent net loss of salt marsh area, as present in 1992; hence, all losses must be compensated by equivalent replacement habitat. In England, “coastal squeeze” by SLR is recognized as a major threat and targets for creating 140 ha/yr of salt marsh to offset past and present losses have been set.

Managed realignment is most appropriate to low-lying, lightly developed or marginal coastal lands; relocating dikes inland may shorten the length required, increasing the cost effectiveness of this measure. Other factors favouring managed realignment as an adaptation measure include (Rupp and Nicholls, 2002):

- The importance placed on maintaining or re-instating intertidal habitat.
- The traditional use of salt marshes as coastal defence mechanisms.
- The current state of dikes; i.e., whether they are “fit for purpose” or near the end of their life.

- Public perception of the “right” to protection.

4.5 Choice of Options

There are a number of factors that need to be considered when determining which option may be appropriate in any given situation. In general the option to “avoid” only applies in undeveloped lands although it can refer to decisions concerning future development or redevelopment. In this latter case the “avoid” option becomes similar to the option to “retreat” – although perhaps in a managed manner. Factors to be considered when determining whether to “protect” and/or “accommodate” versus “retreat” from coastal flooding hazards, include:

- Number of people affected.
- Development density.
- Property value.
- Capacity to move and the cost of structures and assets to be moved.
- Availability of alternative locations for structures, land use or assets to be moved.
- Liability of public agencies vs. private interests.
- The likelihood or probability of being flooded now or at some time in the future.
- Evaluation of the total implications of each option and identification of the appropriate choice of option.

The key stakeholders in the evaluation of appropriate options include, in no particular order:

- Public bodies and authorities responsible for the area in question.
- Project funders (who may be the same as above).
- Project planners and engineers, largely responsible for the assessment, design and maintenance of the area and works in question.
- The general public.
- Insurers.
- Environmental, heritage and other interested groups.

Ongoing structural protection may be a long-term option in highly developed urban areas with a long history of coastal protection and the funding capacity to pay for the potentially high cost of protection. Coastal planning can strategically identify where “protect” options may be appropriate, and make hard protection works a prohibited activity outside these areas. This would send a clear signal about where such measures are appropriate and, more importantly, where they will not be considered.

Such planning measures can be difficult to implement, particularly with shoreline property owners. Yet the complications that arise from not managing coastal development and protection works can be far more complex and expensive in the long run. Some of the public opposition may be reduced by providing good information and participation processes, but acceptability of these measures will never be universal.

Table 4-1 summarizes some of the options for responding to sea level rise in terms of their approach and environmental effects.

Table 4-1: Example Measures for Responding to Sea Level Rise
(adapted from Titus *et al.,* 2009)

Measure	How It Works	Environmental Effects
Avoid		
Setback	Delay the need for shore protection by keeping development out of the most vulnerable lands	Impacts of shore protection delayed until shore erodes up to the setback line; impacts of development also reduced.
Density or size restriction	Reduce the benefits of shore protection and thereby make it less likely	Depends on whether owners of large lots decide to protect shore; impacts of intense development reduced.
Protect		
Seawall	Shoreline armouring used to define a shoreline- reduces erosion, protects against flood and wave overtopping	Elimination of beach; scour and deepening in front of wall; erosion exacerbated at terminus
Revetment	Shoreline armouring used to define a shoreline - reduces erosion, protects land from storm waves, protects new landfill	Prevents inland migration of wetlands and beaches; traps horseshoe crabs and prevents amphibious movement; may create habitat for oysters and refuge for some species.
Dike	Shoreline armouring used to protect against inundation - prevents flooding and permanent inundation (when combined with a drainage system)	Prevents wetlands from migrating inland; thwarts ecological benefits of floods (e.g., annual sedimentation, higher water tables, habitat during migrations, productivity transfers)
Tide gate	Shoreline armouring used to protect against inundation -reduces tidal range by draining water at low tide and closing at high tide	Restricts fish movement; reduced tidal range reduces intertidal habitat; may convert saline habitat to freshwater habitat.
Storm surge barrier	Shoreline armouring used to protect against inundation -eliminates storm surge flooding; could protect against all floods if operated on a tidal schedule	Necessary storm surge flooding in salt marshes is eliminated
Dune	Elevates land - protects inland areas from storm waves; provides a source of sand during storms to offset erosion	Can provide habitat; can set up habitat for secondary dune colonization behind it.
Beachfill	Elevates land - reverses shore erosion, and provides some protection from storm waves	Short-term loss of shallow marine habitat; could provide beach and dune habitat.
Accommodate		
Elevate land and structures	Avoids flooding and inundation from sea-level rise by elevating everything as much as sea rises	Deepening of estuary unless bay bottoms are elevated as well.
Retreat		
Rolling easement[6]	Prohibit shore protection structures	Impacts of shore protection structures avoided

[6] Rolling easement : as defined in Titus, James G. 1998. *Rising seas, coastal erosion, and the takings clause : how to save wetlands and beaches without hurting property owners.* Maryland Law Review 57(4), 1281-1399.

4.6 Applying the Strategies in the Areas of Interest

Table 4-2 illustrates how the climate change adaption options could be applied in BC coastal regions. The indicated levels of development and consequences of flooding are a preliminary assessment only and the identification of appropriate Options will require specific attention from site to site.

Table 4-2: Applying Climate Change Adaption Options to the Areas of Interest

Area of Interest	Preliminary Estimate of Area Value	Estimated Consequences of Flooding	Adaptation Options - in potential order of priority
Fraser River delta – Richmond, Surrey and Delta coastal areas	High	High	Protect Accommodate Retreat - no new or redevelopment Avoid – new development
Lower Fraser River diked areas	High	High	Same as above
Vancouver harbour – no dikes but extensive foreshore development	High	High close to shoreline	Protect Accommodate Retreat
Squamish River delta - no dikes but extensive foreshore development in downtown Squamish, industrial development and high ecological values	Moderate to High	High	Accommodate Avoid (new and redevelopment) Retreat – re-establish wetlands Protect
(South) East Vancouver Island – few sea dikes (Cowichan River estuary) but extensive coastal development, mostly low to moderate density (residential, small scale commercial)	Moderate to Low	Moderate - High	Accommodate Retreat Avoid Protect
West Vancouver Island, North East Vancouver Island, Central Coast and North Coast – intermittent coastal development, a few high-medium density nodes (e.g., Tofino, Ucluelet, Sunshine Coast, Powell River, Prince Rupert)	Low to Moderate (at nodes)	Low - Moderate	Avoid - new development Accommodate Retreat

In most situations, especially where development already exists, it is likely that the optimum solution will consist of a mix of options and that the optimum mix will change or evolve with time. In undeveloped areas the choice should be more straightforward.

As an example of an evolving response, say over the next 25 years, local governments may choose to upgrade an existing dike system, while at the same time organizing or altering Development Permit Areas or Bylaws to influence and minimize the consequences of flooding or the overtopping of an upgraded dike in the more distant future. Each area of BC will merit a separate analysis and assessment.

Some tools to manage Climate Change Adaption Options are discussed briefly below.

Identification of appropriate options will nonetheless require guidelines for defining the Designated Flood Level (DFL) and its attendant derivatives; Flood Construction Level (FCL) and Setback or Sea Dike Crest Elevation that will be required to quantify the costs or benefits of any particular

Option. Policy implications for the DFL and its derivatives are described in Section 5 and 6 of this document.

4.7 Land Use Management Tools

Land use management tools that local governments can use to apply one or more of the Climate Change Adaption Options discussed above include:

- Official Community Plans (OCP).
- Development Permit Areas (DPA) – guidelines and requirements for developing in hazard areas.
- Zoning bylaws.
- Restrictive covenants.
- Public education – about the hazards and ways that individuals can address them.[7]
- Early warning and emergency preparedness programs.

These tools are discussed in more detail below.

4.7.1 Official Community Plan Policies and Development Permits

A local government's Official Community Plan (OCP) provides designations for general land use distribution, transportation and utility servicing, as well as general policies on community development and protection. OCPs must contain general land use policy statements and maps showing restrictions on the use of land that is subject to hazardous conditions. Flooding either from rivers or the sea would be a hazardous condition that OCPs must address, with the goals to reduce impacts on people, property and the environment. OCPs may identify Development Permit Areas (DPA) and create Development Permit Guidelines for Protection of Development from Hazardous Conditions, including flooding and some aspects of climate change[8]. These tools can provide different guidelines for different designated areas, different land uses, and different circumstances.

4.7.2 Flood Plain Bylaws

Current BC Provincial Policy encourages the use of Flood Plain Bylaws according to Section 910 of the Local Government Act. These bylaws designate an area as a floodplain, specify the minimum elevation to which development must be constructed, and establish setback requirements and related enforcement provisions.

4.7.3 Zoning and Other Local Government Bylaws

Zoning bylaw provisions can be an added tool in protecting development and the environment from consequences of flooding, by giving preference in flood plains to low risk uses such as agriculture, forestry, day-use recreation or short term industrial uses as opposed to high risk uses such as urban residential of various densities. An example of "risk" zoning is provided in Table 4-3. Note

[7] under New Zealand's *Building Act*, Land Information Memoranda (LIMs) and Project Information Memoranda (PIMs) provide known site and hazard risk information to help individuals decide for themselves whether to proceed with a purchase of land or development. A LIM is prepared by the local council on request; it is based on all the information a council holds about a piece of land and generally provides a more up-to-date and detailed source of hazard information than may be contained in a district plan. LIM information needs to be periodically updated by district and city councils when new hazard information comes available; the information provided by the LIM may become the basis for liability actions. A PIM is a summary of all the information a council holds in relation to a particular project associated with a piece of land, and outlines all other consents required to complete the project.

[8] *Local Government Act* – Sections 919 and 920.

that zoning on the basis of risk requires that the area in question has been assessed and ranked using a quantitative risk assessment (QRA). A brief background to QRA is provided in Appendix C.

Table 4-3: Zoning for Risk Areas

Source: New Zealand Ministry of Environment, (2008)

Zone	Planning Response
Little or no risk areas	• Flood hazards impose no constraints on planning
Low to medium risk areas	• Not usually necessary to consider flood risk unless local conditions indicate otherwise. Suitable for other than essential services. • A flood risk assessment may be required at upper end of the probability or where the nature of the development or local circumstances indicates heightened risk. • Water-resistant materials and construction may be required. • Generally not suitable for essential civil infrastructure/services such as hospitals, fire stations, emergency depots. • Where such services or infrastructure has to be located in these areas or is being substantially extended - must be capable of remaining operational and accessible during extreme flooding events.
Medium to high risk areas	• Generally not suitable for essential infrastructure such as hospitals, fire stations, emergency depots, schools, ground-based electrical and telecommunications equipment. Land raising may be acceptable. • In areas already built up: May be suitable for residential, institutional, commercial and industrial development, provided flood prevention measures to the appropriate standard already exist, are under construction, or are planned as part of a long-term development strategy. • In allocating sites, preference should be given to those areas already defended to that standard. Water-resistant materials and construction as appropriate. • In undeveloped and sparsely populated areas: Generally not suitable for additional development of any type. • Exceptions may arise if a location is essential for operational reasons; e.g., for navigation or water-based recreation uses, agriculture, transport or some utilities infrastructure, and an alternative lower-risk location is not achievable. Such infrastructure should be designed and constructed to remain operational during floods. • May be suitable for some recreation, sport, amenity and nature conservation uses provided adequate evacuation procedures are in place. Job-related accommodation (e.g., caretakers and operational staff) may be acceptable. • New trailer, mobile home and camping sites should generally not be located in these areas. • If built development is permitted, flood prevention and alleviation measures are required and the loss of storage capacity minimised. • Water-resistant materials and construction as appropriate. • Land should not be developed if it will be needed or have significant potential for coastal managed realignment (retreat) or creation of wetlands as part of an overall flood defence.
Adapted by New Zealand Ministry of Environment, (2008) from Crichton 2005a and Scottish Executive 2004 *Scottish Planning Policy SPP7:* Planning and flooding	

Where other flood regulation tools are not used, building regulations under Section 694 or 698 of the Local Government Act may provide limited mitigation of flood consequences.

4.8 Managing Residual Risk

Risk-avoidance and reduction measures will never completely remove coastal hazard risks. Managing the component of risk that is left over, the residual risk, usually involves transferring that risk. This typically means dealing with any associated consequences via emergency management, insurance, disaster relief or local government liability management. These measures for managing residual risk are briefly discussed below.

4.8.1 Insurance

The insurance industry has an enormous stake in limiting the damage that occurs to insured properties. The approach of insurance companies towards meeting the cost of hazard-induced asset loss has, in the past, been largely reactive. Increased insurance premiums and refusal of reinsurance are based on previous losses incurred. These can provide a disincentive for asset investment within high-risk hazard areas that have previously suffered financial loss.

At the present time insurance against flooding is generally not included in Canadian insurance policies.

Lack of availability of flood insurance can result in extreme pressure on governments to provide ‘protection’ against the hazard. In this situation the usual insurance industry approach may not send a clear signal to property owners, as at-risk areas will not necessarily be affected by insurance premiums unless there have already been hazard events in the past.

However, insurance companies are becoming increasingly proactive in hazard risk management. For example, in 2000, the insurance sector in the United Kingdom threatened to stop providing flood insurance unless the government invested in better protection of 2.2 million properties in flood risk areas. The outcome was that the Association of British Insurers and the British government agreed to the following “standards” (Heap, 2007):

- Provide insurance as a standard feature in areas where the annual probability of flooding is 1.3% or less.
- Maintain flood insurance in areas where improvements to flood protection infrastructure will reduce annual probability of flooding to 1.3% or less.
- Consider providing insurance on a case-by-case basis in other areas.

According to Lloyd’s (2008), if no action is taken, losses in the UK from coastal flooding for high risk properties could double by 2030. The company asserts that adaptation measures combined with flood defences can reduce losses substantially, and that the insurance industry can encourage adaptation through “incentivisation”. “The world cannot insure its way out of climate change”; however, insurance should be viewed as an effective way of managing individual risk that cannot be dealt with by adaptation.

While insurance could be an efficient market-based economic tool to distribute and reflect actual risk for coastal properties, it does not necessarily produce long-term changes in risk. Its efficient application may require intervention and collaboration between governments and insurance companies – and require detailed risk assessment information at the property level, much of which is currently not available.

4.8.2 Disaster Relief

All levels of government may be involved in disaster relief, from the perspectives of emergency preparedness and financial relief. There are limits to the effectiveness of disaster relief for climate change adaption measures. For example:

"The February 2006 winter storm and resulting coastal storm surge damaged over 150 homes in Tsawwassen where the confluence of high tides and high winds sent waves crashing 30-40 feet high over the seawall. Boundary Bay was declared a disaster area, and the Province provided $3 million in disaster relief, covering 80% of residents' damage costs to a maximum of $300,000." (Heap, 2007).

Current limits on disaster relief are unlikely to cover the total cost of recovery or relocation.

"Government is typically more exposed to reconstruction costs of disasters since insured losses usually account for far less than half of total costs. Beyond this, governments are effectively obliged to step in with disaster relief payments whereas insurance companies can choose to discontinue insurance coverage in areas that are judged to be at particular risk..." (Heap, 2007).

It is unlikely that the present umbrella amount in BC would cover the total costs of flooding or inundation due to the expected sea level rise in existing developed areas in BC. In this situation, disaster relief funding can only provide an interim recovery measure.

4.8.3 Local Government Liability

Local governments can be financially liable for the consequences of decisions that are shown to be in breach of statutory or common law duties. Local governments can make use of a range of techniques to reduce the risk of liability, such as (Heap, 2007):

- Certification by a qualified professional that the design and construction will mitigate risks.
- More stringent risk acceptance criteria; e.g., adaptation of a lower AEP for design decision making.
- Warning and evacuation protocols based on thresholds such as rainfall amounts, wind speeds, etc.
- Covenants indemnifying governments should a hazard occur.

However, "care is needed in using these instruments as they may not limit the owner's, or future owners, expectations of further protection, and often have no effect on land value when perhaps they should." (New Zealand Ministry of Environment, 2008)

4.9 General Roles in Defining Suitable Adaptation Options

Virtually everyone has some role to play in addressing the heightened risks of coastal flooding associated with climate change, Table 4-4. A detailed examination of specific policies for components of the matrix in Table 4-4 is beyond the scope of the present document.

Table 4-4: Potential Roles in Managing Risks to Coastal Areas Associated with Climate Change

Role:	Federal government	Provincial government	Local government	Private sector
Research, inventory, assessment of hazards	✓	✓	✓	✓
Information and Education	✓	✓	✓	✓
Land use planning	National protected areas	Flood Protection Guidelines	OCPs, zones, setbacks, DPAs	Influences
Building regulation	Building code	Building code, hazard guidance or regulations	Building requirements	Influences
Land purchase	Grant programs	Grant programs	Purchase programs	Purchase programs
Covenants			✓	
Protective structures	✓ Federal lands	Sea Dike Guidelines, Grant Programs	✓	On private property
Title notice		Require	Implement	Apply
Insurance			Municipal liability insurance	Private property insurance
Emergency response	✓	✓	✓	✓
Disaster Relief	✓	✓	✓	✓

5 Policy Guidelines for Coastal Flood Hazard Areas

5.1 Existing Flood Hazard and Land Use Management Guidelines

The goals of the existing provincial Flood Hazard Area Land Use Management Guidelines: "**Land Use Guidelines 2004**" are:

- To protect against the loss of life; and
- To minimize property damage, injury and trauma associated with flooding events.

The Guidelines were prepared pursuant to Section 5(f)(i) of the Environmental Management Act and must be considered by local governments when making bylaws under section 910 of the Local Government Act. Section 910 authorizes local governments to pass bylaws to designate lands as flood plains and define flood levels and setbacks for development in these floodplains.

Table 5-1 summarizes the main elements of the current Flood Hazard and Land Use Management Guidelines: "**Land Use Guidelines 2004**" that relate to coastal areas. While tsunami hazards are considered in areas outside the Strait of Georgia, there is no specific allowance for global sea level rise or other hazards associated with climate change.

5.2 Updated Guideline Policy Basis

Management of coastal lands that are or may become exposed to coastal flood hazards in a rising sea level scenario requires information on both the expected rise in sea level over time and the present and potential future uses of the exposed lands. The expected rise in sea level over the next several centuries is described in Section 3 of this Policy Document.

In a rising sea level scenario the longevity of the land use, the structures and the buildings on the exposed coastal lands becomes very important. It is necessary to establish management parameters; ie. Flood Construction Levels (FCL) or Setbacks that anticipate the water levels or flood levels and that are applicable up to the end of the lifespan of the land use, structures or buildings in question. In some cases it may also be important to consider the same issues for time frames that extend well beyond the present application.

In general terms, buildings, in particular, have reasonably well defined life spans or renewal cycles. Single Family Residential or Relocatable Manufactured Homes, have a typical lifespan of 50 years. Many other buildings, such as multi-family, commercial or light industrial buildings may have a life span of 75 years. High value concrete or steel buildings for institutional use or for public emergency services may have a life span of 100 years. In each case it is appropriate to consider the FCL or the Setback that is required up to the end of the expected life span.

Figure 5-1 illustrates how planning for the 100 year lifespan of a high value building or land use brings future SLR increases into immediate focus. The graphic illustrates, in 100 year steps, how building elevations will need to be incrementally adjusted (likely higher) to accommodate gradual SLR. The same incremental adjustment will be required, more frequently, for buildings or structures with 25 or 50 year life spans.

Table 5-1: Main Elements of Flood Hazard and Land Use Management Guidelines (2004)

Location	Setback	FCL
Strait of Georgia (SOG) (Sec 3.5.1- p.22)	• 15 m from natural boundary (NB). • 7.5 m from NB where protected from erosion by natural bedrock or protective works designed by professional engineer. • No reduction from 15m in new subdivisions unless each building site is on non-erodible bedrock or local government assumes maintenance responsibility for works designed by a professional engineer. • May be increased (from 15 m) for exposed erodible beaches and areas of known erosion hazard.	• At least 1.5 m above NB • Higher than any FCL established for specific coastal areas
SOG coastal bluffs – new development (p.23)	• Horizontal distance equal to 3 times height of bluff measured from toe, where building site is at top of steep bluff and where toe is subject to erosion and/or is less than 15 m from NB. • May be reduced if supported by a report prepared by a suitably qualified professional.	
SOG coastal bluffs – existing lot (p.23)	• If above setback prevents construction and sufficient protection cannot be provided through engineered works, adopt a modified setback with restrictive covenant stipulating hazard, building requirements and liability disclaimer.	
Outside SOG	• At least 30 m from NB • Established on a site-specific basis taking tsunami hazards into account.	• Established on a site-specific basis, • Take tsunami hazards into account.
Areas protected by standard dikes	• Buildings - minimum 7.5 m from: any flood protection or seepage control structure; or any dike right of way used for protection works. • Fill – not within 7.5 m of inboard toe or side of: any flood protection or seepage control structure; or any dike right of way used for protection works.	• Minimum FCL prescribed for sea adjacent to dike + FCL prescribed for internal drainage (minimum ponding elevation). • Applicable requirements for any secondary sources of flooding within diked areas.

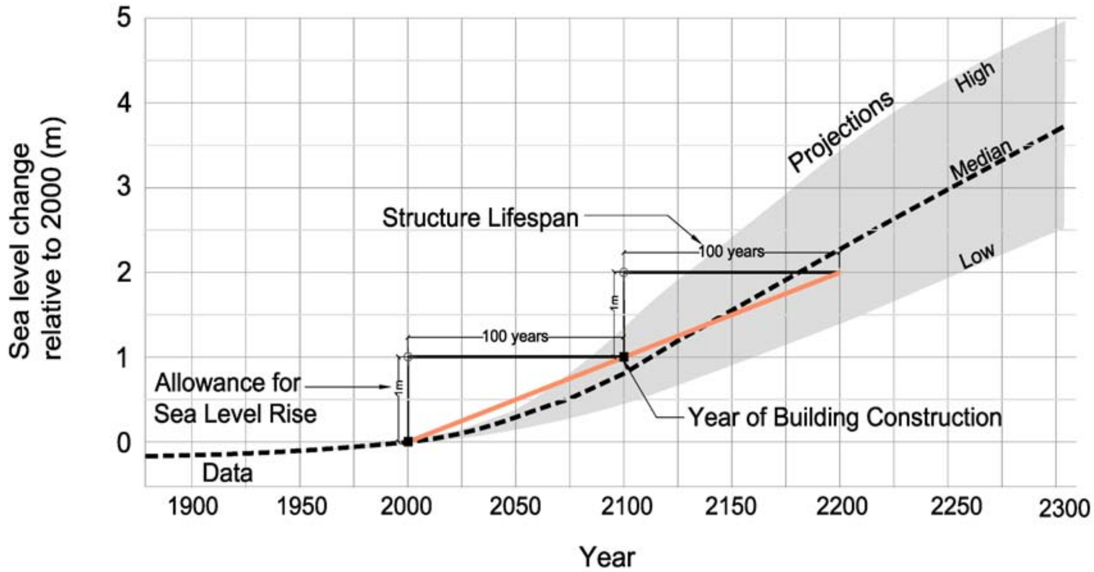

Figure 5-1: Incremental Sea Level Rise Effect on Planning for 100 Year Structures

It is also clear from Figure 5-1 that, initially, anticipation of future sea level rise and the required management parameters, is far more critical for long life span buildings or land use than it is for shorter life span situations. It also illustrates, within the present range of uncertainty, how underestimating future SLR, or the rate of SLR, may require additional measures sooner than anticipated.

To provide an appropriate balance between economic development objectives and a precautionary approach to the uncertainty surrounding future sea level rise, an Adaptive Risk Management approach to Sea Level Rise is warranted. An Adaptive Risk-Management Approach to SLR would plan how short term land uses and structures can be occupied with reasonable risk over their lifespan, but at the same time recognize and allow that future SLR may require the redesign or relocation of the next generation of land uses and structures at a given coastal site. In this approach, the Flood Construction Level and Setback for a given site will have to be increased when a building has reached the end of its planned lifespan. This approach will minimize the initial costs of considering SLR, and the future costs of adaptation.

Guidance on the range of FCLs that may be appropriate on the BC coastline in the future are provided in the updated "**Coastal Land Use Guidelines 2010**" [9] also produced as part of this assignment.

Land use and building approvals based on FCL for 2100 should also include provisions for adaptive management of land uses for SLR to the Year 2200 and beyond. The long term view should also apply when subdivision of new lot parcels or construction of a building implies a change (increase) in the intensity of land use that extends beyond the life of building.

In considering whether to plan for SLR projections of 50, 75, or 100 years out, the complexity of building lifespan is compounded by considerations of underlying land value. Real estate value of

[9] "Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use in BC. Guidelines for Management of Coastal Flood Hazard Land Use". Prepared by Ausenco Sandwell for the British Columbia Ministry of Environment, October 2010.

land is tied, in part, to the bundle of rights to rebuild on that land. SLR may gradually move the natural boundary, reduce parcel size, increase required building height, and thereby reduce the buildability and value of the land. However SLR change is very slow, and may well be balanced by other factors which tend to increase the real estate value of land over extended periods.

The approach taken, therefore, is to strive to allow continuous beneficial land use of the land affected by SLR, provided; however, that land zoning and permissions anticipate and provide for adapting to SLR as it occurs, and as buildings come to the end of their lifespan and redevelopment is planned.

SLR creates serious risks for public health and property in lowlands on the BC coast. In no cases should new development approvals be provided that will burden future generations of the public with the costs of protecting against known SLR risks. To minimize the future growth of SLR risks, SLR Planning Areas should be created throughout coastal BC for settled or new development areas at risk of SLR inundation or related erosion. These SLR Planning Areas will minimize the risk and costs of SLR to both public and private interests, by proactive planning for future land use.

The SLR Planning Area approach also provides a method to gradually adapt larger scale land use patterns to SLR. The specifics of creating and defining SLR Planning Areas are defined in the updated "**Coastal Land Use Guidelines 2010**" [9] also produced as part of this assignment.

The SLR Planning Areas can also be used specifically to define or include the measures required to preserve future dike right of ways, should a "protect" option be used to adapt land use to climate change.

For land use management guidance in BC, allowances for SLR until the Year 2100 should be used in current planning and building approvals. These approvals should also include provisions for adaptive management of land uses to SLR to the Year 2200 and beyond. This guideline should apply for the period from 2010 until the next SLR review, which should be completed by 2015.

6 Policy Guidelines for Sea Dike Design Options

6.1 Existing Dike Design and Construction Guide

The existing **Dike Design and Construction Guide 2003** provides extensive guidance for the design of dikes, primarily in non-tidewater exposed situations, although flood hazards from the ocean are discussed briefly in Section 1.3.1 and flood design levels for sea dikes are discussed in Section 2.9.8 of the existing document.

In the existing document, sea dike crest height is estimated based on the following:

- Tidal fluctuations: the maximum high tide is indicated as the appropriate tidal water level.
- Storm Surge: the 1:200 year average return period storm surge plus a freeboard (normally 0.6 m) is specified.
- Wave Runup: additional considerations for definition of a sea dike crest height "may include wave runup and setup".

The structure of the existing document suggests that the freeboard allowance of 0.6 m is intended to cover uncertainty associated with definition of the 1:200 year average return period storm surge.

The existing document also indicates elsewhere that additional freeboard may be required to allow for long-term dike settlement due to geotechnical foundation conditions. For the purpose of this Draft Policy Document the additional freeboard required for long-term dike settlement is not specifically addressed but it still must be considered. Crustal subsidence or uplift is; however, considered in the definition of the regional SLR

No guidance for dike location, on or near the shoreline, or for the stability design of outer slopes, crest elevations and widths or for the stability of landside slopes, where wave related overtopping may create instability issues, is provided or directed.[10] Coastal erosion hazards, either during a design event or regular ongoing processes are only indirectly addressed in Section 1.3.4 of the existing document.

In most cases, sea dikes in BC were initially constructed landward of the Natural Boundary, but as sea level rises in response to climate change the present location of the Natural Boundary will become submerged and many new considerations, taking into account all aspects of wave-coastline-structure interaction will eventually need to be addressed. The **Dike Design and Construction Guide 2003** also does not specifically refer to vertical or near-vertical seawall type structures that exist or may become necessary in urban settings.

An updated Sea Dike Guideline document needs to address:

- Appropriate designated flood levels, within the context of open water exposure and climate change related effects
- Consideration of acceptable amounts of wave overtopping that must be accommodated on the landside of the sea dike
- Consideration of the implications to the functional geometry of a sea dike located within a space constrained urban setting, i.e. Vancouver Harbour, compared to more common and less developed locations, i.e. the Fraser River Delta or the Squamish River Delta.

[10] Reference is made to a complementary document "Riprap Design and Construction Guide", which deals mainly with river dikes.

- Consideration, at the conceptual level of design, of the implications to wave exposed locations i.e. the Fraser River Delta shoreline, compared to less wave exposed locations, i.e. inside Vancouver Harbour or to river flow dominated settings, i.e. the Squamish River Delta.

6.2 Evolution of Dike Design

Historically, sea dike (and river dike) design and construction practice, worldwide, has evolved through several stages:

- Initially, the location and design of dikes were based on the observations and experience of local inhabitants, where the dike elevation was set based on the highest water levels either experienced directly onsite or suggested by the available history for the area. Where dikes were exposed to open water, the elevation of the dike was increased to allow for exposure to storm related wind and wave setup and wave runup, again based on local experience.
- In the 1950's, following severe flooding in storms experienced around the North Sea, statistical methods began to be used to define expected storm surge levels and associated wind and wave related set-up. These methods evolved, particularly in the Netherlands, due to the early work of a national agency known then as the Delta Committee (Vrijling, 2001). The methodology led to a specification of a total water level, including astronomical tide and storm surge with a defined return period, or annual probability of being exceeded (AEP), and an additional freeboard for wave effects. It was explicitly recognized that some risk of flooding or inundation must be accepted and that it was not economically practical to build defence structures large or safe enough to prevent all flooding. As some overtopping of the sea dike was therefore expected, the dike was designed, constructed and maintained so as to prevent breaching as a result of the expected overtopping.
- The change from experience based criteria to statistically based criteria was also accompanied by the recognition that all potential modes of failure, not just overtopping of water, had to be considered and therefore the components of the dike system had to be designed to an even higher standard to ensure that breaching did not occur at the design total water level.
- In the Netherlands, the early versions of this approach led to the adoption of an annual exceedance probability (AEP) of $1x10^{-4}$, or an average return period of 10,000 years for the design total water level. An additional allowance (freeboard) was also added to account for expected effects of other processes occurring at the same time as the design total water level.
- During the 1980s, the development and application of reliability theory and risk assessment began to be applied in practical terms to the design of coastal structures, and in particular, to the design of storm surge barrier systems in the Netherlands and the UK. Research also began on the application of these techniques to the design of sea defences in general and practical guidelines began to emerge by the 1990s (Technical Advisory Committee on Water Defenses, 1990).
- The evolution of the design approach outlined above is leading to requirements in the Netherlands for dike design to be assessed so that the probability of actually being flooded or inundated, is, in principle, a probability less than what is referred to as the threshold probability of the total design water level. The safety norm for every dike ring in the Netherlands has been defined as the average yearly probability of exceedance of the total design water level.
- This post 1980's risk based process has also led to a range of threshold probabilities for the design total water level that varies for different regions of the Netherlands, depending on the value(s) of the area being protected, the nature of the flooding hazard, and the consequences of the inundation. A summary of the threshold probabilities for the design total water level is provided in Figure 6-1.

The Delta Committee (2008) has since recommended that the overall flood probability for all diked areas should be further reduced by a factor of 10 to 100 to reduce the possibility of sudden large breaches and the possibility of large numbers of casualties. This recommendation partially recognizes that a breach may remain open for some time before it can be closed and flood water removed.

- It should be noted; however, that a reduction in the overall flood probability does not mean that the AEP (or the threshold probability) of the Designated Flood Level, to use the BC definition, should be decreased. The recommendation is tied to a proposed switch, from defining the threshold probability of total water level, to defining a target safety level associated with the total risk of actual flooding or inundation (if a dike actually breaches).

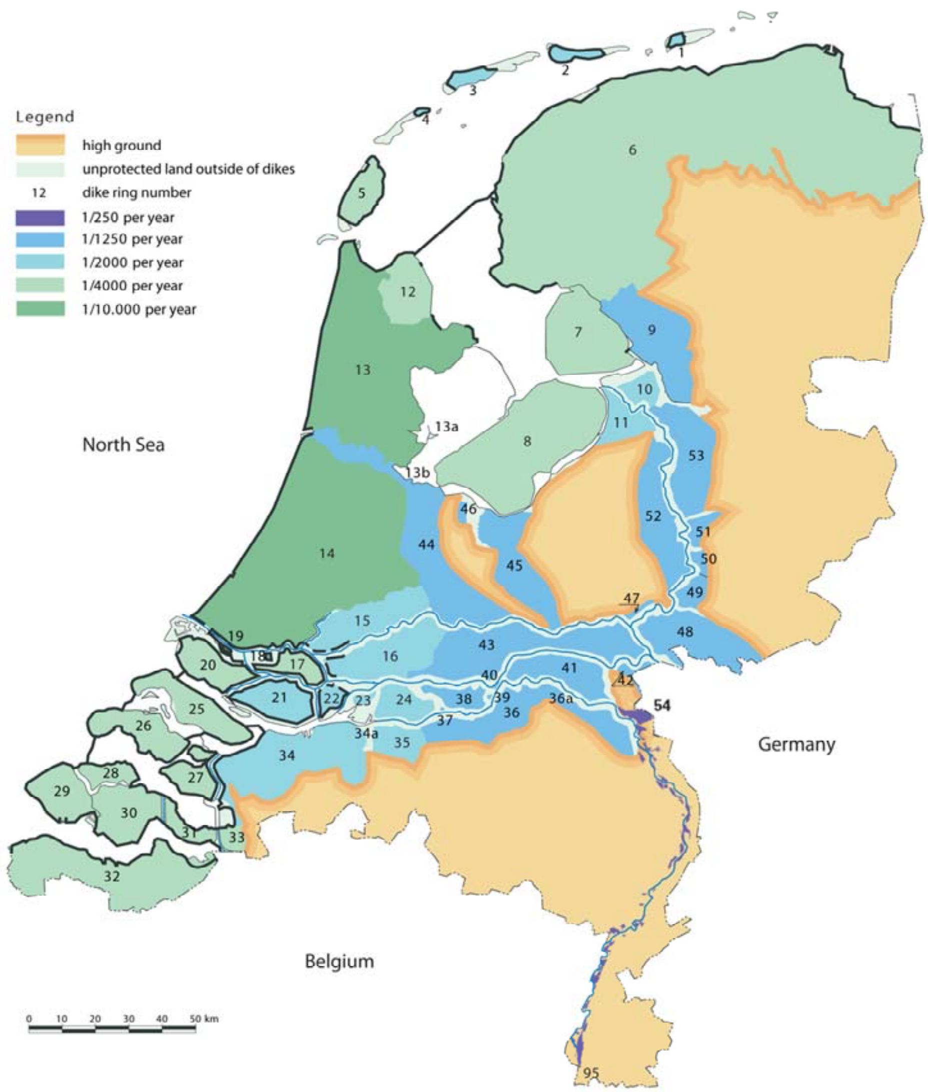

Figure 6-1: Example of the Threshold Probability of Total Design Water Level
source: translated from Rijkswaterstaat (2008)

The present BC guidelines for sea dike design follow the early models for dike design and are based on the specification of a 1:200 year average return period storm surge, coupled with high tide, plus freeboard, regardless of the implications of a more severe storm or of expected overtopping. A sea dike will also very likely be exposed to more than one storm and tide combination in a season.

The basis for the specified 1:200 year return period is understood[11] to be the 1:200 year return period historically assigned to the 1894 Fraser River flood that forms the basis for river dike design in BC[12]. It should be noted; however, that the present 1:200 year return period storm surge event cited in the existing BC guideline document is not directly comparable to the threshold return period events summarized in Figure 6-1, as they represent a total water level, which in the case of the BC guidelines is the summation of the tide level and the storm surge level.

The methodology for estimating the AEP of a combination of tide and storm surge is discussed in more detail in Appendix D of the companion update report "**Sea Dike Guidelines 2010**"[13], also prepared for this project.

Definition of an appropriate design event for a specific sea dike in BC that reflects a quantitative risk analysis approach such as evolved elsewhere is beyond the scope of the present assignment; however, it is reasonable to expect that if a quantitative risk analysis was undertaken, a similar range of annual exceedance probabilities for the total design water level, which depend on the value of the land use and the implications of flooding or inundation in a given area, would emerge that are similar to those summarized in Figure 6-1.

A brief description of a quantitative risk assessment (QRA) process that could be undertaken is provided in Appendix C.

A summary of an interim recommendation for BC sea dike and flooded land management is provided in Section 6.3.

6.3 Policy Implications for Sea Dike Design in BC

There are three related but separate issues regarding the development of policies for sea dikes and coastal flooded land management in BC:

- What future sea level should be accounted for?
- What project life or time interval should be used for planning purposes?
- What design standard for the probability of exceedance should be used for flood protection works?

A brief discussion of each issue is provided below.

6.3.1 Future Sea Level Rise for Sea Dike Design

Recommendations for the future sea level rise that should be accounted for in sea dike design are summarized in Section 3.2.3 of this document.

The appropriate choice of a design SLR value is directly related to the anticipated design life of the sea dike and indirectly to the planning measures undertaken to accommodate the actions required at the end of the expected service life of the sea dike.

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11 Pers comm. J. Shah, P. Eng. BCMOE

12 The estimated return period for the 1894 Flood is now understood to have been increased to 1:500 years based on recent investigations by others.

13 "Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use in BC. Sea Dike Guidelines". Prepared by Ausenco Sandwell for the British Columbia Ministry of Environment, October 2010.

6.3.2 Project Life

It is clear that, in almost all cases, once the decision is made to maintain an existing sea dike or to construct a new sea dike, this decision has important implications well into the future that affect the health and safety of life and property in the protected area. It is clear that a single policy on a recommended project life is impossible to define without extensive discussion among the affected stakeholders. Once a sea dike is in place it represents a commitment in perpetuity unless it is part of a planned program of Adaption Options that anticipates retreat or risk management in some form or another. Issues that must be considered in setting a Project Life include:

- The condition of any existing sea dikes
- Planned phasing of design and construction
- Financing
- Implementation of other Adaptation Options.

6.3.3 Design Standard

The existing guidelines for dike design and construction in BC are essentially based on flooding experience on the Fraser River, translated to the coastline as outlined in Section 6.2. These guidelines suggest that a storm surge level equivalent to a 1:200 year return period plus high tide, should define the design total water level or the Designated Flood Level.

The AEP of this Designated Flood Level can be estimated to be approximately 1/4000 year as discussed in more detail in Appendix D of the companion update report "**Sea Dike Guidelines 2010**" also prepared for this project.

An additional site specific allowance for wave runup and setup should be added to the Designated Flood Level to define the design crest elevation of the sea dike[14].

In contrast, the Flood Protection Act (1996) in the Netherlands defines the following levels of protection for the equivalent of the Designated Flood Level:

- Central Netherlands (exposed to the sea): threshold probability (AEP) of 1/10,000 per year.
- Rest of coast and lower reaches of rivers: threshold probabilities (AEP) of 1/4000 per year.
- Upper reaches of rivers: threshold probability (AEP) of 1/1250 per year.

The corresponding safety target with regard to the probability of actual inundation (i.e. flooding due to expected overtopping or a local dike breach) are one or two orders of magnitude higher – in other words the safety targets, expressed as AEPs, are 10 or 100 times smaller than the values indicated above and shown in Figure 6-1. The variation across regions results from a risk optimization process: zones having a lower population density and a smaller expected loss of assets are assigned lower safety target level than heavily populated and built-up zones. But the net resulting consequences to individuals and to individual assets are similar across all zones and are deemed to be acceptable.

In the absence of detailed risk assessments and cost-benefit analyses for individual sea dikes in BC, Table 6-1 suggests general risk categorizations (as described in Appendix C) and design AEPs for the Designated Flood Level for the areas of interest in this project.

[14] Settlement of the as-constructed dike, including the dike materials and the underlying foundation soils, is factored into the geotechnical design provisions for the dike and the maintenance plan.

As the AEP of the Designated Flood Level is for the total water level, the associated AEP for the storm surge component is also provided in Table 6-1 to allow comparison with the existing guidelines.

Table 6-1: Preliminary Risk Categorization and Design AEPs for areas of interest.

Area of Interest	Suggested Time Line for Risk Assessment	General Risk category	Suggested Design AEP for	
			Designated Flood [a]	Storm Surge [b]
Fraser River delta *– Richmond, Surrey and Delta sea dikes*	100 yr	High	1/10000 yr	1/500 yr
Lower Fraser River dikes	100 yr	High	1/10000 yr	1/500 yr
Vancouver harbour *– no dikes but extensive foreshore development*	100 yr	High	1/10000 yr	1/500 yr
Squamish River delta *- no dikes but extensive foreshore development in downtown Squamish, industrial development and high ecological values*	100 yr	High	1/10000 yr	1/500 yr
(South) East Vancouver Island *– few sea dikes (Cowichan River estuary) but extensive coastal development, mostly low to moderate density (residential, small scale commercial)*	50 yr	Moderate - High	1/4000 yr	1/200 yr
West Vancouver Island, North East Vancouver Island, Central Coast and North Coast *– intermittent coastal development, a few high-medium density nodes (e.g., Tofino, Ucluelet, Sunshine Coast, Powell River, Prince Rupert)*	50 yr	Low - Moderate	1/4000 yr	1/200 yr

Notes:

a: Suggested Design AEP for Designated Flood are for the Designated Flood Level being equalled or exceeded. The probability of dike failure will likely be different, depending on details of the dike system.

b: Follows from the indicated AEP for the Designated Flood Level, based on the probability of a high tide occurring simultaneously as the storm surge being approximately 1/20, as described in Appendix D of the companion update report "**Sea Dike Guidelines 2010"**[13]**.**

7 Uncertainty and Freeboard Allowance

The existing documents for the management of flooded land and for sea dike construction implicitly or explicitly include a freeboard allowance of approximately 0.6 m[15].

It is common practice in offshore and coastal engineering codes and standards of practice to include provision for uncertainties by specifying a minimum freeboard or similar allowance. Generally the freeboard accounts for the known uncertainties in technical elements of the design methodology, ie., the appropriate wave theory for the depth of water or the estimate of wave crest elevation, say for the defining the design loads on the underside of a jetty or platform deck.

In the specific case of a climate change related assessment, whether it is for the purpose of defining the Flood Construction Level or a Sea Dike Crest Elevation, the problem is compounded by uncertainties surrounding the present estimates of the future extent of climate change, the resulting sea level rise, the time frame over which a particular decision is being made and in some cases for the actions or consequences of other stakeholders or property owners that may directly affect a particular shoreline area.

Using a QRA approach, as summarized in Appendix C, all of these uncertainties can be included in the risk assessment process. Freeboard can then treated as a specific parameter that controls the resulting risk. Freeboard can then be calibrated and/or optimized to reflect specific uncertainties in a risk-consistent and economic manner.

Uncertainties related to coastal flooding and sea dike design can be identified as follows:

Climate Change:

- Future GHG emissions
- The rate at which sea levels will change in response to climate change.
- The effect of climate change on storminess, wave setup and runup, and other factors that may affect global and regional sea levels.

Site Conditions

- The actual relationship between MSL and the datum used to define terrestrial elevations
- The bathymetry offshore of the dike or land area
- The presence of and future plans for maintenance or upgrading of any structures that may provide protection to the area in question
- Local micro-climate or oceanographic effects that may result in stronger winds or higher waves (or vice versa) than defined by available data sources for winds, waves, or water levels
- Surface and subsurface soil conditions that may result in variable rates of coastal erosion or sedimentation or of scouring or settlement along the dike or shoreline in question

[15] A summary of the basis for the 0.6 m freeboard allowance in the 1.5 m vertical offset for FCL (see Table 5-1, this document) is provided in the companion document **Coastal Land Use Guidelines 2010** [9]**.**

Design Methodology

- Although coastal engineering is a reasonably developed area of engineering practice, specification of engineering parameters such as wave heights or wave height distributions in shallow water, wave runup, wave overtopping and structural stability of sea dike armour elements generally rely on empirical science and the predictive tools carry forward underlying uncertainty.
- Existing coastal engineering practice guidelines also do not provide all necessary details on stability or overtopping characteristics of all types of potential sea dike structures.

The amount of freeboard applied at any stage of design should follow a precautionary principle, by addressing, separately, any uncertainties that are not included and/or considered, either directly in design or in the QRA. This may include the possible combination of any uncertainty related directly to inundation related hazards with one or more uncertainties related to environmental or other technical issues. Human/operational/organizational considerations should also be considered as uncertainties, and an allowance can be added on top of the above to cover “unknowable unknowns”.

As a minimum, it is recommended that the present freeboard allowance of 0.6 m should be included in both sea dike design and coastal flood land assessment, above and beyond any specific allowances adopted to deal with the known uncertainties identified above. These known uncertainties should be explicitly stated during design. It is reasonable to assume that the existing 0.6 m allowance represents an optimal experienced based allowance for freeboard to accommodate unknowable unknowns. QRA may show that more or less freeboard is needed but without undertaking an analysis it is impossible to know for certain.

8 Policy Conclusions and Recommendations

8.1 Policy Conclusions

Based on the investigations and research summarized in this report, and reflected in the companion reports "**Coastal Land Use Guidelines 2010**" [9] and "**Sea Dike Guidelines 2010**"[13], and the comments from stakeholders in the Consultation Workshop, the following conclusions regarding the establishment of policy for climate change adaptation in the coastal waters of British Columbia have been drawn:

1. Sea level rise (SLR) in the future is expected to be both faster and higher than previously anticipated. While there is still scientific uncertainty related to the present understanding of the future rates and magnitudes, it seems reasonable to anticipate higher SLR than summarized in the **"BC Sea Level Report 2008"**. A large degree of the related uncertainty can be avoided by separating the fact that sea level will rise from the actual rate of SLR. The most uncertainty lies in the prediction of the sea level rise on a given date.
2. For planning purposes it is recommended that the rates and trends reflected in Figure 3-5 and Table 3-2 should be used at present.
3. The choice of appropriate response options or adaptation measures is so site specific that their identification and adoption must be the responsibility of local governments, with guidelines and other support provided by the province. Provincial policy should include updating the basic guidelines for sea dikes, FCLs and Setbacks as defined in the companion documents and requiring the establishment of SLR Planning Regions, as described in Section 5.2.
4. At the present time, scientific information on the expected changes in storms approaching British Columbia coastal waters and their characteristics, specifically on the intensity of the storms, their related wave conditions and the associated storm surges in the future, is only starting to emerge. Based on the available information it appears reasonable to conclude that no significant change is expected in coastal BC waters; however, further investigations are warranted to fully assess the regional implications and to further assess future trends.
5. It is clear that the present recommended rates and trends for SLR have significant implications for British Columbia coastal communities. Detailed quantitative risk analysis (QRA) processes may be appropriate for some communities. In the meantime, and in situations where QRA may not be appropriate, the recommendations outlined in this document, and the companion documents, for design standards, design procedures and planning alternatives can provide a basis for initial planning and responses.

8.2 Next Steps and Recommendations

8.2.1 General Implementation:

1. Because the recommended SLR policies outlined above will have a significant impact on BC coastal communities, it is recommended that an extensive outreach program be undertaken to outline and discuss the implications and steps forward and to initiate the necessary community discussions and planning.
2. The outreach program should include:
    a. Preparation of formal SLR policies in the form of a short policy statement document referencing this document and its companion guideline documents,

b. A provincial government public communications plan and program,

c. Preparation of a schedule for implementation and anticipated updating,

d. Workshops and seminars for local government, professional technical bodies and public consultation.

8.2.2 SLR Planning Area Implementation – Recommendations

1. A key element for the management of future Coastal Flood Hazard is the implementation of the creation of SLR Planning Areas, as described in Section 5.2. The need for and requirements of should be identified in the formal SLR policies discussed above.
2. The Province should initiate a coastal flood plain mapping program throughout coastal British Columbia to acquire detailed topography, including the intertidal regions, to provide sufficient resolution and base mapping to identify the boundaries of SLR Planning Areas. This mapping program will increase local government awareness of SLR issues, encourage SLR planning and provide required information necessary to complete area specific coastal engineering studies.
3. The Province should initiate a provincial program to support SLR Planning, providing both grants and technical assistance to local governments.

8.2.3 Coastal Flood Protection Implementation – Recommendations

1. The Province should initiate an overview engineering study to determine the costs of upgrading coastal flood protection in BC to meet the new standards defined in this document and the companion guideline documents.
2. For the existing Flood Protection Program, sea dike projects should only be approved as sea dike projects that appropriately consider the new guidelines.
3. The new guidelines should be applied as a condition of Dike Maintenance Act approvals.

8.2.4 Coastal Flood Protection Technical Issues - Recommendations

1. The definition of the new Flood Construction Reference Plane includes a simplified estimate of the effect of waves on the shoreline response. The recommended factor is based on calibration against one survey along the exposed coast line of Victoria. A review of the appropriate factor over more regions of coastal British Columbia should be undertaken to validate or refine the recommended factor.
2. The expected future magnitude of storm surges and their properties for SLR planning purposes are based on preliminary analysis of long-term tidal records. A more detailed review of storm surges and their attendant properties should be undertaken to provide necessary technical information throughout coastal British Columbia.
3. Definition of many of the coastal engineering features of the methodology defined in this document and the companion guidelines needs reliable and accepted definitions of wind and wave climate throughout the coastal waters of BC. A detailed program to define the wind and wave climate should be undertaken by the Province to provide a uniform and consistent body of technical information throughout coastal British Columbia waters.

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9 References

Allison, I., N.L. Bindoff, R.A. Bindschadler, P.M. Cox, N. de Noblet, M.H. England, J.E. Francis, N. Gruber, A.M. Haywood, D.J. Karoly, G. Kaser, C. Le Quéré, T.M. Lenton, M.E. Mann, B.I. McNeil, A.J. Pitman, S. Rahmstorf, E. Rignot, H.J. Schellnhuber, S.H. Schneider, S.C. Sherwood, R.C.J. Somerville, K. Steffen, E.J. Steig, M. Visbeck, A.J. Weaver. 2009. *The Copenhagen Diagnosis*, *2009: Updating the World on the Latest Climate Science.* University of New South Wales Climate Change Research Centre (CCRC), Sydney, Australia, 60pp.

Bornhold, B. D. 2008. *Projected sea level changes for British Columbia in the 21st century.* 12 p. Available online at www.env.gov.bc.ca/epd/climate.

Clark, P.U., A.J. Weaver (coordinating lead authors), E. Brook, E.R. Cook, T.L. Delworth, and K. Steffen (chapter lead authors)]. 2008. *Abrupt Climate Change - A Report by the U.S. Climate Change Science Program and the SubCommittee on Global Change Research.*U.S. Geological Survey, Reston, VA, 459 pp.

Delta Committee. 2008. *Working Together with Water - A Living Land Builds for its Future.* http://www.deltacommissie.com : Delta Committee, 2008. pp. 134.

Hanak, E. and G. Moreno. 2008. *California Coastal Management with a Changing Climate*. Public Policy Institute of California. 32 p.

Harford, D. 2008. *Climate Change Adaptation: Planning for BC*. Pacific Institute for Climate Solutions, University of Victoria. 28 p.

Heap, N. 2007. *Hot Properties: How Global Warming Could Transform BC's Real Estate Sector.* David Suzuki Foundation, Vancouver. 32 p.

IPCC. (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (AR4*). S. Solomon et al. eds (Cambridge University Press, Cambridge. UK and New York, NY, USA).

Lowe, J.A., Howard, T.P., Pardaens, A., Tinker, J., Holt, J., Wakelin, S., Milne, G., Leake, J., Wolf, J., Horsburgh, K., Reeder, T., Jenkins, G., Ridley, J., Dye, S., Bradley, L. (2009). *UK Climate Projections science report: Marine and coastal projections*. Met Office Hadley Centre, Exeter, UK.

Lloyd's. 2008. *Coastal communities and climate change: maintaining future insurability.* Risk Management Solutions and Lloyd's. 24 p.

McMullen, C.P. and J. Jabbour. 2009. *Climate Change Science Compendium 2009.* UNEP, Nairobi, EarthPrint. 69p.

Mehdi, B. (ed). 2006. *Adapting to Climate Change: an introduction for Canadian Municipalities. Canadian Climate Impacts and Adaptation Research Network (C-CIARN)*. 32 p.

Mori, N., Yasuda, T., Mase, H., Tom, T., and Oku, Y. (2010). *Projection of Extreme Wave Climate Change under Global Warming*. Hydrological Research Letters, 4, p 15 – 19. Available online at www.jstage.jst.go.jp/browse/HRL.

New South Wales (NSW) Government (2009). *NSW Sea Level Rise Policy Statement 2009*. 6p. + supplementary draft guides and technical notes.

NSW Government. 2009. *Derivation of the NSW Government's Sea Level Rise Planning Benchmarks - Techncial Note.* Sydney, NSW, Australia : Department Environment, Climate Change and Water NSW, 2009. p. 8.

Ausenco Sandwell

New Zealand Ministry for the Environment. 2008. *Coastal Hazards and Climate Change: a Guidance Manual for Local Government in New Zealand.* 2nd Edition revised by D. Ramsay and R. Bell. viii + 127p.

Pfeffer, W. T. et al., (2008) *Kinematic constraints on glacier contributions to 21st Century sea level rise.* Science, 321, p 1340 – 1343.

Rahmstorf, S., (2007). *A Semi-Empirical Approach to Projecting Future Sea Level Rise*. Science 315, p 368 – 370.

Rijkswaterstaat (2008). *De dijk van de toekomst?.* [in Dutch. "The Dike of the Future?"]. Report RWS 2008.052.

Rupp, S. and R. Nicholls. 2002. *Managed Realignment of Coastal Flood Defences: a comparison between England and Germany*. 10 p.

Solomon, S., Plattner, G., Knutti, R. and Friedlingstein (2009). *Irreversible climate change due to carbon dioxide emissions.* PNAS, The National Academy of Sciences of the USA.

Technical Advisory Committee on Water Defenses, 1990. *Probabilistic Design of Flood Defenses, Center for Civil Engineering Research and Codes, Report 141,* CUR, Postbus 420, 2800 AK Gouda, The Netherlands.

Thomson, R.E., Bornhold, B.D., and Mazzotti, S. 2008. *An examination of the factors affecting relative and absolute sea level in coastal British Columbia.* Can. Tech.Rep. Hydrogr.Ocean Sci. 260: v + 49 p. Available online at www.env.gov.bc.ca/epd/climate.

Titus, J.G. 1998. *Rising seas, coastal erosion and the takings clause: how to save wetlands and beaches without hurting property owners*. Maryland Law Review 57(4): 1281-1399.

Titus, J.G., E. K. Anderson, D. Cahoon, S. K. Gill, R. E. Thieler, and J. S. Williams. 2009. *Synthesis and Assessment Product (SAP) 4.1: Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*. A report by the U.S. Climate Change Program and the Subcommittee on Global Change Research. , U.S. Environmental Protection Agency, Washington, D.C. 298 p.

Turbott, C. and A. Stewart. 2006. *Managed Retreat from Coastal Hazards: Options for Implementation.* Environment Waikato (Regional Council) Technical Report 2006/48. New Zealand. 89 p.

Ulbrich, U., Leckebusch, J. and Pinto, J.G. (2008). *Extra-tropical cyclones in the present and future climate: a review*. Theoretical Applied Climatology. Published online: 17 January 2009.

US Army Corps of Engineers. 2009. *Water resource policies and authorities incorporating sea level change consideration in civils works programs*. Expires 1 July 2011. Circular No. 1165-2-211. 31 p.

USCCSP (2008). *Abrupt Climate Change - A Report by the U.S. Climate Change Science Program and the SubCommittee on Global Change Research*. [Clark, P.U., A.J. Weaver (coordinating lead authors), E. Brook, E.R. Cook, T.L. Delworth, and K. Steffen (chapter lead authors)]. U.S. Geological Survey, Reston, VA, 459 pp.

Vrijling, J K. 2001. Probabilistiic *Design of Water Defense Systems in The Netherlands*. Reliability Engineering and System Safety. 2001, Vol. 74, pp. 337-344.

WBGU – German Advisory Council on Global Change (2006). *The Future Oceans – Warming Up, Rising High, Turning Sour.* Special Report. Available online at www.wbgu.de.

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Appendix A – Definitions, Terminology and Acronyms

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Contents

1 Definitions

The incorporation of climate change related sea level rise considerations into existing BC Ministry of Environment documents is structured into three documents:

- **Draft Policy Discussion Paper 2010**
- **Sea Dike Guidelines 2010**
- **Guidelines for Management of Coastal Flood Hazard Land Use 2010**.

The definitions in these documents follow, where possible, the definitions and terminology that are either consistent with the existing documents or consistent with existing practise worldwide. In some cases existing definitions or terminology require modification or clarification for application to coastal flooding or sea dike application in a climate change driven sea level rise scenario.

Existing definitions are provided below in italics followed by any necessary modification, clarification or addition to the definitions or terminology in the existing documents.

Acronyms associated with the definitions that are used in the text are shown in brackets.

1.1 Annual Exceedence Probability (AEP)

The probability, likelihood or chance of a particular event (e.g., a storm or a storm surge) being equalled or exceeded in any one year. It is defined either as a number between 0 and 1 or as a corresponding percentage.

An AEP of 0.01 means there is a 1% chance of an event, of a given magnitude or larger, occurring in any single given year. An AEP of 0.01 or 1/100 yr also suggests that on average, under certain conditions, the Average Return Period, or interval between recurrences of this event, is approximately 100 years.

1.2 Average Return Period

Over a long period of time, the average number of years between occurrences of a particular event. In general, the average return period is the reciprocal of the AEP – the relationship is illustrated in the following table:

AEP probability	AEP per cent	Average Return Period (years)	
0.5	50%	2	Probability decreases ↓
0.1	10%	10	
0.01	1%	100	
0.005	0.5%	200	
0.001	0.1%	1000	
0.0005	0.05%	2000	
0.0002	0.02%	5000	
0.0001	0.01%	10000	

Using AEP to define the likelihood of hazard events is preferable to the average return period as return period can lead to a false sense of security created by the belief that the indicated number of years will pass before the next event of that magnitude occurs.

1.3 Designated Flood

A flood, which may occur in any given year, of such a magnitude as to equal a flood having a 200-year recurrence interval based on a frequency analysis of unregulated historic flood records or by regional analysis where there is inadequate streamflow data available. Where the flow of a large watercourse is controlled by a major dam, the designated flood shall be set on a site-specific basis.

In coastal areas, the existing definition of a Designated Flood is not appropriate as the probability of flooding from the sea is the result of the joint occurrence of tide and a storm crossing the coastal waters of British Columbia and at some time in the future, sea level rise due to climate change.

In estuaries, where a river discharges into the sea, the definition of the Designated Flood applies to the river.

In these documents the definition “Designated Flood” is replaced with the term “Designated Storm” as defined below.

1.4 Designated Flood Level (DFL)

The observed or calculated elevation for the Designated Flood and is used in the calculation of the Flood Construction Level.

In coastal areas, the Designated Flood Level (DFL) includes the appropriate allowance for future sea level rise, tide and the total storm surge expected during the designated storm.

1.5 Designated Storm (DS)

A storm, which may occur in any given year, of such a magnitude as to equal a storm having the designated annual exceedence probability (AEP).

The Designated Storm has several phenomena associated with it that will define components of the Designated Flood Level, including storm surge, wind set-up, wave run-up and overtopping for the storm. These include:

- A time series of atmospheric pressure during the passage of the storm over the area in question
- A time series of wind speed and direction during the passage of the storm over the area in question
- A time series of wave conditions, including wave heights, periods and directions during the passage of the storm in question.

1.6 Diking Authority

(a) The commissioners of a district to which Part 2 of the Drainage, Ditch and Dike Act applies,

(b) A person owning or controlling a dike other than a private dike,

(b1) If the final agreement of a treaty first nation so provides, the treaty first nation in relation to dikes on its treaty lands,

(c) A public authority designated by the minister as having any responsibility for maintenance of a dike other than a private dike, or

(d) A regional district, a municipality or an improvement district.

1.7 Flood Construction Level (FCL)

Uses the Designated Flood Level plus an allowance for Freeboard to establish the elevation of the underside of a wooden floor system or top of concrete slab for habitable buildings. In the case of a manufactured home, the ground level or top of concrete or asphalt pad, on which it is located, shall be equal to or higher than the above described elevation. It also establishes the minimum crest level of a Standard Dike. Where the Designated Flood Level cannot be determined or where there are overriding factors, an assessed height above the natural boundary of the water-body or above the natural ground elevation may be used (as defined in the Land Use Guidelines 2004).

In coastal areas the FCL does not relate to the crest level of a sea dike, nor does it relate to the crest level of flood proofing fill exposed directly to the designated flood level. The FCL does; however, include wave – structure interaction effects, to be determined at the location of the site of the building.

1.8 Flood Construction Reference Plane (FCRP)

The vertical elevation of an estimated future Natural Boundary from which the FCL is determined.

1.9 Flood Plain

A lowland area, whether diked, flood proofed, or not, which, by reasons of land elevation, is susceptible to flooding from an adjoining watercourse, ocean, lake or other body of water and for administration purposes is taken to be that area submerged at the Designated Flood Level.

In coastal areas the concept of the Flood Plain has been extended to a “Sea Level Rise Planning Area”; defined below. Special measures may be warranted in this area.

1.10 Flood Proofing

The alteration of land or structures either physically or in use to reduce flood damage and includes the use of building setbacks from water bodies to maintain a floodway and allow for potential erosion. Flood Proofing may be achieved by all or a combination of the following:

- *Building on fill, provided such fill does not interfere with flood flows of the watercourse, and is adequately protected against floodwater erosion*
- *Building raised by structural means such as foundation walls, columns, etc.*
- *A combination of fill and structural means.*

In coastal areas exposed to flooding, construction of fill as a flood proofing measure may substantially increase the freeboard required to define the FCL, if the fill is directly exposed to the Designated Flood Level. In this case, the FCL must be equivalent to the crest level of a sea dike with the same characteristics as the seaward face of the fill..

1.11 Freeboard

A vertical distance added to the Designated Flood Level. Used to establish the Flood Construction Level.

In coastal areas, the vertical distance to be added to a Designated Flood Level is site and structure specific.

1.12 Natural Boundary

Means the visible high watermark of any lake, river, stream or other body of water where the presence and action of the water are so common and usual and so long continued in all ordinary years as to mark upon the soil of the bed of the lake, river, stream or other body of water a character distinct from that of the banks thereof, in respect to vegetation, as well as in respect to the nature of the soil itself (Land Act, Section 1). In addition, the natural boundary includes the best estimate of the edge of dormant or old side channels and marsh areas. For coastal areas, the natural boundary shall include the natural limit of permanent terrestrial vegetation.

Natural Boundary is an established concept in BC law – and reflects a change in vegetation and soil based on effects of the sea. In the **Flood Hazard Area Land Use Guidelines 2004,** building setbacks were established from Natural Boundary, on the unstated assumption that the location of Natural Boundary is relatively static (other than erosions and accretions).

Natural boundary is, in practice, often difficult to determine in the field or from remote survey. In coastal areas, the Natural Boundary reflects a snapshot historical record of tide, storm surge and wave runup effects, which may be the mark of a recent storm in an ordinary year or it may be the mark of the most severe storm in recent times. There is no way of knowing for certain. A technical basis for the Natural Boundary in coastal areas is site and time specific. In the future the location and elevation of a Natural Boundary will change from time to time due to changes associated with sea level rise and it will likely lag sea level rise. It is also unlikely to immediately reflect the action of the water, especially the storm surge and waves, during a Designated Storm.

1.13 Project Life

The number of years a particular project; including a sea dike, a building or a community, is intended to serve before it is replaced, upgraded or dismantled. Regular maintenance to ensure the project provides the intended purpose is expected during the project life.

1.14 Sea Dike

A dike, floodwall or any other thing that prevents flooding of land by the sea. As defined in the Dike Maintenance Act, "dike" means "an embankment, wall, fill, piling, pump, gate, flood box, pipe, sluice, culvert, canal, ditch, drain".

1.15 Sea Dike Crest Elevation

Sea Dike Crest Elevation has essentially the same meaning as "*dike crest height*" in the existing document "**Dike Design and Construction Guide 2003**". However, the existing definition of dike height suggests that consideration of wave run-up and set-up is optional. The term Sea Dike Crest Elevation is defined to specifically cover scenarios where wave run-up, overtopping and wind and wave setup must be included in defining the height of the dike.

1.16 Sea Dike System

A system of: dikes, dunes, berms or natural shorelines that provide a similar function; and associated engineering works (e.g., tidal gates, outfalls, outlet structures, seawalls, quay walls, ramps, adjacent building features, etc.) used to protect land from flooding or inundation.

In the Netherlands where dike systems are highly evolved, a dike system is termed a "dike ring" that forms the flooding defence for a region. There are approximately 95 such rings in the Netherlands and each ring is the responsibility of a separate organizational entity, subject to national overview.

In BC, multiple Diking Authorities may share responsibility for the same sea dike system.

1.17 Sea Level Rise (SLR)

An allowance for increases in the mean elevation of the ocean associated with future climate change, including any regional effects such as crustal subsidence or uplift.

1.18 Sea Level Rise Planning Area (SLR Planning Area)

An area of land that may be subject to future flooding due to Sea Level Rise. This area defines a future coastal flood plain. The SLR Planning Area extends from the existing Natural Boundary landward to the highest predicted point of potential flooding related to SLR plus flooding expected from the combination of high tide, total storm surge and expected wave runup during the Designated Storm.

Predictions of SLR for the SLR Planning Area definition shall use best predictions for minimum periods of 90-100 years and 200 years forward. From time to time, both the Natural Boundary and the predictions for SLR are subject to change, and therefore the extent of a SLR Planning Area may be revised at regular intervals in the future.

1.19 Seastate

The term “seastate” is used to encapsulate, in a general way, all of the parameters and characteristics that may be needed during design to define the waves at a given instant in time. The sea state is the general condition of the free surface of a body of water—with respect to wind waves and swell—at a certain location and moment. The sea state is characterized by statistics, including wave height(s), period(s), distribution and power spectrum. The sea state varies with time, as the weather or oceanographic factors change. For engineering purposes the seastate is often characterized by the significant wave height, H_s.

1.20 Setback

Means withdrawal or siting of a building or landfill away from the natural boundary or other reference line to maintain a floodway and to allow for potential land erosion.

1.21 Standard Dikes

Dikes built to a minimum crest elevation equal to the Flood Construction Level and meeting standards of design and construction approved by the Ministry of Environment and maintained by an ongoing authority such as a local government body.

1.22 Storm Surge

A change in water level caused by the action of wind and atmospheric pressure variation on the sea surface. The typical effect is to raise the level of the sea above the predicted astronomical tide level, although in some situations, such as when winds blow offshore, the actual water level may be lower than that predicted. The magnitude of a storm surge on the BC coast will be dependent on the severity and duration of the storm event in the North Pacific, its track relative to the BC coast and the seabed bathymetry at the site.

1.23 Total Storm Surge

The combination of the storm surge generated in deep water plus the additional local surge or wind setup generated by the effect of the winds during the Designated Storm over shallow water at a particular site. In general the deep water storm surge is nearly the same as that recorded at a tidal gauging station. Additional surge may occur at other sites. For planning purpose, winds during a Designated Storm will start to generate local surge in water depths less than 30 m.

1.24 Wave Run-up

The vertical distance that waves run-up the seaward slope of a structure or a shoreline. The vertical distance is measured from the mean water level, which is the same as the Designated Flood Level.

For coastal flooding hazard management the Wave Run-up is taken as 50 per cent of the calculated run-up elevation on the natural shoreline. This ratio is based on analysis completed for this assignment (2010) and may be revised as more information becomes available.

For defining a Sea Dike Crest Elevation the Wave Run-up is taken to be the vertical distance exceeded by no more than 2% of the waves during the Designated Storm at the toe of the sea dike

1.25 Wave Set-up

An increase in mean water surface close to the shoreline caused by wave action; important during storm events as it results in a further increase in water level above the tide and surge levels, landward of the location where waves start to break. Wave set-up will lead to larger waves existing at the seaward toe of a sea dike than might otherwise be expected.

1.26 Wave Overtopping

The passage of water over the top of a sea dike as a result of wave runup or related surge and setup. Water overtopping a sea dike may pass over the dike as a flow of water or as spray and the specific characteristics are site and structure specific.

1.27 Wind Set-up

A rise of the water surface above the water level on the open coast due to the local action of wind stress on the water surface.

2 Acronyms and Symbols

2.1 CD

Tide and chart datum – in Canadian waters the plane below which the tide will seldom fall. Tide datum and chart datum is usually the same provided the chart is the largest scale available chart for area. For a site specific survey tide and chart (sounding) datum may be different and the specifics should be stated explicitly.

2.2 CGD

Canadian Geodetic Datum. In 2010 the vertical reference plane in Canada is in the process of being changed from a MSL related datum plane – technically known as CGVD28 – to a geoid based datum plan. The update program is described at http://www.geod.nrcan.gc.ca/hm/index_e.php. The term CGD is taken to mean the datum as defined in 2010 and approximately equal to MSL.

2.3 CHS

Canadian Hydrographic Service

2.4 CIRIA; CUR; CETMEF

European agencies sponsoring the "Rock Manual"

2.5 DPA

Development Permit Area

2.6 EA, ENW, KFKI

European agencies sponsoring the "EurOtop" Manual

2.7 GCM

Global Climate Model

2.8 GHG

Green house gases

2.9 $H_{1/10}$

Mean height of the highest 10 per cent of waves in a given seastate

2.10 H_s

Significant wave height – the mean height of the highest 1/3 of waves in a given seastate – approximately equal to the wave height estimated at sea by experienced observers.

2.11 HHWLT

Higher high water large tide

2.12 HHWMT

Higher high water mean tide

2.13 IPCC

International Panel on Climate Change

2.14 LLWLT

Lower low water large tide

2.15 LLWMT

Lower low water mean tide

2.16 MWL

Mean water level

2.17 QRA

Quantitative Risk Analysis

2.18 $R_{2\%}$

Wave run-up height exceeded by 2% of waves in a given seastate

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Appendix B – Uplift and Subsidence Rates

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1 Uplift and Subsidence Rates

1.1 Introduction

This Appendix provides a brief summary of the available information on subsidence and uplift rates along the British Columbia coast.

The **BC Sea Level Report (2008)** – Chapter 3 **-** provides a description of crustal movements along the coast of British Columbia and a brief summary of rates for selected locations. More specific site detail is provided in Table 1-1 based on an unpublished addendum to the **BC Sea Level Report (2008)** provided by BCMOE.

1.2 Site Specific Data

The data in Table 1-1 summarizes the rates of uplift (positive) or subsidence (negative) and the standard error based on relative sea-level rates corrected for eustatic sea level rise (tide gauge stations) or on absolute trends of vertical motion (GPS stations).

Table 1-1: Table of Current (2010) Uplift and Subsidence Rates for Tide Gauge and GPS stations in British Columbia

Station					Uplift / Subsidence Rate	
Name	**Data Type**	**Lat.**	**Lon.**	**T**	**V uplift (+)**	**σ**
	TG = tide gauge station GPS = GPS station	**°N**	**°W**	**Years of record**	**(mm/yr)**	
Prince Rupert	TG	54.317	130.324	77	0.5	0.2
Queen Charlotte City	TG	53.252	132.072	45	2.2	0.3
Bella Bella	TG	52.163	128.143	45	2.3	0.4
Winter Harbour	TG	50.513	128.029	18	1.7	0.8
Zeballos	TG	49.979	126.846	13	5.1	1.6
Gold River	TG	49.679	126.126	13	0.7	1.8
Tofino	TG	49.154	125.913	58	2.7	0.3
Port Alberni	TG	49.233	124.814	40	2.5	0.6
Bamfield	TG	48.836	125.136	37	1.6	0.4
Port Renfrew	TG	48.555	124.421	27	-0.4	0.6

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Station					Uplift / Subsidence Rate	
Name	**Data Type**	**Lat.**	**Lon.**	**T**	**V uplift (+)**	**σ**
	TG = tide gauge station GPS = GPS station	**°N**	**°W**	**Years of record**	**(mm/yr)**	
Port Hardy	TG	50.722	127.489	43	2.5	0.4
Alert Bay	TG	50.587	126.931	33	3.5	0.4
Campbell River	TG	50.042	125.247	37	4.1	0.5
Little River	TG	49.741	124.923	25	3.0	0.6
Point Atkinson	TG	49.337	123.253	73	1.3	0.2
Vancouver	TG	49.287	123.110	58	1.2	0.2
New Westminster	TG	49.200	122.910	38	4.6	2.0
Fulford Harbour	TG	48.769	123.451	40	1.4	0.2
Patricia Bay	TG	48.654	123.452	31	1.7	0.8
Victoria	TG	48.424	123.371	98	1.2	0.2
Sooke	TG	48.370	123.726	12	3.3	0.9
Albert Head (Colwood)	GPS	48.390	123.487	10.8	0.6	0.7
Bamfield	GPS	48.835	125.135	4.5	3.9	1.5
Langley	GPS	49.104	122.657	3.9	-0.7	0.9
Richmond	GPS	49.115	123.147	3.9	-2.1	0.9
Telegraph Cove	GPS	50.544	126.843	6	4.0	1.0
Port Hardy	GPS	50.686	127.375	5.5	3.9	1.3
Surrey	GPS	49.192	122.860	3.9	0.7	0.9
Vancouver	GPS	49.276	123.089	3.8	-0.3	1.0
Eliza (W of Zeballos)	GPS	49.873	127.123	6.2	1.0	1.1
Esquimalt	GPS	48.429	123.429	6.6	1.4	0.8

Station					Uplift / Subsidence Rate	
Name	**Data Type**	**Lat.**	**Lon.**	**T**	**V uplift (+)**	σ
	TG = tide gauge station GPS = GPS station	**°N**	**°W**	**Years of record**	**(mm/yr)**	
Holberg	GPS	50.640	128.135	10.8	2.4	0.9
Nanoose Bay	GPS	49.295	124.086	10.8	2.1	0.8
Nootka Island	GPS	49.592	126.617	6.2	3.2	1.0
Patricia Bay	GPS	48.648	123.451	7.1	1.4	0.8
Port Alberni	GPS	49.256	124.861	4.5	3.7	1.0
Chemainus	GPS	48.923	123.704	3.4	2.0	1.3
Ucluelet	GPS	48.926	125.542	10.8	2.6	0.8
Prince Rupert	GPS	54.277	130.435	2.0	-1.7	1.7
Sandspit	GPS	53.254	131.807	1.8	2.0	1.9
Bella Bella	GPS	52.158	128.110	1.7	3.8	2.0

Notes:
Source: "Addendum to Thomson, R.E., Bornhold, B.D., and Mazzotti, S. 2008. An Examination of the Factors Affecting Relative and Absolute Sea Level in Coastal British Columbia. Can. Tech. Rep. Hydrogr.Ocean Sci. 260: v + 49 p" – provided by BCMOE, T Neale, 23 March 2010

Appendix C – Quantitative Risk Analysis

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Contents

1 Quantitative Risk Analysis and Risk Management Approach

1.1 Quantitative Risk Analysis (QRA)

Risk is generally understood to include elements of both the likelihood of occurrence of a hazardous event, the consequences of the event, and the manner in which the hazard is perceived by individuals and/or stakeholders. Risk can be expressed, qualitatively, as:

Risk = Probability x Perceived Consequences

A risk-based approach to a hazard such as flooding therefore requires an understanding of the likelihood of a flooding event, the consequences of the flooding, and their perception by stakeholders and their proxies. By necessity, evaluation of the risk and a determination of its acceptability require a broadly based evaluation that involves all stakeholders involved in the particular situation.

In the next sections an appropriate QRA framework for a spatially distributed system subject to a natural hazard is detailed. Risk acceptance is discussed followed by risk-based optimization and calibration which results in optimal risk-based design specifications and risk control/mitigation measures.

1.2 QRA Framework

Quantitative risk analysis (QRA) focuses on what can go wrong with systems and on the likelihood that any undesirable outcomes may occur. In a QRA, systems must be well-defined and may include engineering systems such as infrastructure, environmental systems, and human systems affecting health, welfare, and quality of life. Typically, the systems being assessed are subject to considerable uncertainties which can be intrinsic or external to the system. In addition, QRA usually involves spatially distributed systems such as urban areas, or multi-unit systems such as process plants or aircraft, while the systems are themselves subject to uncertain temporal variations, such as deterioration, climate change, or socio-economic growth/decline.

Various modern standards exist worldwide as well as nationally, which provide detailed protocols and guidelines for performing QRA. The benefits of QRA are numerous and well documented (JCSS, 2008a). QRA provides a basis for both operational and strategic decision making. Operational risk-based decision making includes for instance: the selection of optimal design solutions, reliability based design, performance-based design, and development of optimal risk mitigation measures for a specific system/hazard. Examples of strategic risk-based decisions are: risk-based maintenance/repair planning, optimal resource allocation, optimal spreading of risk between lifecycle phases, optimal hazard response planning, and hazard policy development.

QRA is normally concerned with the risks associated with not just one asset, e.g. a single structure, or an infra-structure network, or a single hazardous activity, but with a portfolio of assets. If risk assessments are not performed consistently for the individual components of the asset, then it is not possible to assess the overall portfolio risk. Furthermore, and more importantly, it is then also impossible to develop consistent strategies in terms of resource allocation and actions affecting risk control and mitigation.

As in the case of the present project, QRA often focuses on risk resulting (directly or indirectly) from one principal hazard. In that case, it provides the basis for the management of risks before, during and after the occurrence of such hazards:

- before the hazard occurs the issue of concern is to optimize investments into preventive measures such as protecting assets, optimizing adequate design specifications, and developing preparedness and emergency strategies.

- during the occurrence of the hazard the issue is to limit consequences by containing damages and by means of rescue and evacuation.
- after the hazard, the situation is to some degree comparable to the situation before the event, however, the issue here is to decide on the rehabilitation of the losses, the repair of functionalities and the re-consideration of future preventive measures.

The basic QRA framework in the case of one principal hazard (such as a flood) and a spatially distributed system (such as a coastal zone) is shown in Figure 1-1. The left-hand side shows the "inductive" part of the QRA which addresses the question how the hazard can occur. Typically, fault tree analysis and logical Bayesian net analysis is used to analyse the various causal sequences that lead from a root cause such as an extreme event or a failure to the occurrence of the central hazard. The right-hand side chiefly involves a "deductive" type of analysis (event trees, Bayesian nets, etc.) to determine and aggregate the different consequences caused by the hazard (JCSS, 2008b)

It is important to realize that all the "boxes" in the original, intermediate and final steps of the analysis shown in Figure 1-1 are stochastic, i.e. they need to be treated probabilistically. The QRA must therefore account for all uncertainties associated with the system, the characterization of the hazard, the hazard models, and the consequence models.

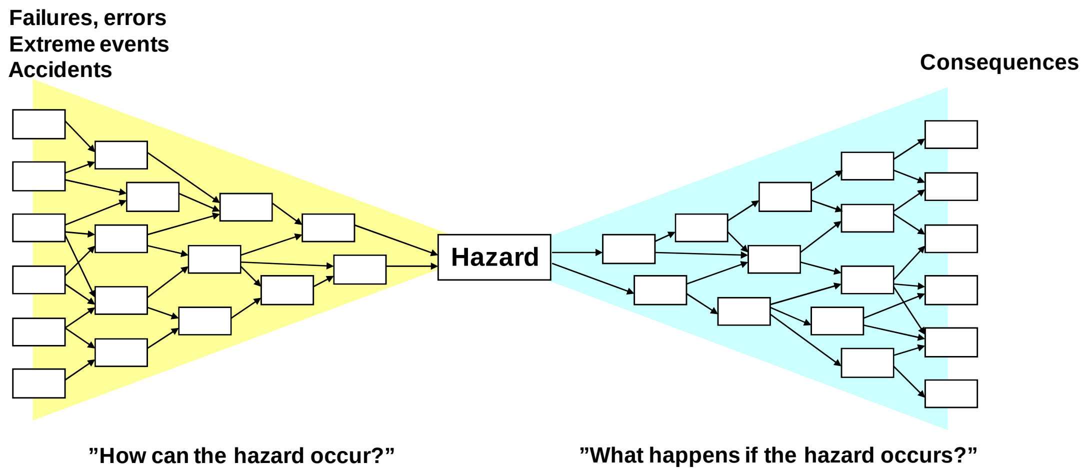


Figure 1-1: Quantitative Risk Analysis (QRA) for a system exposed to a hazard (general framework).

In the specific case where the hazard is a flood/inundation, the framework for the QRA is shown in Figure 1-2. Some of the boxes in the failure sequences (LHS) and the consequence chains (RHS) are labelled to illustrate the analysis. A special "climate change" box is also included as it affects several "starting" variables such as storm frequency, storm intensity, sea level, etc. This allows the QRA to cover a long-term period such as the planning horizon or the specified design life.

It is important to realize that in Figure 1-2, all the "boxes" in the LHS yellow triangle are affected by design specifications and policy measures. In other words, the probabilities associated with the various sequences leading to the central "hazard" event are "controlled" by these specifications and measures. Similarly, all of the boxes in the RHS blue triangle can be affected and "controlled' by various risk mitigation measures which affect the extent and the magnitude of the consequences.

Essentially then, QRA amounts to the analysis of a well-defined sequential probabilistic network that can be externally controlled by the design/policy measures on both sides of the "flood/inundation hazard". In the format depicted in Figure 1-2, the QRA amounts to a 'forward" analysis – this means that it provides us with the aggregated risks associated with flooding for a defined coastal area during a specified long term period of time.

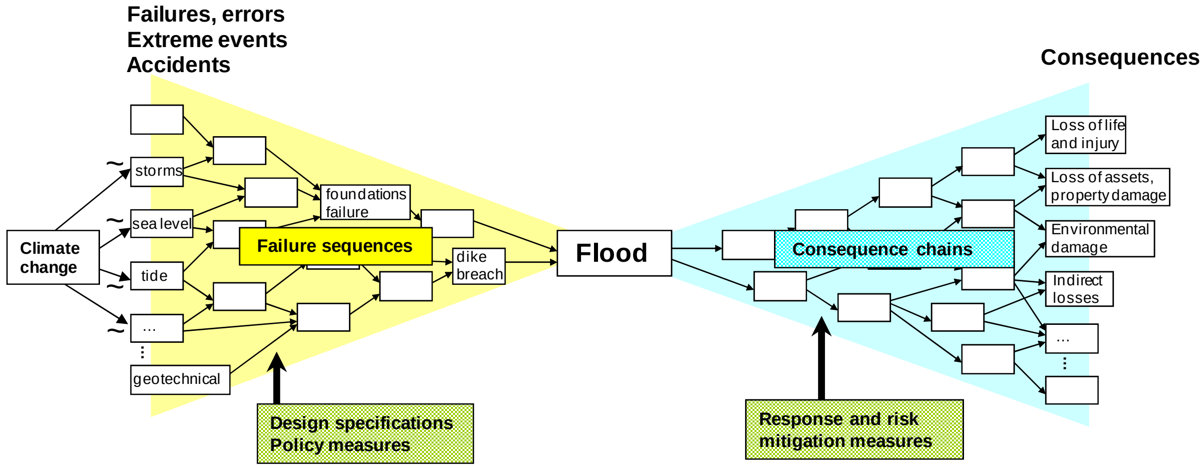


Figure 1-2: QRA for a specific coastal zone subject to a flooding or inundation hazard.

1.3 Risk Comparison and Risk Acceptability

The assessment of the risk and evaluation of its acceptability involves quantification of the consequences of possible scenarios in terms of safety, economics and the environment, and the likelihood of these consequences. These consequences can be evaluated in two ways: qualitatively, or quantitatively. The former applies when a more or less informal risk assessment is performed, while the latter is called for when a full hazard QRA is performed as described in the previous section.

In a qualitative risk assessment, the acceptability of risk can be subdivided into three classes:

- Low or broadly acceptable risk –where the likelihood of occurrence is insignificant and the resources or effort required to further reduce the consequences is disproportionate to the achieved risk reduction
- Medium or tolerable risk – where the measures to further reduce the consequences are either impractical or actions can be defined and implemented (including warning systems, evacuation, monitoring or compensation) to further minimize or manage the consequences
- High or unacceptable risk – where the risk is high and cannot be justified except in extraordinary circumstances.

The evaluation of a risk in terms of safety is generally resolved in terms of the protection of human life and the related probability of being death, which in the context of an individual is generally assessed in terms of accident statistics and which sets the probability of death by accident or natural illness, on an annual basis as approximately 1:10,000 or 10^{-4}. In the context of society in general, elements of voluntariness, the numbers of people exposed to the hazard and the nature of the activity become involved. The more involuntary the situation, or the more people involved, the lower the acceptable probability of occurrence becomes.

The evaluation of a risk in terms of economics is generally resolved in terms of the benefit – cost ratio of the proposed works, with appropriate ratios being defined by the concerned stakeholders. The evaluation of risk in terms of the environment is not well defined in quantitative terms although in many cases an evaluation of the economic consequences of a lost or depleted environment resource and the cost of recovery or restoration of the resources may be undertaken.

A qualitative risk evaluation/management process will eventually lead to a Risk Evaluation Matrix along the lines illustrated in Table 1-1.

Table 1-1: Risk Evaluation Matrix

Likelihood	Decreasing likelihood	Virtually certain					
		Very likely					
		Likely					
		About as likely as not					
		Unlikely					
		Very unlikely					
		Exceptionally unlikely					
			Insignificant	Minor	Moderate	Significant	Major
			Consequence				

Low risk *Moderate risk* *High risk*

A specific example of a qualitative risk evaluation matrix for flooding showing the factors considered for climate change adaption planning (from New Zealand), is provided in Table 1-2.

Similarly, when consequences and their probabilities have been fully quantified using a formal QRA, the question is how to compare and interpret risks, how to evaluate if they are acceptable, and if they need to be managed or reduced. Risk acceptance must be meaningful for individuals, stakeholders and for the public at large. In the case of flood risks, past and current practice is considerable, and practice normally sets the tone for risk acceptance. Moreover, risk evaluation for floods is quite similar to risk evaluation for other natural hazards (subject to a similar QRA framework). In the case of BC, for instance, experience with seismic risk acceptance is quite relevant.

Table 1-2: An Example of Consequence Evaluation
Source: New Zealand Ministry for the Environment (2008)

Receptor	Consequence				
	Insignificant	**Minor**	**Moderate**	**Significant**	**Major**
People displaced (no. or permanency)	< 10 Short-term inconvenience	10–50 Disruption for several days	50–100 Disruption for weeks – months	100–200 Permanent loss of some homes	> 200 Permanent loss of many homes
People (no. of injuries)	< 5	1–10	10–25	25–50	> 50
People (no. of fatalities)	0	0	1	< 5	> 5
Economic impact	Minimal financial losses	Moderate financial loss for a small number of owners	High financial losses probably for multiple owners	Major financial losses for many individuals and/or companies	Huge financial losses involving many people and/or corporations and/or local government
Essential services	Short-term inconvenience	Disruption for a day or two	Disruption for several days to weeks	Some long-term impacts	Large long-term loss of services
Infrastructure	Short-term inconvenience	Disruption for a day or two	Disruption for several days to weeks	Loss requiring reinstatement of parts of infrastructure network	Loss of significant parts of infrastructure network requiring reinstatement or relocation
Commercial services	Short-term inconvenience	Disruption for a day or two	Disruption for several days to weeks	Some long-term impacts	Extensive long-term loss of services
Cultural assets	Some minor impacts	Some impacts on significant cultural assets	Moderate impacts on significant cultural assets	Some irreversible damage to cultural assets	Complete loss of significant cultural assets
Ecosystems	Short-term impact	Some impacts on valued natural environment	Moderate impacts on valued natural environment	Major impacts on valued natural environment	Complete loss of important natural environment

Regulatory criteria concerning risk acceptance are typically specified in terms of the As Low As Reasonably Possible/Practicable (ALARP) format. The idea is that risks, depending on their magnitude, can be evaluated to be negligible, tolerable or non-acceptable, as shown in Figure 1-3 in the specific case of life safety (similar representations can be made for other type of consequences). Figure 1-3 shows the relationship between consequences (C) – the number of fatalities and their frequency (F), and is commonly referred to as a FC diagram.

In Figure 1-3 the ALARP region is shown together with a scrutiny line which aims to indicate in which case measures for risk reduction must be developed.

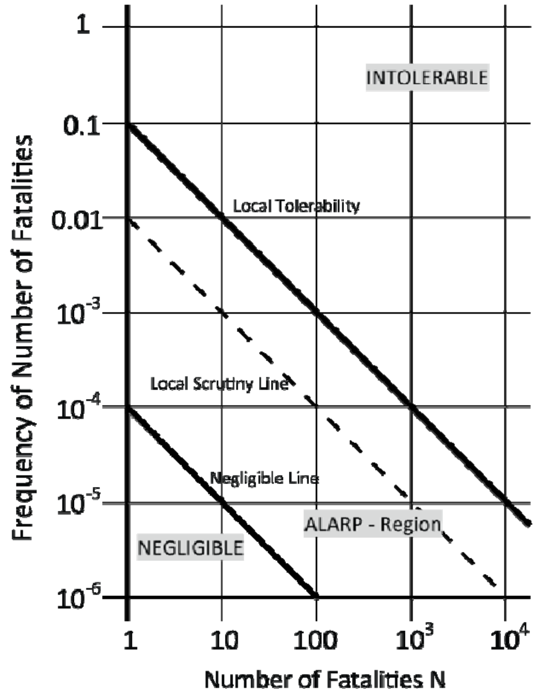


Figure 1-3: Illustration of Typical Implementation of ALARP in Life Safety Risk Regulation.

The acceptance lines in Figure 1-3 show a linear dependency between the logarithms of the consequences and their exceedance probabilities. Typically, except for the UK, a non-linear dependency is introduced such that events associated with severe consequences are weighed more heavily in the evaluation of acceptance. Such non-linear criteria are adjusted to represent what is commonly referred to as risk aversion or disaster averseness.

Risk acceptance and risk management must be also be viewed in relation to the problem of rational allocation of available economical resources for risk reduction (JCSS, 2008c). The willingness to pay for risk reduction (WPRR) is fundamental to risk acceptance, and it is closely related to the life quality index method (LQI) for risk comparison or the so-called LQI principle (JCSS, 2008d). The use of the WPRR and the LQI principle allows risks to be evaluated for specific engineered facilities and/or hazards.

Under normal conditions no individual person would willingly accept life and property risks without some prospect of benefits or direct compensation; the LQI principle is an assessment of the marginal life saving cost associated with a given policy decision such as specifying dike heights.

Following the LQI principle, acceptability is an issue which has to be viewed in relation to a decision. The decision must satisfy the requirement that a certain limiting amount of economical resources are invested into saving human lives and protecting assets. The LQI principle helps in assessing risk independent of societal sectors, industry, field of engineering, etc. Both societal risks as well as risks to individuals are covered by the use of the principle in the sense that the criteria derived from the LQI hold irrespectively for all persons.

1.4 Risk-based Optimization and Calibration of Design Specifications and AEPs

The “forward” QRA analysis framework shown in Figure 1-1 and Figure 1-2 can be reversed in order to perform a “backward” optimization. This is shown schematically in Figure 1-4. In this type of analysis, the consequences and their likelihoods in the boxes on the RHS of the diagram are assumed to be given or constrained. What this means in practice, is that their F-C characteristics in a typical FC diagram as shown in Figure 1-3, are satisfactorily located within an acceptable risk zone, or, providing appropriate risk mitigation/management are in place, within an ALARP zone.

The unknown elements in Figure 1-4 are now the set of design parameters, specifications, or measures in the two rectangular boxes below the two sequence triangles. These can be obtained on the basis of a 'stochastic optimization" which typically amounts to a minimization of the overall cost subject to the constraint that all risks are acceptable. If there is just one single or a very small number of design parameters that need to be optimized, then the backward analysis is referred to as a risk-based calibration of these design parameters. Essentially, this type of analysis allows us to develop risk-based measures that exert acceptable and affordable control of the hazard.

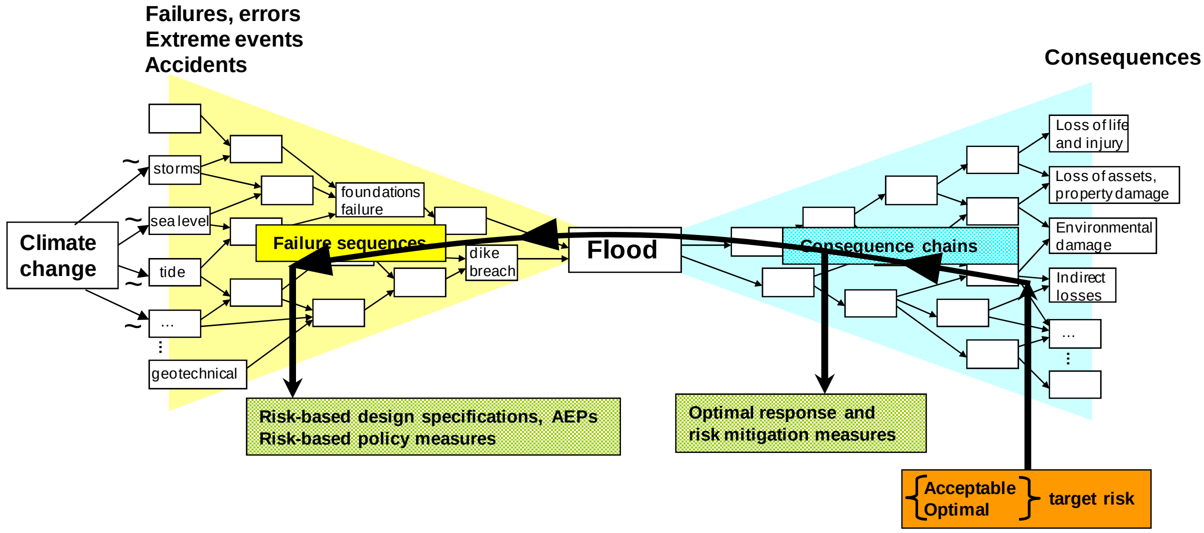


Figure 1-4: Developing and Calibrating Consistent Risk-based Measures and Criteria.

In the case of inundation, one overall risk-based optimization would not be effective as the spatial distribution of flood consequences would be too extensive to result in site-specific specifications.

For instance, the use of one overall AEP would not be economically effective. Therefore, a practice called "risk-zonation" is used to create geographic subsets of zones having more or less similar consequences, e.g. in terms of affected population/assets. For each zone, a separate set of design parameters such as AEPs can then be calibrated which accounts for the likely flooding consequences specific to a given zone. This approach would allow an effective calibration and fine-tuning of the appropriate AEPs throughout coastal BC.

1.5 Annual Risk versus Design Lifetime Risk

The probability *P*(*t*) of a hazard event occurring during a design life *T* (or, a project life *T*; or a planning horizon *T*; or an exposure of duration *T*) is related to the annual exceedance probability (AEP) of the hazard event or to its return period 1/AEP as follows (Borgman 1963):

$$p(T) = (1 - e^{-AEP * T}) \times 100$$

where:

p(*T*) = probability (in percent) of the hazard event occurring during *T*

T = planning timeline or the design life (in years)

AEP = annual exceedance probability of this hazard event (in 1/years).

The relationship between the design lifetime probability, the planning or design life time *T* and the AEP, over typical time lines that are relevant to planning or design of sea dikes or the administration of coastal flood risks, is illustrated in Table 1-3.

Table 1-3: Relationship between Lifetime Probability (%), Design Life (years) and AEP
- for clarity AEP is expressed as 1/Return Period, as shown – with rounding

Lifetime Probability *p*(*T*) in %	**Design Life or Planning Time Line - *T* - (in years)**					
	1	10	25	50	100	200
64%	AEP=1/1	AEP=1/10	AEP=1/25	AEP=1/50	AEP=1/100	AEP=1/200
50%	1/2	1/15	1/40	1/75	1/145	1/300
25%	1/4	1/35	1/90	1/175	1/350	1/700
10%	1/10	1/95	1/240	1/475	1/1000	1/2000
1%	1/100	1/1000	1/2500	1/5000	1/10000	1/20000

Note that the above equation and table assume a stationary long-term situation with each year being independent from, and identically distributed as, any other year.

1.6 Risk Reduction and Risk Management

The results of a QRA approach may identify risks that are found to be unacceptable or need to be reduced (ALARP). In such a case, a risk management process would aim to move a given system, subject to hazards from a high, or perhaps a medium risk, to a low risk expected outcome. The options available include:

- Reducing or minimizing the consequences as quantified in a form similar to Table 1-2
- Increasing the design related parameters to a lower AEP (a longer average return period)
- Decreasing the time line over which the particular scenario is exposed to the risk

Risk can be managed by a combination of measures that reduce or limit the probability (i.e., preventive measures) or limit the consequences (proactive, preparatory and response measures). Preventive measures include dike building and reinforcement. Proactive measures aim to avoid hazard situations, such as zoning and building regulations.; preparatory measures includes disaster planning and practice; and response measures include emergency response programs and insurance.

The optimum combination of measures “depends on the nature of the disaster, the properties of a dike system and the cost effectiveness of the various types of measures”, Delta Committee (2008).

To compare approaches to risk management taken by different nations: in the Netherlands, with its extensive system of dikes and flood structures, the primary emphasis is on prevention; there, flood protection is seen as a "paramount collective good" (Delta Committee, 2008). In the USA and the UK, the focus is on dealing with consequences with organized damage control, disaster management and insurance programs. According to the Delta Committee (2008), "Japan has the best coverage of the entire safety chain, from spatial planning and prevention (flood defences) to disaster management and recovery".

In the case of British Columbia, the desired approach still needs to be defined.

1.7 References

Borgman, L.E. (1963). *Risk Criteria*. J. Waterways and Harbors Div., ASCE, Vol 89, No. WW3, pp 1-35.

Delta Committee. 2008. *Working Together with Water - A Living Land Builds for its Future.* http://www.deltacommissie.com : Delta Committee, 2008. pp. 134.

Joint Committee of Structural Safety (JCSS). 2008a. *Risk Assessment in Engineering: Principles, System Representation, and Risk Criteria*.www.jcss.ethz.ch.

Joint Committee of Structural Safety (JCSS). 2008b. *Theoretical Framework for Risk Assessment.* Background document #1 to JCSS (2008a). www.jcss.ethz.ch.

Joint Committee of Structural Safety (JCSS). 2008c. Risk *Acceptance Criteria*. Background document #3 to JCSS (2008a). www.jcss.ethz.ch.

Joint Committee of Structural Safety (JCSS). 2008d. *Optimization with a LQI Acceptance Criterion*. Background document #5 to JCSS (2008a). www.jcss.ethz.ch.

IR2-12 Coastal Geomorphology – Climate Change: Predicted Changes in Hydrology, Sediment Loads, and Salinity

Information Source(s)

EIS Volume 2: Section 9.5.7.2

Context

In Section 9.5.7.2 of the EIS, the Proponent indicated that accurate predictions of future trends in sediment yield in the Fraser River basin related to climate change had not been studied. Furthermore, the Proponent stated that given the likelihood that the climate change signal would be very difficult to identify in such a large watershed, it was assumed that Fraser River discharge and sediment yield during Project operation will remain within the same range as has been measured in the recent past.

Climate change may affect future Fraser River discharge through earlier onset of snowmelt-driven peak discharge, increased winter and spring runoff, decreased summer runoff, and/or a possible shift from a snow-dominant to hybrid or rain-dominant system. This could also result in a change in salinity levels in the Fraser River estuary.

Information Request

Based on a review of scientific literature, document predicted changes in Fraser River hydrology, sediment loads and salinity conditions in the Fraser River estuary due to climate change at a time horizon no less than 50 years in the future.

Based on the predicted changes in hydrology, sediment loads and salinity, describe the effects of climate change on aquatic valued components within the Regional Assessment Area.

VFPA Response

Based on a review of scientific literature, document predicted changes in Fraser River hydrology, sediment loads and salinity conditions in the Fraser River estuary due to climate change at a time horizon no less than 50 years in the future.

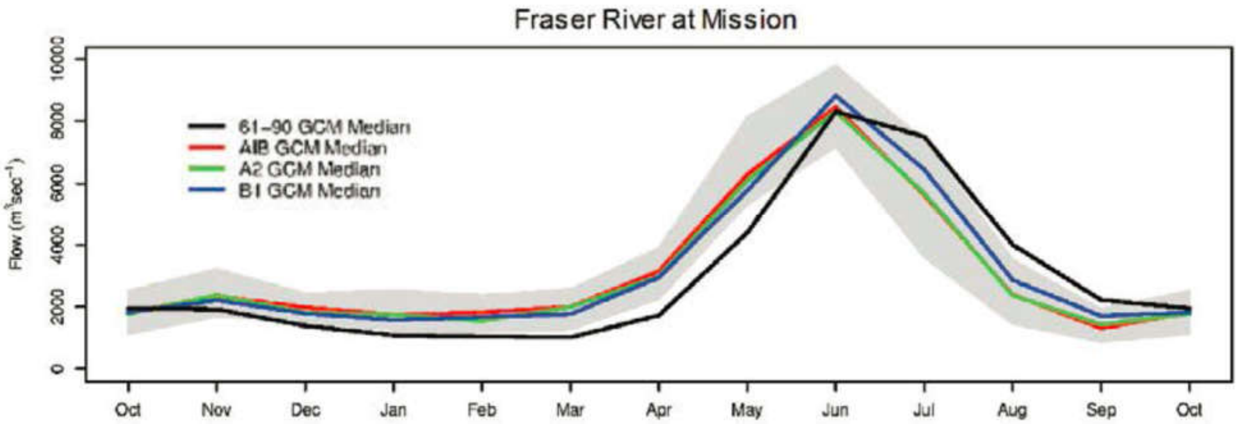
Climate change could appreciably change four of the macroscale factors that influence Roberts Bank: i) sea level, ii) Fraser River discharge, iii) Fraser River sediment loads, and iv) wave climate, as described in EIS Section 9.5.7 and EIS Appendix 9.5-A: Section 4.5. Although global changes in climatic conditions are generally accepted within the scientific community, predictions of global trends do not necessarily scale down to permit the prediction of local conditions or trends.

Since the Fraser River basin encompasses a wide range of climatic and physiographic regions, the hydrologic response of the Fraser River to future climate change is expected to be complex, and given the large drainage area, the response to climate change could potentially be largely self-moderating (as discussed in the EIS Section 9.5.7.2). EIS Appendix 9.5-A: Section 4.5.3 acknowledges that scientific literature is limited with respect to studies on sediment transport and associated geomorphic responses down-river, or on future trends in sediment yield related to climate change. Recent scientific studies that have examined the influence of future climate conditions on Fraser River hydrology include the following:

- Shrestha et al. (2012) present the results of a modelling study using the macro-scale VIC[1] model to assess the spatial and temporal variability of climate-induced changes in the Fraser River basin. Gridded observational data and downscaled output from general circulation models (GCMs) were used as model inputs to compare the observed conditions for the period 1961-1990 ("the 1970s") to predicted conditions for the period 2041-2070 ("the 2050s"). Future climate scenarios were derived from eight separate GCMs under three emissions scenarios. Although the results show a wide variation in the predicted hydrological response, the general conclusion is that summer runoff is generally projected to decrease, and winter and spring runoff are projected to increase. The timing of peak flow occurrence is expected to be earlier in the year under all scenarios, though there is considerable variation (2 to 45 days). Although the range in the future predictions is included, the comparison is made with reference to the 1970s mean conditions. The results of this study are synthesised in Vadeboncoeur (2016) and reproduced in **Figure IR2-12-1**.
- A subsequent study by Kang et al. (2014) has further investigated the influence of warming climate conditions and the declining influence of snow as a contributor to runoff in the Fraser River basin. This paper provides no further information on the timing and volume of Fraser River discharge, but provides further support for the conclusions of the Shrestha et al. (2012) study.

[1] Variable Infiltration Capacity (VIC) macroscale hydrology model.

Figure IR2-12-1 Projected Change in the Monthly Streamflow for the Fraser River at Mission under Four Scenarios



Note: The black line represents mean observed conditions in the period of 1961 to 1990, while the grey shaded area indicates the projection range for future predictions shown by the red, green and blue lines.
Source: Vadeboncoeur 2016.

With relatively limited information in the scientific literature to draw upon at the time of EIS preparation, the extent of changes of Fraser River outputs at the river mouth were discussed by the Coastal Geomorphology Technical Advisory Group (TAG) participants[2] prior to undertaking any assessment of future changes. The participants concluded that Fraser River flows will likely be different with climate change than today, and acknowledged the following, which are aligned with the conclusions of the recent scientific studies presented above:

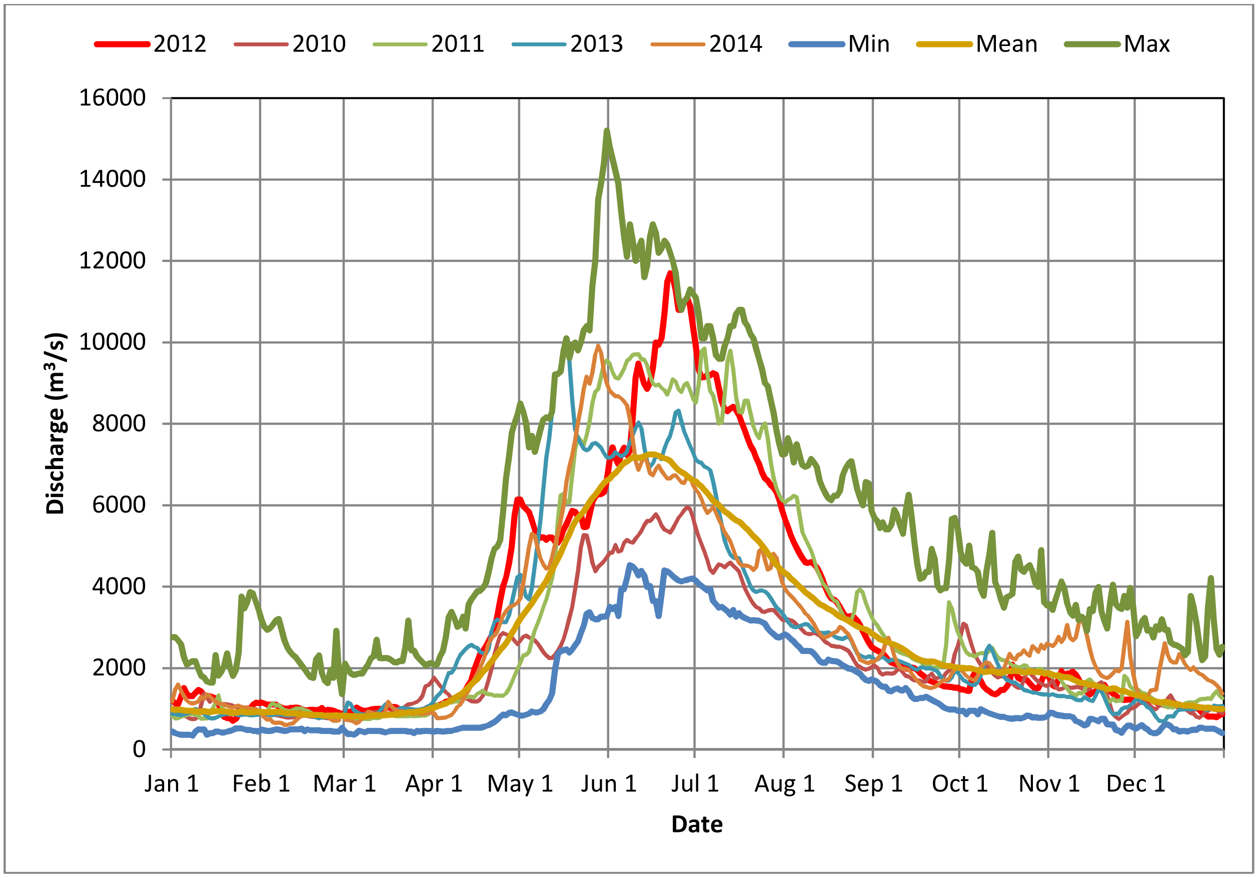
- A future scenario would likely include higher winter flows and lower summer flows, with the magnitude of the largest floods remaining about the same;
- There would likely be little change in sediment output to the Roberts Bank area with climate change;
- It was unlikely that changes in land-use upstream of the Project would substantially affect sediment production on a scale important for the assessment of the Project; and
- Human-induced changes in closer proximity to the proposed Project in Canoe Passage (e.g., from channel dredging) are likely to be more important to Roberts Bank geomorphology than the effects of climate change.

An evaluation of Fraser River discharges was also undertaken as part of the assessment of changes to coastal geomorphology as a result of the Project (see EIS Section 9.5.6.1). Extensive data collected at Water Survey of Canada station 08MF0005 at Hope, B.C., shown in **Figure IR2-12-2**, illustrates the range of Fraser River hydrologic conditions from 1913 to 2014. These ranges highlight the natural variability in Fraser River flows that influence environmental conditions in the Fraser River estuary (including sediment loading and salinity). Average Fraser River low flow is approximately 850 cubic metres per second (m^3/s) in March

[2] Refer to the Preamble at the beginning of this IR response package and Appendix IR2-A for details on the TAG, including expert participants and climate change discussions.

and average peak flow is about 7,200 m³/s in June for the period of 1913 to 2014. The 2012 discharge period was incorporated in hydrodynamic modelling in the coastal geomorphology study, as described in Section 9.5.5.1 of the EIS. This period is recognised as a larger freshet event (i.e., approximately 15-year return period), and is within the range of historical hydrographic data observations. The coastal geomorphology assessment, therefore, provides an assessment of 'increased winter and spring runoff' stated in the context from the Panel, and changes in salinity associated with higher freshet flows that may be experienced as a result of climate change.

Figure IR2-12-2 Annual Historical Fraser River Discharge at Hope, B.C.



Note: Min (minimum), Max (maximum), and Mean are calculated from daily flow records for the period 1913 to 2014.

In summary, changes to average annual Fraser River flows are likely under future climate change scenarios—namely, an increase in the winter/spring flow, a decrease in the summer flow, and earlier occurrence of the peak freshet flow is expected. These changes fall within the range of conditions that have been experienced over the period from 1913 to 2014 and are not expected to result in measurable changes to the discharge of sediment from Fraser River, or measurable changes to coastal geomorphology from changes in Fraser River hydrology. Changes to salinity may occur in the regional assessment area related to the timing and magnitude of flows. Such changes have been assessed by comparing the changes to salinity that the Project may have based on 2012 summer flows versus changes based on 2012 winter flows (i.e., aligned with the range of conditions expected to be experienced with any climate change induced influences), and changes to salinity from future climate change are predicted to fall within the range of variability based on the existing record of flows.

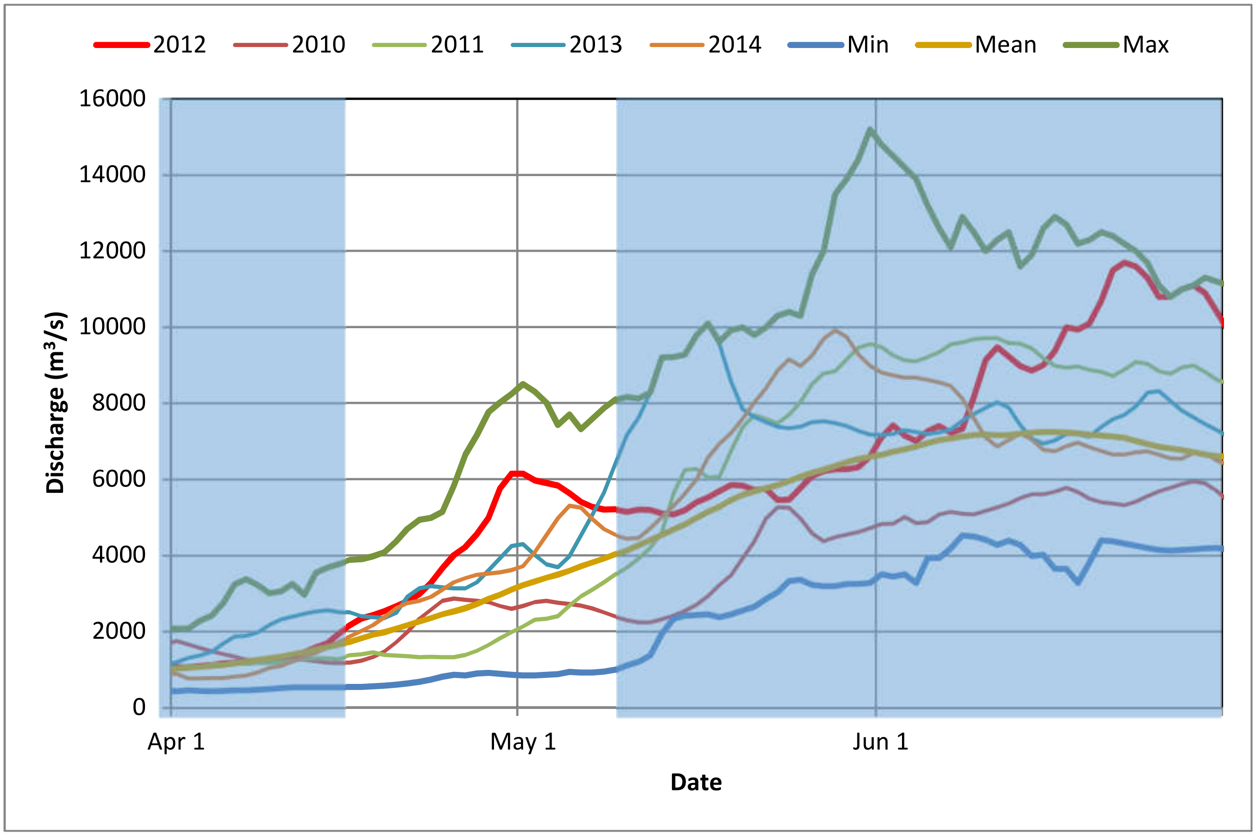
Based on the predicted changes in hydrology, sediment loads and salinity, describe the effects of climate change on aquatic valued components within the Regional Assessment Area.

As stated above, changes to hydrology, sediment loads, and salinity in the regional assessment area from future climate change are predicted to fall within the range of variability based on the existing record of Fraser River flows. Information pertaining to naturally varying environmental conditions at Roberts Bank and the Fraser River estuary and effects on aquatic valued components is provided in EIS Sections 10.0 to 15.0. Additional information was provided during the completeness review phase in Additional Information Request #13 (AIR-12.04.15-13), Schedules 13-1 to 13-5 for marine vegetation, marine invertebrates, marine fish, marine mammals, and coastal birds, respectively (CEAR Document #388[3]).

As an example of the natural variability observed during the Fraser River freshet, **Figure IR2-12-3** illustrates the variation in discharge during migration period for migratory birds (April to end of June) observed over 1913 to 2014 period (minimum, maximum, and mean), as well as annual hydrographs for 2010 to 2014. For the mid-April to early-May period (shown in the white zone), the average low and peak Fraser River discharges are approximately 530 m^3/s and 8,500 m^3/s, respectively, with an average discharge ranging from 1,800 m^3/s to 4,000 m^3/s during that period. Species have adapted to a range of conditions within the regional area influenced by the Fraser River. For further information pertaining to characterisations of existing conditions for marine invertebrate, marine fish, marine mammal, and coastal bird species found in, or migrating through each valued component regional study area (including the local study area) refer to Additional Information Request #9 (AIR-12.04.15-9) (CEAR Document #388).

[3] CEAR Document #388 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements Follow-Up (See Reference Document # 345) including 22 Technical Data Reports

Figure IR2-12-3 Annual Historical Fraser River Freshet Variability (1913 to 2014) at Hope, B.C. During Spring Northward Bird Migration (April, May, June)



References

Kang, D. H., X. Shi, H. Gao, and S. J. Déry. 2014. On the Changing Contribution of Snow to the Hydrology of the Fraser River Basin, Canada. Journal of Hydrometeorology, 15, 1344–1365.

Shrestha, R. R., M. Schnorbus, A. T. Werner, and A. J. Berland. 2012. Modelling Spatial and Temporal Variability of Hydrologic Impacts of Climate Change in the Fraser River Basin, British Columbia, Canada. Hydrological Processes, (26), 1840–1860.

Vadeboncoeur, N. 2016. Perspectives on Canada's West Coast Region. In D. S. Lemmen, F. J. Warren, T. S. James, and C. S. L. Mercer Clarke (Eds.), Canada's Marine Coasts in a Changing Climate (pp. 207–252). Government of Canada, Ottawa, ON.

IR2-13 Coastal Geomorphology – Hydrodynamics: Salinity Conditions

Information Source(s)

EIS Volume 2: Appendix 9.5-A, Appendix B

Context

The Proponent identified the uncertainty of salinity concentrations at the Coastal Geomorphology model's open boundaries as an important source of model salinity uncertainty on Roberts Bank, and stated that the model results could be improved if additional field salinity profiles had been available. Fisheries and Oceans Canada expects that it is unlikely that changes in salinity at relatively distant open boundaries, at Port Renfrew and Hornby Island for example, would have an important impact on model salinity predictions at Roberts Bank.

According to Fisheries and Oceans Canada, the inability of the model to accurately represent the complex hydrodynamics of the Fraser River plume is a more likely reason for model inaccuracies. A sensitivity test of the model where the open boundary salinity values would vary, incorporating the influence of the Fraser River plume, is recommended to provide greater clarity regarding the sources of the uncertainty in the model results.

Information Request

Conduct a sensitivity test of the Coastal Geomorphology model, incorporating the hydrodynamics of the Fraser River plume as well as the influence of variable boundary salinity conditions.

VFPA Clarification

This information request (IR) in part was originally posed and answered in questions 1.5 and 1.7 in CEAR Document #547. The Canadian Science Advisory Secretariat (CSAS) review (CEAR Document #893) stated that the supplemental information provided in CEAR Document #547 was considered in their review of the assessment of coastal geomorphology, and indicated that this supplemental information had addressed several of their issues (see CEAR Document #893, section 3.2.4). Outstanding issues listed in section 3.2.4, page 9 of CEAR Document #893, did not mention further concern with uncertainty associated with salinity modelling. The following response elaborates on the VFPA's response to questions 1.5 and 1.7 in CEAR Document #547.

The IR refers to the "Coastal Geomorphology model"; however, a number of models that comprise the TELEMAC-MASCARET modelling system (TELEMAC) were used to assess various aspects of coastal geomorphology (see Section 2 of EIS Appendix 9.5-A: Appendix B). For the purposes of responding to this IR, the VFPA has assumed that the request is referring to TELEMAC-3D, the hydrodynamic model that calculates tidal currents, incorporating the density effects of varied water salinity. The Panel's context to the IR cites Fisheries and

Oceans Canada's (DFO's) view that "the inability of the model to accurately represent the complex hydrodynamics of the Fraser River plume is a more likely reason for model inaccuracies." The source of this statement is not clear from the IR or DFO's submissions (CEAR Document #893). In response to this, the VFPA has provided information on how the Fraser River plume was incorporated into the TELEMAC-3D.

In addition, this response also provides a brief overview of how uncertainty with respect to salinity outputs of the TELEMAC-3D model was considered in the assessment of effects of the Project on valued components.

VFPA Response

An additional sensitivity test of the hydrodynamic model incorporating the hydrodynamics of the Fraser River plume, as well as the influence of variable boundary conditions, has not been undertaken for the following reasons:

- The sensitivity of the TELEMAC-3D model to various input parameters has already been evaluated during the model development phase;
- The hydrodynamic processes of the Fraser River plume are incorporated into the TELEMAC-3D model code;
- A sensitivity test on the influence of variable boundary conditions is unlikely to influence modelled salinity at Roberts Bank (as acknowledged in CEAR Document #893); and
- Uncertainty associated with model predictions were factored into the assessment of the potential effects of the Project on some valued components.

Further discussion is provided below.

Sensitivity of Input Parameters

As described in the VFPA's response to question 1.7 in CEAR Document #547, the sensitivity of the TELEMAC-3D model to the various input parameters was evaluated during the model development phase, rather than as part of a post-modelling sensitivity analysis as is common practice with simpler numerical models that can be run in a short time period. This is an accepted approach that has emerged in response to the development of increasingly complex models (e.g., see Roelvink and Reniers 2012). After verifying that the model inputs reproduced conditions were consistent with the known physical parameters, the model results were validated against measured environmental parameters. The results of model validation in respect to salinity are described in Section 4.5 of EIS Appendix 9.5-A: Appendix B, with further information provided in IR2-01. Any adjustments to input parameters were noted in a model log sheet so that adjustment to the results in the model development phase could be compared during subsequent model runs. When the model reached an advanced stage of development, the results of longer model runs were compared to other information sources (e.g., airphotos, LiDAR, etc.) to check for consistency.

Hydrodynamics of the Fraser River Plume

The IR asks that the hydrodynamics of the Fraser River plume be incorporated into the model during the sensitivity tests, implying that these processes were not already considered in the model runs presented in the EIS. The following dominant processes governing the hydrodynamics of the Fraser River plume are incorporated into the TELEMAC-3D model code, which was not altered while conducting the model study, providing assurance that the model is capable of adequately representing this complex physical environment (see Section 2.1 in Appendix B of EIS Appendix 9.5-A):

- Influence of salinity on density;
- Bottom friction;
- Influence of the Coriolis force;
- Influence of weather elements (wind); and
- Dry areas in the computational domain—tidal flats.

As described in Section 4 of EIS Appendix 9.5-A: Appendix B, the model reproduces the timing of the salt intrusion well at the Canoe Passage station for spring tides with large tidal currents, but it is acknowledged that the model does not predict the salinity intrusion very well during the neap tides with relatively weak tidal currents (Figure 15 in Appendix B in EIS Appendix 9.5-A). The Canoe Passage station is physically distant from Project-influenced salinity changes on the tidal flats north of the causeway. More importantly, modelled salinity profiles for the Roberts Bank intertidal zone are comparable to measured salinity profiles at Roberts Bank as the model reproduced the spatial and vertical distribution of the Fraser River plume well during various stages of tidal conditions, as shown in Figure 15 of EIS Appendix 9.5-A: Appendix B for August 2012 and Figure IR2-01-14 in IR2-01 for the period of August 1 to December 31, 2012.

Influence of Variable Boundary Salinity Conditions and Sensitivity Test

A sensitivity test of the hydrodynamic model to evaluate the effect of varying salinity at the open boundary has not been undertaken for the reasons acknowledged by DFO (section 3.1.2 in CEAR Document #893), and explained further below:

> *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.*

The VFPA agrees with the context from the Panel and with DFO (CEAR Document #893) that varying salinity at the open boundaries is unlikely to influence modelled salinity at Roberts Bank. The VFPA has, therefore, not undertaken a sensitivity analysis on varying salinity at the open boundaries in this response. Further rationale is provided below.

The IR refers to the following statement made in Section 4.5 of EIS Appendix 9.5-A: Appendix B that discusses possible reasons for discrepancies between observed data and model results:

A notable source of uncertainty is the limited availability of salinity data at the model's open boundaries (Port Renfrew and Hornby Island). The initial salinity field and salinity profiles along the open boundaries were estimated based on April, June and September 2012 water properties data collected by Department of Fisheries and Oceans Canada. The model results can be improved if additional field salinity profiles at Port Renfrew and Hornby Island were available as inputs; however, to the best of our knowledge, data were only collected during the months stated above.

As stated in question 1.5 in CEAR Document #547, the above statement refers to the confidence in the results and not whether the results are inaccurate. Salinity at the open boundaries was not adjusted to test the model's response for two main reasons, which are explained below.

First, the variation across seasons at the two input stations (i.e., Port Renfrew and Ballenas Island) located at the model's open boundaries[1] was very small. Measurements were available to describe the pre-freshet (April), freshet (June), and post-freshet (September) periods in 2012. Figure 6 in CEAR Document #547 shows the salinity profiles that defined the salinity at the open boundaries. Salinity levels across the three seasons at Ballenas Island varied by up to 0.5 PSU (practical salinity units), while salinity levels at Port Renfrew varied by approximately 1 PSU. Given the very small change to salinity at these locations during 2012 freshet conditions, it was assumed that salinity levels would be similar in winter.

Second, such small changes in salinity will have a negligible effect on water density, and therefore have no influence on the hydrodynamic processes represented in the model for the local study area.

Managing Salinity Uncertainty in the Effects Assessment

Uncertainty associated with model predictions for salinity were factored into the assessment of the potential effects of the Project on some valued components. For example, the ecosystem model study, along with other lines of evidence, was used to predict potential effects of the Project on the productivity of a number of valued components such as marine vegetation, marine invertebrates, marine fish, and coastal birds. For that study, a sensitivity analysis on salinity was undertaken by varying the salinity outputs from the TELEMAC-3D model by ±20% as described in Section 3.2 in EIS Appendix 10-D and section 2.13 of CEAR Document #547. The shorebird foraging opportunity model modelled three scenarios: salinity associated with two high flow freshet scenarios and salinity associated with an average flow freshet scenario. By modelling this flow range, the shorebird foraging opportunity model effectively captured a range of saline conditions incorporated into the assessment of potential

[1] Artificial boundaries were selected for the hydrodynamic model to limit the model domain. An open boundary refers to an artificial boundary which consists of open water, where inflow and outflow occurs. The prescription of open boundary conditions requires extensive information for physical parameters such as water level elevations and salinity levels at specific points in time and space. Once boundary conditions were prescribed for the open boundaries at Port Renfrew in Juan de Fuca Strait and Ballenas Island, just south of Hornby Island in the Strait of Georgia, the hydrodynamic model was used to simulate conditions in the local study area. For locations, refer to Figure IR2-01-1 in IR2-01.

effects of the Project to coastal birds (see Section 15.7.2.2 and Appendix 15-B of the EIS for more information), thus mitigating uncertainty in the TELEMAC-3D output by considering a range of salinities.

References

Roelvink, D. and A. D. Reniers. 2012. A Guide to Modelling Coastal Morphology. Advances in Coastal and Ocean Engineering. Volume 12.

IR2-14 Coastal Geomorphology – Hydrodynamics: Two Week Spin Up

Information Source(s)

EIS Volume 2: Section 9.5; Appendix 9.5-A

CEAR Doc #547

Context

In CEAR Doc #547, the Proponent stated that the two-week spin up period was considered to be of sufficient duration to ensure that salinity and water levels had reached a state of statistical equilibrium for coastal geomorphology numerical modeling simulations. However, no evidence of the equilibrium state was presented.

Information Request

Provide information to demonstrate that the two week spin up period for the coastal geomorphology model was:

- sufficient to allow the hydrodynamic model to adjust to boundary forcing; and
- of sufficient duration to ensure that salinity, water levels and ocean currents reached a state of statistical equilibrium.

VFPA Clarification

The VFPA understands the information request (IR) to be asking, through two slightly different requests, to demonstrate that modelled conditions are in close agreement with measured conditions for areas within the model domain by the end of the two week spin up period. The VFPA provides the response to this request below.

As a point of clarification, the IR refers to the "Coastal Geomorphology model"; however, three models that comprise the TELEMAC SYSTEM were used to assess various aspects of coastal geomorphology (see Section 2.1 of EIS Appendix 9.5-A: Appendix B). For the purposes of responding to this IR, the VFPA has assumed that the request is referring to TELEMAC-3D, the hydrodynamic model that computes the physical processes of tidal currents by incorporating information such as water levels and the density effects of salinity.

VFPA Response

This response provides supplemental information that demonstrates that the two week spin up period was of sufficient duration to ensure salinity, water levels, and ocean currents reached a state of statistical equilibrium and adjustment following the initial forcing of boundary conditions.

To help answer the IR, a brief overview of what is meant by 'boundary forcing' and 'spin up period' is provided. Boundary forcing is the *a priori* selection of hydrodynamic conditions at the open boundaries of the TELEMAC-3D model (located at Port Renfrew and Ballenas Island as shown in Figure IR2-01-1 in IR2-01), which subsequently drives hydrodynamic conditions in the rest of the model domain over a specified period of time. For example, salinity values at the open boundary locations were selected based on data acquired from Fisheries and Oceans Canada (DFO; discussed further in IR2-13) and water levels were specified based on predicted tides calculated using the WebTide Tidal Prediction model (DFO 2005).

Spin up period is the time taken for a numerical model to reach a state of statistical equilibrium after being initialised by boundary forcing. Uncertainties associated with the observational data that are used to specify these forced conditions can cause initial predictions to be unreliable while the model attempts to stabilise. Such uncertainties can include the spatial and temporal resolution of the observational data. Once the fields have adjusted and model outputs stabilise, the outputs become more reliable within limits that can themselves be documented through comparisons with observational data. The model outputs from the spin up period are, therefore, not included with the model results incorporated in the coastal geomorphology assessment.

As one of the starting points for all hydrodynamic models is the forcing of boundary conditions, all subsequent adjustments during the spin up period follow from this point. In addition to demonstrating how model conditions compare with measured salinities, comparisons of modelled water levels and currents to observational data also demonstrate model performance with respect to adjusting to boundary forcing after the two week spin up period. The responses to the two requests in this IR are inherently connected, and by answering the second part of the request, the VFPA believes the first request has been implicitly answered, which the VFPA believes to be the intent behind the statement in section 3.1.1 of CEAR Document #893:

> *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 remainder of the response therefore provides information to demonstrate that the two-week spin up period was of sufficient duration to ensure that salinity, water levels, and currents reached a state of statistical equilibrium.

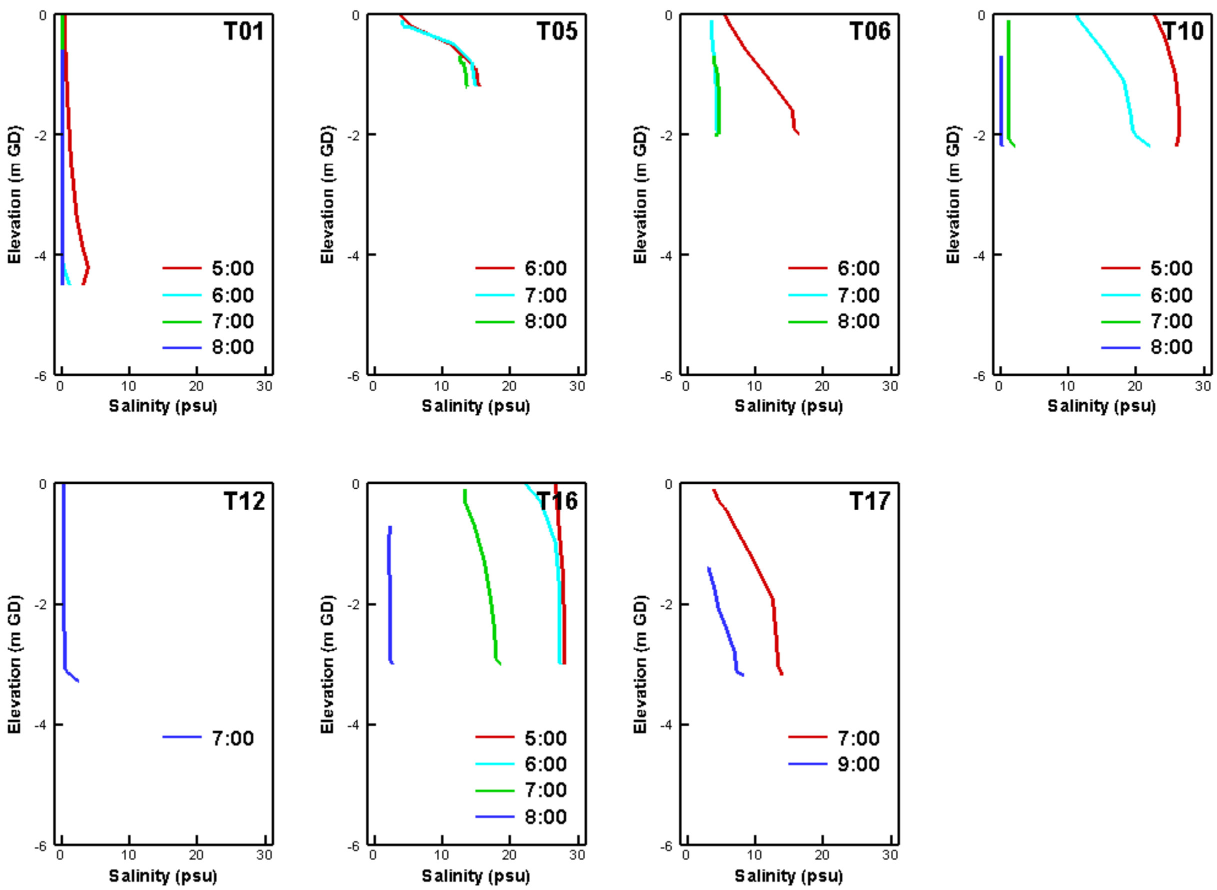
Salinity

Salinity measurements at Roberts Bank were collected intermittently at various locations in June, July, and August 2012 and continuously at the Canoe Passage station from May 8 to December 31, 2012 (see Figures 7 and 16 of EIS Appendix 9.5-A: Appendix B for locations).

To illustrate the effect of spin up period on the salinity field, a model spin up simulation was conducted over a two-week period from June 7 to 21, 2012. This period was selected as there was corresponding field data to compare to model outputs at the end of the spin up period.

Modelled salinity profiles at the end of the two week spin up period on June 20, 2012[1] during a high-slack falling tide condition are shown in **Figure IR2-14-1.** Observed salinity profiles for the same period of a high-slack falling tide condition on June 20, 2012 are shown in **Figure IR2-14-2**.

Figure IR2-14-1 Modelled Salinity Profiles on June 20, 2012 for Simulation Started on June 7, 2012



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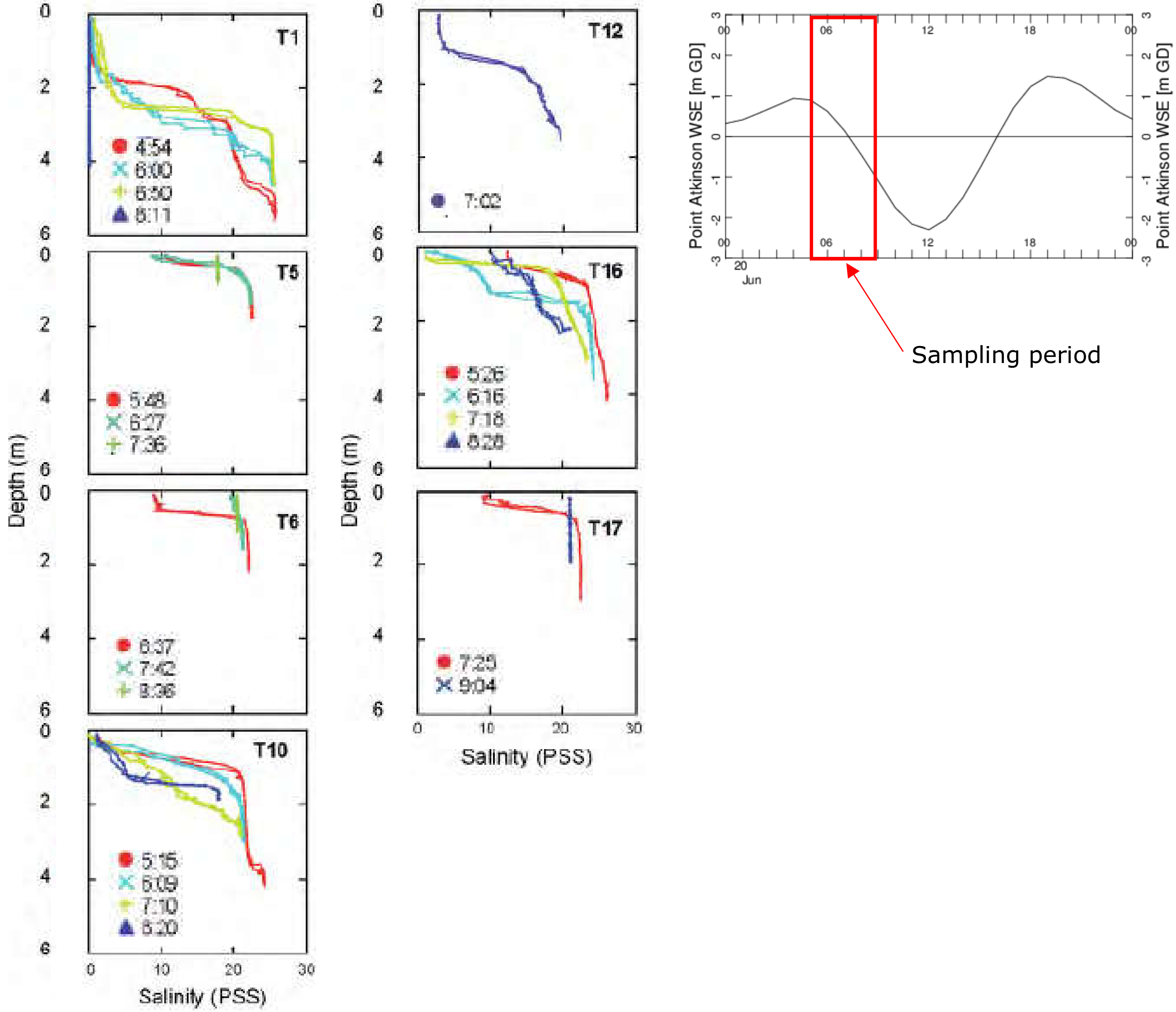
[1] Model outputs were compared against available field data from a high slack falling tide on June 20, 2012, as there was no field data to compare against for June 21, 2012.

Figure IR2-14-2 Measured Salinity Profiles on June 20, 2012

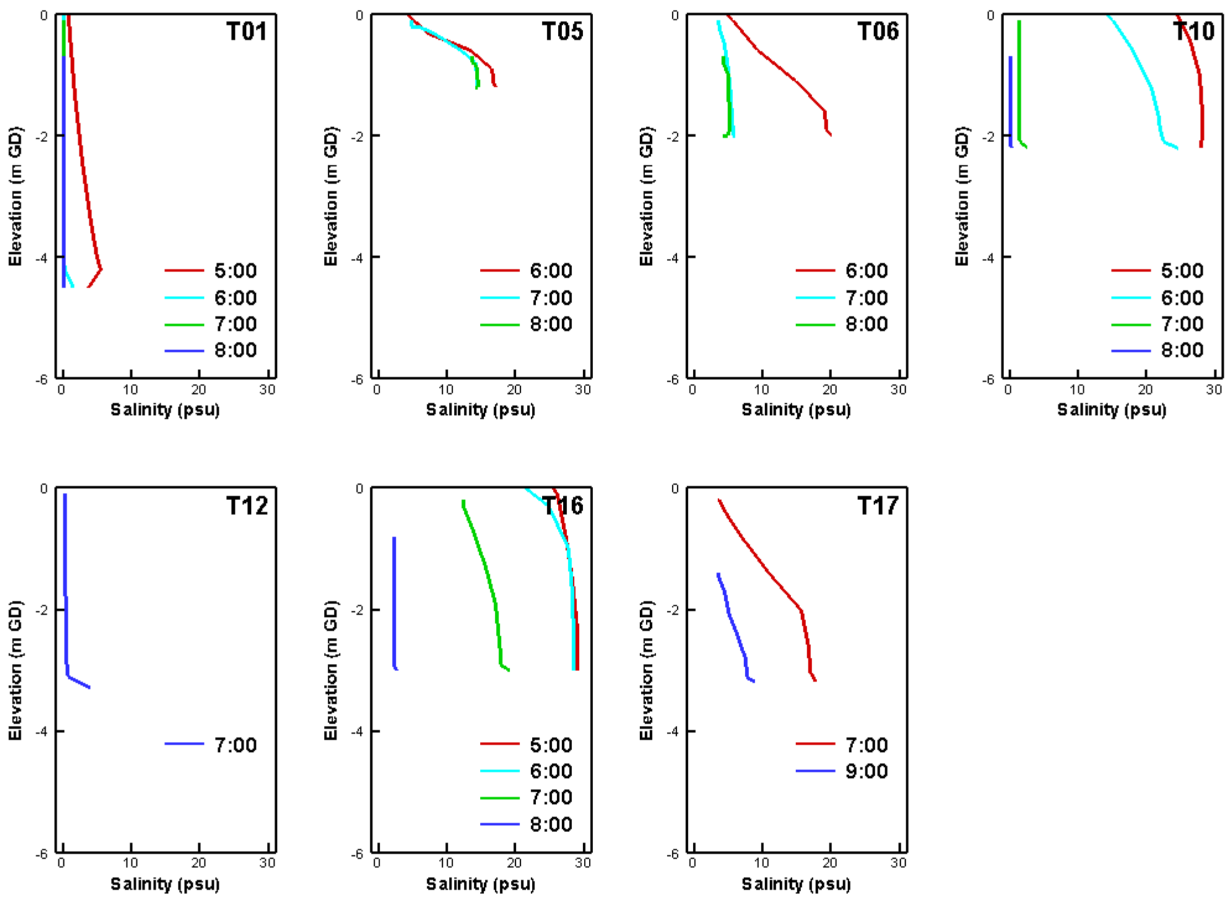


The figures show that there is reasonable agreement between the predicted and observed salinities with respect to how the profiles change during the falling tide on June 20, 2012 at stations T05, T06, and T17 near the Roberts Bank causeway. The modelled salinity for stations within the Canoe Passage channel (T1 and T12) indicate a very strong freshwater influence, while the field measurements show that saline water was present at depth within the channel. Despite the noted discrepancies between the modelled results and observed profiles, which are not related to spin up (see below), it has been demonstrated that the model represents the dominant processes well (see response to IR2-01), and is therefore suitable to predict the changes that the Project will have on the environment.

Further evidence that the two week spin up period is of sufficient duration with regards to salinity modelling is demonstrated by a comparison between modelled results on June 20, 2012 that are based on the short (two week) model run (**Figure IR2-14-1**) to those that are based on the months long simulation that was initiated in mid-April (**Figure IR2-14-3**).

The salinity profiles are essentially the same, indicating that the model has established a statistical equilibrium after the two-week of spin up period. Any minor discrepancies that existed at the end of the April spin up period, and which were included in the results for May, June, and July, were extremely small compared to large number of data points (based on hourly results) that were considered in the statistical representation of salinity (see response to IR2-02) for the three-month freshet period.

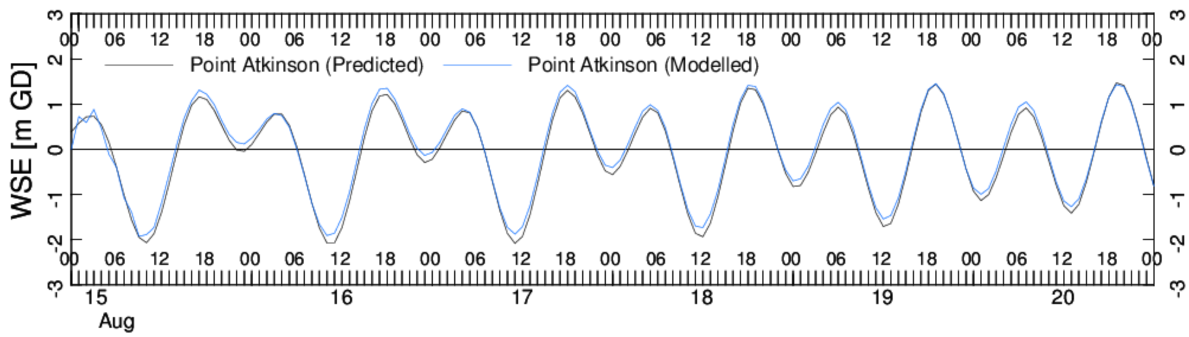
Figure IR2-14-3 Modelled Salinity Profiles on June 20, 2012 for Simulation Started Mid-April 2012



Water Levels

Modelled water levels can be compared to DFO predicted water levels for any period in 2012 because tide predictions are available for the entire period at numerous locations within the model domain. IR2-01 describes how DFO predicted and observed water level elevations were used in the model validation process. A model spin up simulation was conducted from August 15 to 31, 2012 at Point Atkinson (see Figure IR2-01-1 in IR2-01 for location). **Figure IR2-14-4** compares modelled water levels to predicted water levels at Point Atkinson, and illustrates that modelled water level experienced some fluctuations in the first six hours of simulation but stabilised after about 24 hours of simulation, again indicating the appropriateness of a two-week spin up period[2].

Figure IR2-14-4 Modelled and Measured Water Levels at Point Atkinson



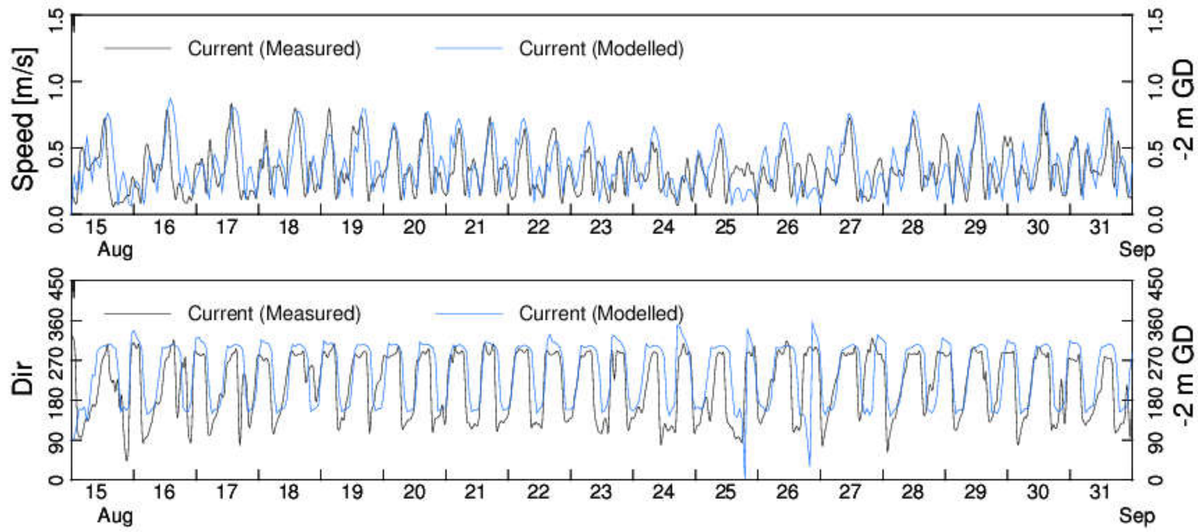
Note: Since modelled water levels stabilised after 24 hours, the full spin up period from August 15 to 31, 2012 is not shown.

Currents

The same model spin up period for water levels was used for currents. Modelled currents were compared to measured data at the AWAC station located at Roberts Bank (see Figure IR2-01-1 in IR2-01 for location). **Figure IR2-14-5** provides information on current speed and direction, and shows that currents are slightly off the phase at the beginning of the simulation and stabilised after 72 hours, again confirming the appropriateness of a two-week model spin up period.

[2] In **Figure IR2-14-4**, since the modelled water levels stabilised after 24 hours, the full spin up period from August 15 to 31, 2012 is not shown.

Figure IR2-14-5 Modelled and Measured Currents at the AWAC Station Showing Current Speed (top panel) and Direction (bottom panel)



References

Fisheries and Oceans Canada (DFO). 2005. WebTide Tidal Prediction Model (v0.7.1). Bedford Institute of Oceanography. http://www.mar.dfompo.gc.ca/science/ocean/coastal_hydrodynamics/WebTide/webtide.html>. Accessed February 2017.

IR2-15 Coastal Geomorphology – Geomorphic Modelling: Model Runs

Information Source(s)

EIS Volume 2: Section 9.5; Appendix 9.5-A

Context

Clarification is required on the specific coastal geomorphology model runs that were completed in the preparation of the EIS.

Information Request

Provide a table summarizing the coastal geomorphology model runs, including the simulation period, model components, and specific model forcings.

VFPA Response

Table IR2-15-1 in **Appendix IR2-15-A** summarises the model runs that were completed in the preparation of EIS Section 9.5 (and supporting appendices). For each run, information is provided pertaining to simulation period, future condition (i.e., with or without the Project), key process incorporated in the run (i.e., hydrodynamic, wave, sediment transport, and salinity), and the specific model forcings at the model boundaries. The model forcings include water elevations at open boundaries, Fraser River at New Westminster, salinity at open boundaries, and wind forcing.

Appendices

Appendix IR2-15-A Tabulated Information on Coastal Geomorphology Model Runs

APPENDIX IR2-15-A

TABULATED INFORMATION ON COASTAL GEOMORPHOLOGY MODEL RUNS

Appendix IR2-15-A: Tabulated Information on Coastal Geomorphology Model Runs

Table IR2-15-1 Model Runs Completed to Inform the Assessment of Coastal Geomorphology Described in EIS Section 9.5 and Supporting Appendices

EIS Section	Model Description		Key Processes				Boundary Conditions			
	Simulation Period	Future Condition Case	Hydrodynamic	Wave	Sed. Trans.	Salinity	Water Elevations at Open Boundaries[1]	Fraser River at New Westminster[2]	Salinity at Open Boundaries[3]	Wind Forcing[4]
EIS Section 9.5.8.2; EIS Appendix 9.5-A Section 6.2 - Ocean Circulation and Section 6.4 - Wave Climate	freshet (May to Jul)	Without Project	yes	yes	no	no	Webtide	NHC Mike11 model	n/a	yes
	freshet (May to Jul)	With Project	yes	yes	no	no	Webtide	NHC Mike11 model	n/a	yes
	non-freshet (Oct to Dec)	Without Project	yes	yes	no	no	Webtide	NHC Mike11 model	n/a	yes
	non-freshet (Oct to Dec)	With Project	yes	yes	no	no	Webtide	NHC Mike11 model	n/a	yes
EIS Appendix 9.5-A Section 6.3 - Salinity	freshet (May to Jul)	Without Project	yes	no	no	yes	Webtide	NHC Mike11 model	DFO Apr/Jun profiles	yes
	freshet (May to Jul)	With Project	yes	no	no	yes	Webtide	NHC Mike11 model	DFO Apr/Jun profiles	yes
	non-freshet (Oct to Dec)	Without Project	yes	no	no	yes	Webtide	NHC Mike11 model	DFO Sep profiles	yes
	non-freshet (Oct to Dec)	With Project	yes	no	no	yes	Webtide	NHC Mike11 model	DFO Sep profiles	yes
EIS Section 9.5.7.2; EIS Appendix 9.5-A Section 6.5 - Effect of Climate Change on Nearshore Wave Climate	freshet (May to Jul)	Without Project	yes	yes	no	no	Webtide + SLR	NHC Mike11 model	n/a	yes
	freshet (May to Jul)	With Project	yes	yes	no	no	Webtide + SLR	NHC Mike11 model	n/a	yes
	non-freshet (Oct to Dec)	Without Project	yes	yes	no	no	Webtide + SLR	NHC Mike11 model	n/a	yes
	non-freshet (Oct to Dec)	With Project	yes	yes	no	no	Webtide + SLR	NHC Mike11 model	n/a	yes
EIS Appendix 9.5-A Section 7.1 - Morphodynamic Modelling Approach	3 winter months	Without Project	yes	yes	yes	no	Webtide	NHC Mike11 model	n/a	yes
	3 winter months	With Project	yes	yes	yes	no	Webtide	NHC Mike11 model	n/a	yes
	3 winter months	Without Project	yes	no	yes	no	Webtide	NHC Mike11 model	n/a	yes
	3 winter months	With Project	yes	no	yes	no	Webtide	NHC Mike11 model	n/a	yes
EIS Section 9.5.7.2 and EIS Section 9.5.8.2; EIS Appendix 9.5-A Section 7.2 - Morphodynamic Model Results	1,440 model days	Without Project	yes	no	yes	no	Webtide	NHC Mike11 model	n/a	yes
	1,440 model days	With Project	yes	no	yes	no	Webtide	NHC Mike11 model	n/a	yes
EIS Appendix 9.5-A Appendix B Section 3.6.1 - Water Levels at Point Atkinson and Canoe Passage	August	Without Project	yes	yes	no	no	Webtide	NHC Mike11 model	n/a	yes
EIS Appendix 9.5-A Appendix B Section 3.6.2 - Flow Across Canoe Passage Station	August	Without Project	yes	yes	no	no	Webtide	NHC Mike11 model	n/a	yes
EIS Appendix 9.5-A Appendix B Section 3.6.3 - Salinity	October	Without Project	yes	no	no	yes	Webtide	NHC Mike11 model	DFO Sep profiles	yes
EIS Appendix 9.5-A Appendix B Section 3.6.4 - Currents	August	Without Project	yes	yes	no	no	Webtide	NHC Mike11 model	n/a	yes
EIS Appendix 9.5-A Appendix B Section 3.6.5 - Waves	August	Without Project	yes	yes	no	no	Webtide	NHC Mike11 model	n/a	yes

Notes:
[1] Department of Fisheries and Oceans. 2005. WebTide Tidal Prediction Model (v0.7.1). Bedford Institute of Oceanography.
[2] NHC. 2008. Fraser River Hydraulic Model Update. Report prepared for the BC Ministry of Environment.
[3] http://www.pac.dfo-mpo.gc.ca/science/ocean
[4] Spatial and temporal wind field developed from hourly data from Nanaimo Airport, Pam Rocks, Race Rocks, Sand Heads, Victoria, Halibut Bank, Cherry Point, Port Townsend, Smith Island, and West Pont.
Sed. Trans. = Sediment Transport; SLR = sea level rise (incorporated as climate change effect in future conditions with and without the Project); n/a = not applicable

IR2-16 Coastal Geomorphology – Geomorphic Changes: Construction Phase

Information Source(s)

EIS Volume 2: Section 9.5, Appendix D

Context

In Appendix D of Appendix 9.5-A, the Proponent provided an assessment of erosion-related seepage from the containment dyke. However, no assessment was conducted for the other components of the proposed Project during the construction phase.

The Proponent stated that the approach adopted for assessing the proposed Project was to assess the future changes to coastal geomorphology arising from the completed Project, and not for the consideration of changes associated with incremental stages of the Project during the construction phase. This approach was taken because the Proponent considered the rate of geomorphic change as slow in comparison with the implementation rate of the construction schedule.

An analysis of the changes in coastal geomorphology associated with the construction phase of the proposed Project is required.

Information Request

For each component of the proposed Project, provide an analysis of the potential changes to coastal geomorphology from Tsawwassen Ferry Terminal to Canoe Pass for the Project construction phase.

VFPA Response

For clarity, potential Project-related changes to coastal geomorphology in the area between the Tsawwassen Ferry Terminal (the B.C. Ferries Terminal) and Canoe Passage were assessed for the construction phase as well as the operation phase. Only the expanded causeway component of the Project is expected to result in a potential change to coastal geomorphology during the construction phase that is different from the change expected during the operation phase.

EIS Appendix 9.5-A: Section 8.2 outlines construction-related activities that were considered during the scoping phase of the coastal geomorphology assessment for four components: berth pocket, marine terminal, expanded tug basin, and widened causeway. Construction activities for these Project components are described in EIS Section 4.4.1 and illustrated in Figures 4-10 to 4-20 in incremental stages. Marine-based activities considered for inclusion in the coastal geomorphology assessment included the following activities:

- Dredging of in situ sediments from the berth pocket and caisson trench;
- Disposal of sediment-laden water from dredge basin dredgeate;

- Densification of in situ sediment below the base of the dredged berth pocket and installation of mattress rock to prevent scour and stabilise the toe of the adjacent caisson structure;
- Construction of containment dykes for terminal land development and causeway widening; and
- Expansion of the existing tug basin by dredging, followed by removal of the existing crest protection structure and replacement with a new structure around the perimeter of the expanded tug basin to mitigate the formation of tidal channels.

Based on changes observed from previously completed projects at Roberts Bank that involved similar components and marine-based activities, it was anticipated during scoping that Project-related morphological changes will result from the following:

- Long-term changes associated with the terminal and tug basin footprints (the assessments of which are described in EIS Section 9.5.8.2); and
- Short-term changes associated with construction of the causeway containment dykes (the assessment of which is described in EIS Section 9.5.8.1[1]).

Hence, although the assessment of coastal geomorphology considered all Project components and marine-based activities described in Section 4.0 of the EIS, only those with the potential to result in change to geomorphological conditions were incorporated in order to focus the assessment on activities relevant to Project-related changes.

Footprint-related coastal geomorphological changes associated with the terminal and expanded tug basin during Project construction were described in the operation phase sections for the following reasons:

1. The presence of the terminal containment dykes, the installation of which occurs early in the construction schedule, are expected to alter coastal processes to the same extent in both the construction and operation phases (as described in EIS Section 9.5.8.1). Morphological changes were evaluated considering completed dykes for the construction phase, as incremental stages of construction will have less of an effect than full development since the amount of flow being diverted around the physical structure will increase as perimeter dyke construction progresses. In addition, since the rate of anticipated geomorphic change is anticipated to be slow compared to the implementation rate of the construction schedule, the approach taken to assess full development for both phases provided for a more conservative assessment compared to assessing interim gradual changes during the construction phase and full development during the operations phase. Since construction and operation phase changes are anticipated to be the same, and changes will occur over a longer duration in the operation phase, changes from the terminal footprint are described in the operation phase section (EIS Section 9.5.8.2) for both phases.
2. For the tug basin, the timing of expansion activities is flexible as they are independent of other Project construction activities aside from possible re-use of the dredged

[1] Appendix D of EIS Appendix 9.5-A provides additional information on the seepage study that was undertaken on the causeway containment dyke.

material for infilling (refer to EIS Section 4.4.1.18 for more information). As such, changes from tug basin expansion over a two-month duration may occur early or late in the construction phase, and any changes that are anticipated to occur from expansion will continue into the operation phase. As with the terminal footprint, since changes are anticipated to be the same for the construction and operation phases and the duration of changes will be longer in the operation phase, the changes associated with the tug basin footprint are described in the operation phase section (EIS Section 9.5.8.2) for both phases.

In summary, changes in coastal geomorphology associated with the construction and operation of all Project components have been assessed for the local study area, which extends from the B.C. Ferries Terminal to Canoe Passage.

IR2-17 Coastal Geomorphology – Geomorphic Changes: Assessment Area

Information Source(s)

EIS Volume 2: Section 9.5; Appendix 9.5-A; Section 9.6; Appendix 9.6-A

Context

In the EIS, the Proponent predicted an overall increase in percent sands and decrease in percent fines in inter-causeway area and stated that this may be a reflection of the lower delivery of fines anticipated to result from construction of the causeway.

Figure 1 of Appendix 9.5-A indicated that the southern margin of the Study Area is defined by the Tsawwassen Ferry Terminal causeway. Coastal geomorphology and hydrodynamic processes, including currents, sediment transport, and erosion patterns including longshore drift to the south of the Tsawwassen Ferry Terminal causeway and adjacent to Point Roberts, could also be affected by the Project.

Information Requested

Provide an analysis of potential geomorphological and hydrodynamic changes from the Project on areas south of the Tsawwassen Ferry Terminal as far as the boundary used in the EIS of the Local Assessment Area for the surficial geology and marine sediment assessment.

Provide an assessment of the short- and long-term effects of the decrease in fines on invertebrate valued components in the inter-causeway area.

VFPA Clarification

The VFPA would like to clarify that the statement from the context section above, regarding fines in the inter-causeway area, is not what the Proponent predicted. Rather, the Proponent predicted that Project-related changes in the inter-causeway area are not anticipated to occur. Reference to sediment dynamics and transport within the inter-causeway area described in the EIS is in relation to changes from past disturbances. Past disturbances have resulted in changes in the degree of influence of the Fraser River outflow plume on the inter-causeway area, and a reduction in the average percent fines in surface sediment in the high intertidal zone within the inter-causeway area. The following coastal geomorphology assessment sections describe past disturbances and changes in the inter-causeway area in more detail:

- EIS Section 9.5.1 Selection of Coastal Geomorphology Intermediate Component
- EIS Section 9.5.6 Existing Conditions
    - Section 9.5.6.1 Fraser River
    - Section 9.5.6.2 Roberts Bank (Table 9.5-3)
    - Section 9.5.6.3 Morphology of Roberts Bank

In addition, EIS Section 9.6.6.2 describes existing conditions in the inter-causeway area that are, in part, attributed to the construction of the original Roberts Bank causeway in 1969, which effectively blocked the Fraser River plume from the inter-causeway area. Relevant statements from this EIS section are as follows:

- "Lower percent fines were observed within the inter-causeway area, isolated from the Fraser River outflow plume by the Roberts Bank causeway, compared to areas at equivalent tidal elevations north of the causeway (Brunswick Point and Westham Island)."
- "Changes in sediment grain size distribution at Roberts Bank have been observed over time. Tsawwassen First Nation (Elders) have noticed increased amounts of finer sediments (i.e., sandy beach replaced by mud) in intertidal areas since completion of the Westshore and the B.C. Ferries terminals compared to historical conditions (Tsawwassen First Nation (Elders) 2014)."
- "Evaluation of more recent trends from 1993 (McLaren and Tuominen 1999) to 2013 suggest a decrease in fines since 1993 in the inter-causeway area and a decrease in percent of sands adjacent to the Roberts Bank terminals. This trend in the inter-causeway area is again consistent with the diminished influence of the Fraser River plume."

Past influences and how they have affected existing conditions are discussed in EIS Section 9.5.6 and further information on marine invertebrates is provided in Additional Information Request #13 (AIR-12.04.15-13), Schedule 13-2 Marine Invertebrates Total Cumulative Effects Assessment (CEAR Document #388[1]). EIS Sections 9.5.8 and 9.6.8 describe future changes anticipated from the Project on coastal geomorphology and on surficial geology and marine sediment, respectively. Both sections consider potential changes associated with widening of the existing causeway.

VFPA Response

Provide an analysis of potential geomorphological and hydrodynamic changes from the Project on areas south of the Tsawwassen Ferry Terminal as far as the boundary used in the EIS of the Local Assessment Area for the surficial geology and marine sediment assessment.

There are no anticipated changes to coastal geomorphology or hydrodynamic processes in areas south of the Tsawwassen Ferry Terminal. The EIS describes the assessment of Project-related changes within the local study areas (LSAs) for the coastal geomorphology and the surficial geology and marine sediment intermediate components in Sections 9.5.6 and 9.6.8, respectively. Coastal geomorphology comprises both the driving forces as well as the physical environment that has resulted from those driving forces. The various Project components will change coastal geomorphology by creating physical structures that interact with the driving coastal processes, including tidal currents and wind-generated waves. Changes to the coastal processes will in turn result in changes to sediment transport, erosion and deposition, the

[1] CEAR Document #388 From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements Follow-Up (See Reference Document # 345) including 22 Technical Data Reports

elevation of the seabed, and the distribution of freshwater from the Fraser River, as previously stated in EIS Section 9.5.8.2 and Appendix 9.5-A: Section 8.3.

Project-related changes on geomorphological and hydrodynamic conditions are predicted to occur only within the LSA selected for the study of coastal geomorphology (EIS Figure 9.5-1), which forms part of the LSA for the assessment of surficial geology and marine sediment (EIS Figure 9.6-1). The rationale for the boundary of the LSA used to determine the potential changes of the Project on coastal geomorphology is described in EIS Section 9.5.5.2. This area represents "the maximum extent of the likely zone of influence of the Project based on alterations in physical processes that are the key determinants of geomorphology. The LSA also incorporates the existing natural boundaries (e.g., shoreline, Canoe Passage channel, intertidal, subtidal zones) and human-made boundaries (i.e., causeways and terminals) influencing the transfer of sediment and freshwater across Roberts Bank by various processes, including waves, river currents, and ocean currents."

As outlined in EIS Section 9.5.8, changes to coastal geomorphology and hydrodynamic conditions in areas on the south side of the existing Roberts Bank causeway, including the inter-causeway area and areas south of the B.C. Ferries Terminal, that are related to the Project components on the north side of the causeway are not anticipated because areas on the south side are hydrodynamically isolated from the north side of the Roberts Bank causeway by deep water and the presence of the existing causeways (refer to IR2-02 for more information). The only Project component expected to influence coastal geomorphology or hydrodynamics in the inter-causeway area is the expanded tug basin, which is expected to result in localised changes to the existing coastal landforms in that area (see Table 9.5-6 and Figure 9.5-34 in the EIS). Predicted changes to coastal geomorphology and hydrodynamics as a result of the Project are not predicted to change conditions south of the B.C. Ferries Terminal or to the extent of the boundary of the LSA for the surficial geology and marine sediment assessment.

Provide an assessment of the short- and long-term effects of the decrease in fines on invertebrate valued components in the inter-causeway area.

The Project is not expected to result in a decrease in fines in the inter-causeway area. Rather, past disturbances have resulted in changes in the degree of influence of the Fraser River outflow plume on the inter-causeway area. Information pertaining to effects on marine invertebrates from changes in sedimentation and coastal processes at Roberts Bank from past and present developments and activities is provided in Additional Information Request #13 (AIR-12.04.15-13), Schedule 13-2 Marine Invertebrates Total Cumulative Effects Assessment (CEAR Document #388).

References

As previously provided in EIS Section 9.6.12:

McLaren, P. and T. Tuominen. 1999. Sediment Transport Patterns in the Lower Fraser River and Fraser Delta. Pages 81–92. T. Tuominen and C. B. Grey, eds. Health of the Fraser River Aquatic Ecosystem: A Synthesis of Research Conducted under the Fraser River Action Plan. Volume 1. Environment Canada.

Tsawwassen First Nation (Elders). 2014. April 24, 2014 Meeting with TFN Elders re: Aboriginal Traditional Knowledge.

IR2-18 Coastal Geomorphology – Clarification

Information Source(s)

EIS Volume 2: Appendix 9.5-A, Appendix B

Context

Fisheries and Oceans Canada identified a probable error in the EIS. Appendix B of Appendix 9.5-A, Section 4.2, reported that "The model generally overestimated the outflow and underestimated the inflow". This is in opposition to the actual bias seen in Figure 8 in Appendix B of Appendix 9.5-A.

Information Request

Confirm the error identified by Fisheries and Oceans Canada in Appendix 9.5-A, Section 4.2 of the EIS.

VFPA Response

Confirmed. The statement quoted above is erroneous. EIS Appendix 9.5-A: Section 4.2 should state the following (changes are bolded):

> The model generally **underestimated** the outflow and **overestimated** the inflow at Canoe Passage **compared to the stage-discharge relationship developed for this location from field data**.

This is consistent with the actual bias seen in Figure 8 in Appendix B of EIS Appendix 9.5-A. As stated in EIS Appendix 9.5-A: Section 4.2, this difference is within the natural variability of the system and uncertainties associated with the observed flow values that were interpolated from the stage-discharge curve. This bias is unlikely to affect the predicted local hydrodynamics around Roberts Bank. As described in the response to IR2-01 and IR2-13, there is good agreement between observed data and model predictions in the area around Roberts Bank, despite the weaker performance of the model at the Canoe Passage monitoring station, which is relatively removed from the area of primary interest.

Additionally, for clarification, the caption to Figure 8 in Appendix B of EIS Appendix 9.5-A, instead of stating, "Modelled and observed flow at NHC's Canoe Passage station – August 2012" should state the following (changes are bolded):

> Modelled **flow compared with flow predicted from a stage-discharge relationship developed based on observed flow** at NHC's Canoe Passage station – August 2012

IR2-19 Geotechnical Considerations – Tsunami

Information Source(s)

EIS Volume 2: Section 9.1.3.4, Table 9.1.3-4
EIS Volume 5: Section 31.2.4

Context

In Section 9.1.3.4 of the EIS, the Proponent described two types of tsunamis that could affect the proposed Project. Based on the information provided in this Section, the height of a tsunami-generated wave at the proposed Project site was estimated to be less than four metres and most likely equal to or less than one metre.

Although Table 9.1.3-4 of the EIS indicated that the stability of the wharf and perimeter dykes following a tsunami is of concern, it also indicated that the ability to withstand tsunamis was not explicitly included in the preliminary design of the Project.

In Section 31.2.4.1 of the EIS, the Proponent outlined the potential effects of a tsunami on the environment and on the Project. However, it is unclear whether the effects presented in Section 31.2.4 were based on the worst-case scenario of a four-metre tsunami, or on another size of wave.

Information Requested

Clarify whether the effects on the environment and on the Project as described in Section 31.2.4 of the EIS considered the worst-case scenario of a four-metre tsunami. If a four-metre tsunami worst-case scenario was not taken into consideration in the assessment, elaborate on the effects on the environment and on the Project that are predicted to result from a four-metre tsunami.

VFPA Response

The effects of the environment on the Project described in Section 31.2.4 of the EIS considered the worst-case scenario of a four-metre tsunami as they were based on tsunamis ranging between 1 m to 4 m in wave height. The rationale for this range and for the low likelihood of a tsunami occurring in the vicinity of Roberts Bank is described in Sections 9.1.3.4 and 31.2.4.2 of the EIS. However, in the unlikely event that a tsunami did occur, the most probable wave height is estimated to be 1 m or less, which would not affect the stability of the Project's wharf or perimeter dykes.

In addition, as described in EIS Section 31.2.4.2, during construction and operation, the Project will have tsunami-specific emergency response procedures which will be implemented should a tsunami event occur.

IR2-19a Geotechnical Considerations – Tsunami, Generated Waves

Information Source(s)

Proponent Response to IR2-19 (CEAR Doc#961)

EIS Volume 2: Section 9.1.3.4

EIS Volume 5: Section 31.2.4.1

Context

In Section 9.1.3.4 of the EIS, it was reported that predicted tsunami wave heights were generated by two hypothetical and numerically simulated landslides. It is unclear how the results of the simulated landslides were used in conjunction with other lines of evidence to determine the probability of occurrence of a 1-metre and 4-metre tsunami wave at Roberts Bank.

In its response to Review Panel information request IR2-19, the Proponent stated that Section 31.2.4.1 of the EIS considered the worst-case scenario of a four-metre tsunami wave even though, in the unlikely event that a tsunami did occur, the most probable wave height was estimated to be 1 metre or less. Additional information is required to determine the differences in severity of the potential effects, on the proposed Project and on the environment, that could result from a 1-metre and a 4-metre tsunami driven wave.

Information Request

Explain the method whereby the probability distribution of tsunami-driven wave heights was determined.

In reference to the statement in the response to Review Panel information request IR2-19 that the most probable wave height was estimated to be 1 metre or less, provide the probability of wave heights greater than 1 metre and the probability that a 4-metre or higher tsunami-driven wave would occur.

In a table, provide a comparison of the potential effects of a 1-metre and 4-metre tsunami driven wave on the proposed Project and marine shipping associated with the Project in Segment A.

VFPA Response

Explain the method whereby the probability distribution of tsunami-driven wave heights was determined.

The probability distribution of tsunami driven wave heights was inferred from empirical evidence. No statistical analysis was conducted. This is appropriate since the maximum possible tsunami driven wave heights potentially to be experienced at the Project site created from a Cascadia Subduction Zone Event were calculated to be approximately 1 m (Cherniawsky et al. 2007, Clague et al. 2005, Clague et al. 2000, Leonard et al. 2012, Ng et al. 1990). A maximum wave height of approximately 1 m is supported by the fact there is no evidence of any tsunami events larger than 1 m in the geologic record in the Richmond/Delta or Fraser River delta dating back 3,000 to 4,000 years or from the oral history of local Aboriginal peoples (Clague et al. 2005).

In reference to the statement in the response to Review Panel information request IR2-19 that the most probable wave height was estimated to be 1 metre or less, provide the probability of wave heights greater than 1 metre and the probability that a 4-metre or higher tsunami-driven wave would occur.

The potential for a tsunami wave height in the 4-m range was theorised in a report by Rabinovich et al. (2003) entitled *Numerical Modeling of Tsunami Generated by Hypothetical Landslides in the Strait of Georgia, British Columbia*. This study looked at the potential for tsunamis generated from landslides, including a hypothetical 750 million cubic metre (M m^3) landslide and a hypothetical 250 M m^3 landslide. These hypothetical volumes were selected based on the work of Christian et al. (1997), which assumed a failure surface could occur at depth of about 100 m through a zone of postulated sensitive clay. However, Rabinovich et al. (2003) noted in their study that there are no specific geotechnical data which would suggest that, under anticipated earthquake loading, failure would actually occur. Hence, the study merely assumed that failure would occur and then estimated the potential size of the resultant tsunami wave produced.

Subsequent work by Golder (2011, 2012) concluded the following:

1) The potential for a deep-seated failure like the one hypothesised by Christian et al. (1997) was low and the hypothetical volumes used were "grossly conservative"; and
2) Earthquake-induced underwater landslides along the delta foreslope near the Project would be in the 5 M m^3 to 15 M m^3 range (i.e., more than order of magnitude lower than the hypothetical landslides described above) for seismic events corresponding to A475 and A2475, respectively. The 5 M m^3 to 15 M m^3 range is backed by evidence from the underwater landslide in 1985 at Sand Heads, which only generated volumes in the order to 1 M m^3 to 3 M m^3.

Further, recent work using actual deep soil samples, advanced laboratory techniques, and analysis by Stantec et al. (2017) concluded there is an extremely low possibility of a deep-seated failure that would generate landside volumes in the range of 250 M m^3 to 750 M m^3 at the Project site.

Although Section 31.2.4.1 of the EIS considered a worst-case 4-m tsunami-induced wave, this was an overly conservative consideration, as such an event has an extremely low probability of occurrence.

In a table, provide a comparison of the potential effects of a 1-metre and 4-metre tsunami driven wave on the proposed Project and marine shipping associated with the Project in Segment A.

Comparisons of the potential effects of a 1-m and 4-m tsunami-induced wave on the Project and on marine shipping associated with the Project are provided in **Table IR2-19a-1**.

Table IR2-19a-1 Summary of Potential Effects of Tsunami-induced Waves 1 m and 4 m in Height on the Project and on Marine Shipping Associated with the Project

Segment A Potential Effects	1-m Tsunami-induced Wave	4-m Tsunami-induced Wave
Potential Effects on the Project	A 1-m tsunami-induced wave would not reach the surface of the terminal, although the higher currents associated with the passing of a tsunami wave could move or dislodge some of the rip-rap armour at the corners of the terminal. As described in EIS Section 31.2.4.1, the potential effects of a landslide-generated tsunami on RBT2 would ultimately depend on a variety of factors, including, but not limited to, the source, geometry, and rate of displacement of underwater sediments. During operation, damage to the terminal structure from a 1-m tsunami-induced wave could range from negligible to serious, but is likely to be technically and economically feasible to repair given the performance criteria included in its design with respect to high waves. The nature and magnitude of environmental effects would depend on the extent of tsunami-related damage to the Project. Examples of potential effects include a decrease in marine water quality due to elevated turbidity and total suspended sediment levels, and habitat alteration or loss in areas of sediment deposition or physical disturbance. Such effects, however, would not be unique to the Project, as a tsunami with the capacity to damage the Project would likely result in adverse environmental effects throughout the Fraser River delta.	As with a 1-m tsunami-induced wave, the potential effects of a 4-m wave on RBT2 would ultimately depend on a variety of factors. Although an extremely unlikely event (as described above), should a 4-m tsunami-induced wave occur, the wave could partially overtop the terminal surface during high tide conditions. The wave crest would be below the terminal surface elevation +8.75 m (i.e., 8.75 m is higher than the combined water height during a higher high tide condition of 4.1 m plus a 4.0-m tsunami-induced wave), but upon impacting the terminal face, water would still overtop the wharf face, carrying enough energy to possibly disrupt terminal operations. Damage to the terminal structure from a 4-m tsunami-induced wave could range from minor to serious, which in an extreme case, may not be technically or economically feasible to repair. Depending on the orientation that the wave hits the terminal, containers and equipment on the terminal surface could be dislodged and moved. Due to the width of the terminal, however, it is unlikely that any terminal assets would be dislodged and carried into the marine environment. In addition to the movement of mobile assets (i.e., containers and equipment), the storm drain system could be temporarily overwhelmed (i.e., water levels would subside shortly after the wave inundation), some electrical systems could be affected if manholes were filled with water, and higher currents from the wave could also dislodge some of the dyke armour. Water quality is not anticipated to be affected by the terminal operations itself, as products on the terminal are containerised and, since rain is common in this region, contaminants are not expected to accumulate on the terminal surface. As with a 1-m tsunami-induced wave, the nature and magnitude of environmental effects would depend on the extent of tsunami-related damage to the Project. Effects to the environment would not be unique to the Project, as a tsunami with the capacity to damage the Project would likely result in adverse environmental effects throughout the Fraser River delta.

Segment A Potential Effects	1-m Tsunami-induced Wave	4-m Tsunami-induced Wave
Potential Effects on the Marine Shipping Associated with the Project	No effect to marine vessels associated with the Project as waters in Segment A are greater than 100 m deep, and a 1-m tsunami-induced wave would not affect the sea state in deep waters. A 1-m wave height is well within the range of wave heights encountered by vessels in transit in both open and sheltered waters.	No effect to marine vessels associated with the Project as waters in Segment A are greater than 100 m deep, and a tsunami-induced 4-m wave would not affect the sea state in deep waters. In addition, this wave height is within the range of typical wave heights encountered by vessels in transit in the open ocean, as well as during storm events in the marine shipping area.

References

Cherniawsky, J. Y., V. V. Titof, K. Wang, and J-Y. Li. 2007. Numerical Simulations of tsunami Waves and Currents for Southern Vancouver Island from a Cascadia Megathrust Earthquake. Pure appl. Geophys. 164 (2007) 465-492.

Christian, H. A., D. C. Mosher, T. Mulder, J. V. Barrie, and R. C. Courtney. 1997. Geomorphology and Potential Slope Instability on Fraser River Delta Foreslope, Vancouver, British Columbia. Can. Geotech. J. 34, 432-446.

Clague, J. J., I. Hutchinson, and J. E. Lesemann. 2005. Tsunami Hazard to Richmond and Delta, British Columbia. Presented to The Corporation of Delta and The City of Richmond.

Clague, J. J., P. T. Bobrowsky, and I. Hutchinson. 2000. A Review of Geological Records of Large Tsunamis at Vancouver Island, British Columbia. Quaternary Science Reviews, v. 19, p. 849-863.

Golder Associates Ltd. (Golder). 2011. Roberts Bank Seismic Evaluation. Final Report V2. May 18.

Golder Associates Ltd. (Golder). 2012. Preliminary Geotechnical Design Input. Final Report V2. March 8.

Leonard, L. J., G. C. Rogers, and S. Mazzotti. 2012. A Preliminary Tsunami Hazard Assessment of the Canadian Coastline. Geological Survey of Canada, Open File 7201.

Ng, M., P. Leblond, and T. Murty. 1990. Numerical Simulation of Tsunami Amplitudes on the Coast of British Columbia, Science of Tsunami Hazards. 8, 97-127.

Rabinovich, R., R. Thomson, B. Bornhold, I. Fine, and E. Kulikov. 2003. Numerical Modelling of Tsunamis Generated by Hypothetical Landslides in the Strait of Georgia, British Columbia. Pure Applied Geophysics, 160 (1273-1313).

Stantec Consulting Ltd. (Stantec), Earth Mechanics Inc., and Moffatt & Nichol. 2017. Supplemental Geotechnical Investigation – Factual Data Report. Prepared for Vancouver Fraser Port Authority.

IR2-20 Geotechnical Considerations – Seismicity: National Building Code of Canada

Information Source(s)

EIS Volume 1: Appendix 4-A
EIS Volume 2: Section 9.1.3.2

Context

In Appendix 4-A of the EIS, the Proponent referenced the 2010 National Building Code of Canada (NBCC) to determine various parameters used for the basis of design of the proposed Project. The provisions in the 2010 NBCC were also used in Section 9.1.3.2 to describe potential ground-shaking levels at the Project site.

However, as underlined by Natural Resources Canada, a 2015 version of the NBCC is now available, which outlines significant changes in the seismic hazard levels – especially at long periods - compared to the 2010 NBCC values. The 2015 NBCC values should be used to update the ground-shaking levels reported in Section 9.1.3.2 and Table C of Appendix 4-A of the EIS.

Information Request

Update the ground shaking levels information in Section 9.1.3.2 and Table C of Appendix 4-A to reflect the 2015 National Building Code of Canada.

VFPA Response

The Project will comply with relevant statutes, regulations, policies, and other laws (including building codes) applicable at the time it is constructed. Therefore, if at the start of construction, the 2015 National Building Code of Canada (NBCC) is current, it will be followed. However, if the 2015 NBCC has been superseded before construction commencement, the latest version of the NBCC would be followed.

As requested by the Panel, the VFPA has updated Section 9.1.3.2 and Table 9.1.3-1 in the EIS. The third paragraph on page 9.1-23 and Table 9.1.3-1 should be replaced by the following (changes are bolded):

> Table 9.1.3-1 provides the PGA [peak ground acceleration] established for RBT2 for a range of return periods **with consideration of crustal, sub-crustal, and subduction earthquakes. The ground-motion parameters are based on the 5th Generation Seismic model developed by NRC** [Natural Resources Canada]**, which has been adopted by the 2015 NBCC.** These ground-motion parameters are for **Site Class C soils (very dense/stiff soil)** that are found at RBT2 at depths of approximately 100 m **to 200 m** below current **mudline**.

Table 9.1.3-1 Shaking Levels at Roberts Bank Terminal 2 from Regional Earthquakes **with Different Return Periods**

Description	Peak Ground Acceleration		
	100-year	475-year	2,475-year
Probability of exceedance per annum	0.01	0.0024	0.000404
Probability of exceedance in 50 years	40%	10%	2%
PGA	**0.10 g**	**0.23 g**	**0.42 g**

Note: Based on data presented in **NBCC 2015** and provided by **NRC 2015**.

Section 5.6 in EIS Appendix 4-A should be revised to the following (changes are bolded):

Roberts Bank Terminal 2 would be located in one of the areas of higher seismic risk designations in Western Canada. Site-specific ground motion parameters as published by Natural Resources Canada (NRC) for site coordinates of 49.022 degrees north and 123.173 degrees west are presented in Table C (see NRC website **http://www.earthquakescanada.nrcan.gc.ca/hazard-alea/interpolat/index_2015-en.php**)

Table C Site Specific Ground Motion Parameters

Description	Return Period of Ground Motions		
	1 in 100-year	1 in 475-year	1 in 2,475-year
Probability of Exceedance per Annum	0.01	0.002	0.0004
Probability of Exceedance in 50 Years	40%	10%	2%
PGA	**0.10 g**	**0.23 g**	**0.42 g**
S_a (0.2 s)*	**0.24 g**	**0.52 g**	**0.98 g**
S_a (0.5 s)*	**0.20 g**	**0.46 g**	**0.88 g**
S_a (1.0 s)*	**0.10 g**	**0.24 g**	**0.49 g**
S_a (2.0 s)*	**0.05 g**	**0.14 g**	**0.29 g**

*Spectral acceleration values

Applicable **amplification factor as a function of period, F_T**, for the site will be determined during detail design.

In Section 13 of EIS Appendix 4-A, the Natural Resource Canada reference should be replaced with the following (changes are bolded):

Natural Resources Canada. **2015.** Determine **2015** National Building Code of Canada seismic hazard values. Available at **http://www.earthquakescanada.nrcan.gc.ca/hazard-alea/interpolat/index_2015-en.php**. Accessed **December 2016.**

IR2-21 Geotechnical Considerations – Seismicity: Geological Faults

Information Source(s)

EIS Volume 2: Section 9.1.3

Context

Section 9.1.3 of the EIS did not present information on local geological faults in the vicinity of the proposed Project. The potential for nearby, crustal earthquakes should be a consideration for seismic design of the Project, in addition to probabilistic hazard assessment.

Information Request

Present a map indicating the location of local geological faults within 100 kilometres of the proposed Project site.

Discuss the potential of a seismic event resulting from local faults to affect the Project and describe how potential effects from this type of seismic event were considered in seismic design of the proposed Project.

VFPA Clarification

Nearby crustal earthquakes were considered as part of the probabilistic assessment using the Geological Survey of Canada's 4th Generation Seismic Hazard Model. With the 4th Generation Seismic Hazard Model, only a Cascadia Subduction Zone event is required to be considered separately; this was completed. This approach is consistent with best engineering practice in Canada as well as in the U.S.A.

Since the EIS was submitted, the Geological Survey of Canada has issued its 5th Generation Seismic Hazard Model. The Infrastructure Developer will be required to use the latest model to further the seismic designs from their current level to "Final" (see IR1-15 in CEAR Document #897[1]). This 5th Generation model considers crustal, sub-crustal, and Cascadia Subduction Zone events probabilistically.

VFPA Response

Present a map indicating the location of local geological faults within 100 kilometres of the proposed Project site.

A map showing all known faults is provided in **Appendix IR2-21-A**. The map uses best available information (see **Appendix IR2-21-A** for data sources).

[1] CEAR Document #897 From the Vancouver Fraser Port Authority to the Review Panel re: Responses to Information Request Package 1 (See Reference Document #559)

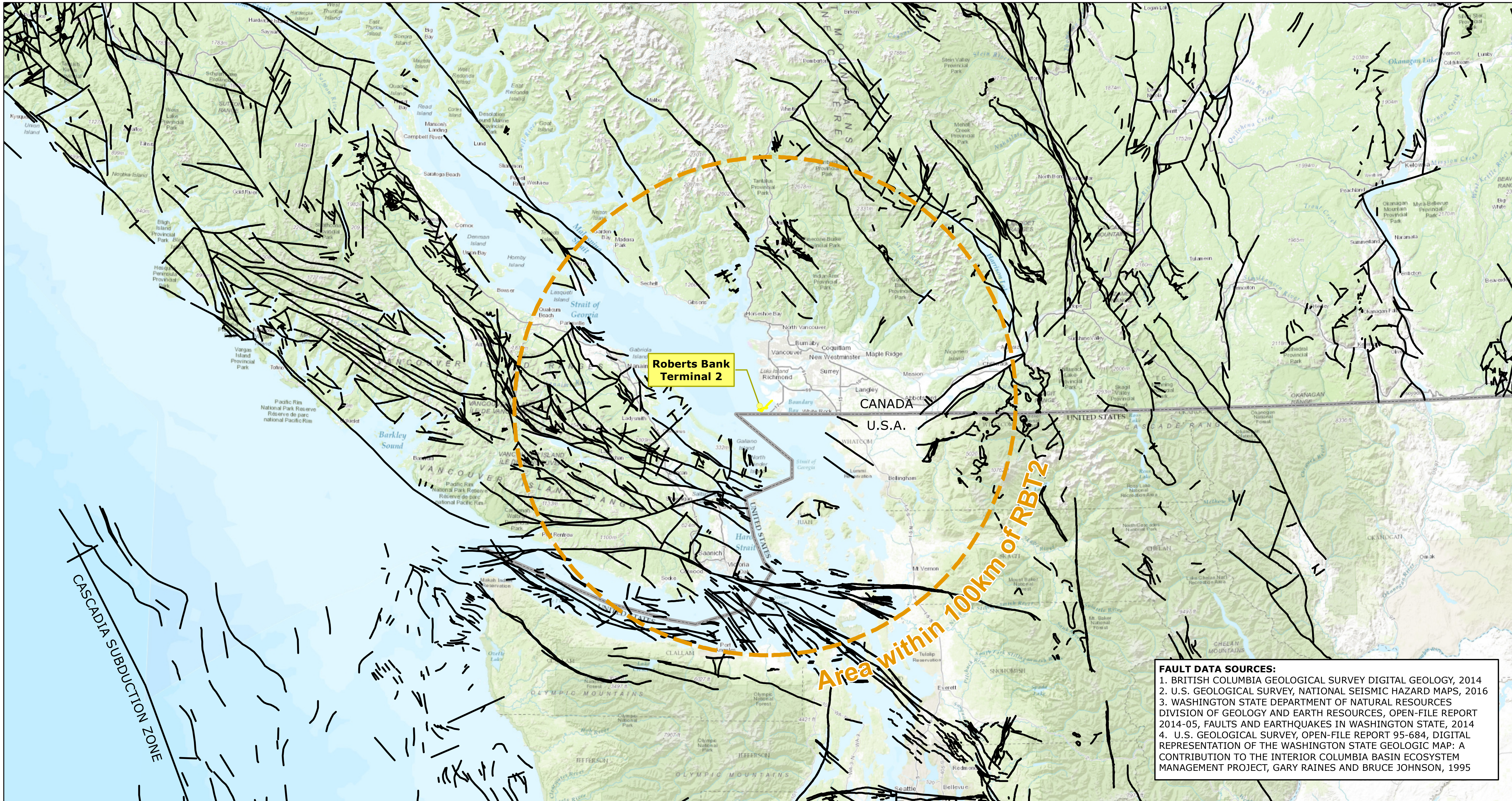
Discuss the potential of a seismic event resulting from local faults to affect the Project and describe how potential effects from this type of seismic event were considered in seismic design of the proposed Project.

Potential for a seismic event due to a local fault is considered extremely low, as none of the local faults are active. The 4th Generation Seismic Hazard Model used for the EIS and the latest 5th Generation Seismic Hazard Model both account for crustal earthquakes associated with local faults. The effects of these earthquakes on the Project are described in Section 31.2.2.1 of the EIS.

Appendices

Appendix IR2-21-A Fault Locations

APPENDIX IR2-21-A
FAULT LOCATIONS



FAULT DATA SOURCES:
1. BRITISH COLUMBIA GEOLOGICAL SURVEY DIGITAL GEOLOGY, 2014
2. U.S. GEOLOGICAL SURVEY, NATIONAL SEISMIC HAZARD MAPS, 2016
3. WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES DIVISION OF GEOLOGY AND EARTH RESOURCES, OPEN-FILE REPORT 2014-05, FAULTS AND EARTHQUAKES IN WASHINGTON STATE, 2014
4. U.S. GEOLOGICAL SURVEY, OPEN-FILE REPORT 95-684, DIGITAL REPRESENTATION OF THE WASHINGTON STATE GEOLOGIC MAP: A CONTRIBUTION TO THE INTERIOR COLUMBIA BASIN ECOSYSTEM MANAGEMENT PROJECT, GARY RAINES AND BRUCE JOHNSON, 1995

Legend

BOUNDARY OF PROJECT AREA
U.S.A.-CANADA BORDER
FAULT

0 25 50
Kilometres
1:1,500,000
NAD 1983 UTM Zone 10N
N

Note:
- This map shows the locations of faults in published databases.

PORT of vancouver

ROBERTS BANK TERMINAL 2

FAULT LOCATIONS

DATE:	FIG No.
02/03/2017	IR2-21-1

Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community; British Columbia Digital Geology, 2014; Digital Representation of the Washington State Geologic Map, Raines and Johnson, 1996; National Seismic Hazard Maps, 2016

Path: \\CD1183-F05\workgroup\1158\active\115815019\7_drawings\16_project\20160707_seismic_performance\01-20100-MAP-OE-RBT2_Faults_Locations.mxd

IR2-22 Geotechnical Considerations – Seismicity: Seismic Hazard Deaggregation

Information Source(s)

EIS Volume 1: Appendix 4-A
EIS Volume 2: Section 9.1.3.2

Context

As stated by the Proponent in Section 9.1.3.2 of the EIS, seismic risk at the proposed Project site is due to three basic types or sources of earthquakes:

- relatively shallow crustal earthquakes;
- deep intra-plate earthquakes within the subducted plate; and
- subduction earthquakes.

However, the Proponent did not carry out seismic hazard deaggregation, which would allow a prediction of the type of earthquake that would dominate the hazard at the Project site, and the frequency (and strength) of shaking that would dominate.

In Section 9.1.3.2 of the EIS, the Proponent stated that soil conditions, such as those at the proposed Project site, would amplify the intensity of shaking for the 100-year return period and deamplify the intensity of shaking for the 475-year and 2475-year return periods, as waves propagate to the surface. As indicated by Natural Resources Canada, this "nonlinearity effect" is not related to return-period, but rather to strength of shaking, and is controlled by local soil conditions, strength of shaking, and wave frequency. Non-linear response is an important factor at strong shaking levels, especially on soft soils. It is unclear whether the Proponent conducted a non-linear response analysis to assess soil response during strong shaking at the proposed Project site.

Information Request

Carry out seismic hazard deaggregation for the proposed Project site, taking into consideration the 3 types of earthquakes - relatively shallow crustal earthquakes; deep intra-plate earthquakes within the subducted plate; and subduction earthquakes - that contribute to seismic risk.

Summarize the results of seismic hazard deaggregation and highlight any changes this would cause to shaking and potential liquefaction at the Project site.

Confirm that a non-linear response analysis has been conducted to assess soil response during strong shaking at the Project site. If not, carry out this analysis in conjunction with the above seismic hazard deaggregation for the proposed Project, and summarize these results.

VFPA Response

Carry out seismic hazard deaggregation for the proposed Project site, taking into consideration the 3 types of earthquakes - relatively shallow crustal earthquakes;

deep intra-plate earthquakes within the subducted plate; and subduction earthquakes - that contribute to seismic risk.

Seismic deaggregation are completed by Natural Resources Canada with the results presented on seismic deaggregation plots. Natural Resources Canada completed seismic deaggregation for earthquakes with different return periods using their 5th Generation Seismic Hazard model; these seismic deaggregation plots are provided in **Appendix IR2-22-A**.

Summarize the results of seismic hazard deaggregation and highlight any changes this would cause to shaking and potential liquefaction at the Project site.

The results of Natural Resources Canada's seismic hazard deaggregation are presented in **Appendix IR2-22-A**. The deaggregation plots for the 100-year return period earthquake show the seismic hazard is dominated by contributions from subcrustal earthquakes for peak ground acceleration and spectral accelerations up to approximately 2.0 seconds. For spectral accelerations greater than 2.0 seconds, hazard contributions are mostly from three main sources: subcrustal earthquakes in the Juan de Fuca Plate, subduction earthquakes along the Cascadia Interface, and subduction earthquakes along the Explorer interface (i.e., where the Explorer Plate is subducted beneath the North American Plate, to the north of the Juan de Fuca Plate).

For the 475-year, and 2,475-year return period earthquake motions, seismic hazard at the Project location is predicted to be dominated by deep intraplate (subcrustal) earthquakes for peak ground accelerations and spectral accelerations for periods less than approximately 1.0 seconds. For spectral accelerations with periods greater than 1.0 seconds, Cascadia subduction earthquakes are predicted to dominate the hazard.

The results of the seismic hazard deaggregation is not expected to change potential liquefaction at the Project site.

Confirm that a non-linear response analysis has been conducted to assess soil response during strong shaking at the Project site. If not, carry out this analysis in conjunction with the above seismic hazard deaggregation for the proposed Project, and summarize these results.

Non-linear response analysis is a design task associated with detailed design, which will be completed by the Infrastructure Developer. For context, the detailed design will be undertaken by the Infrastructure Developer, and is expected to come at a later stage. However, as part of the VFPA's due diligence, a two-dimensional non-linear response analysis using computer software known as FLAC (Fast Lagrangian Analysis of Continua) was performed on the Roberts Bank area considering the "as-is" case (i.e., natural state, without any development). The results concluded that with ground improvement measures, the seismic loading-induced lateral displacements could be reduced to acceptable levels. The specific details of these ground improvement measures will be determined by the Infrastructure Developer during detailed design.

Appendices

APPENDIX IR2-22-A
SEISMIC DEAGGREGATION PLOTS

A100 EARTHQUAKE LEVELS

[Plot 1]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Adam McIntyre, Stantec

2016/07/27

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter peak ground acceleration (PGA)

at a probability of 0.010000 per annum, seismic hazard = 0.102 g

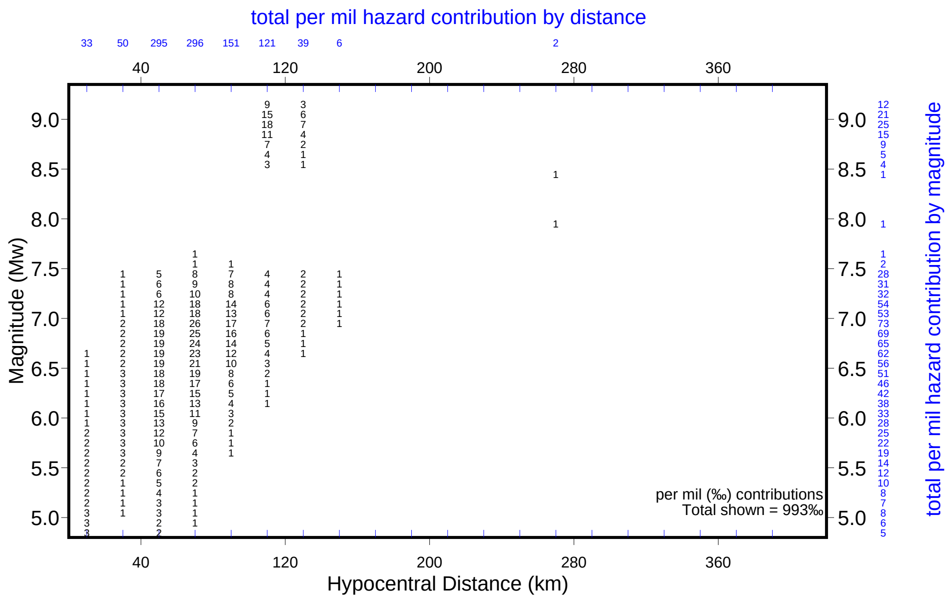
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

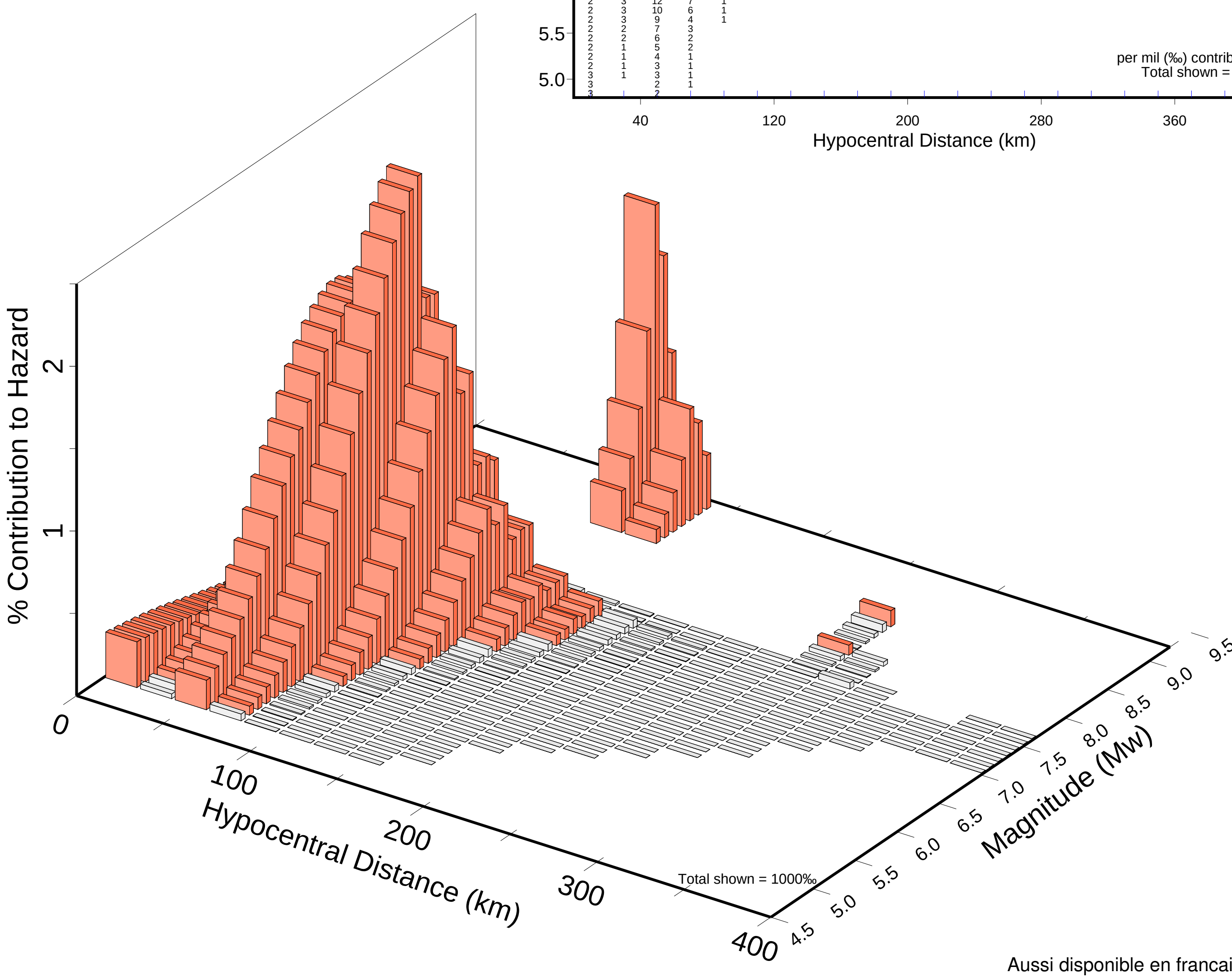
Mean magnitude (Mw) 6.76 Mean distance 72 km

Mode magnitude (Mw) 6.950 Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 2]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Adam McIntyre, Stantec

2016/07/27

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter peak ground velocity (PGV)

at a probability of 0.010000 per annum, seismic hazard = 0.119 m/s

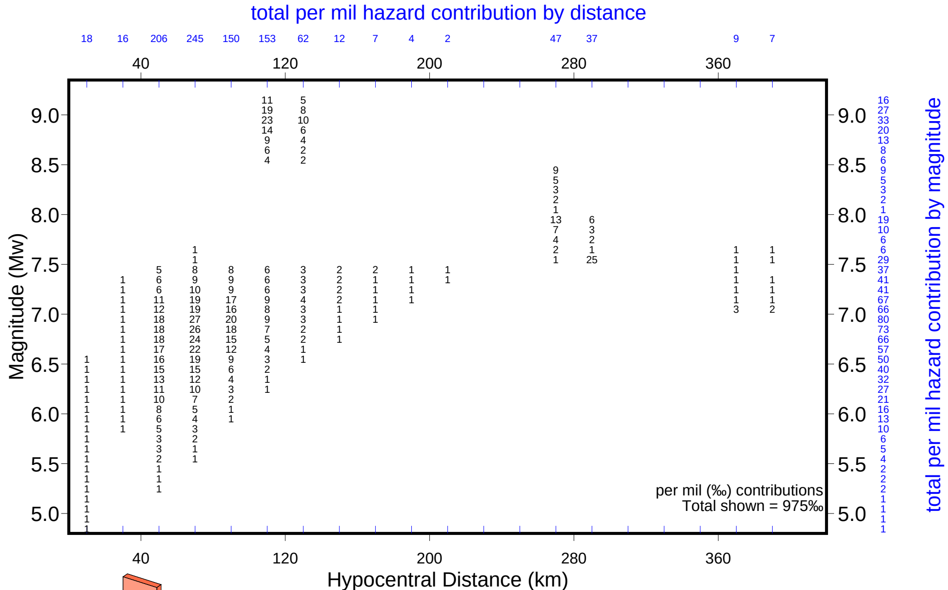
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

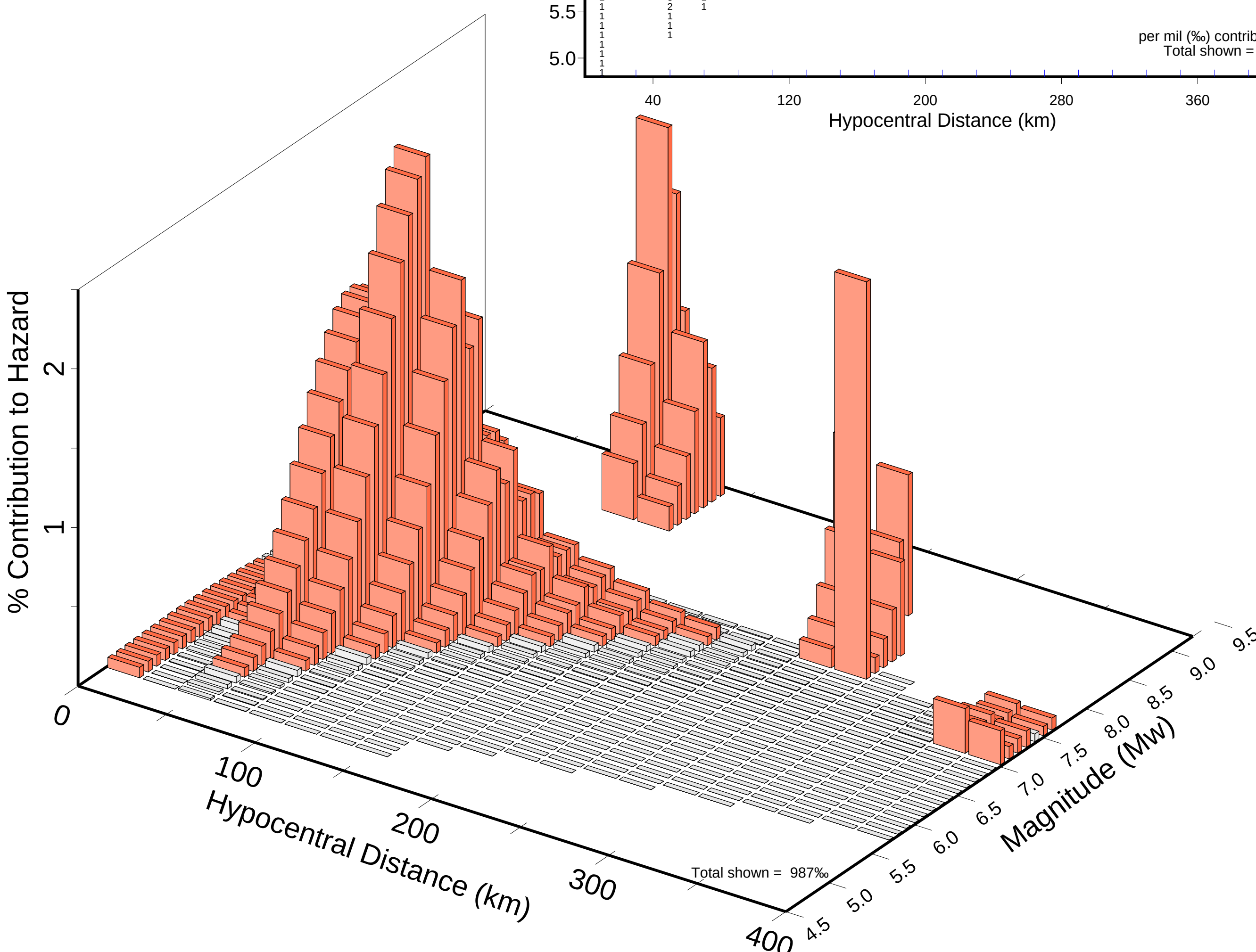
Mean magnitude (Mw) 7.14   Mean distance 107 km

Mode magnitude (Mw) 6.950   Mode distance   70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 3]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Adam McIntyre, Stantec

2016/07/27

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 0.05 seconds

at a probability of 0.010000 per annum, seismic hazard = 0.124 g

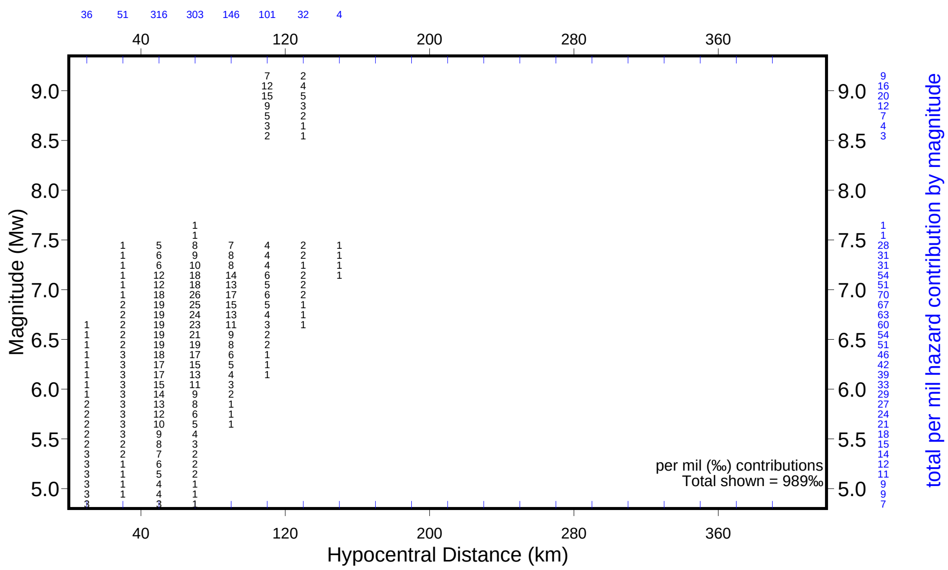
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

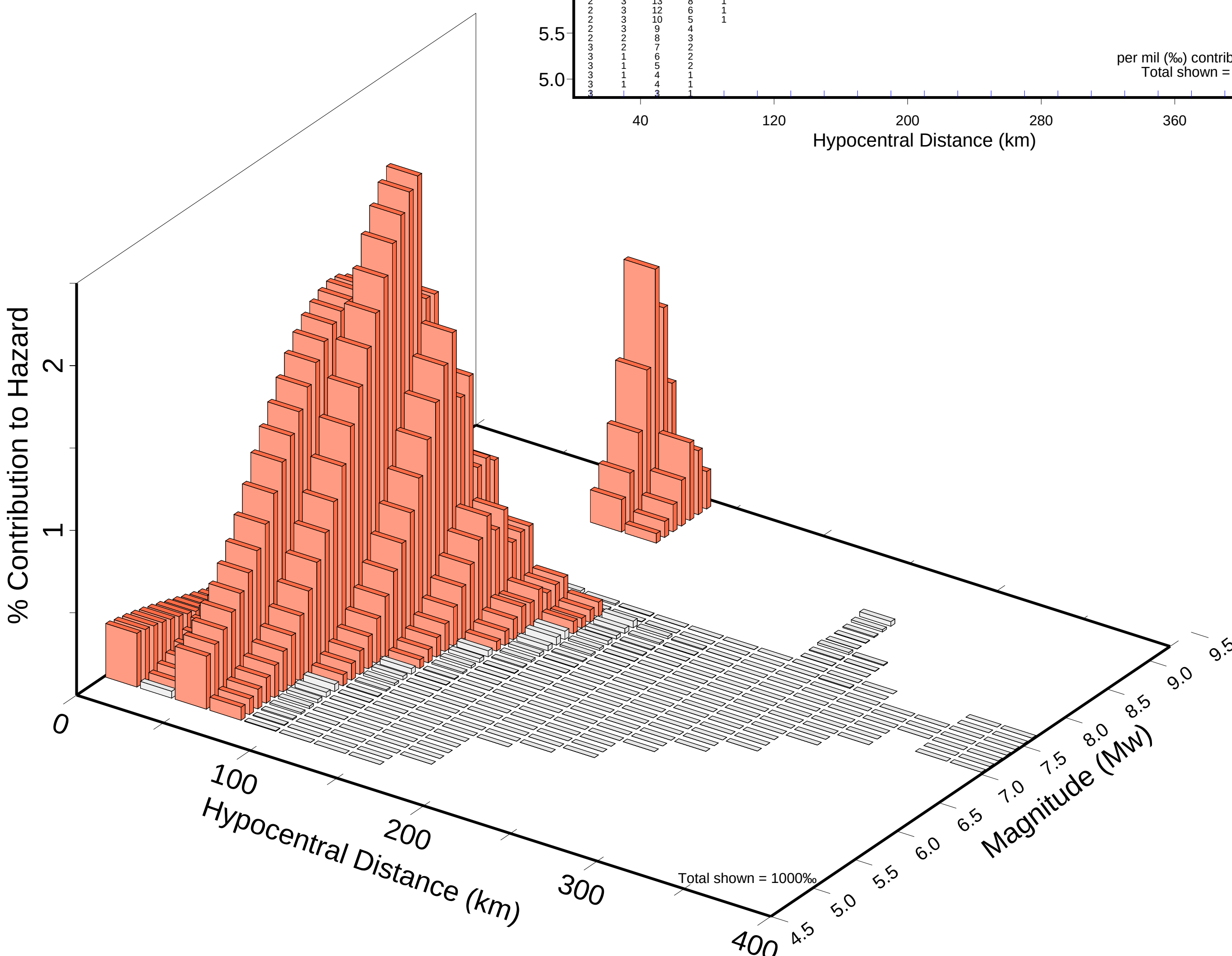
Mean magnitude (Mw) 6.66   Mean distance   69 km

Mode magnitude (Mw) 6.950   Mode distance   70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

Natural Resources Canada   Ressources naturelles Canada

Canada

[Plot 4]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Adam McIntyre, Stantec 2016/07/27

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 0.10 seconds

at a probability of 0.010000 per annum, seismic hazard = 0.189 g

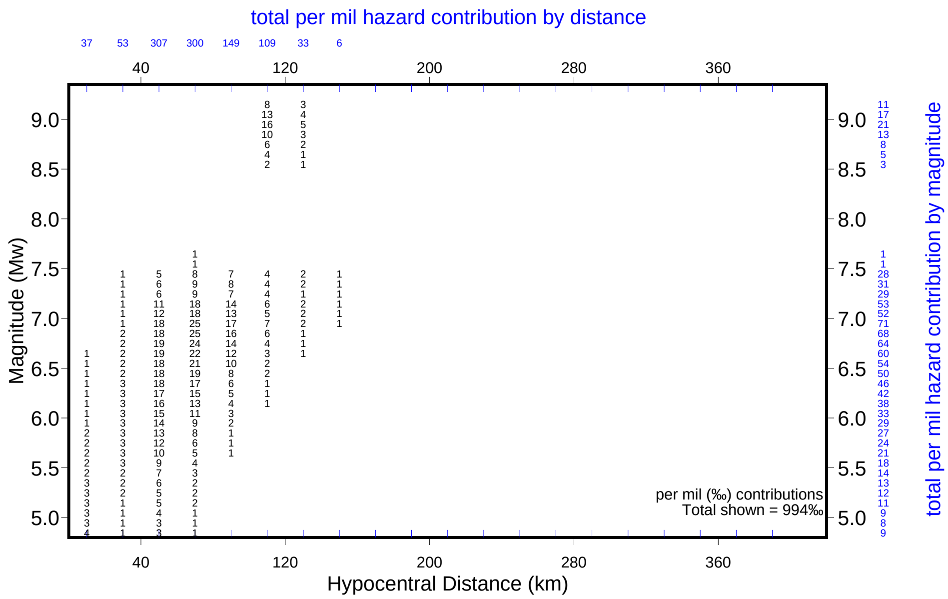
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

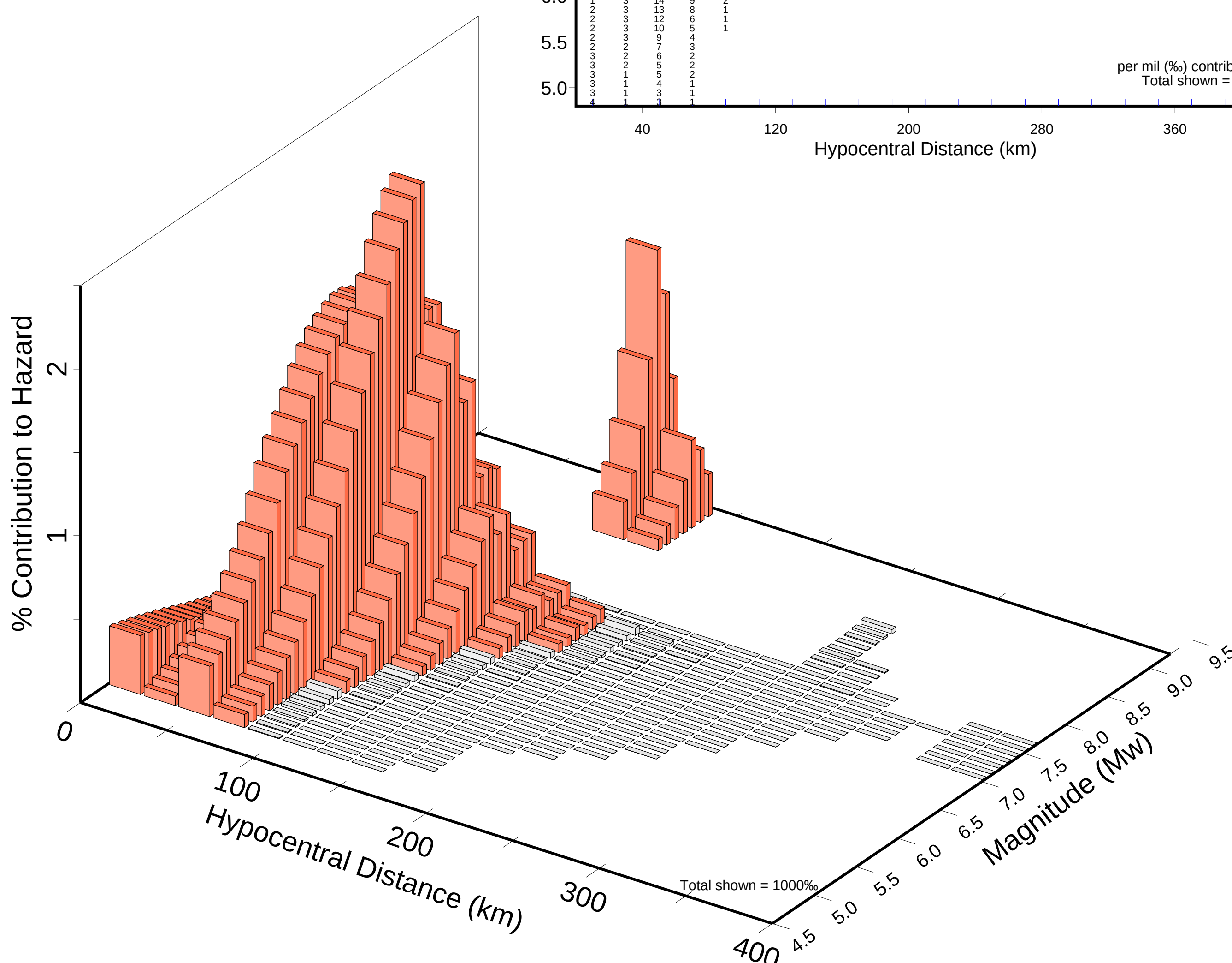
Mean magnitude (Mw) 6.68 Mean distance 70 km

Mode magnitude (Mw) 6.950 Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

Natural Resources Canada   Ressources naturelles Canada

Canada

[Plot 5]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Adam McIntyre, Stantec

2016/07/27

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 0.20 seconds

at a probability of 0.010000 per annum, seismic hazard = 0.236 g

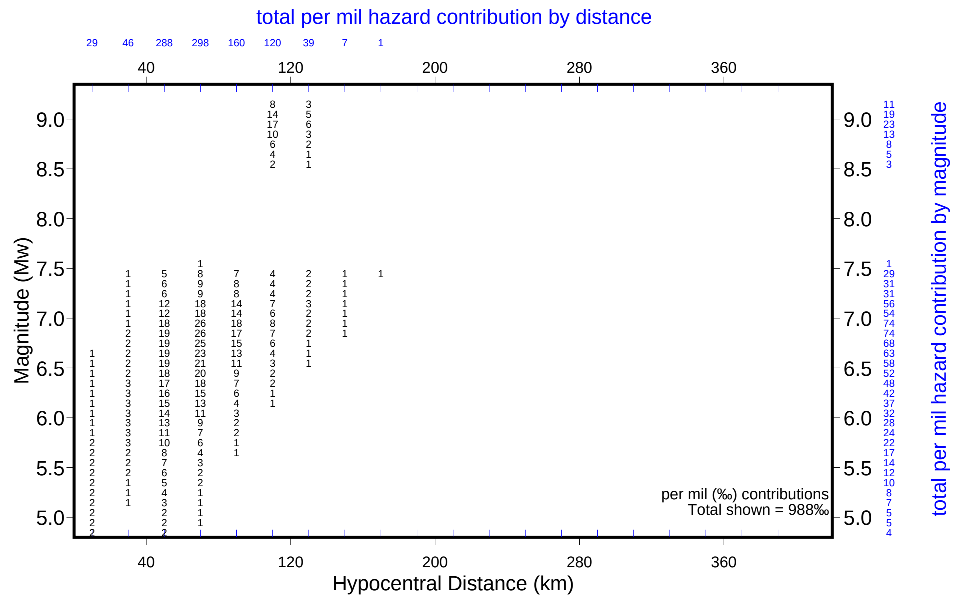
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

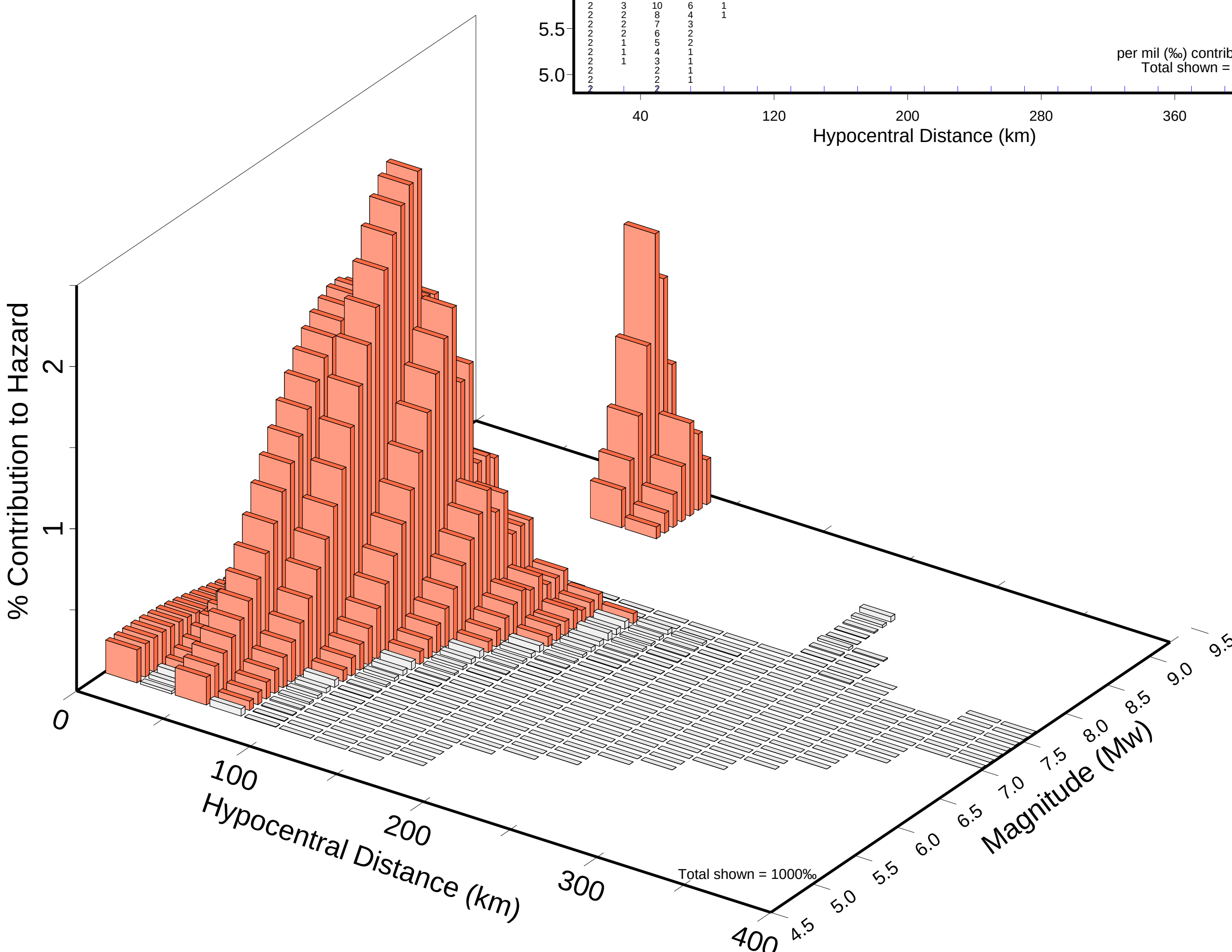
Mean magnitude (Mw) 6.75   Mean distance 72 km

Mode magnitude (Mw) 6.950   Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 6]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Adam McIntyre, Stantec

2016/07/27

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 0.30 seconds

at a probability of 0.010000 per annum, seismic hazard = 0.237 g

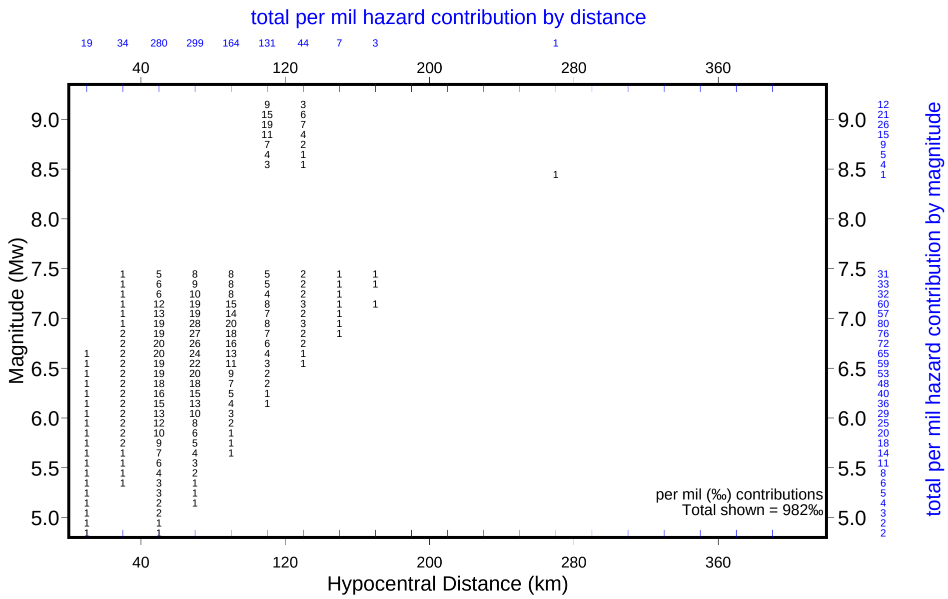
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

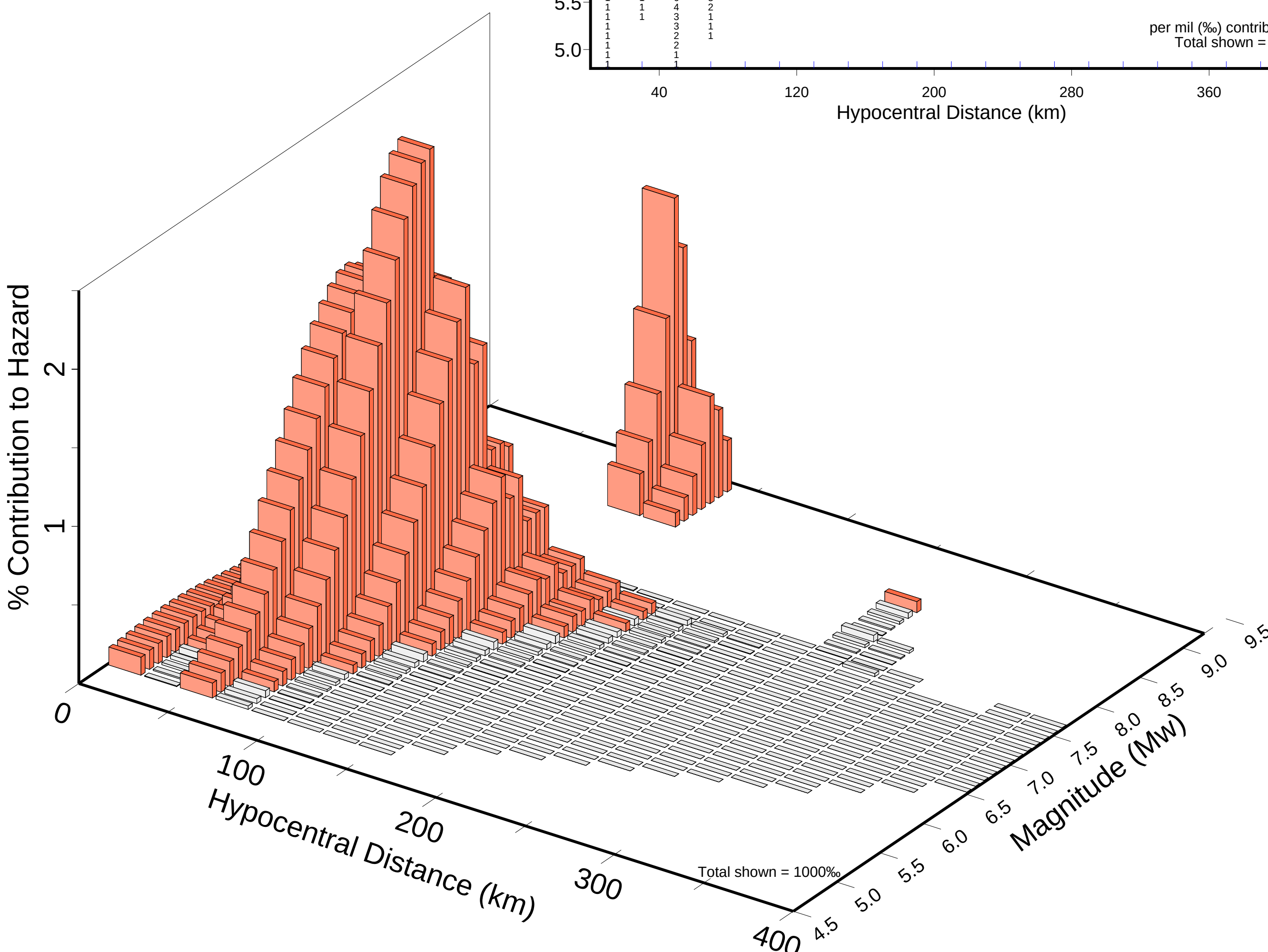
Mean magnitude (Mw) 6.83 Mean distance 75 km

Mode magnitude (Mw) 6.950 Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 7]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Adam McIntyre, Stantec

2016/07/27

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 0.50 seconds

at a probability of 0.010000 per annum, seismic hazard = 0.195 g

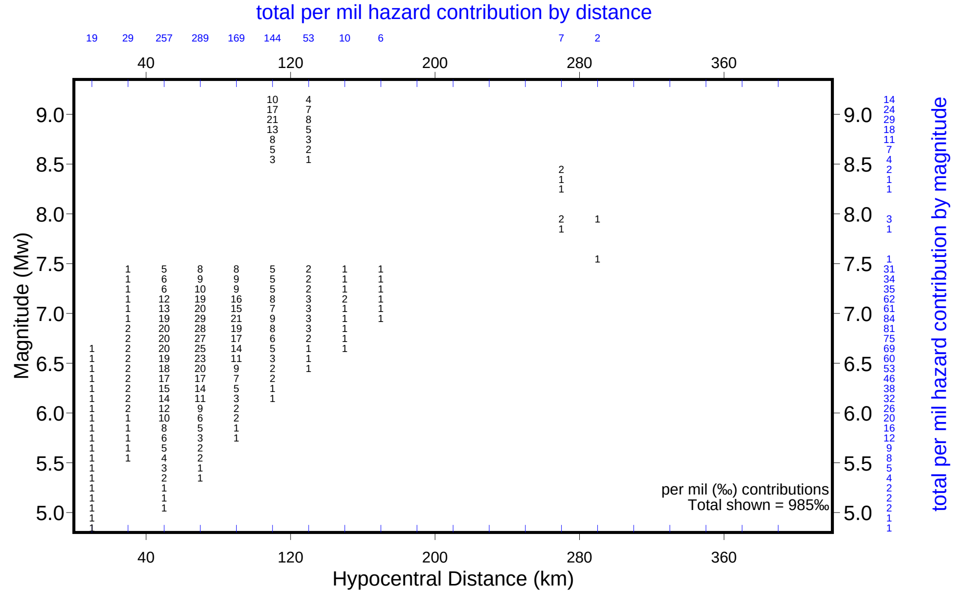
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

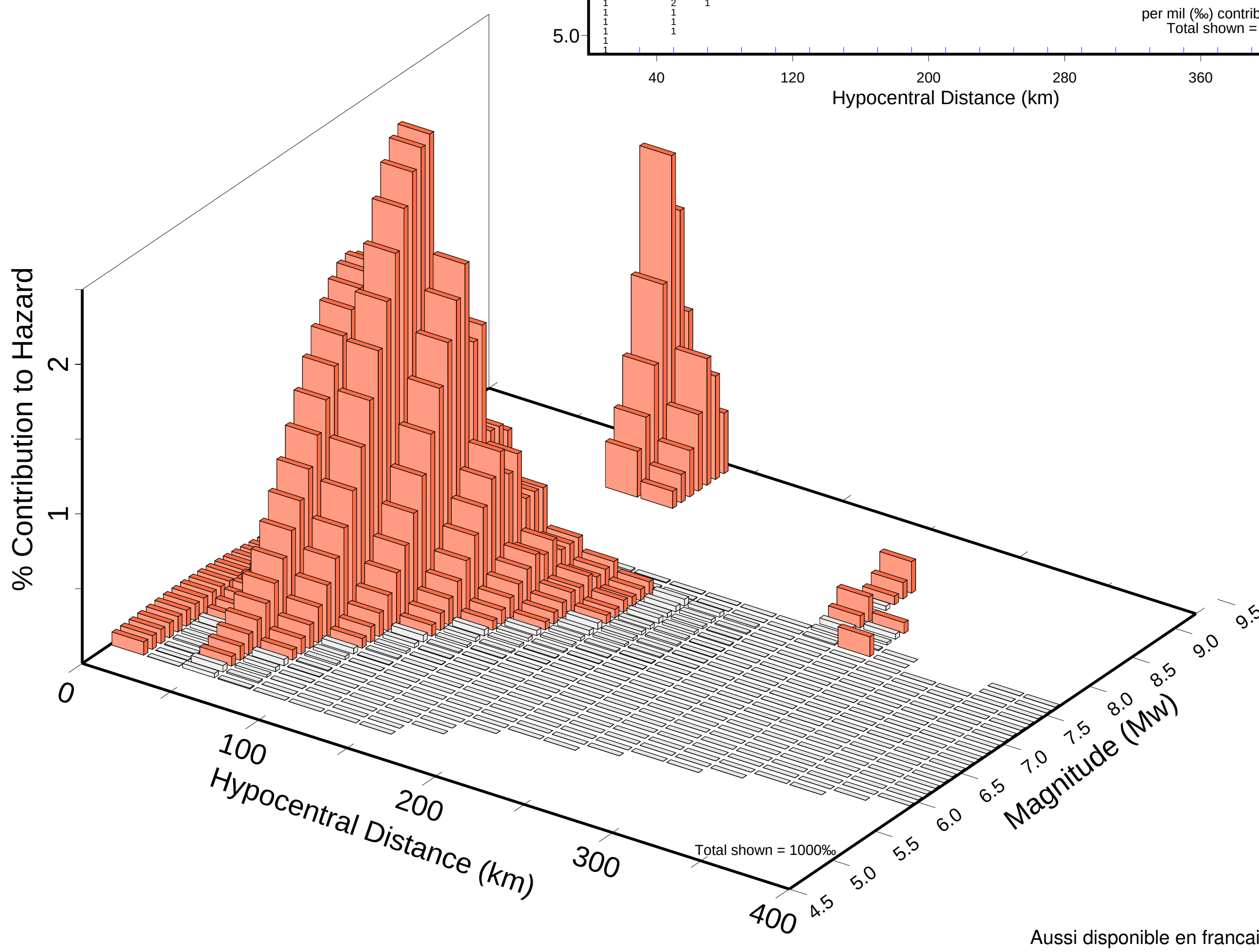
Mean magnitude (Mw) 6.93 Mean distance 79 km

Mode magnitude (Mw) 6.950 Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 8]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Adam McIntyre, Stantec

2016/07/27

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 1.0 seconds

at a probability of 0.010000 per annum, seismic hazard = 0.095 g

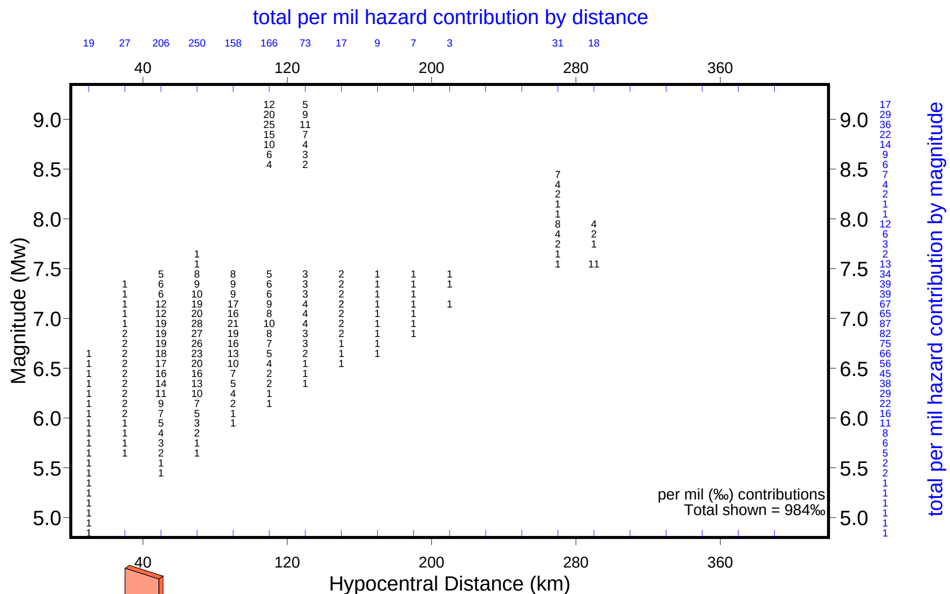
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

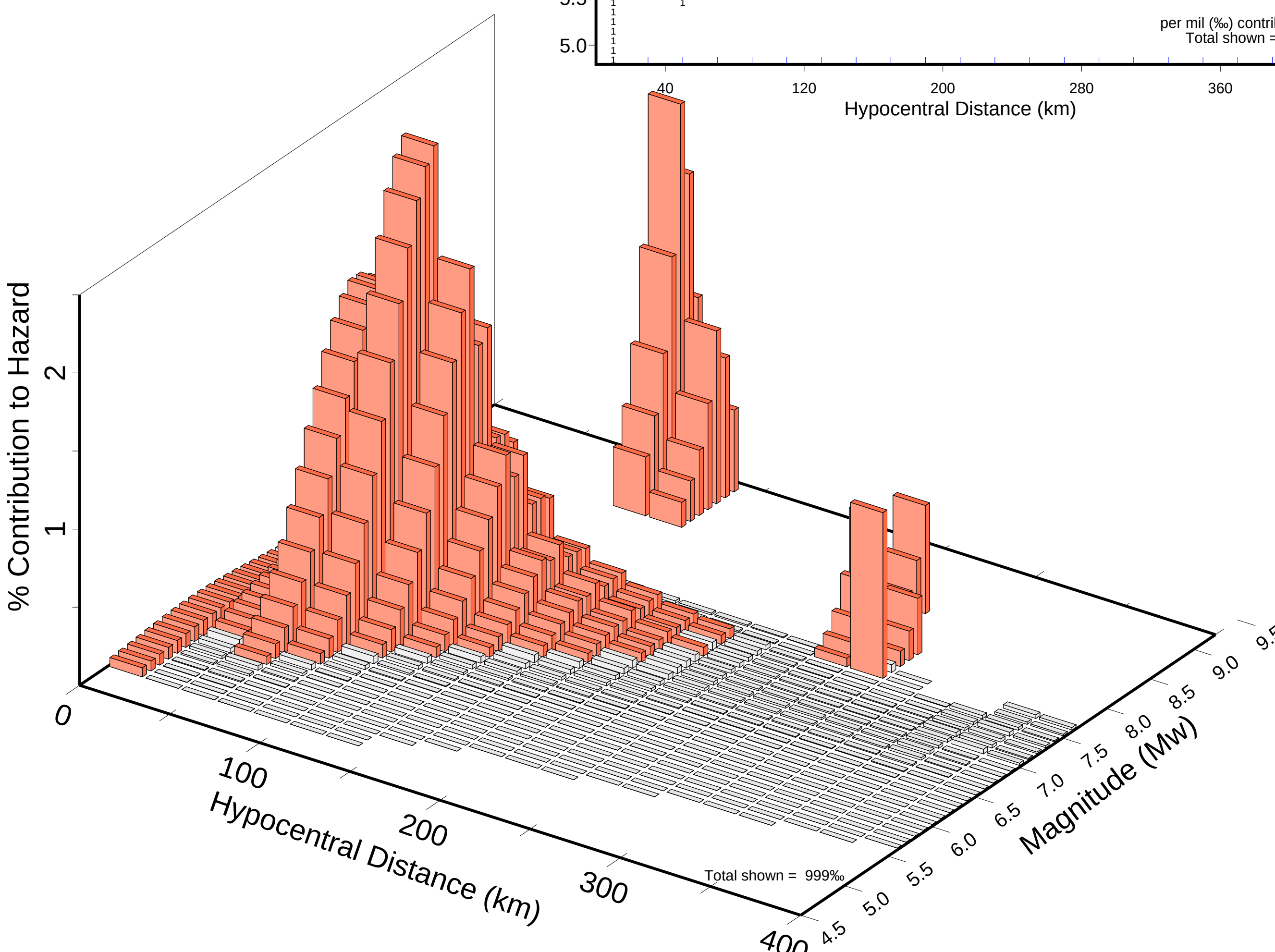
Mean magnitude (Mw) 7.11   Mean distance 95 km

Mode magnitude (Mw) 6.950   Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 9]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Adam McIntyre, Stantec

2016/07/27

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 2.0 seconds

at a probability of 0.010000 per annum, seismic hazard = 0.050 g

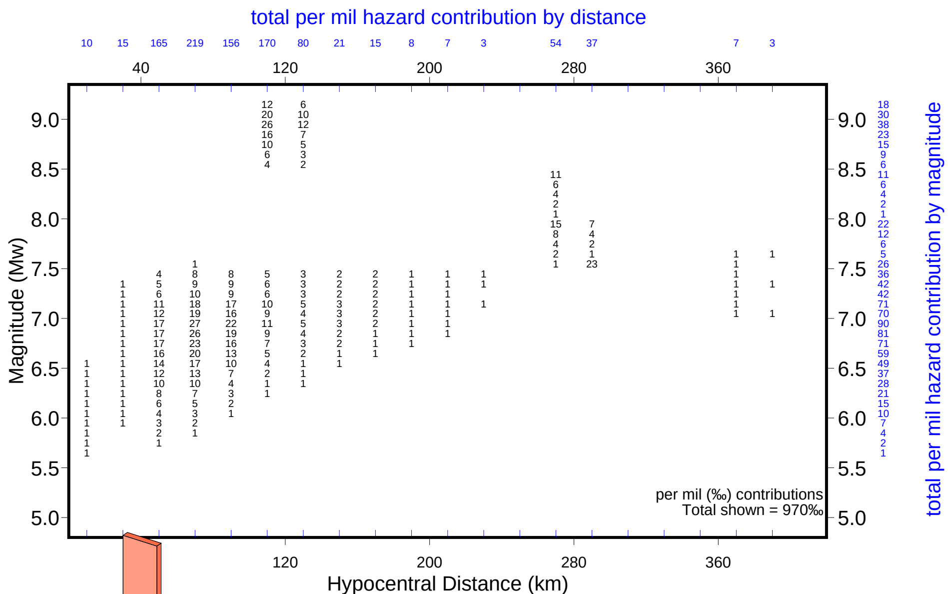
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

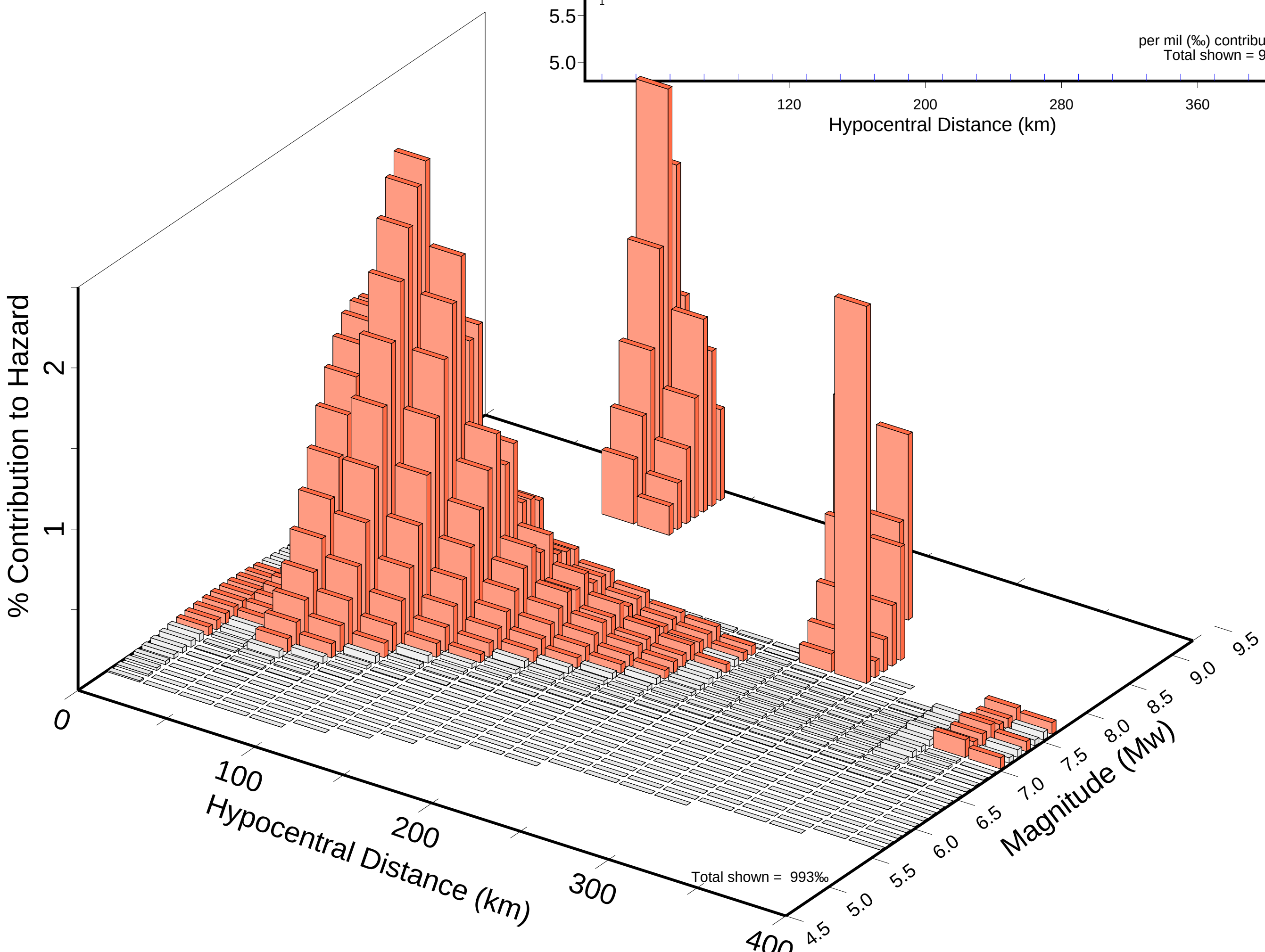
Mean magnitude (Mw) 7.24   Mean distance 113 km

Mode magnitude (Mw) 6.950   Mode distance   70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 10]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Adam McIntyre, Stantec

2016/07/27

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 5.0 seconds

at a probability of 0.010000 per annum, seismic hazard = 0.010 g

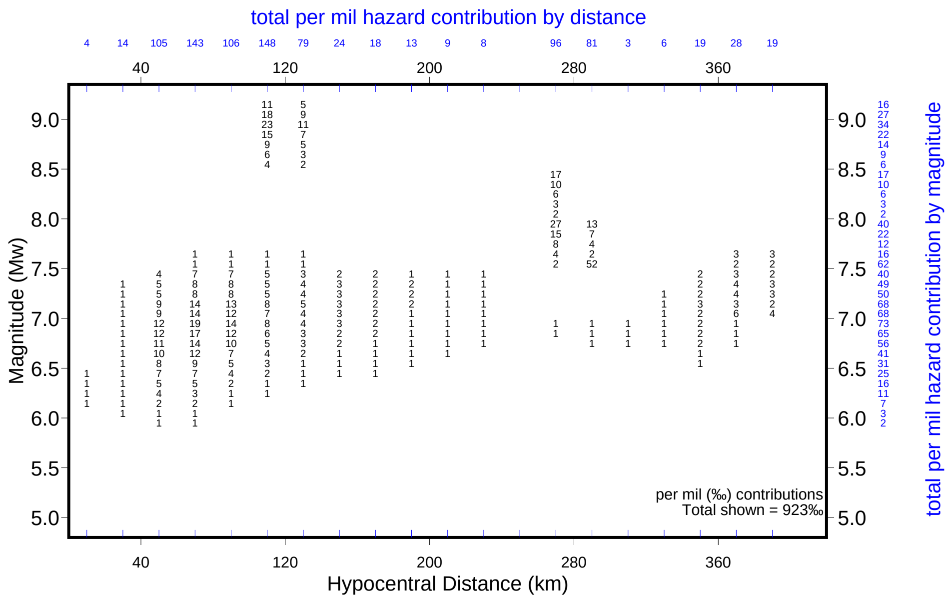
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

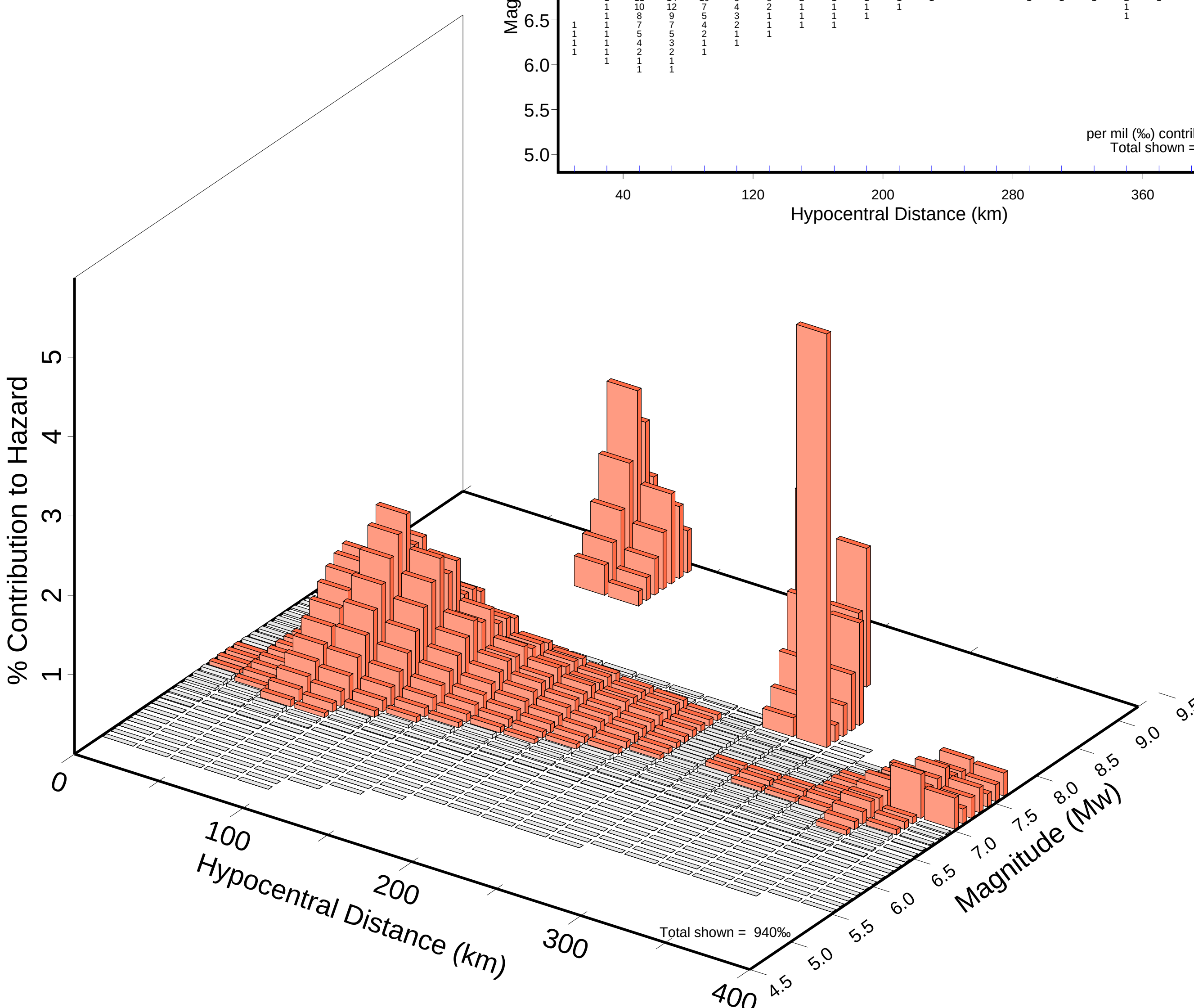
Mean magnitude (Mw) 7.39   Mean distance 174 km

Mode magnitude (Mw) 7.550   Mode distance 290 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 11]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Adam McIntyre, Stantec

2016/07/27

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 10.0 seconds

at a probability of 0.010000 per annum, seismic hazard = 0.004 g

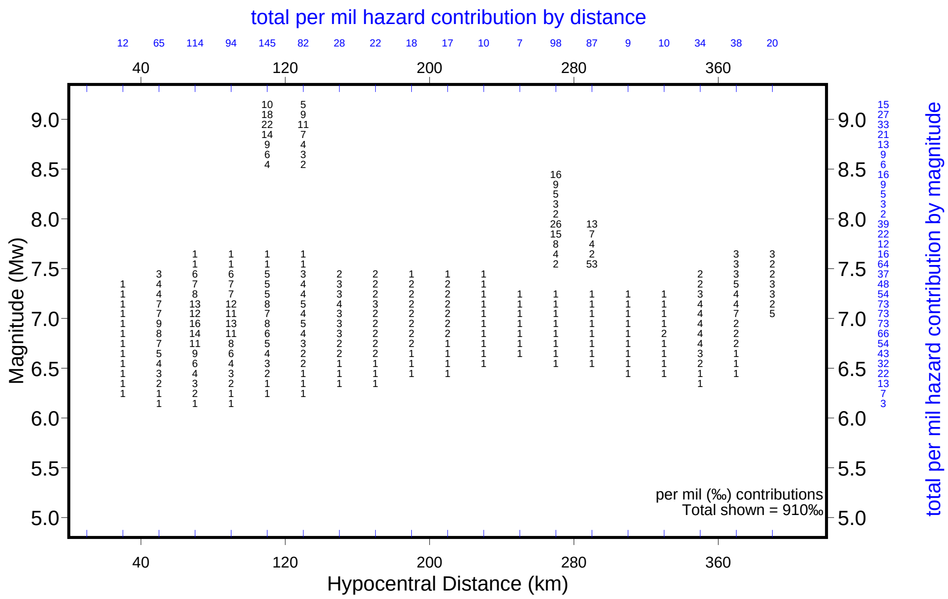
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

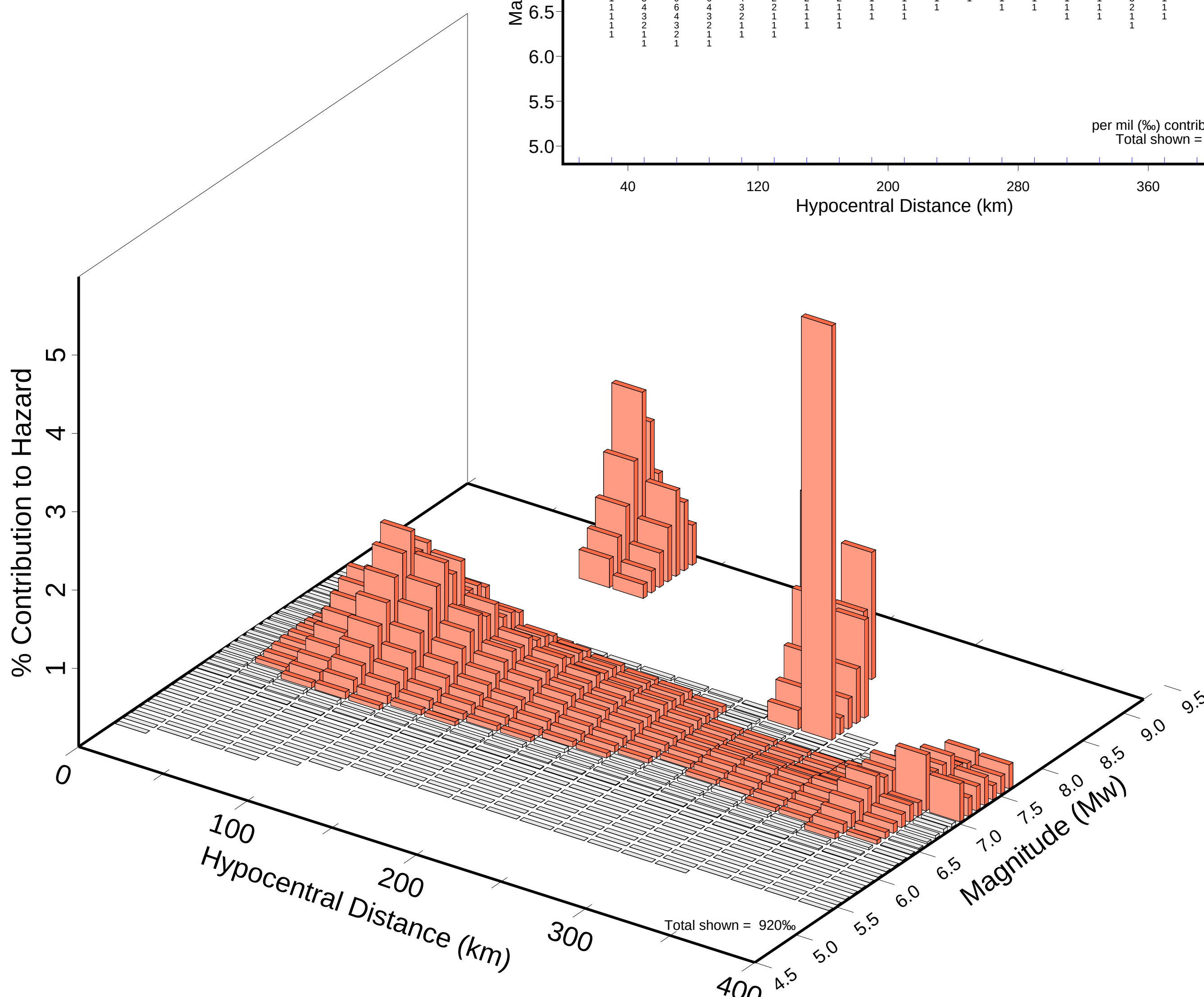
Mean magnitude (Mw) 7.39   Mean distance 199 km

Mode magnitude (Mw) 7.550   Mode distance 290 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

Natural Resources Canada   Ressources naturelles Canada

Canada

A475 EARTHQUAKE LEVELS

[Plot 12]

Seismic Hazard Deaggregation

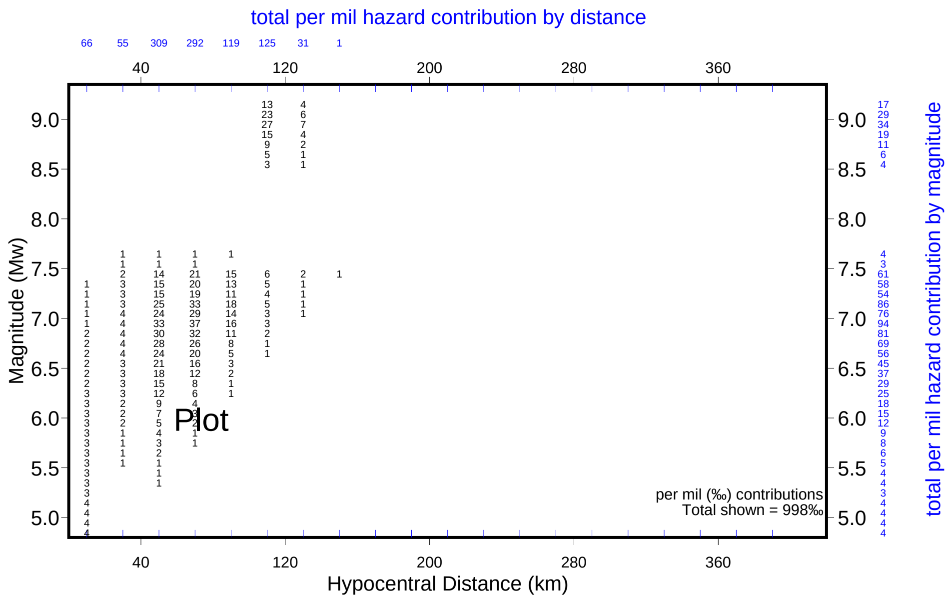
calculated by the Canadian Hazards Information Service

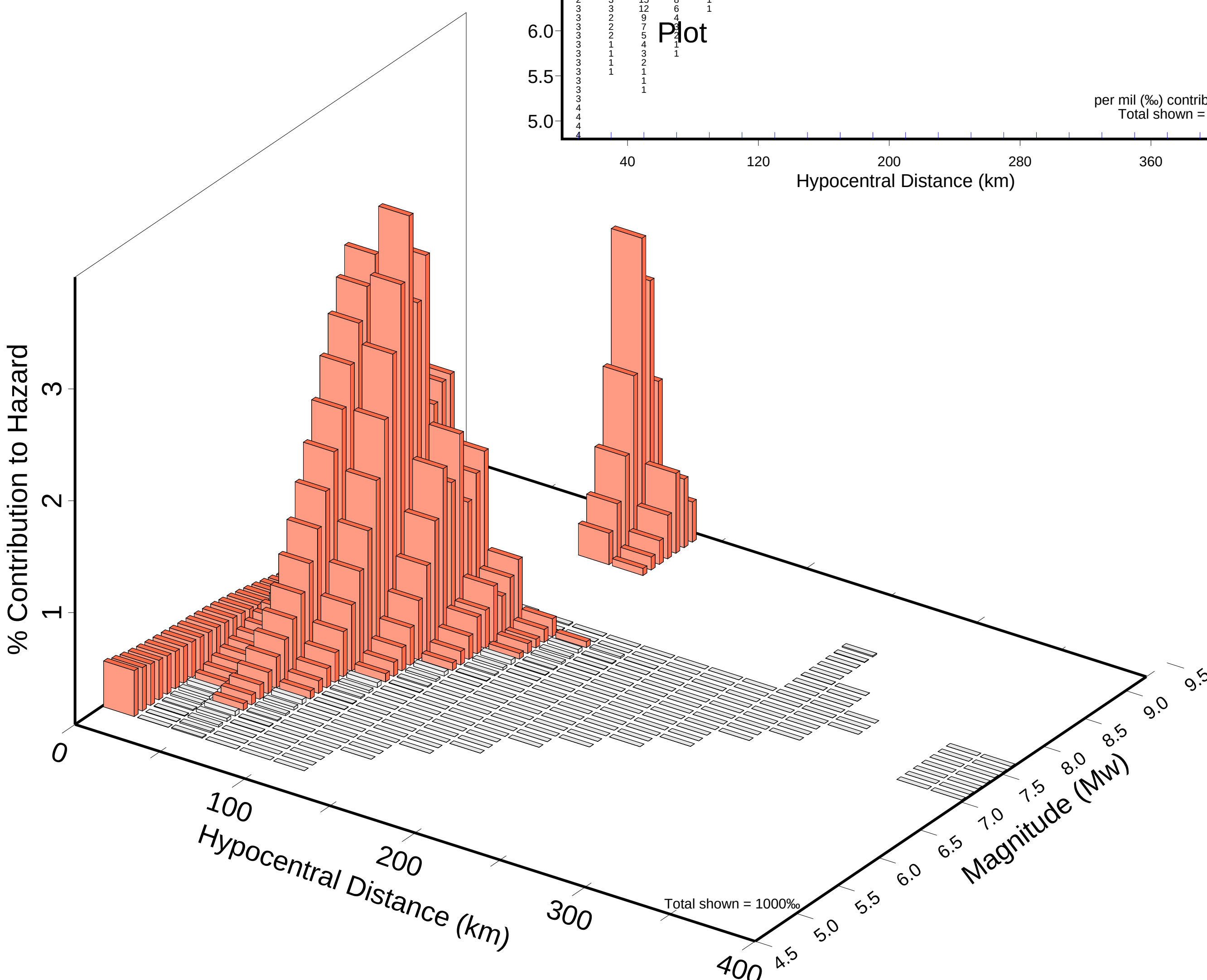
INFORMATION: *EarthquakesCanada.nrcan.gc.ca*
Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada 2016/07/20
For site Delta, BC at 49.019 N 123.185 W
For ground motion parameter peak ground acceleration (PGA)
at a probability of 0.002100 per annum, seismic hazard = 0.225 g
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

Mean magnitude (Mw) 7.05 Mean distance 67 km
Mode magnitude (Mw) 6.950 Mode distance 70 km
Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

Natural Resources Canada
Ressources naturelles Canada
Canada

[Plot 13]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada

2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter peak ground velocity (PGV)

at a probability of 0.002100 per annum, seismic hazard = 0.311 m/s

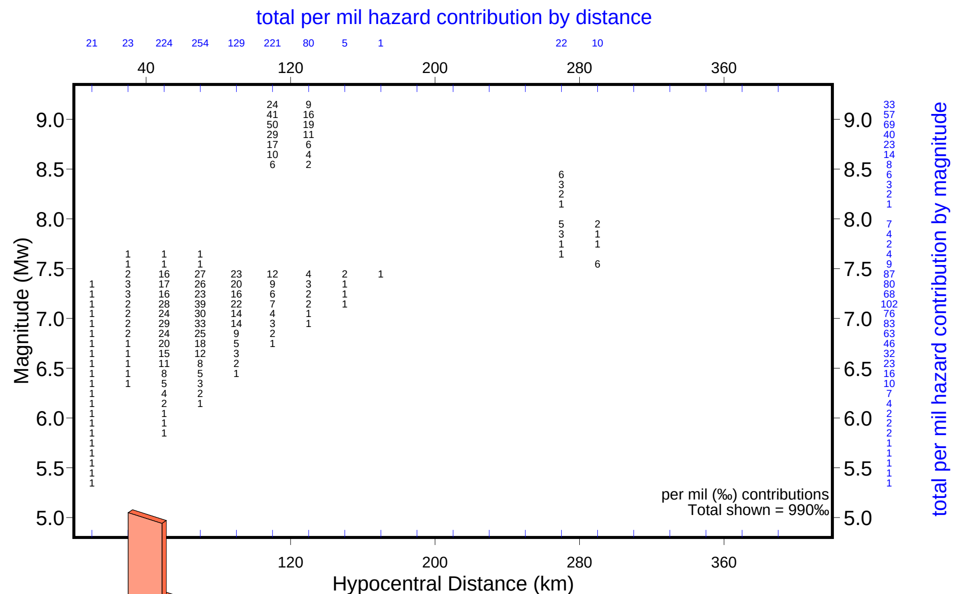
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

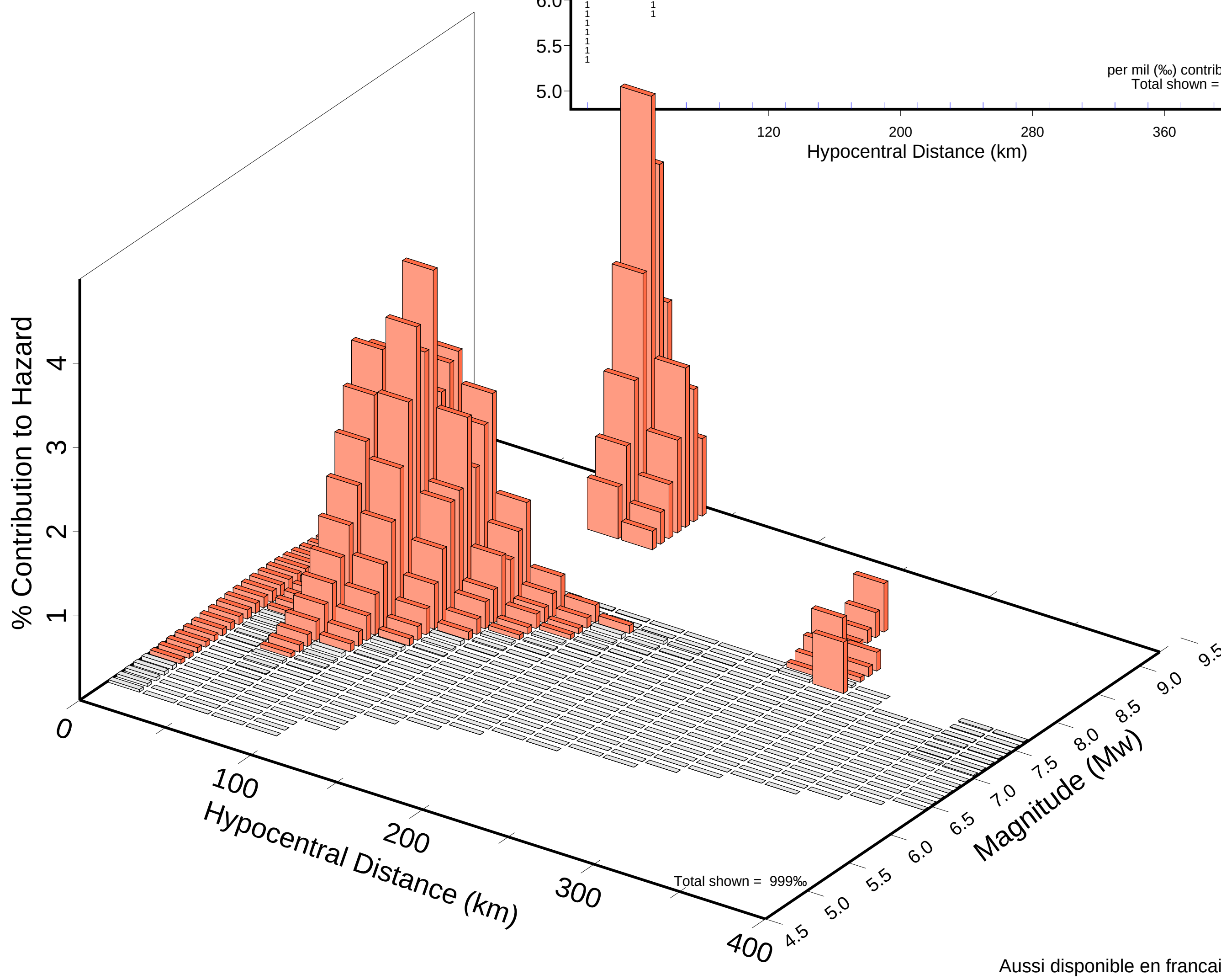
Mean magnitude (Mw) 7.53   Mean distance   87 km

Mode magnitude (Mw) 8.950   Mode distance 110 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

Natural Resources Canada   Ressources naturelles Canada

Canada

[Plot 14]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*
Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

CANADA 1842 GEOLOGICAL SURVEY - COMMISSION GÉOLOGIQUE

Requested by: Natural Resources Canada

2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 0.05 seconds

at a probability of 0.002100 per annum, seismic hazard = 0.271 g

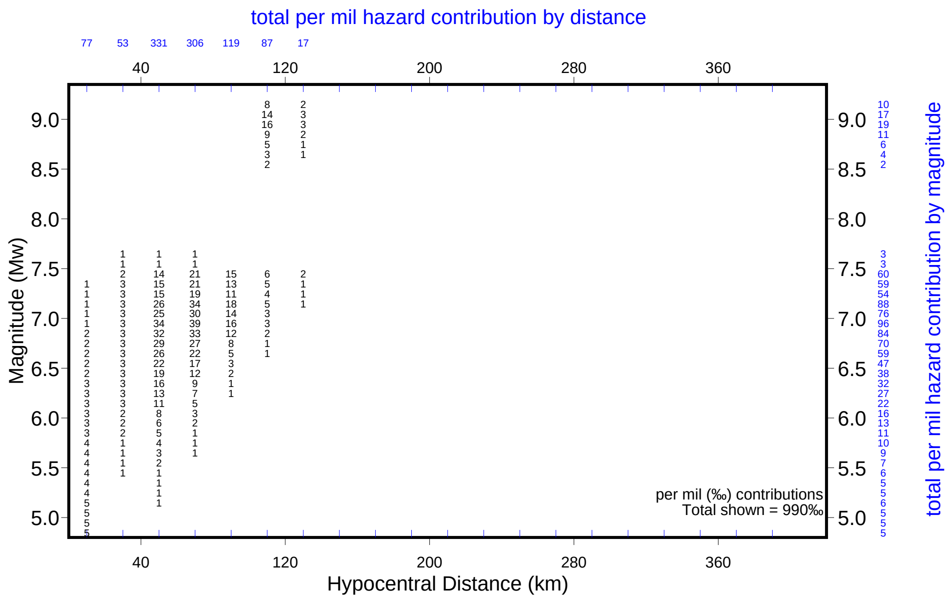
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

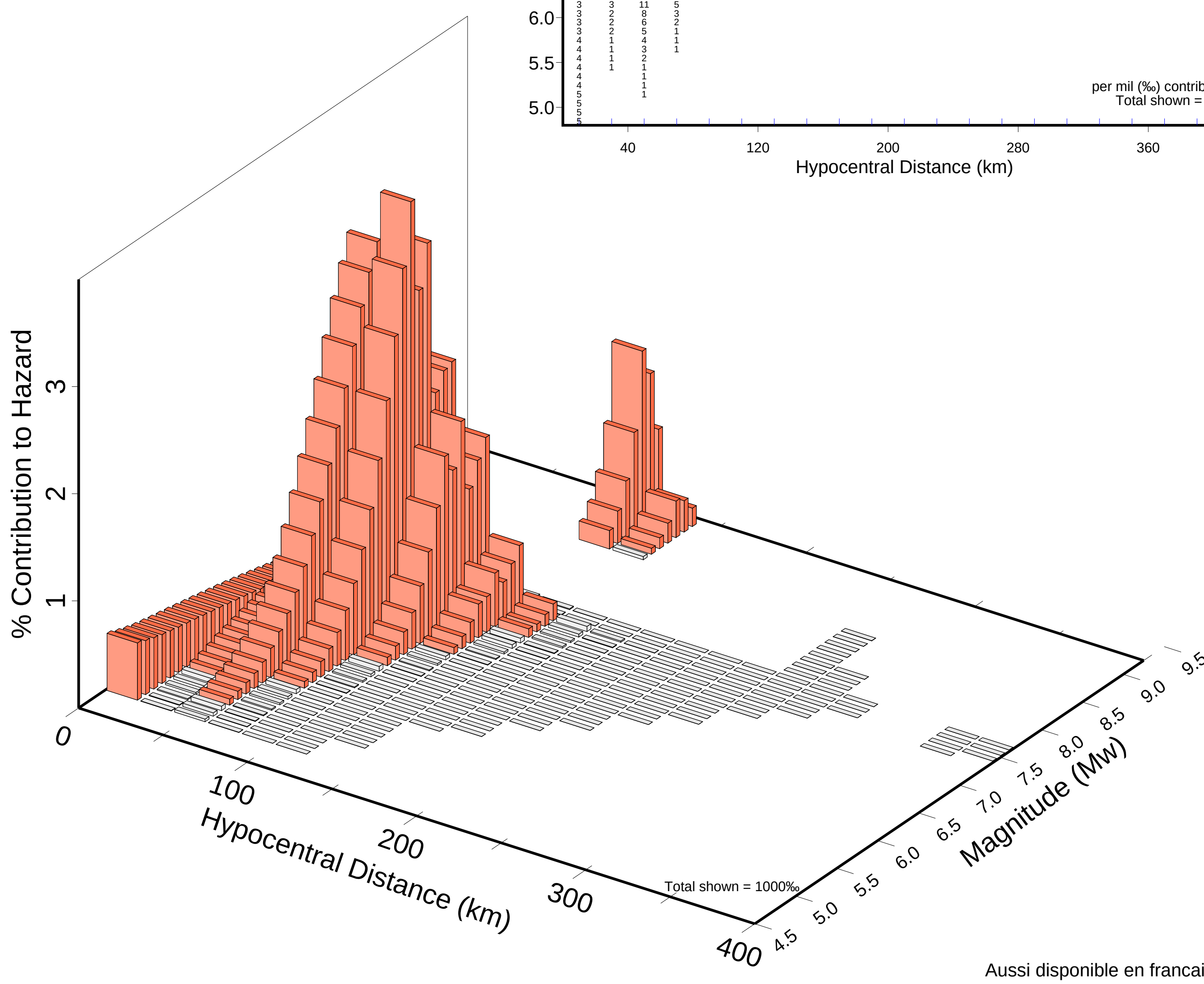
Mean magnitude (Mw) 6.91 Mean distance 64 km

Mode magnitude (Mw) 6.950 Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 15]

Seismic Hazard Deaggregation

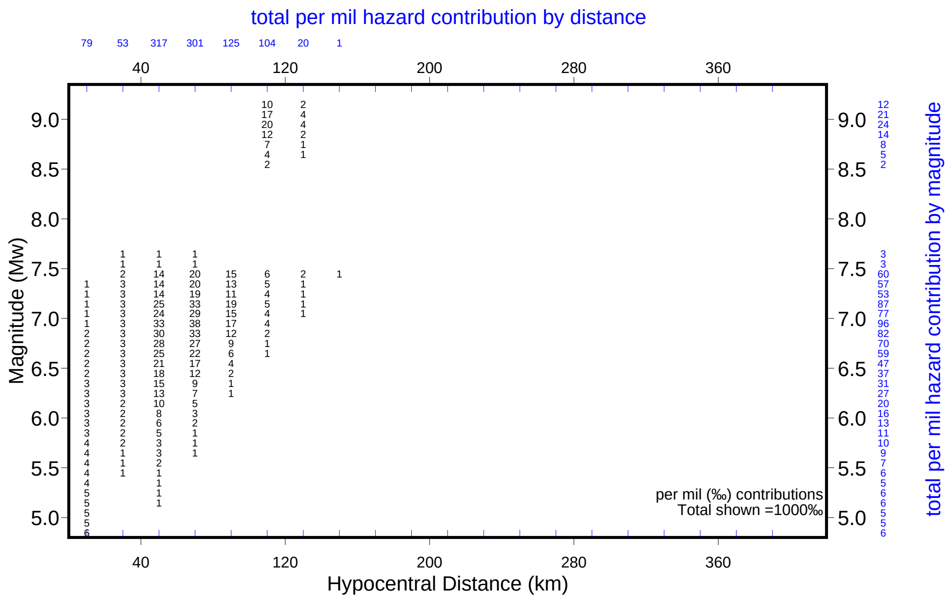
calculated by the Canadian Hazards Information Service

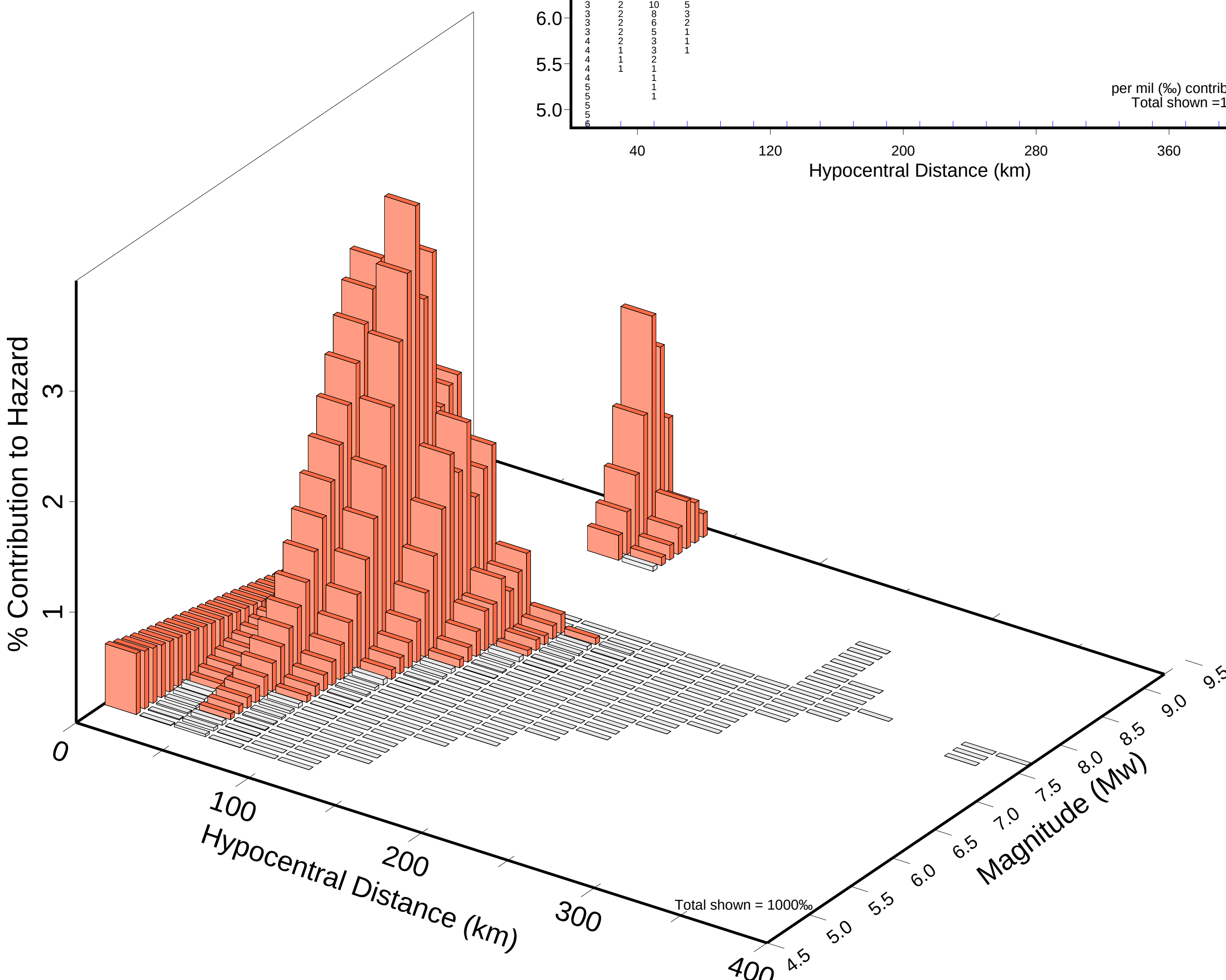
INFORMATION: *EarthquakesCanada.nrcan.gc.ca*
Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada 2016/07/20
For site Delta, BC at 49.019 N 123.185 W
For ground motion parameter spectral acceleration with a period of 0.10 seconds
at a probability of 0.002100 per annum, seismic hazard = 0.414 g
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

Mean magnitude (Mw) 6.94 Mean distance 65 km
Mode magnitude (Mw) 6.950 Mode distance 70 km
Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 16]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada 2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 0.20 seconds

at a probability of 0.002100 per annum, seismic hazard = 0.520 g

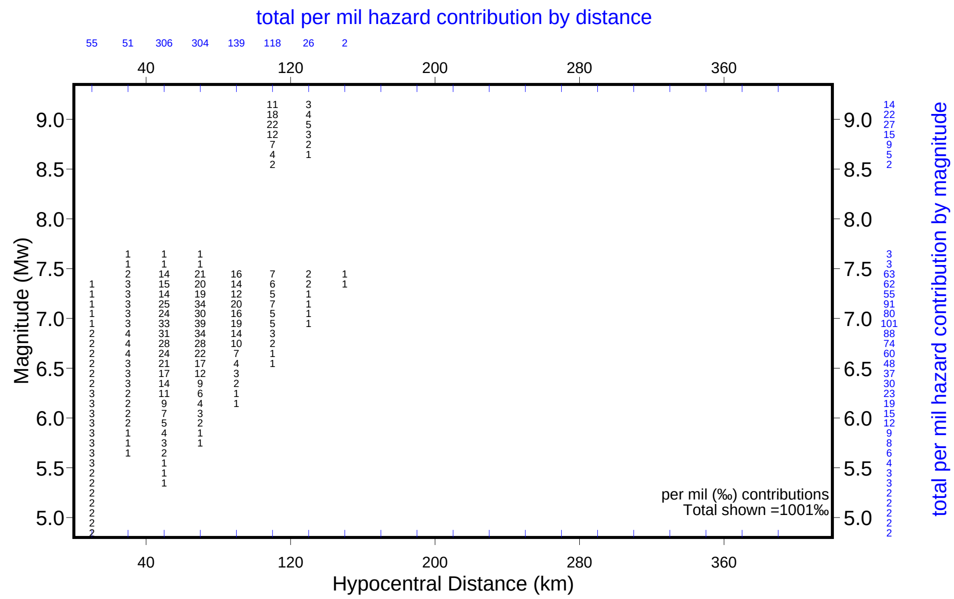
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

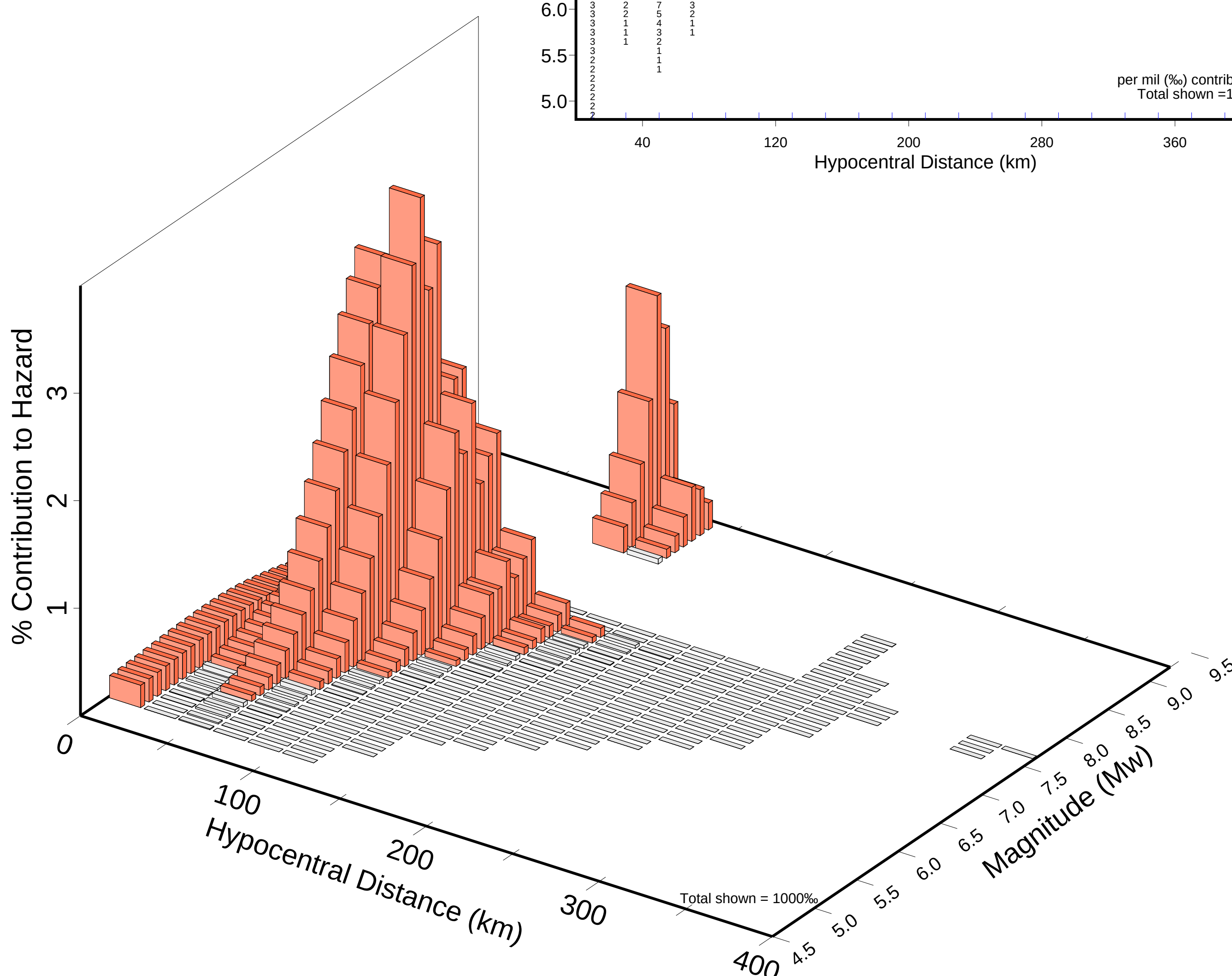
Mean magnitude (Mw) 7.02   Mean distance   68 km

Mode magnitude (Mw) 6.950   Mode distance   70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 17]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada 2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 0.30 seconds

at a probability of 0.002100 per annum, seismic hazard = 0.529 g

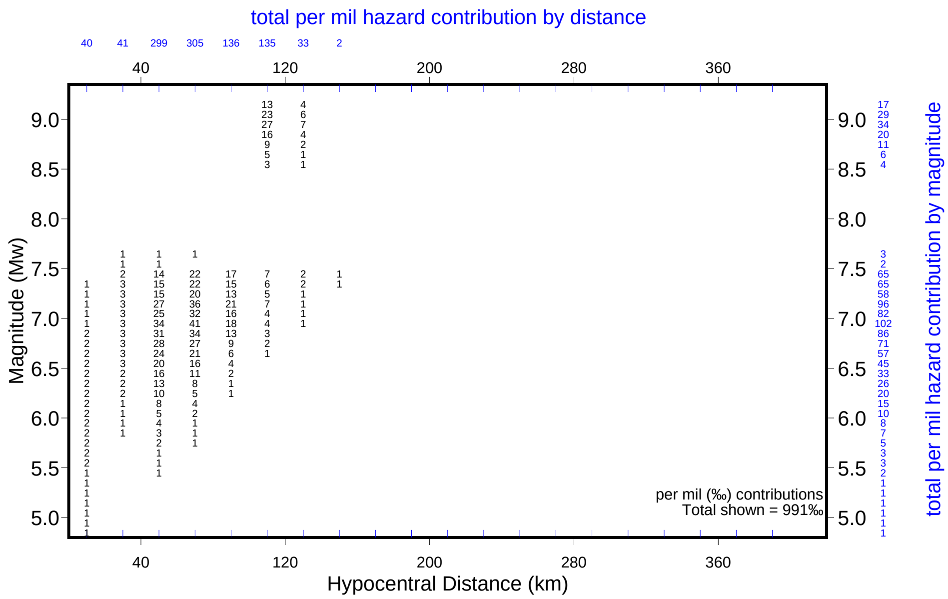
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

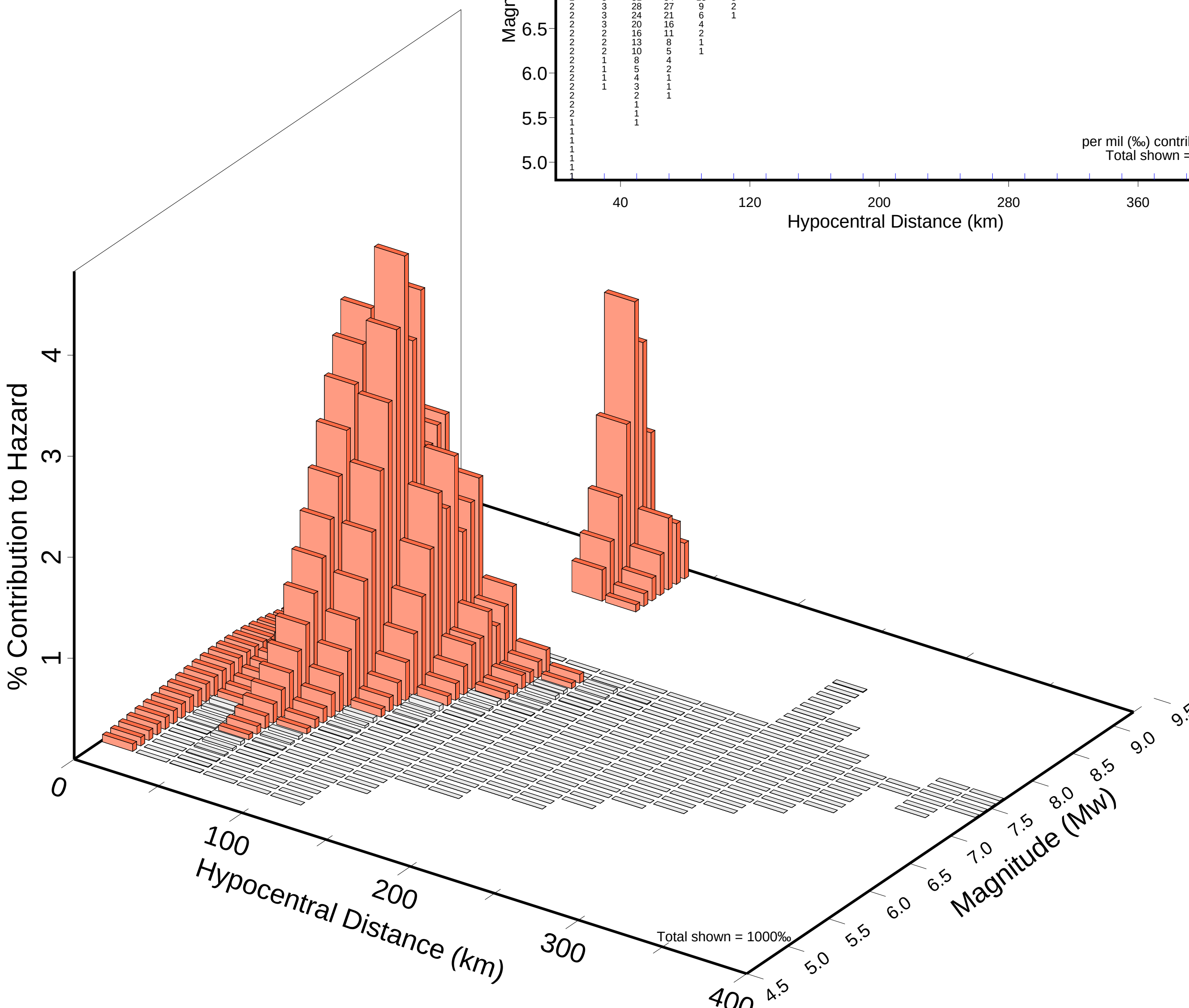
Mean magnitude (Mw) 7.13 Mean distance 71 km

Mode magnitude (Mw) 6.950 Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 18]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada 2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 0.50 seconds

at a probability of 0.002100 per annum, seismic hazard = 0.460 g

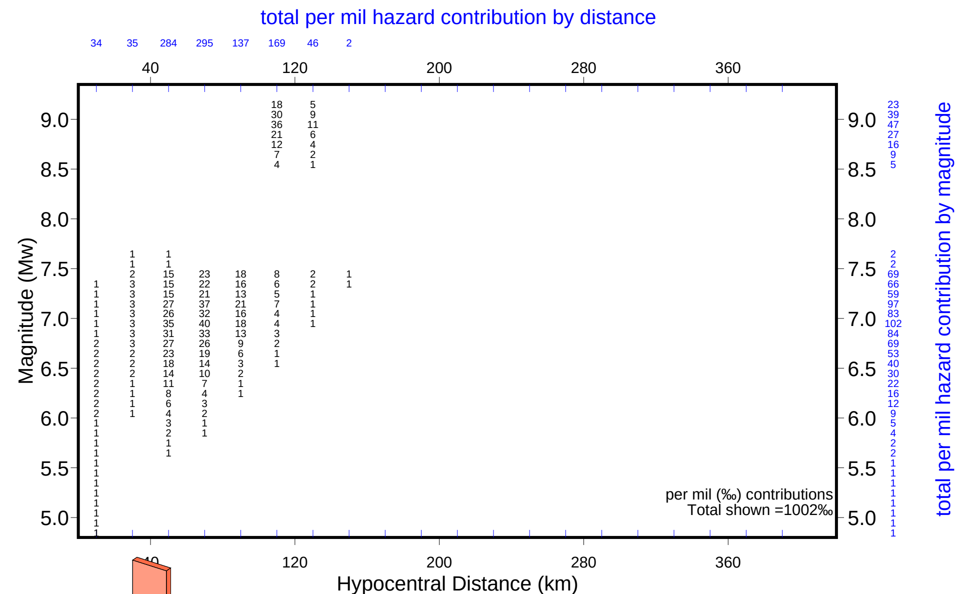
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

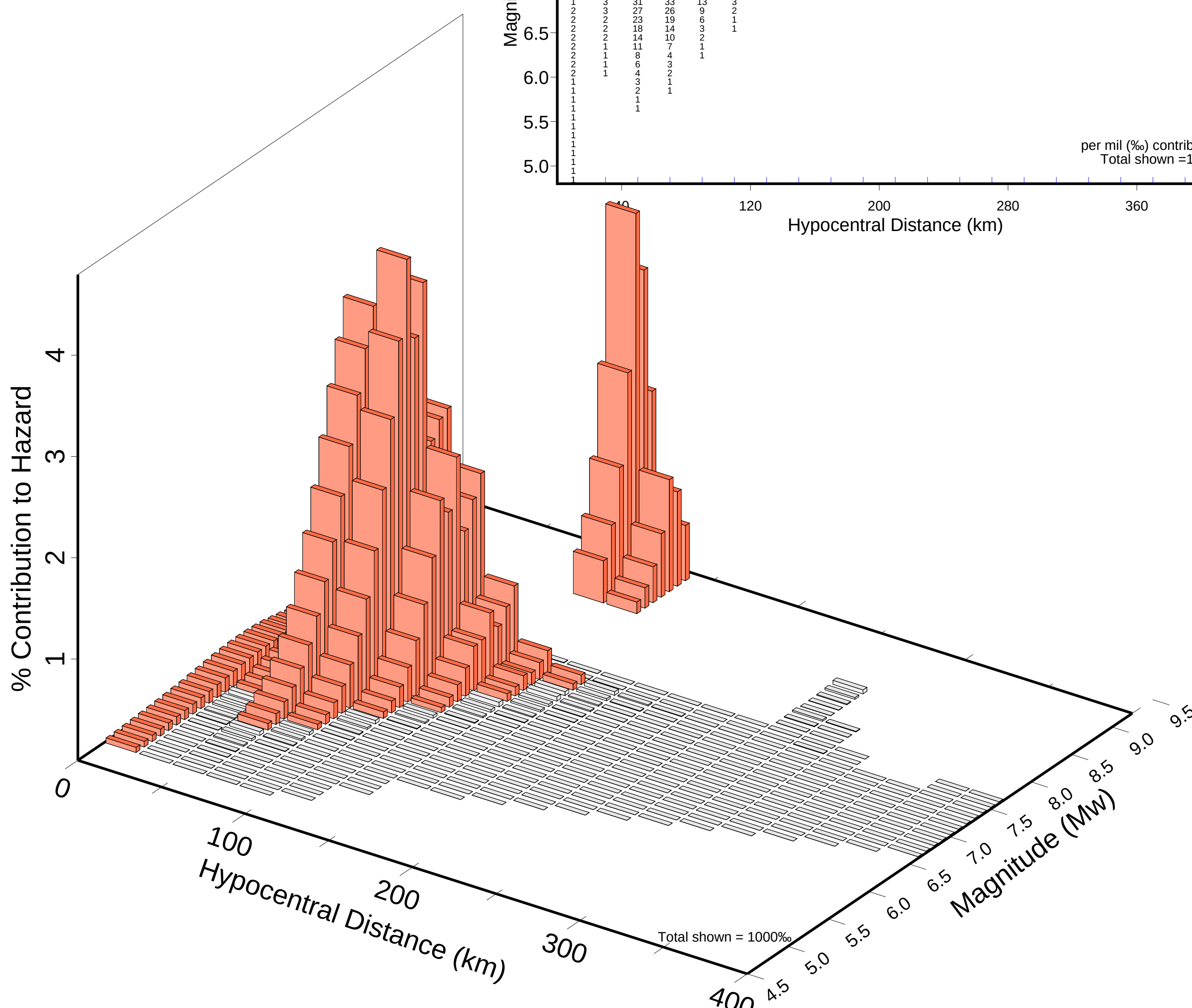
Mean magnitude (Mw) 7.26 Mean distance 74 km

Mode magnitude (Mw) 6.950 Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 19]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada 2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 1.0 seconds

at a probability of 0.002100 per annum, seismic hazard = 0.241 g

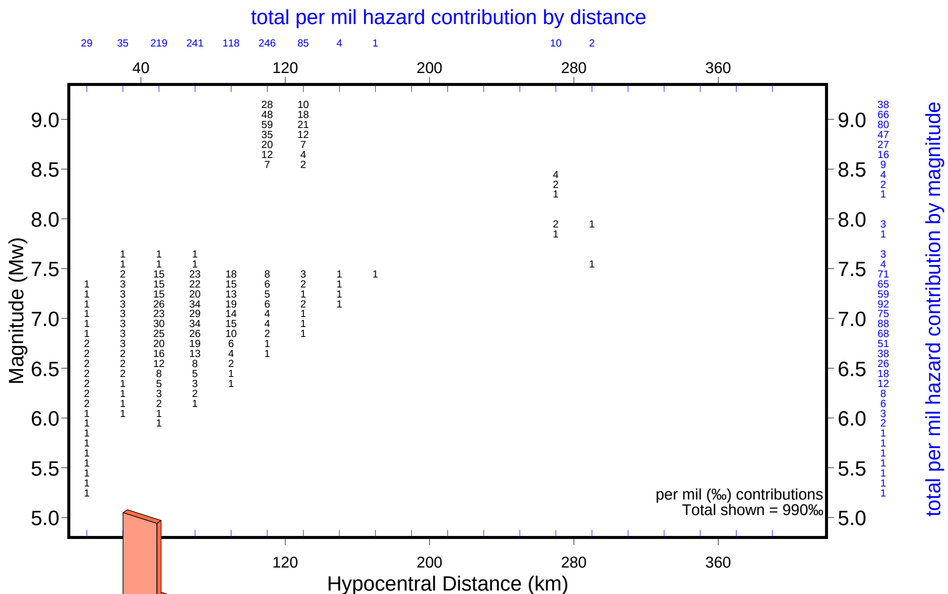
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

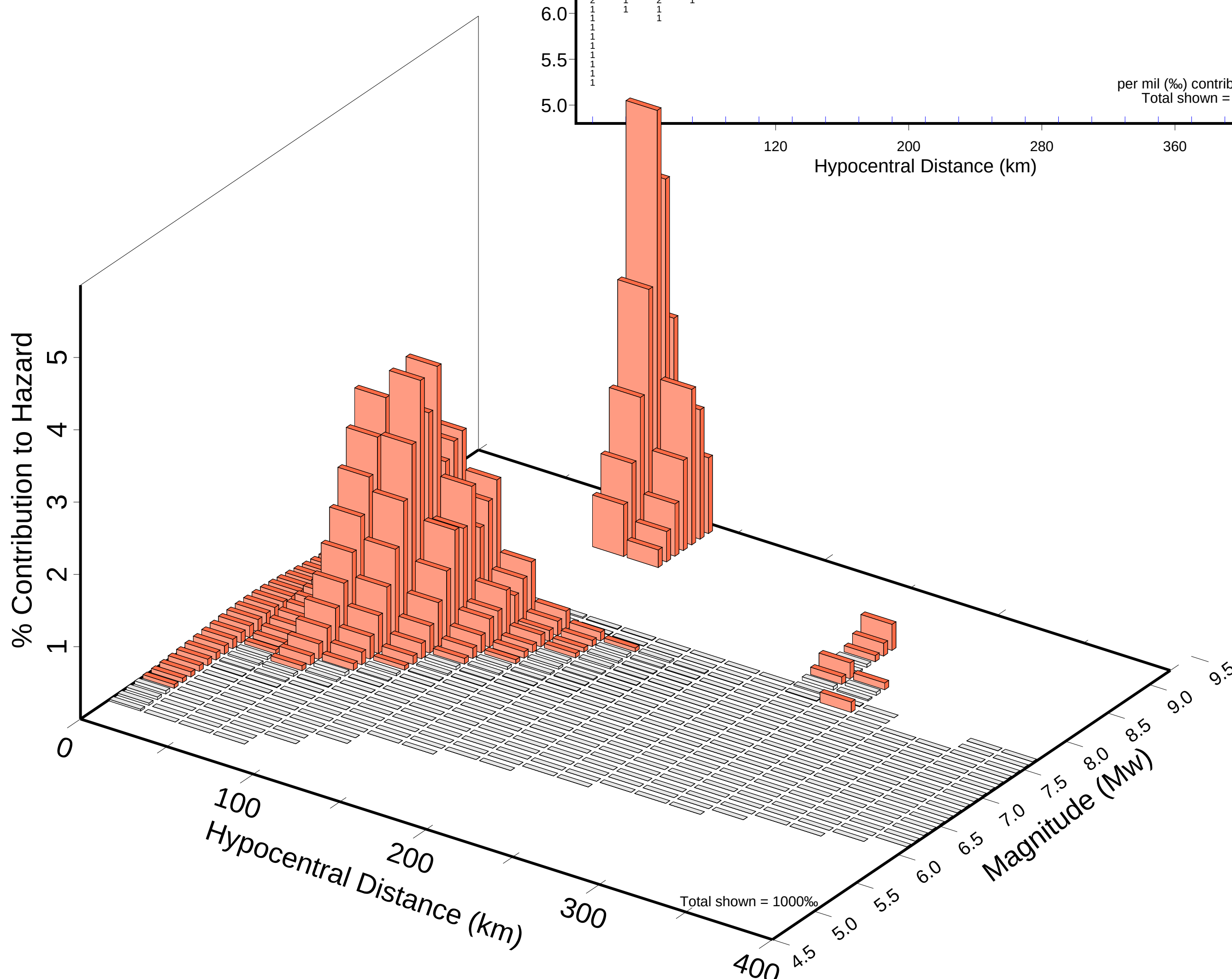
Mean magnitude (Mw) 7.56 Mean distance 84 km

Mode magnitude (Mw) 8.950 Mode distance 110 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

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[Plot 20]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada

2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 2.0 seconds

at a probability of 0.002100 per annum, seismic hazard = 0.135 g

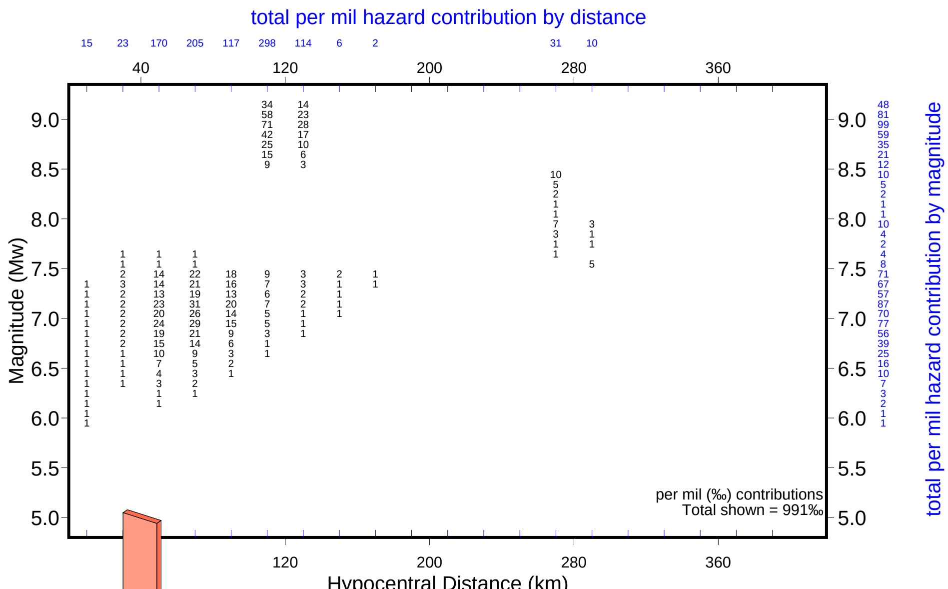
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

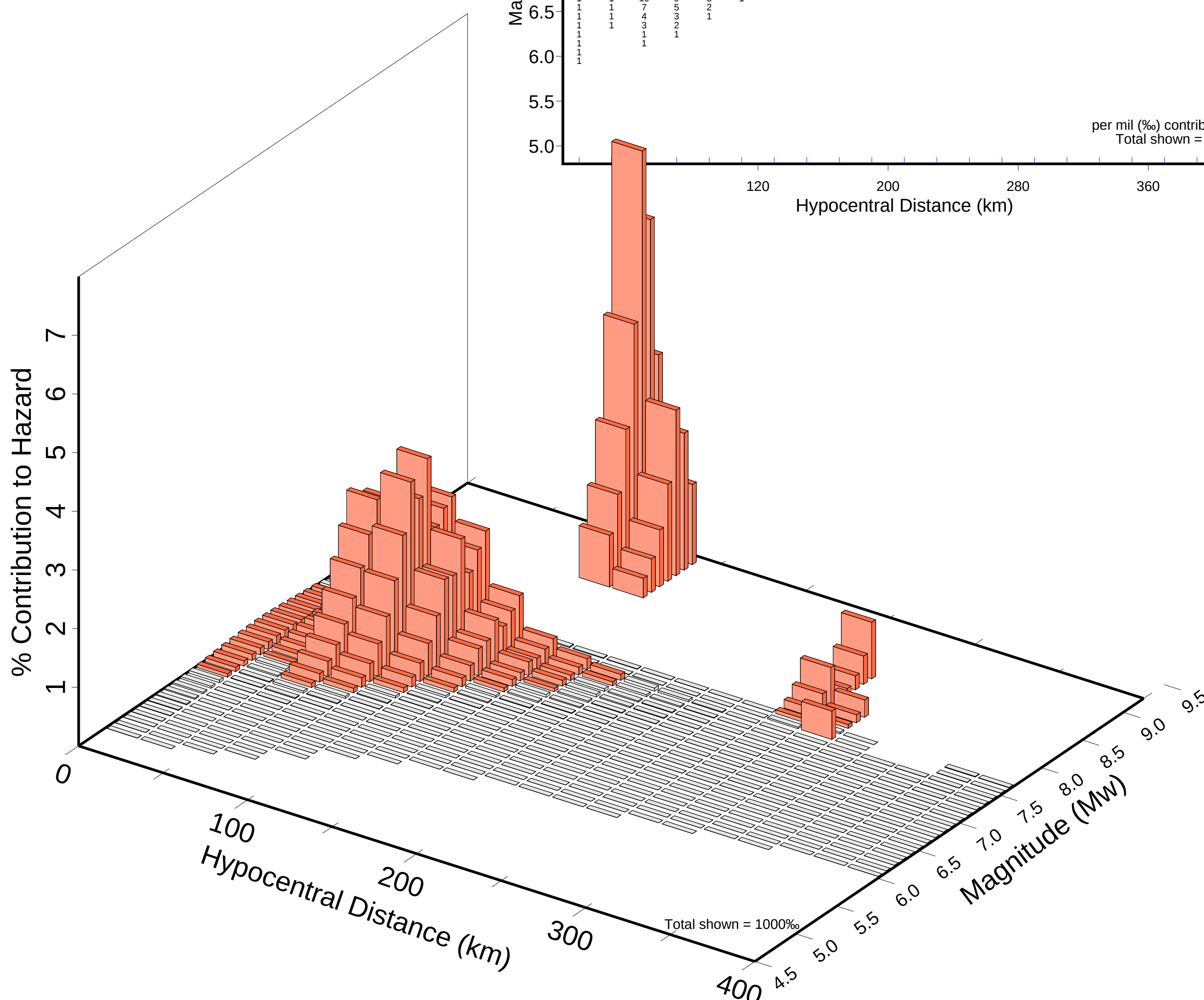
Mean magnitude (Mw) 7.76   Mean distance   96 km

Mode magnitude (Mw) 8.950   Mode distance 110 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

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[Plot 21]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada

2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 5.0 seconds

at a probability of 0.002100 per annum, seismic hazard = 0.031 g

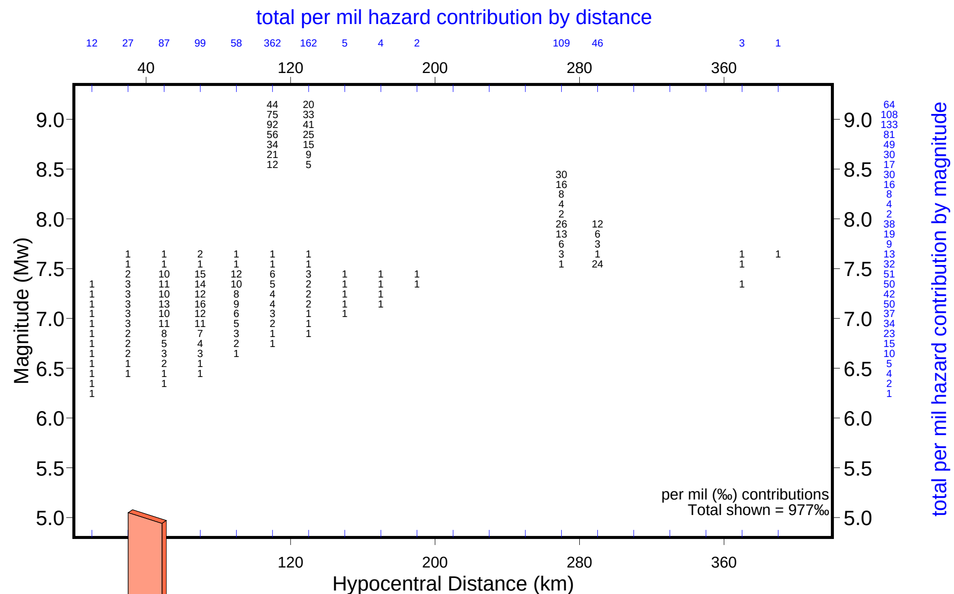
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

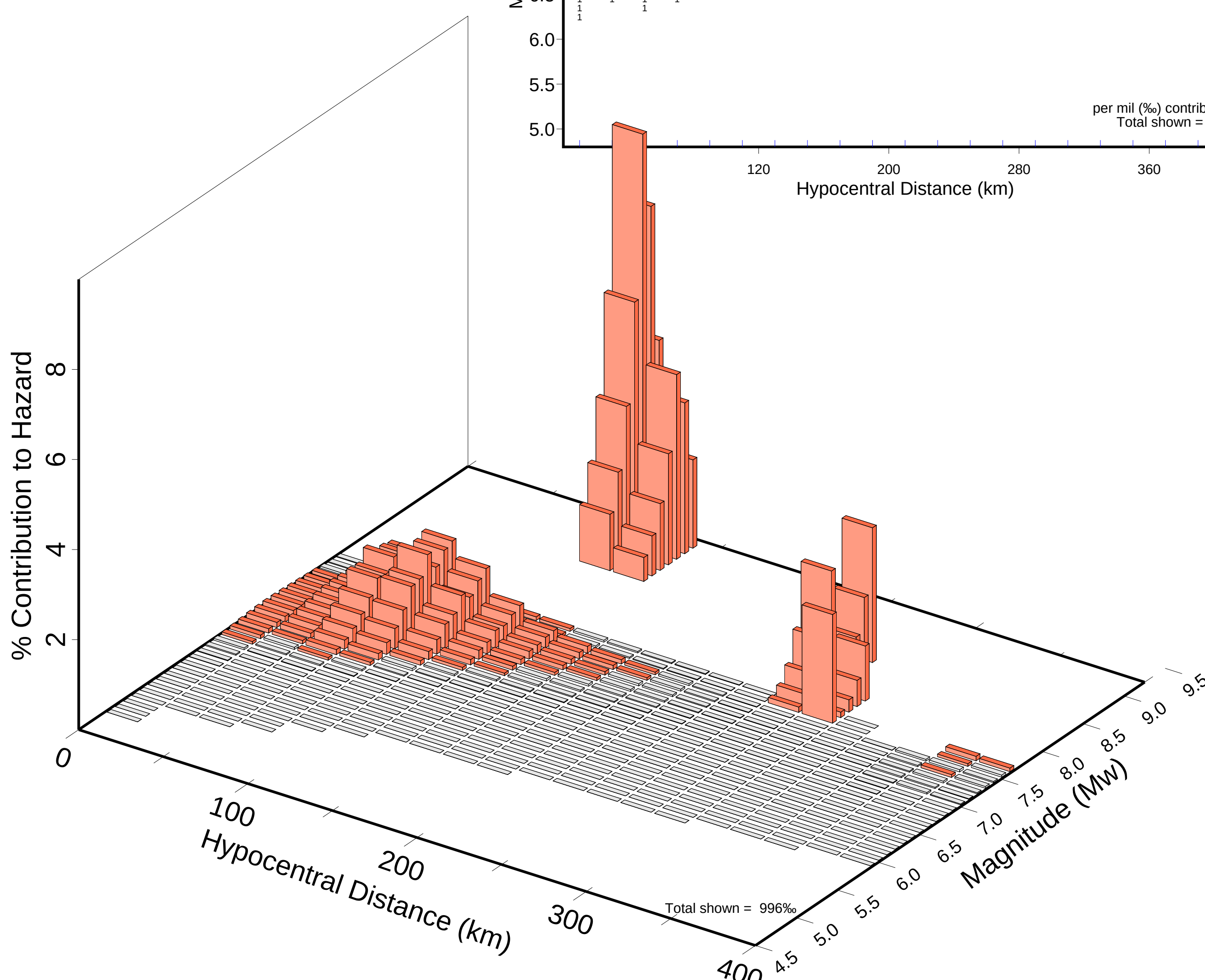
Mean magnitude (Mw) 8.14   Mean distance 130 km

Mode magnitude (Mw) 8.950   Mode distance 110 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

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[Plot 22]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada

2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 10.0 seconds

at a probability of 0.002100 per annum, seismic hazard = 0.011 g

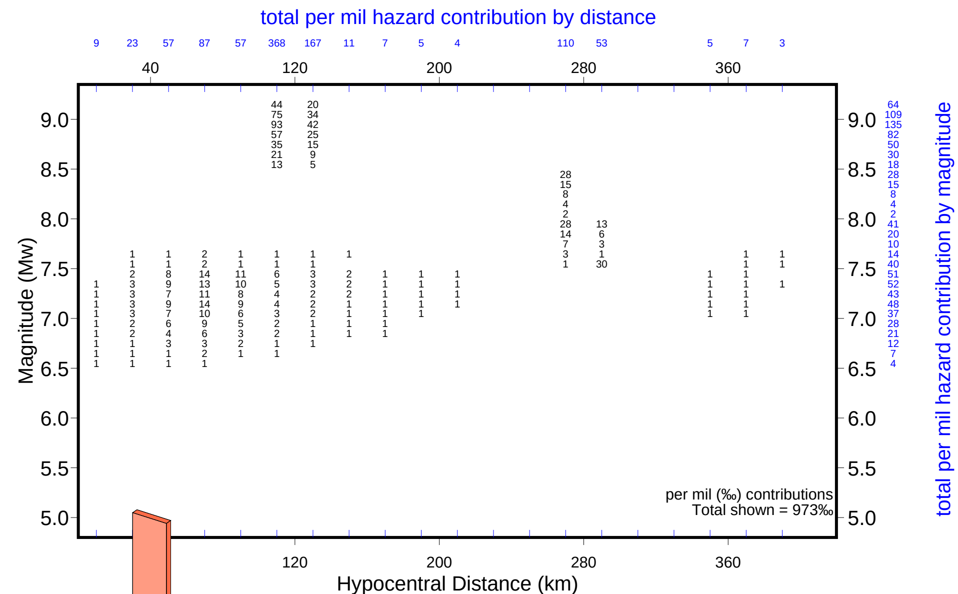
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

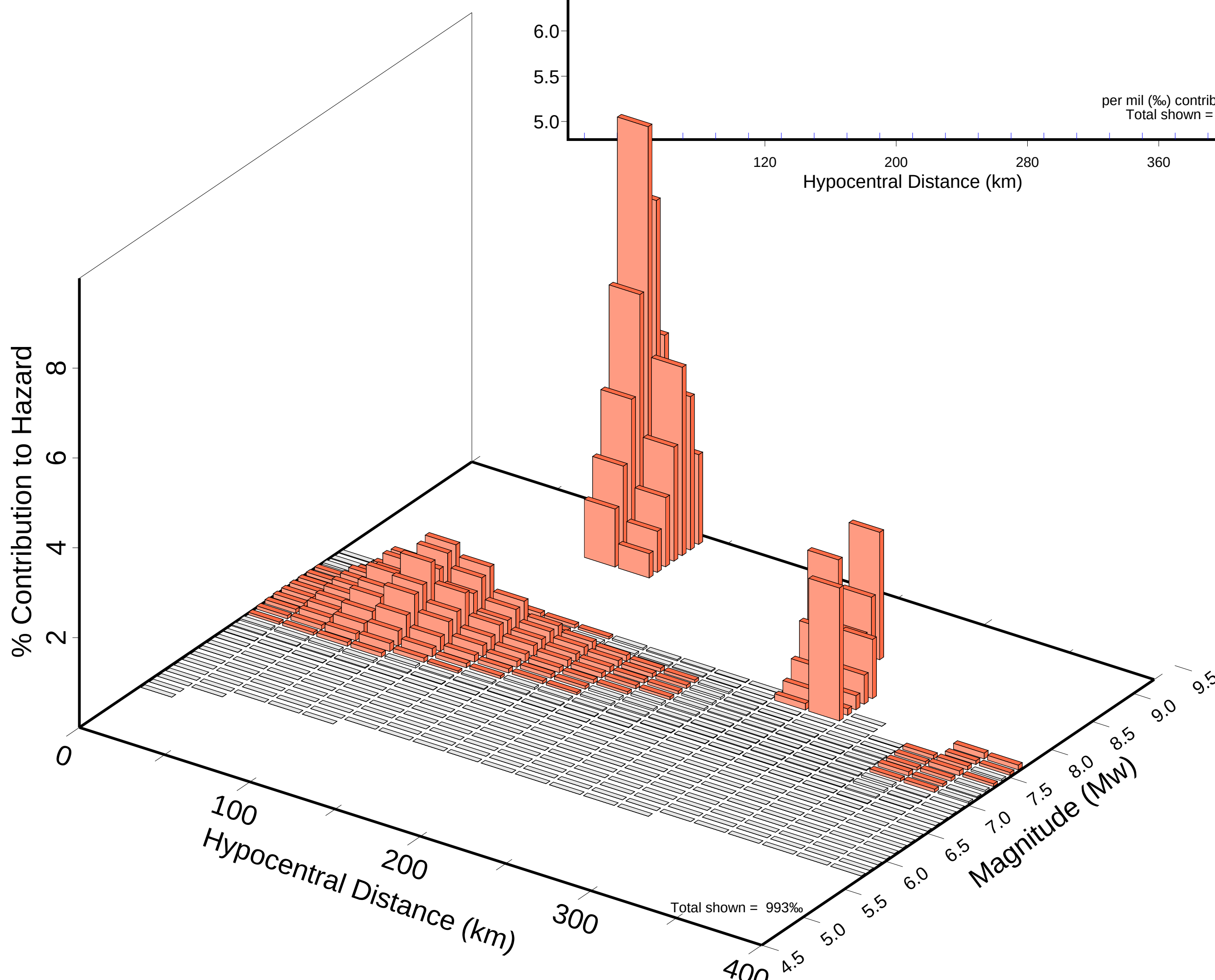
Mean magnitude (Mw) 8.17 Mean distance 140 km

Mode magnitude (Mw) 8.950 Mode distance 110 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

A2475 EARTHQUAKE LEVELS

[Plot 23]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada 2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter peak ground acceleration (PGA)

at a probability of 0.000404 per annum, seismic hazard = 0.423 g

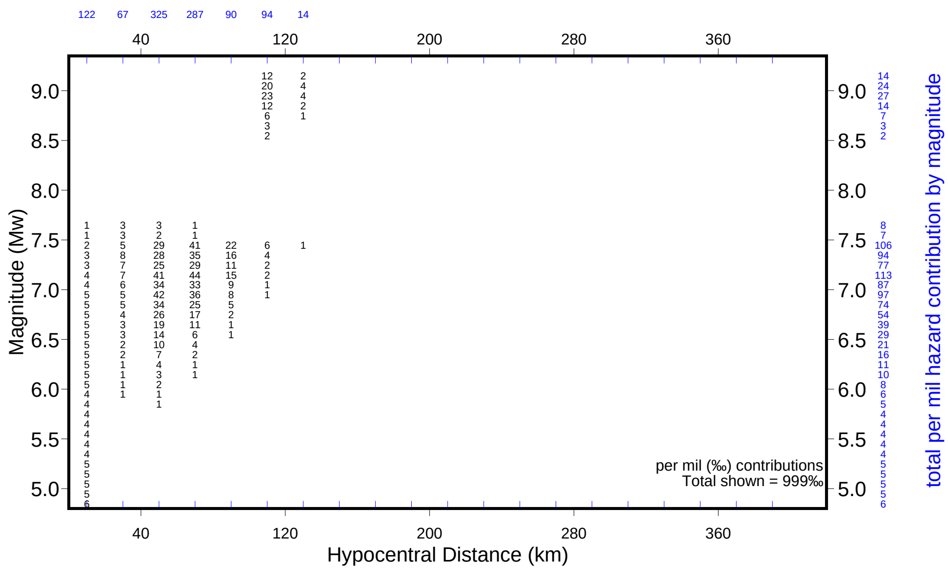
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

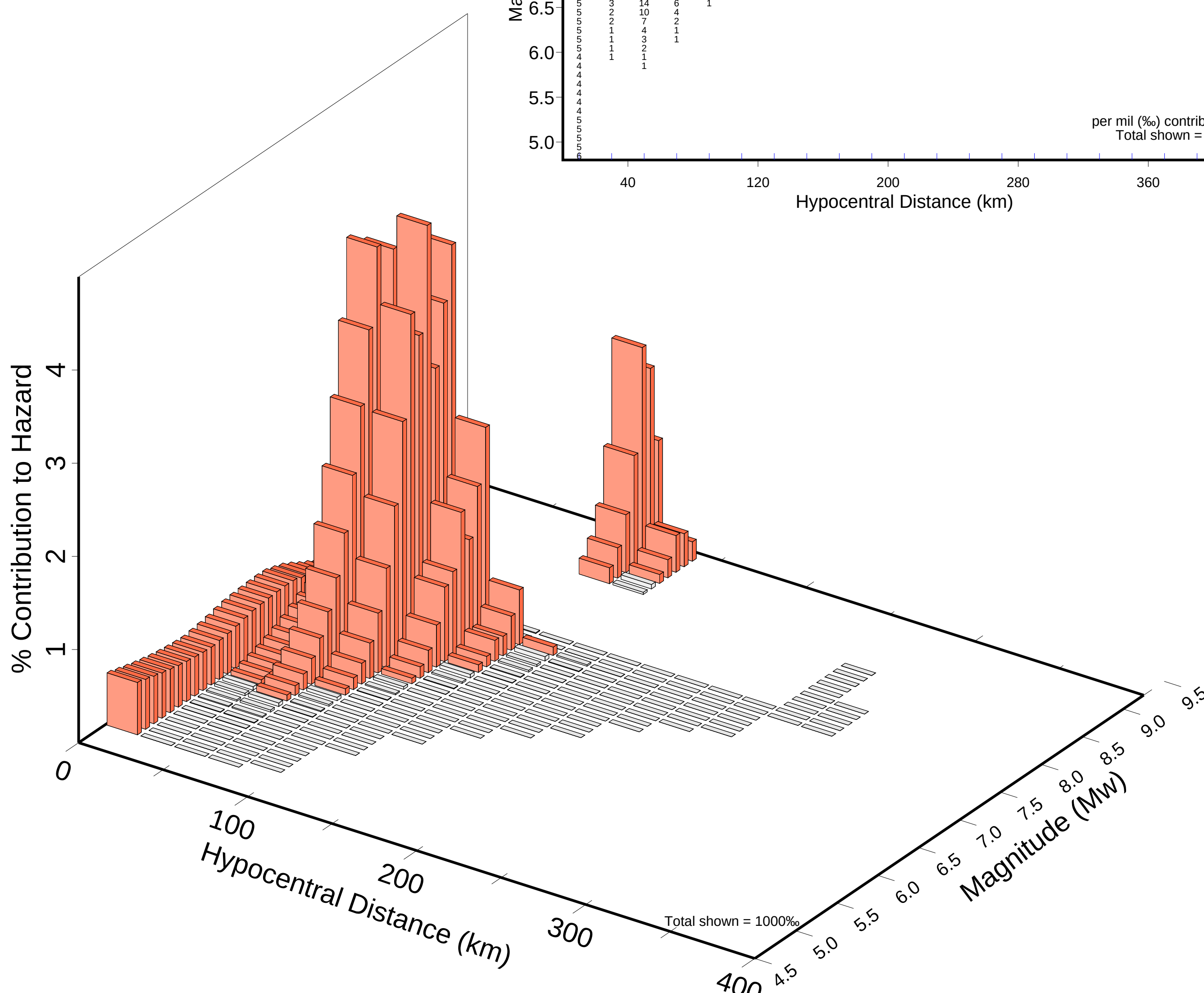
Mean magnitude (Mw) 7.11 Mean distance 60 km

Mode magnitude (Mw) 7.150 Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

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[Plot 24]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada

2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter peak ground velocity (PGV)

at a probability of 0.000404 per annum, seismic hazard = 0.642 m/s

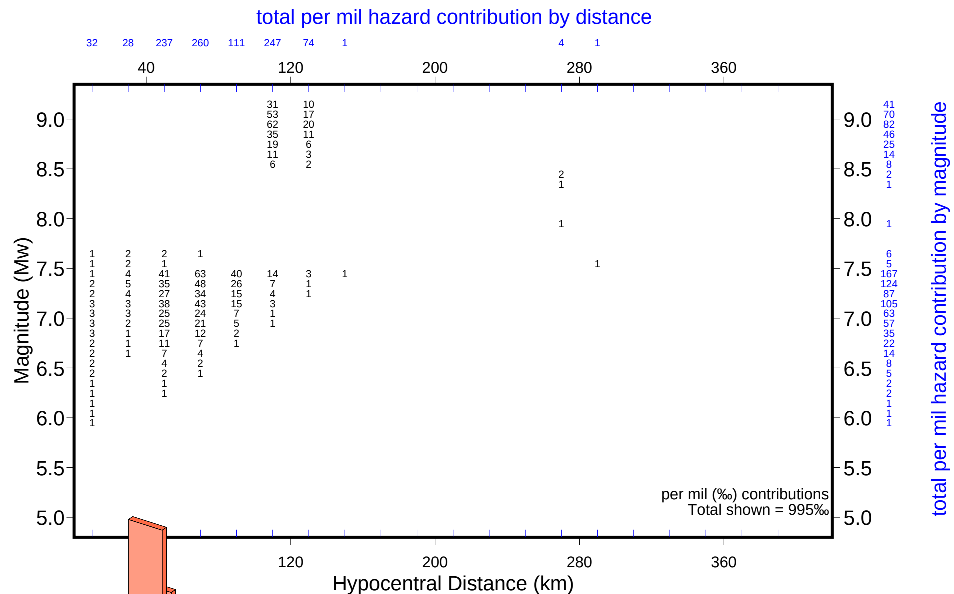
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

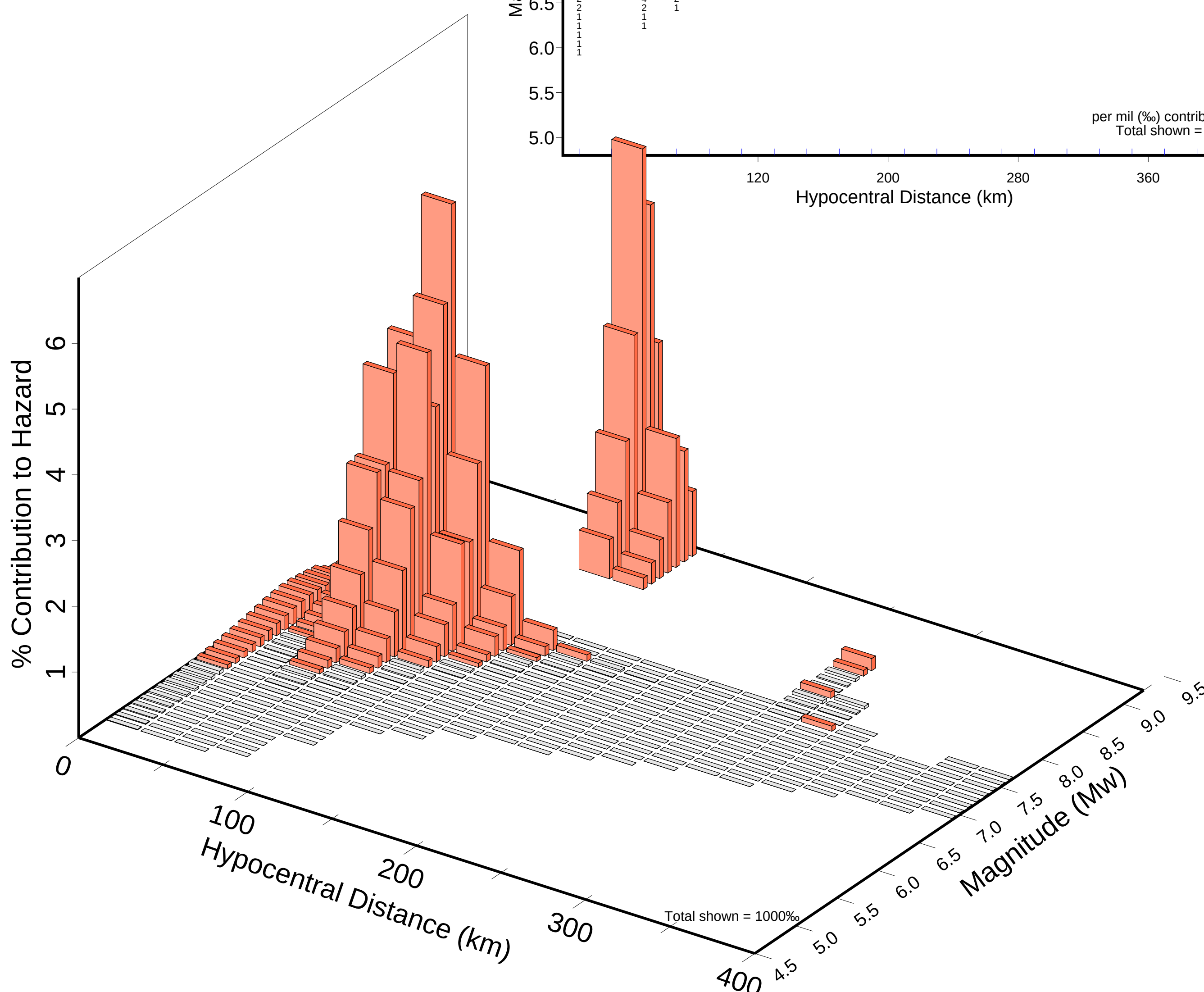
Mean magnitude (Mw) 7.69 Mean distance 80 km

Mode magnitude (Mw) 7.450 Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 25]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada

2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 0.05 seconds

at a probability of 0.000404 per annum, seismic hazard = 0.516 g

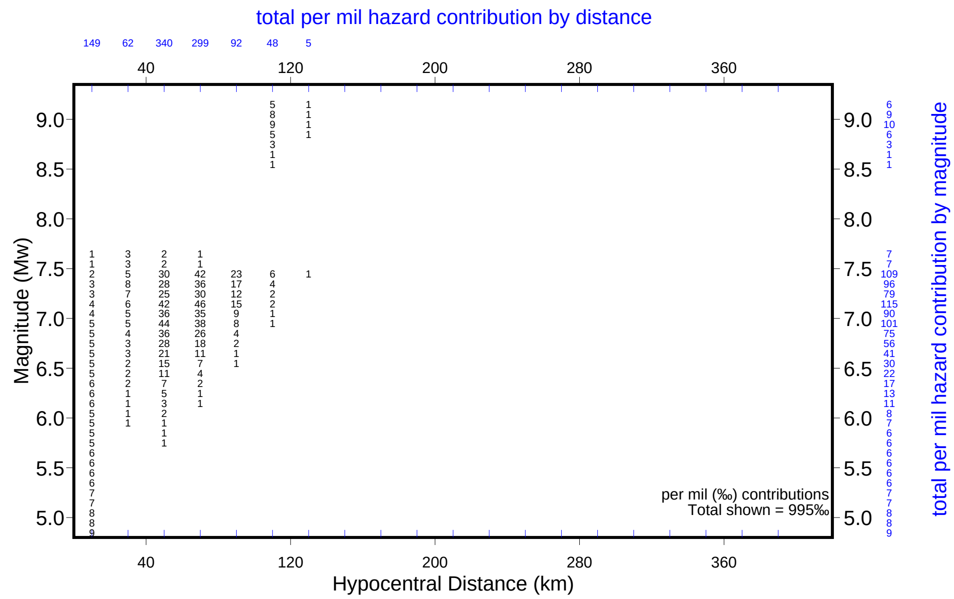
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

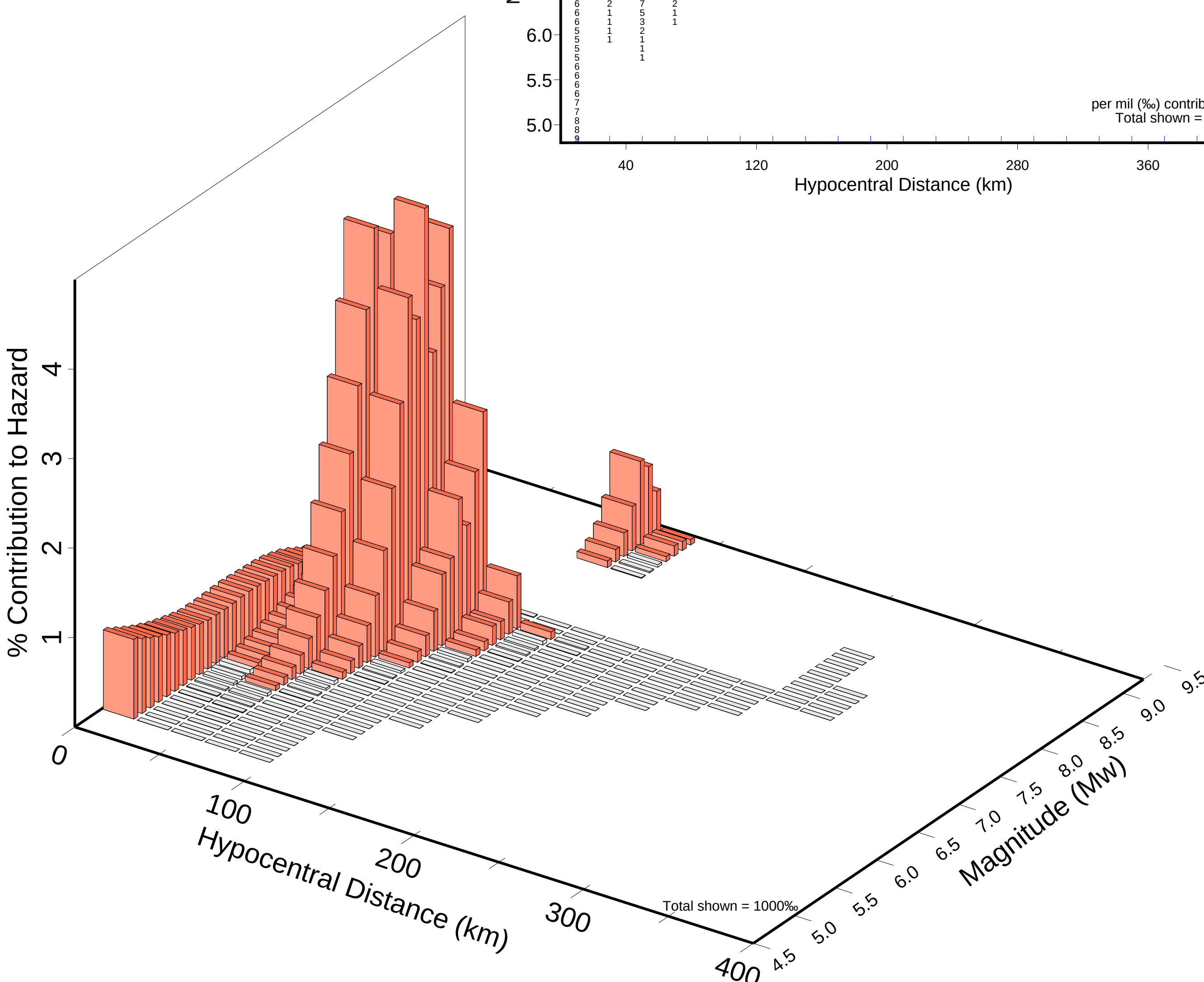
Mean magnitude (Mw) 6.95 Mean distance 56 km

Mode magnitude (Mw) 7.150 Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 26]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada

2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 0.10 seconds

at a probability of 0.000404 per annum, seismic hazard = 0.784 g

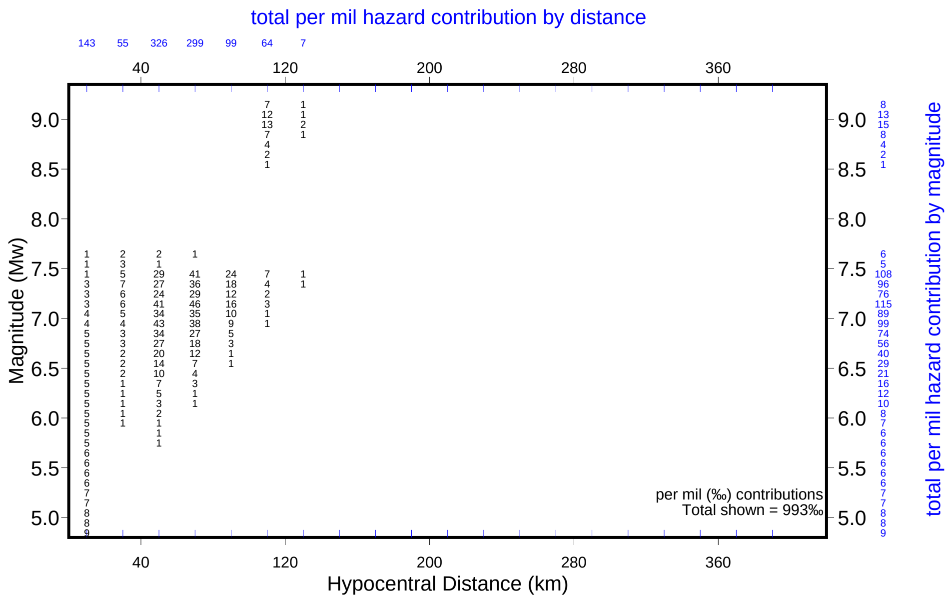
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

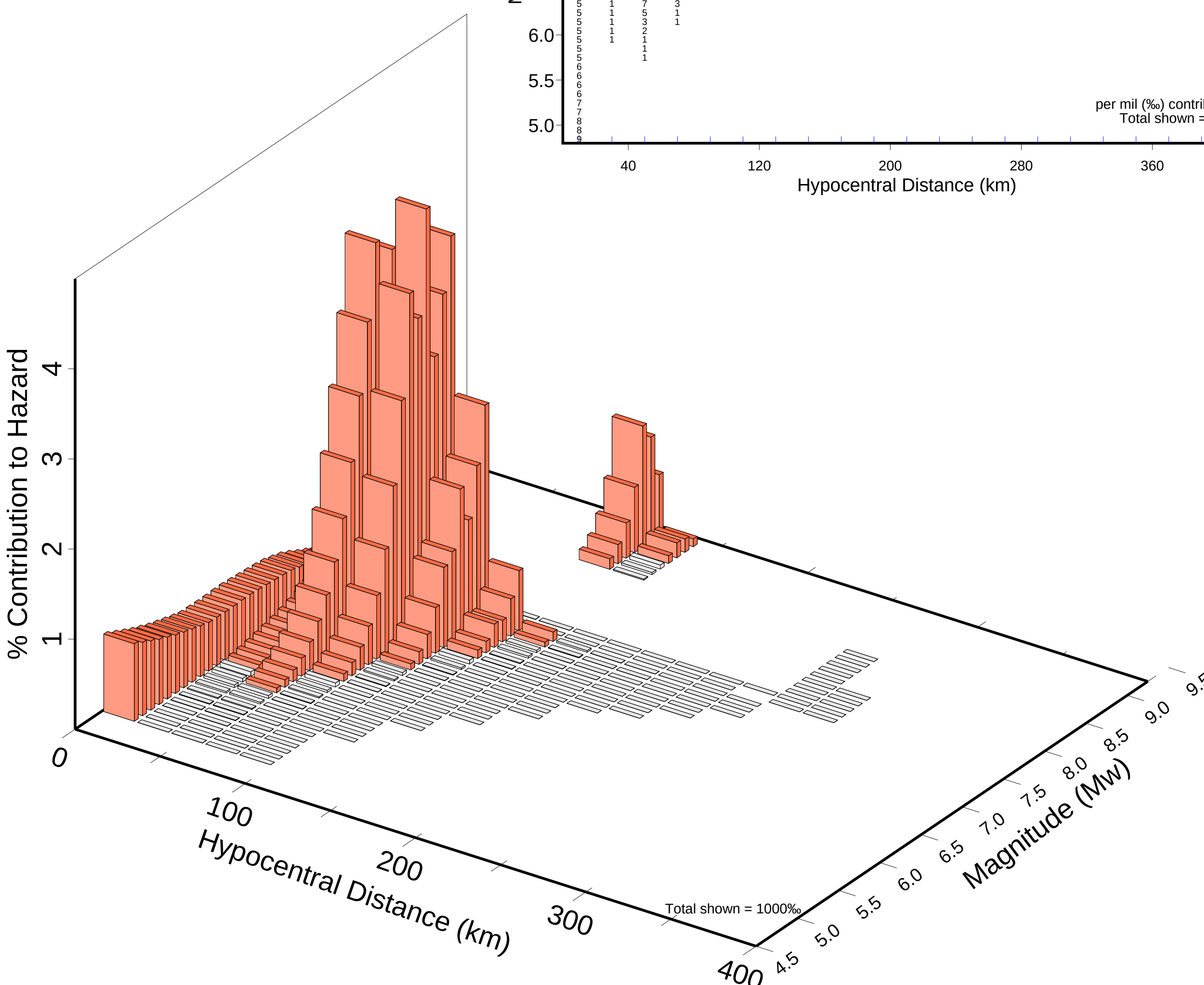
Mean magnitude (Mw) 6.99 Mean distance 58 km

Mode magnitude (Mw) 7.150 Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





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[Plot 27]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada 2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 0.20 seconds

at a probability of 0.000404 per annum, seismic hazard = 0.978 g

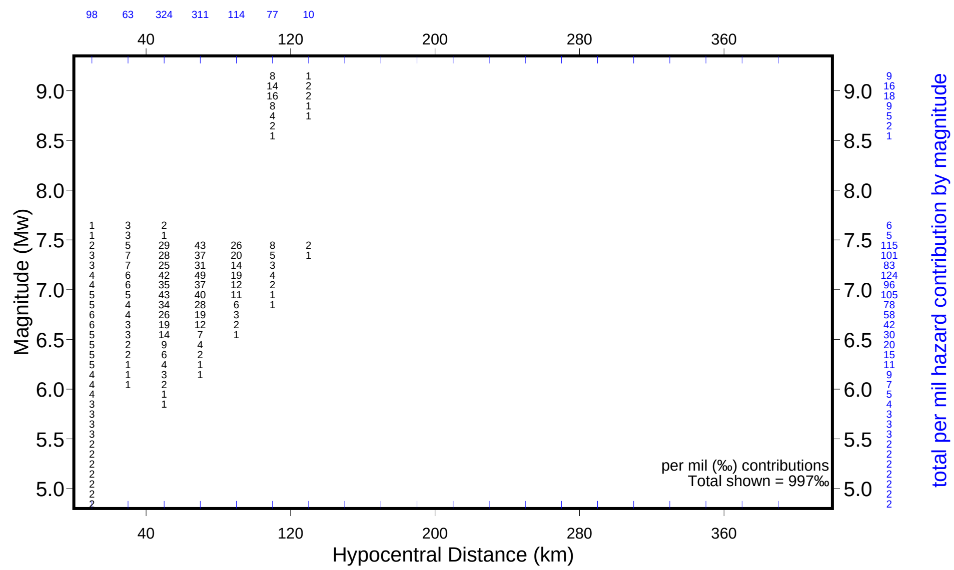
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

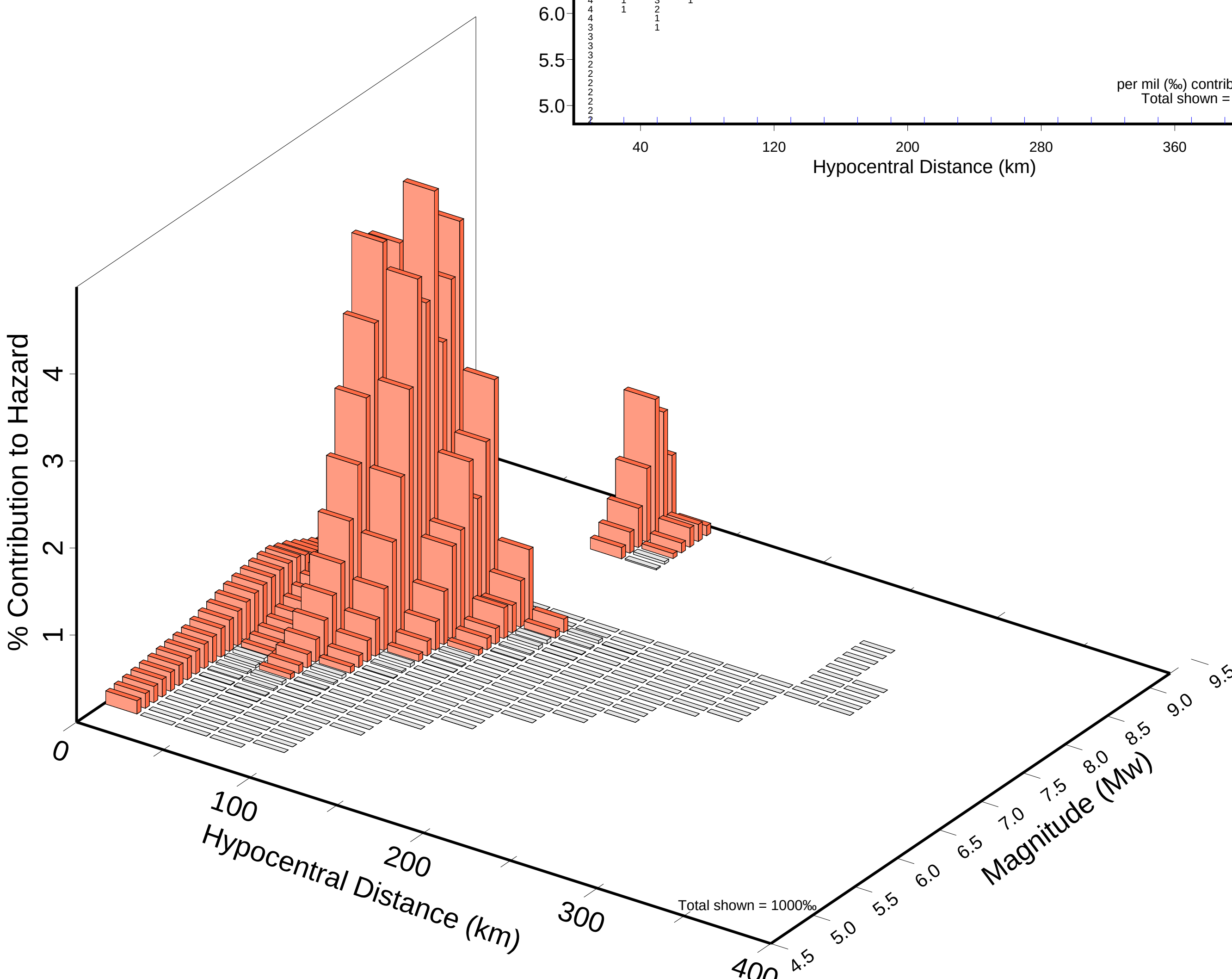
Mean magnitude (Mw) 7.11 Mean distance 61 km

Mode magnitude (Mw) 7.150 Mode distance 70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

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[Plot 28]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada

2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 0.30 seconds

at a probability of 0.000404 per annum, seismic hazard = 0.995 g

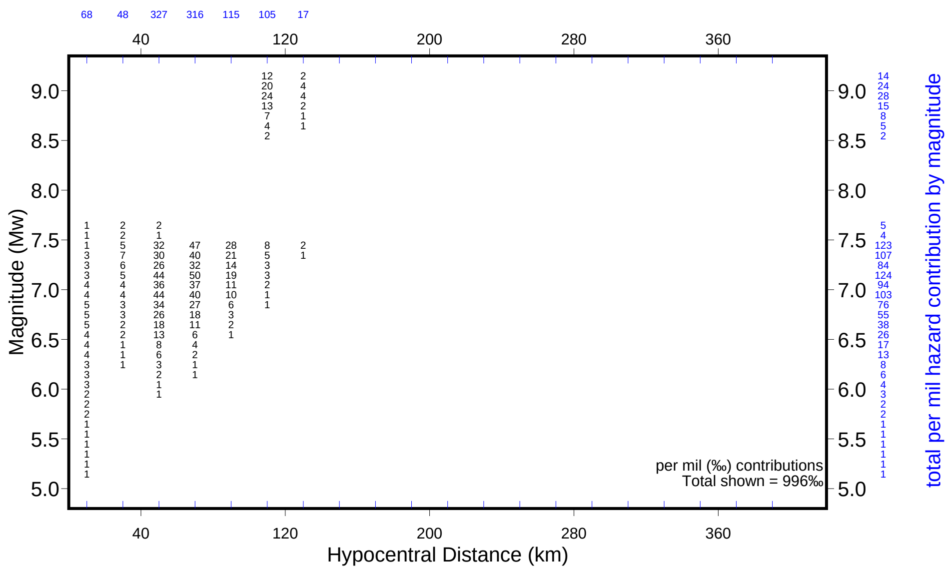
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

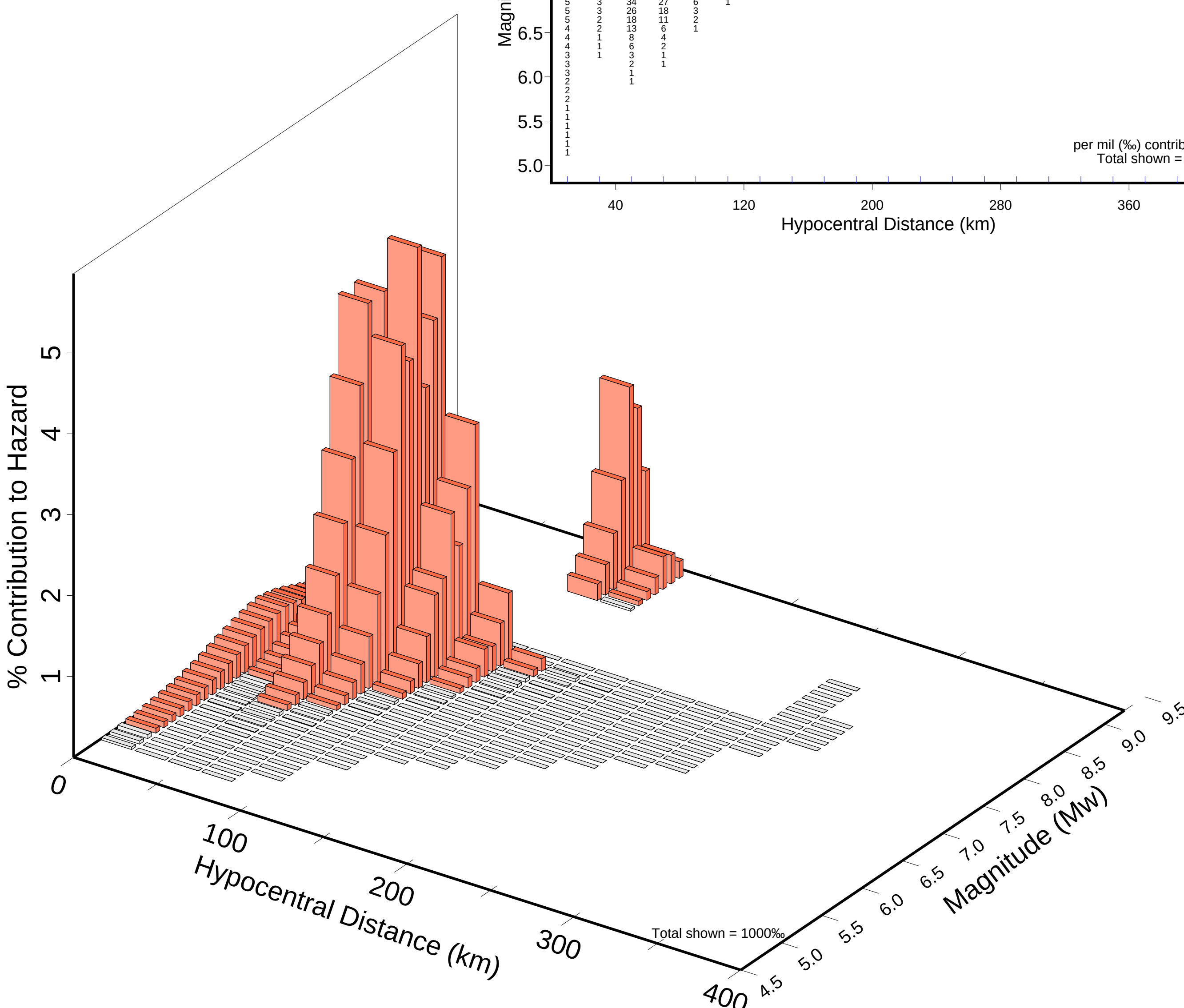
Mean magnitude (Mw) 7.22   Mean distance   65 km

Mode magnitude (Mw) 7.150   Mode distance   70 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

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[Plot 29]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*
Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

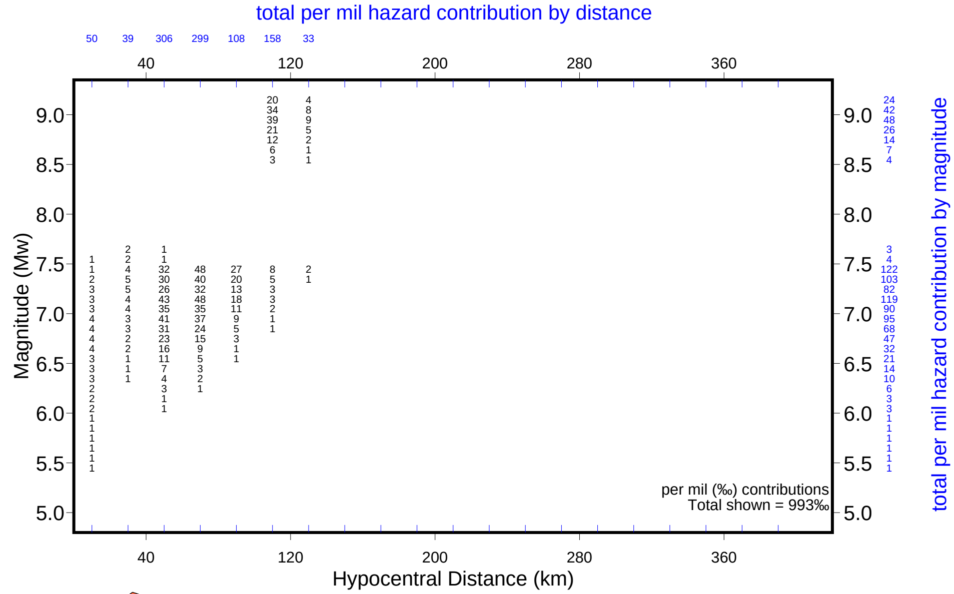
Requested by: Natural Resources Canada

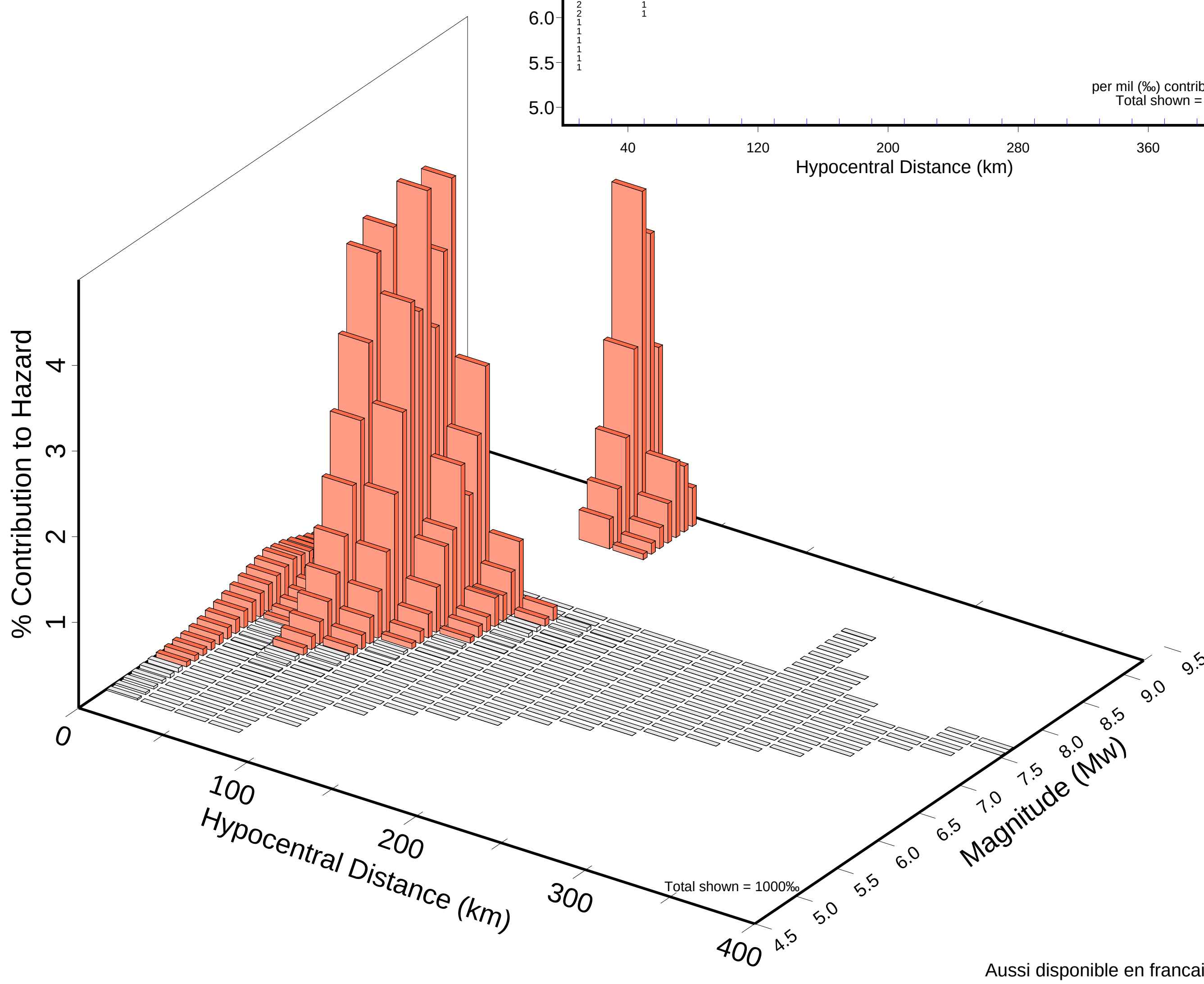
2016/07/20

For site Delta, BC at 49.019 N 123.185 W
For ground motion parameter spectral acceleration with a period of 0.50 seconds
at a probability of 0.000404 per annum, seismic hazard = 0.883 g
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

Mean magnitude (Mw) 7.38   Mean distance   70 km
Mode magnitude (Mw) 7.150   Mode distance   70 km
Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 30]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada

2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 1.0 seconds

at a probability of 0.000404 per annum, seismic hazard = 0.492 g

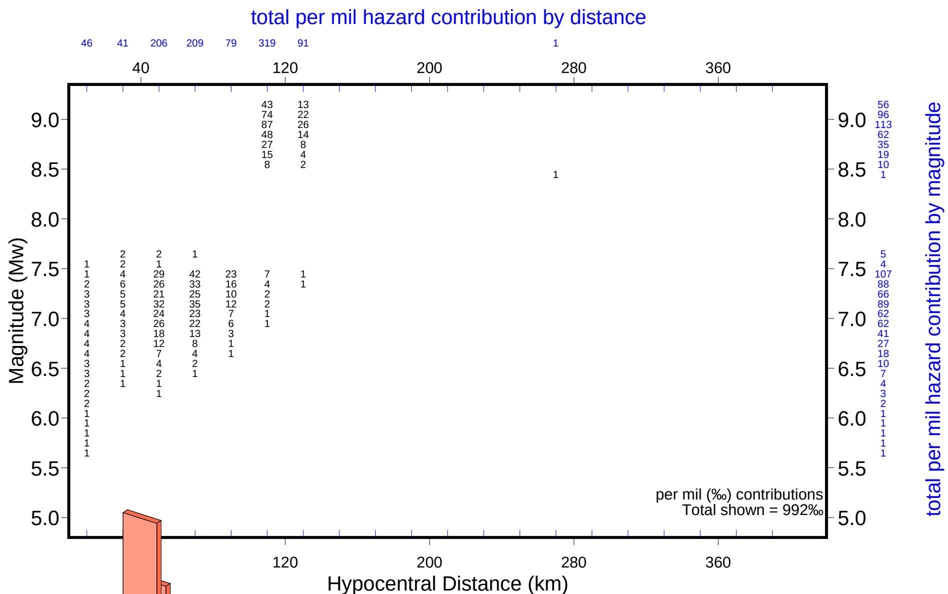
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

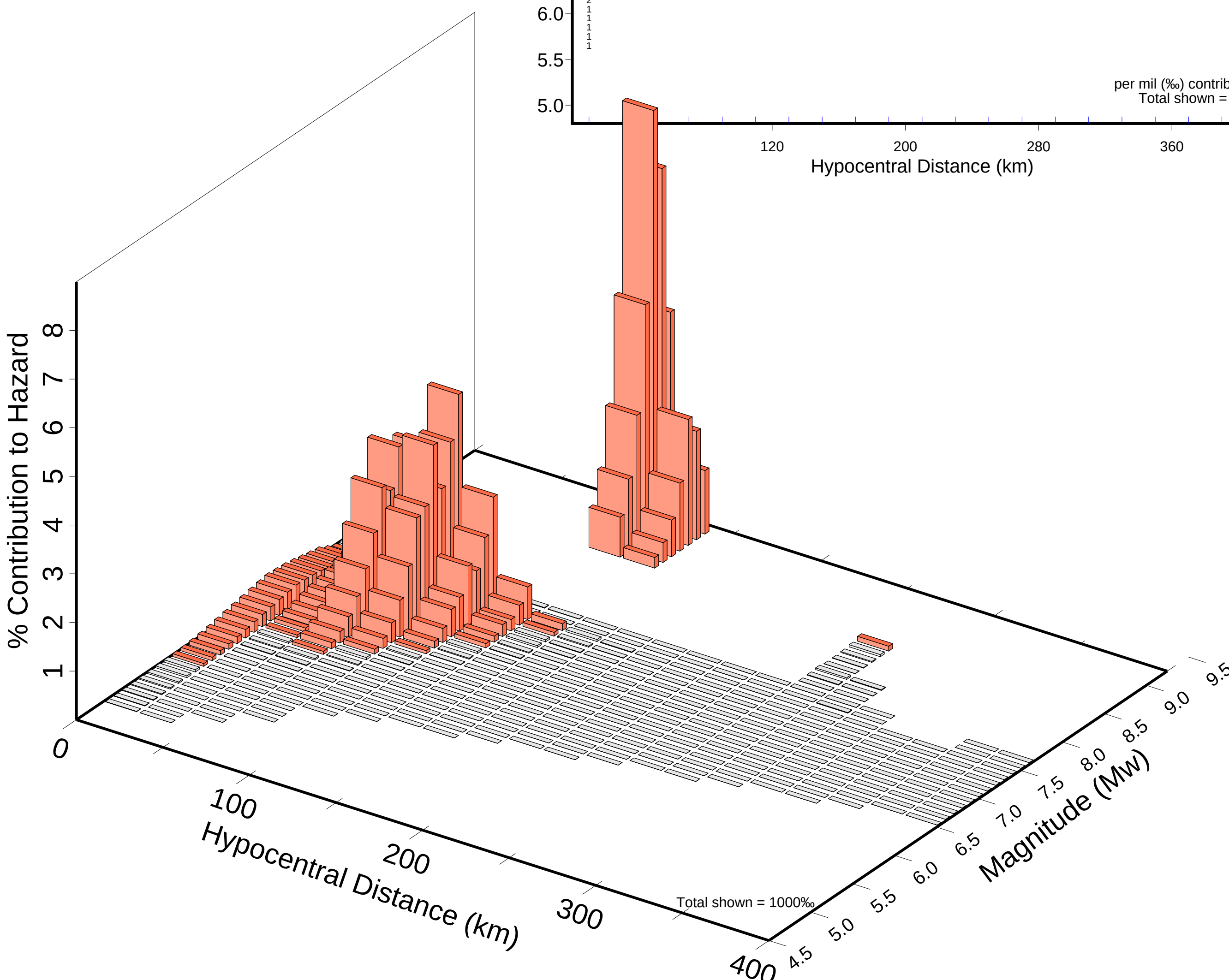
Mean magnitude (Mw) 7.84   Mean distance   82 km

Mode magnitude (Mw) 8.950   Mode distance 110 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model





Aussi disponible en francais

[Plot 31]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada

2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 2.0 seconds

at a probability of 0.000404 per annum, seismic hazard = 0.294 g

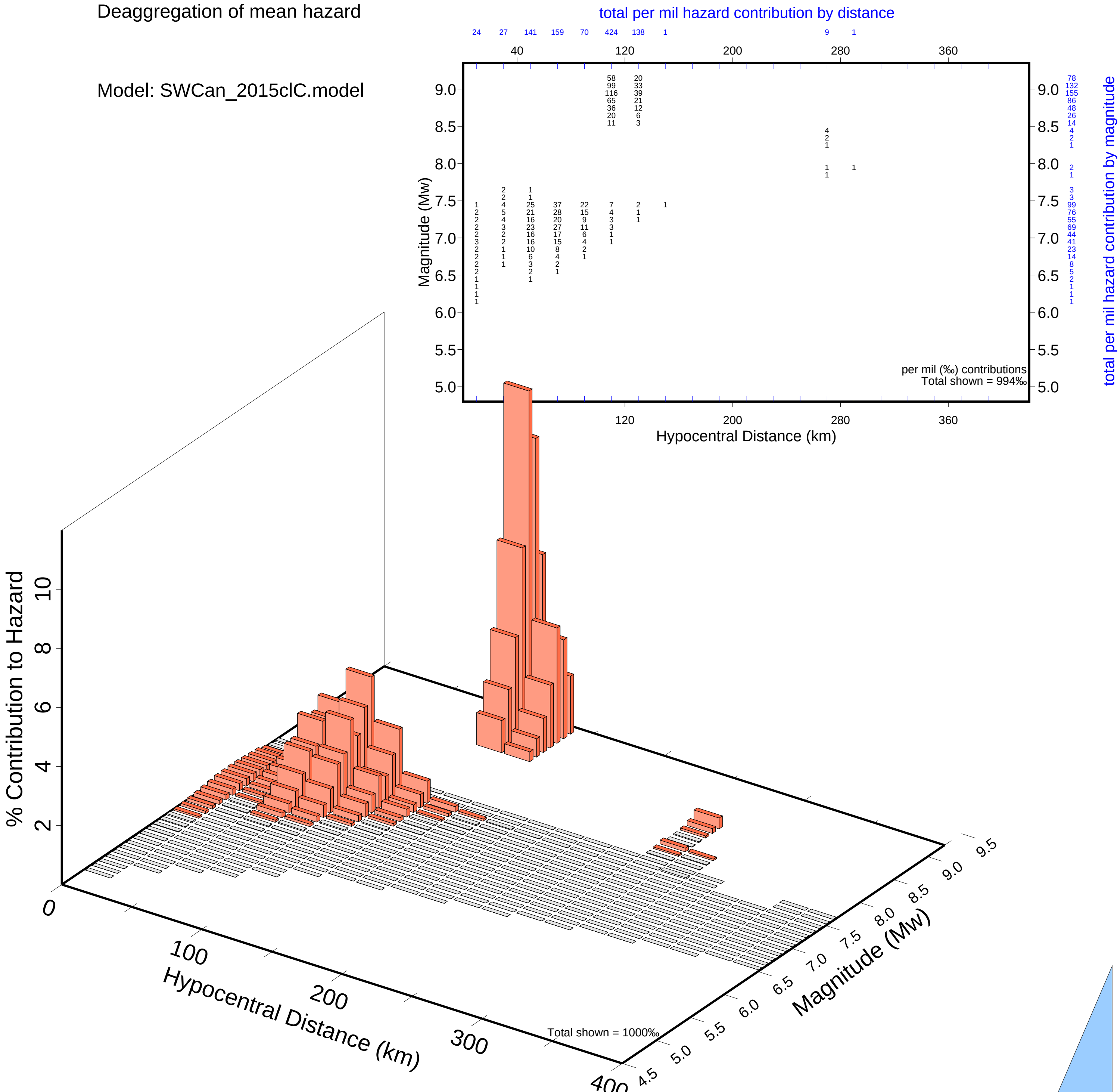
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

Mean magnitude (Mw) 8.14 Mean distance 93 km

Mode magnitude (Mw) 8.950 Mode distance 110 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model



Aussi disponible en francais

[Plot 32]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada

2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 5.0 seconds

at a probability of 0.000404 per annum, seismic hazard = 0.090 g

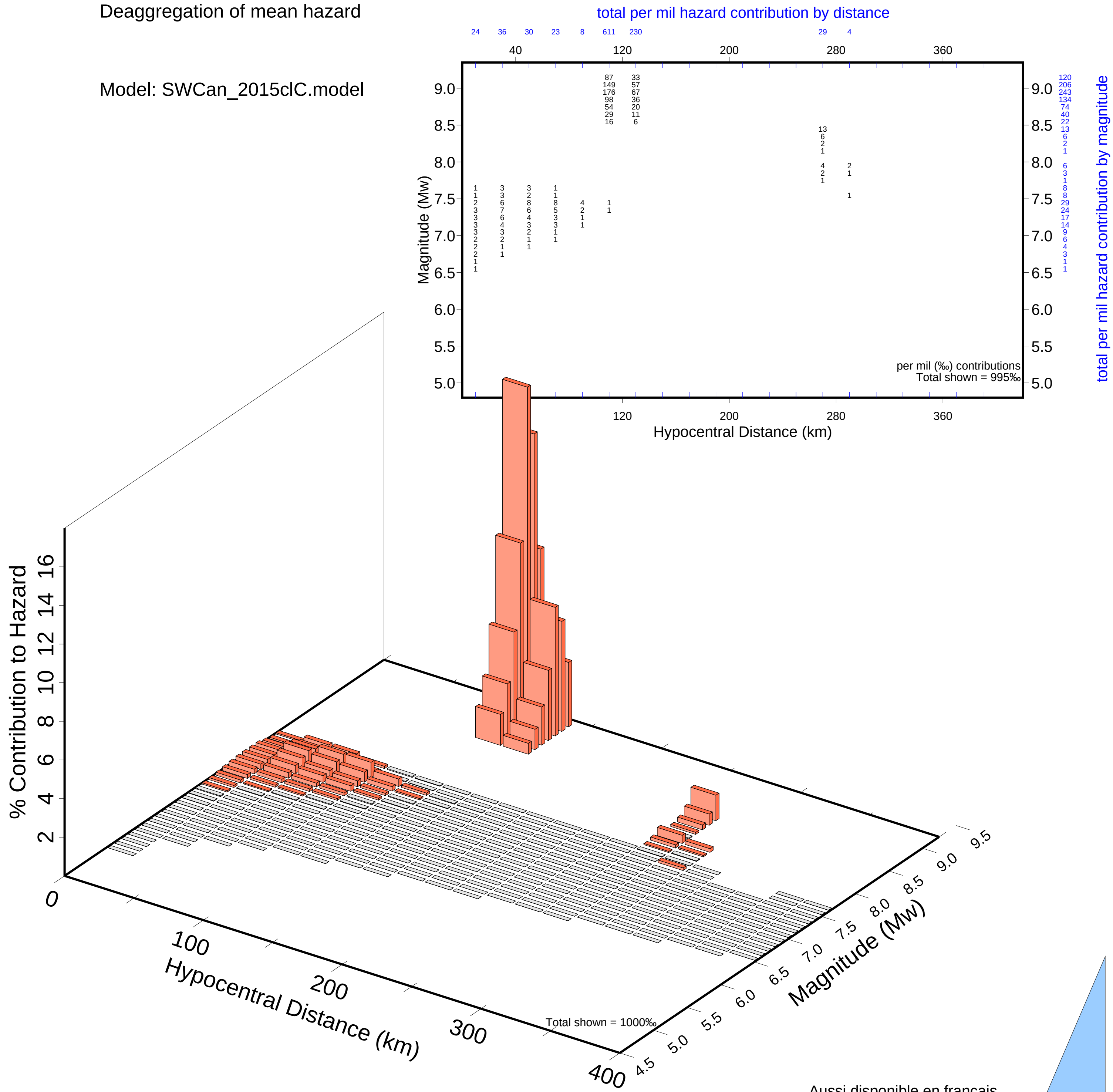
Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

Mean magnitude (Mw) 8.71 Mean distance 112 km

Mode magnitude (Mw) 8.950 Mode distance 110 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model



Aussi disponible en francais

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[Plot 33]

Seismic Hazard Deaggregation

calculated by the Canadian Hazards Information Service

INFORMATION: *EarthquakesCanada.nrcan.gc.ca*

Eastern Canada (613) 995-5548 Western Canada (250) 363-6500

Requested by: Natural Resources Canada — 2016/07/20

For site Delta, BC at 49.019 N 123.185 W

For ground motion parameter spectral acceleration with a period of 10.0 seconds

at a probability of 0.000404 per annum, seismic hazard = 0.032 g

Soil Class C, 2015 Geological Survey of Canada 5th Generation model as prepared for NBCC2015

Mean magnitude (Mw) 8.77   Mean distance 115 km

Mode magnitude (Mw) 8.950   Mode distance 110 km

Deaggregation of mean hazard

Model: SWCan_2015clC.model