Appendix IR2020-1.1-A3

Land Tenure Application & Management Plan for Land Tenure Application – South Arm Jetty Tidal Marsh

MANAGEMENT PLAN FOR LAND TENURE APPLICATION

SOUTH ARM JETTY TIDAL MARSH

Submitted to: Ministry of Forests, Lands and Natural Resource Operations

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July 2018

Management Plan for Land Tenure Application:

South Arm Jetty Tidal Marsh

Submitted to Ministry of Forests, Lands and Natural Resource Operations

Signed: Date: July 20, 2018

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1.0 BACKGROUND

1.1 PROJECT OVERVIEW

The proposed South Arm Jetty Tidal Marsh Project (the Project), near the City of Richmond, British Columbia, is a proposed habitat enhancement project under the Vancouver Fraser Port Authority's (VFPA's) Habitat Enhancement Program (HEP). HEP is a VFPA initiative focused on creating and enhancing fish and wildlife habitat. This program is a proactive measure intended to provide a balance between a healthy environment and future infrastructure development projects that may be required for port operations.

The Project is being pursued in accordance with a Habitat Banking Agreement between VFPA and Fisheries and Oceans Canada (DFO) which guides the collaborative development of proposed habitat enhancement projects that will be deposited to VFPA's Habitat Bank. The proposed project could create up to 40 ha of intertidal brackish marsh and rocky rip rap habitat on the north side of the Steveston North Jetty, at the mouth of the South Arm of the Fraser River, near Richmond (the Site).

The Site is a predominantly un-vegetated intertidal sand and mudflat. Immediately adjacent to the Site is an expansive area of existing productive marsh. The Project would increase the availability of tidal marsh for the benefit of juvenile salmonids and other fish and wildlife.

As the Site is located on Provincial Crown land, VFPA is applying to the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) for tenure of the waterlot.

1.2 INVESTIGATIVE WORK

Table 1 below outlines some of the geophysical, biological and archaeological investigative work undertaken in support of the Project to date.

Table 1 Geophysical, Biological and Archaeological Investigative Work Undertaken for the Project

Activity	Brief Description of Activity	Status/Comments
Site Assessment	Reconnaissance site inspections and surveys to assess Project feasibility	Site assessments were undertaken between May 2013 and August 2017.
Topographic Survey	Topographic surveys to document existing biophysical characteristics at the Site (e.g. substrates, marsh vegetation species and ground elevations)	Surveys were undertaken at the Site between July 2013 and August 2017.

Activity	Brief Description of Activity	Status/Comments
Geotechnical Investigation	An assessment to understand anticipated geotechnical conditions and considerations for the design and construction of the Project	A geotechnical assessment was conducted for the Project by Golder Associates Ltd. (Golder 2015)
Coastal Engineering Assessment	An assessment prepared to assess changes to the current patterns and wave environment that may result from the Project	A coastal engineering assessment was conducted for the Project by Moffatt & Nichol (M&N 2014)
Bird Surveys	Surveys undertaken to document baseline shorebird use and general avian abundance within and in proximity to the Site	Multiple surveys were undertaken in 2014 and 2015 by Hemmera Envirochem Inc. (Hemmera 2015a, 2015b) which indicated that the Site is of intermediate or less-than-intermediate quality for shorebirds relative to the rest of the Fraser River estuary, with the Site observed to be predominantly used by gulls and swans
Biofilm Analysis	Sampling to analyze for presence and biomass of biofilm[1]; a known food source for migratory shorebirds – surveys undertaken to augment data obtained during shorebird dropping surveys	Sampling was undertaken in 2014 by WorleyParsons Ltd. (WorleyParsons 2015) and in 2017 by Hemmera (Hemmera 2018a) indicating lower overall biofilm abundance at the Site relative to Roberts Bank
Archaeological Overview Assessment (AOA) and Preliminary Field Reconnaissance (PFR)	A desktop assessment and field reconnaissance undertaken to assess archaeological potential at the Site and potential for encountering heritage resources	The AOA and PFR was conducted by Stantec Inc. (Stantec 2014, 2015). See **Section 4.1.6** for more information

1.3 PERMITS, AUTHORIZATIONS AND APPROVALS

The Project will meet all applicable regulatory requirements and VFPA will obtain necessary authorizations, permits and approvals prior to initiation of Project works. The key anticipated permits required for the Project are listed in **Table 2** below.

[1] Biofilm is a thin (~2 mm) organic aggregate that consists predominantly of diatoms, bacteria, and detritus found on the surface of shallow freshwater, marine, and estuarine sediments.

Table 2 Key Permits Anticipated for the Project

Permit Name	Permitting Agency	Comments
Project and Environmental Review Permit	VFPA	The Project will undergo VFPA's Project and Environment Review process and a Project and Environmental Review permit will be required prior to commencing works.
Disposal at Sea Exemption for Beneficial Use	Environment and Climate Change Canada, Disposal at Sea Program	VFPA will be requesting a Disposal at Sea exemption for beneficial use of materials for construction of the Project.
Assisted Assessment of Serious Harm under the *Fisheries Act* (if a project review is required)	Fisheries and Oceans Canada (if a project review is required)	An Assisted Assessment undertaken by a Qualified Environmental Professional (QEP) determined that the Project will not result in Serious Harm to fish that are part of commercial, recreational or Aboriginal fisheries. A copy of the Assisted Assessment is provided in **Appendix A**.
BC *Environmental Assessment Act* (BCEAA) Exemption	BC Environmental Assessment Office (BCEAO)	For administrative purposes, VFPA applied for a Project exemption under the BCEAA from BCEAO. An exemption from the BCEAO was issued in September 2016 and. A copy of the BCEAO is provided in **Appendix B**.

1.4 Confirmation of Safety Plan

Safety planning for the Project will be guided by the Occupational Health and Safety criteria set out by Worksafe BC. Prior to the commencement of works, the contractor retained by VFPA will develop and implement a health and safety plan that meets all appropriate regulations.

1.5 First Nations

An integral part of development and implementation of this Project is the relationship between VFPA and Aboriginal communities. There is an awareness and recognition at VFPA of the critical importance of appropriately and effectively consulting and engaging with the various Aboriginal communities within VFPA's jurisdiction. At the policy level, this has resulted in the development and implementation of several important initiatives such as Aboriginal Consultation Principles and guidance materials for VFPA staff, an Aboriginal Engagement Strategy and Participation Funding Guidelines, as well as the development of working protocols with Aboriginal groups within VPFA's jurisdiction. VFPA recognizes and respects that local Aboriginal communities and their leadership want meaningful and

ongoing input into the planning, operation and expansion of port facilities and related transportation infrastructure. Accordingly, VFPA is committed to continued and active engagement with Aboriginal groups who have interests that may potentially be impacted by the Project. Consultation is ongoing and VFPA will continue to share project-related information with Aboriginal groups, while seeking to address any concerns and/or questions that arise regarding the Project.

VFPA's Aboriginal Consultation approach is based on the Government of Canada's Aboriginal Consultation and Accommodation - Updated Guidelines for Federal Officials to Fulfill the Duty to Consult - March 2011. VFPA's consultation and engagement for the Project aims to identify and address project-related impacts, to design and implement appropriate mitigation measures, and to explore opportunities for Aboriginal involvement in the Project such as participation in field studies and/or employment, training and contracting. VFPA may consider additional benefits and project-related opportunities that may be extended to potentially impacted communities as a means of accommodating any unresolved impacts.

Currently, it is VFPA's understanding that Aboriginal groups consider the Project a benefit to fish and fish habitat. The Project is not expected to interfere with the current use of the Project area by Aboriginal groups for traditional purposes, and construction planning will focus on ensuring there are no impacts to Aboriginal interests during Project delivery. In accordance with the objectives of HEP, VFPA is exploring opportunities to support Aboriginal businesses and provide training and employment during construction of this habitat enhancement project.

A letter of support for the Project from the Musqueam Indian Band and an email of support from the Semiahmoo First Nation have been received for the Project. These documents are provided in **Appendix C**.

2.0 LOCATION

2.1 GENERAL DESCRIPTION

The Site is located in the intertidal zone on the right (northeast) bank of the South Arm of the Fraser River in the Steveston Bend reach, immediately north of the Steveston North Jetty (**Figure 1**). It is located just downstream from Steveston Village in an area known as Sturgeon Bank.

The Site is located within the Strait of Georgia, near the City of Richmond. The Site is directly south of the Sturgeon Bank Wildlife Management Area (WMA), a 5,152 ha area managed by MFLNRO. The Sturgeon Bank WMA was designated in 1998 for the conservation of internationally important habitat for resident, migrating and wintering waterfowl and shorebird populations, and for the preservation of important fish habitats (MFLNRO 2017). The Site is also close to the shoreline of the City of Richmond, which is regionally designated as an Environmentally Sensitive Area, and to Garry Point Park, a popular recreational area along the City's southern shoreline. Richmond's shoreline near the Site includes parcels of regionally-, provincially- and federally-owned land.

Path: S:\Geomatics\Projects\989565\South Arm Jetty Tidal Marsh Project\05\mxd\Fig1_989565_05_SouthArm_LandTenureMgmtPlan_170820.mxd

Sturgeon Bank

STURGEON BANK WMA BOUNDARY

TOE OF SLOPE

COBBLE BEACH BERM LIMIT

EXISTING SAND ISLAND (CUT AREA)

CONTRACTOR LAYDOWN AREA

DRAINAGE DITCH

DL 5738

DL 7681

TEMPORARY ACCESS (EG. CULVERT) MAY BE REQUIRED

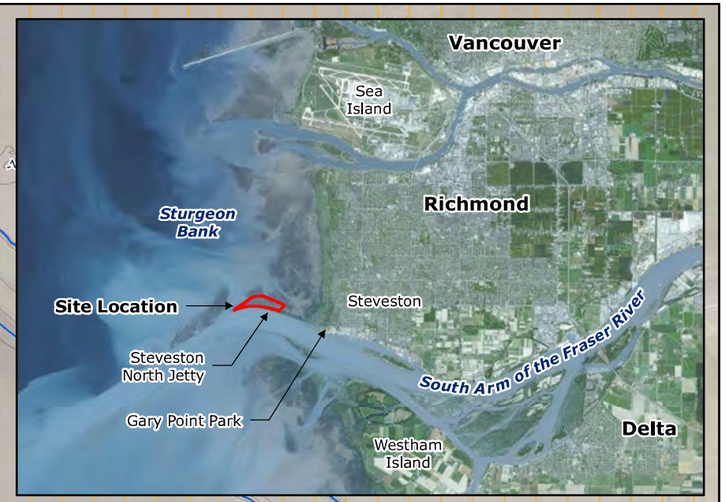
STEVESTON BEND

EXISTING STEVESTON NORTH JETTY

EXISTING SUBMERGED BERM

EXISTING MARSH EDGE

MAIN NAVIGATION CHANNEL



Legend

- LEASE AREA
- STURGEON BANK WILDLIFE MANAGEMENT AREA
- DRAINAGE DITCH
- LOWER LOW WATER MEAN TIDE (LLWMT)
- BATHYMETRY (METRES)

PROPOSED HABITAT FEATURES (PRELIMINARY)

- COBBLE BEACH BERM
- CONTRACTOR LAYDOWN AREA
- MARSH AREA

EXISTING HABITAT FEATURES

- MARSH (MAPPED AUGUST 10, 2017)
- PATCHY MARSH (MAPPED AUGUST 10, 2017)
- SAND ISLAND (CUT AREA)
- SUBMERGED BERM

0 100 200
Metres

1:6,500

NAD 1983 UTM Zone 10N

N

PORT METRO vancouver

HABITAT ENHANCEMENT PROGRAM

LAND TENURE MANAGEMENT PLAN SITE LOCATION

DATE:	FIG No.
08/21/2018	1

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

2.2 LOCATION JUSTIFICATION

The Site was chosen by VFPA as a site where existing habitat can be enhanced to increase its productive capacity to benefit fish and wildlife species. The Fraser River estuary is an important migratory, rearing and spawning area for fish, including ecologically and economically important salmonids. The estuary is also globally recognized as a key migratory stop-over and wintering area for millions of waterfowl and shorebirds, and as a habitat for many resident bird species.

However, estuarine marsh habitats in the Fraser River estuary have been adversely affected by historic development. Within the Fraser River estuary, more than 70 per cent of the original tidally influenced habitats (including brackish marshes) have been lost over the past 100 to 150 years due to diking, filling and other human development activities (FRESSC 1978, Lievesley et al. 2017). HEP has prioritized intertidal marsh enhancement due to its high ecological value and the extensive history of human development in the Fraser River estuary that has affected this habitat type.

Directly north of the Project's location, historic losses of brackish intertidal marsh vegetation have been well-documented by regulators and researchers. This Site was chosen for enhancement as it is an un-vegetated intertidal flat at a prime estuarine location that can be protected and enhanced to increase its habitat value. The Project may also provide valuable learning opportunities on how to manage the loss of intertidal marsh on Sturgeon Bank. Specific ecological and physical functions that can be restored or improved through construction of intertidal marsh at the Site include:

- Increasing primary productivity;
- Supplementing the detritus-based food web;
- Creating intertidal habitat for invertebrates (e.g. chironomids) that are important benthic and drift prey items for juvenile salmonids and other fish;
- Providing intertidal vegetation cover and refuge for juvenile salmonids (particularly juvenile coho (*Oncorhynchus kisutch*), chinook (*O. tshawytscha*) and chum (*O. keta*) salmon as they migrate downstream and utilize shoreline habitats prior to out-migrating to the Strait of Georgia;
- Providing foraging and loafing habitat for waterbirds; and
- Providing shoreline protection from storm waves (wave dampening), promoting sediment accretion and reducing erosion.

The design team, which includes appropriately qualified engineers, coastal geomorphologists and professional biologists, anticipates the Project would provide long-term benefits to ecosystem productivity at this location. Final site selection for this project was based on

various factors, including need, relatively low existing habitat productivity, site location, feasibility and cost, sustainable habitat creation, land ownership and tenure, and consideration towards Aboriginal groups and communities.

2.3 SEASONAL EXPECTATIONS OF USE

The seasonal expectations of use are based on the need to access the site for construction, post-construction planting and for subsequent annual post-construction monitoring, as outlined in Table 3 below.

Table 3 Seasonal Expectations of Use at the Site

Project Phase	Brief Description of Activity/Works	Season
Construction	Placement of fill material (i.e. beneficial reuse of silts and sands from the annual Fraser River maintenance dredging program) will occur following construction of a cobble beach berm. The final construction methodology needs to be determined but placement of fill may involve a combination of piping and/or direct placement of material over the jetty. Conventional land-based equipment (e.g. excavators and loaders), delivered to the Site by barge, would likely be used to construct the cobble beach berm and grade and level the fill material in order to achieve design specifications. Construction of the Project would be undertaken over a multi-month construction period. A phased construction scenario whereby the Project is built in stages over multiple years is also being considered. This approach will allow for the assessment of the effectiveness of the design and construction approach before committing to full build-out.	The timing for placement of dredged materials will depend on material availability from dredging activities. Any high-risk in-water work activities that pose an unacceptable risk to downstream migrating juvenile salmonids, would need to be undertaken during the applicable least risk window (August 16th to February 28th annually).
Planting	After allowing adequate time for settlement of the marsh substrate, vegetation establishment at the Site would be achieved either by transplantation, natural spread or a combination of these methods. An approach for planting methodology is currently under development. Access to the Site for planting would be by boat, with physical planting by manual labour during low tides.	If planting is undertaken at the Site, it would occur during a favorable growth season (e.g. in spring).

Project Phase	Brief Description of Activity/Works	Season
Operations	Upon completion of construction and planting, no further physical works are anticipated. The Site will be monitored annually, per requirements of the Habitat Banking Agreement between VFPA and DFO.	Annual monitoring is anticipated to occur in the late summer to adequately assess marsh establishment and growth.

3.0 INFRASTRUCTURE

3.1 New Facilities or Infrastructure

The proposed Project involves the creation of intertidal brackish marsh and rocky rip rap habitat on existing un-vegetated intertidal flats. Marsh establishment would be achieved through construction of a perimeter cobble beach berm (along the north and west ends of the Site), followed by the placement of suitable fill material. The perimeter cobble beach berm would provide rocky rip rap habitat for marine invertebrates and macroalgae.

The perimeter berm, approximately 60 m wide and 1.7 km long, has been designed to contain and stabilize the placed fill material and to protect the constructed habitat from wave erosion. The berm would be approximately 9 ha (90,000 m^2) and consist of 5 kg angular rock with a seaward slope of 20 (horizontal) to 1 (vertical) and a landward slope of 5 (horizontal) to 1 (vertical). Approximately 44,250 m^3 of rock would be required for construction of the perimeter berm. The total quantity of fill would be approximately 225,000 m^3 while the total gross area of created intertidal marsh and rocky rip rap habitat is anticipated to be approximately 29.4 ha (294,000 m^2) and 9 ha (90,000 m^2), respectively.

No additional infrastructure, or associated facilities, are proposed as part of this project.

3.2 Access

Access for construction material and equipment is anticipated to occur via water, by barge and/or boat at the westernmost end of the Site over the Steveston North Jetty. The use of municipal roads is not anticipated for the delivery of materials as rock for the cobble beach berm would be loaded directly to a barge at the quarry site.

3.3 Utilities Requirements and Sources

The scope of the proposed habitat enhancement activities will not require the utilization of existing or temporary power, electrical or telecommunications infrastructure.

3.4 Water Supply

The scope of proposed habitat enhancement activities will not require the utilization of existing or new water infrastructure. In addition, no known sewer outfalls or drinking water sources are located in close proximity to the Site.

3.5 Waste Collection, Treatment and Disposal

Any waste generated during construction will be collected in appropriate waste containers and disposed of offsite. The requirement for sewage disposal services is limited to the

construction period and will be achieved through the use of a portable toilets, which would be professionally maintained, with waste appropriately disposed of offsite.

4.0 ENVIRONMENTAL

4.1 LAND IMPACTS

4.1.1 Vegetation Removal

The Site is an intertidal flat that is mainly un-vegetated. No trees or shrubs are located within the footprint of the Project. There are a few patches of invasive Japanese eelgrass (*Zostera japonica*) in wetted depressions and shallow tidal channels, as well as the occasional patch of marsh vegetation including species such as seaside arrowgrass (*Triglochin maritima*), threesquare bulrush (*Schoenoplectus americanus*) and Lyngbye's sedge (*Carex lyngbyei*). Natural intertidal marshes and productive intertidal habitats are also located adjacent to the Site. Environmental management plans will be put in place to avoid or minimize impacts to existing intertidal marshes and habitats.

4.1.2 Soil Disturbance

Some intertidal substrate disturbance will be required during construction. The current substrates at the Site consist mainly of sands with some mud sediments. As a result of previous enhancement efforts undertaken at the Site in 1980, deposited sand is still present at the Site. These substrates, in combination with the proposed addition of new sands and silts, will provide an anchoring platform and a nutrient bank for plants, and are of suitable consistency to promote stability and drainage under intertidal conditions.

There is some potential for the placement of fill material to result in sedimentation in the Strait of Georgia. However, fluvial geomorphologists/engineers (M&N) have determined that fill placed at the Site can be properly stabilized and maintained. Construction would be undertaken with appropriate mitigation and monitoring in place to ensure that any potential construction-related effects are minimized. A site-specific Environmental Protection Plan (EPP) will be developed and will include appropriate mitigation measures to address potential downstream sedimentation.

4.1.3 Riparian Encroachment

The Site is located within the intertidal zone. No works will be completed within or adjacent to any riparian zones.

4.1.4 Pesticides and Herbicides

No pesticides or herbicides will be used during the construction, operations and/or maintenance phase of the Project.

4.1.5 Visual Impacts

The Site is situated in view of Garry Point Park and the South Dyke Trail in Richmond. During construction, some equipment (e.g. dredges, loaders, dozers etc.) will be visible at or adjacent to the Site. This potential visual impact would be temporary. Following construction, the placement of the cobble beach berm and establishment of marsh vegetation is not anticipated to have an adverse effect on the surrounding area.

4.1.6 Archaeological Sites

An AOA, was completed for the Project (Stantec 2014). The AOA did not identify any archaeological, historic or ethnographically named sites within 500 m of the Site. Two archaeological sites (a shell midden located on the west end of Lulu Island and a historic building and pre-contact habitation feature located at Garry Point) were identified within 2 km of the Site. Both archaeological sites are considered to have been disturbed or destroyed by previous activities. A historic shipwreck was also identified on the north shore of Steveston Island, within 2 km of the Site. Thirteen recorded place-names were identified along the shorelines between 1.4 and 8 km from the Site.

A preliminary field reconnaissance (PFR), which is a visual surface survey used to identify observable archaeological sites and areas with potential for buried archaeological sites, was conducted in February 2015. The PFR was undertaken by Stantec and representatives of the Musqueam Indian Band and Semiahmoo First Nation. As a result of the PFR, the Project area was assessed as having low potential for archaeological resources and no further archaeological work was recommended (Stantec 2015). A "Chance Find Protocol" will be applied during construction in the unlikely event that archaeological materials are found during Project construction.

4.1.7 Construction Methods/Materials

Proposed activities include the construction of a perimeter cobble beach berm, followed by the placement of suitable fill material (see **Section 2.3** and **3.1** for more information on quantities and construction methodology).

Construction of the Project is forecast to begin in September 2021 and would likely be undertaken over a multi-month construction period. Any high-risk in-water work activities, that pose an unacceptable risk to downstream migrating juvenile salmonids would be undertaken during the applicable least risk window (August 16th to February 28th annually). A phased construction scenario whereby the Project is built in stages over multiple years is also being considered.

4.2 ATMOSPHERIC IMPACTS

4.2.1 Sound, Odour, Gas or Fuel Emissions

Potential notable adverse atmospheric impacts would only apply throughout the Project's construction period. Activities with the potential for negative atmospheric impacts are limited to the use of barges, boats and equipment used to support the construction, planting and monitoring crews. Construction will cause the following impacts, which are not anticipated to disturb wildlife or nearby residents:

- Sound – will be short-term; and
- Fuel emissions – will be short-term.

Project construction is not anticipated to result in any notable odours or gasses that could disturb wildlife or nearby residents. The constructed intertidal marsh is expected to provide long-term atmospheric benefits, through the absorption of carbon dioxide from the atmosphere (i.e. carbon sequestration), which will help reduce some of the greenhouse gases responsible for climate change.

4.3 WATER OR LAND COVERED BY WATER IMPACTS

4.3.1 Drainage Effect

The finished marsh design elevation will be approximately 0.5 m (geodetic datum). To promote drainage over the large area of placed fill, it may be necessary to grade the surface of fill material to have a gentle slope and incorporate designed and/or naturally forming drainage channels within the marsh. The substrates used for marsh construction will have characteristics that promote stability and drainage under intertidal conditions.

4.3.2 Public Access

The Project is not likely to result in changes to public access. The Site is located in Sturgeon Bank, offshore of Steveston Village, and is not easily accessible to members of the public (i.e. it is accessible only by boat). Dense residential neighborhoods in the Steveston area, including Gary Point Park, are located more than 1.5 km east of the Site. No known land uses, including hunting (e.g. waterfowl) or harvesting values for aquatic species (e.g. shellfish) are known to occur at the Site.

4.3.3 Flood Potential

The Project will not impact the existing flood protection infrastructure (M&N 2015) and is not anticipated to result in an increased potential of flooding to nearby communities. Numeric modelling has determined that no indirect adverse effects to tidal currents, flow

rates, and sedimentation beyond the Project site are likely to result from the Project (M&N 2015).

4.4 Fish and Wildlife Habitat

4.4.1 Disturbance to Fish, Wildlife or Wildlife Habitat

Although the existing un-vegetated intertidal flats near the Site provide some value for a variety of different waterbirds, including shorebirds, the existing site generally has low to moderate aquatic and wildlife habitat values. Bird surveys undertaken in 2014 and 2015 (Hemmera 2015a, 2015b) indicate that the Site provides intermediate or less-than-intermediate quality habitat for shorebirds in the context of the Fraser River estuary.

Existing marshes at Sturgeon Bank and their associated channels are classified as important rearing, feeding and refuge area for fish as well as important transition zones for fish adapting to salinity and temperature changes in up- and down-river migrations (Hemmera 2018b). The Project will create more complex, productive, high value intertidal marsh habitat for salmonids, thus increasing overall primary productivity at the Site, as well as contributing to the detritus-based food web. As productivity is currently limited at the Site by the lack of vegetation, the enhanced habitat will benefit benthic and drift invertebrates that are particularly important prey items for juvenile salmonids that utilize tidal marsh habitats prior to out-migrating to the Strait of Georgia and Pacific Ocean. Project benefits will also extend to other fish species, as at least 80 species of fish are known to use the Fraser River estuary near Richmond (Hemmera 2018b).

The Project is not anticipated to result in adverse effects to fish, wildlife or wildlife habitat.

5.0 SOCIO-COMMUNITY

5.1 LAND USE

The Site is located in an intertidal area adjacent to the South Arm of the Fraser River. There are no known current land uses at the Site (i.e. no hunting or harvesting are known to occur).

5.1.1 Land Management Plans and Regional Growth Strategies

The Site is located in the Fraser River estuary within the City of Richmond and Metro Vancouver and outside of the Sturgeon Bank WMA. The Site falls within the boundaries covered by the former Fraser River Estuary Management Plan (FREMP 2003).

There are no land and resource management plans, coastal plans, provincial or regional growth strategies or local government plans with zoning, management policies or use restrictions in place that could limit or preclude the proposed use of the land.

5.2 SOCIO-COMMUNITY CONDITIONS

5.2.1 Adjacent Users or Communities

The Site is located in an intertidal area with limited access for the public (see **Section 4.3.2**). The Project will not impact the ability of adjacent land owners or tenure holders to access their property or tenures.

Public and stakeholder consultation and engagement for the proposed Project will be undertaken prior to the start of construction. Consultation and engagement will include opportunities for the public and stakeholders to provide feedback on proposed features related to the Project. VFPA will conduct a separate but parallel consultation process with Aboriginal groups.

Public engagement may include:

- Emails and phone calls to key stakeholders in advance of the consultation period;
- Notification advertisements in local newspapers;
- A Discussion Guide and Feedback Form, available in hard copy and online;
- Public open house meeting(s); and,
- A Consultation Summary Report outlining feedback received during the consultation period(s), and a Consideration Memo detailing how the project team will consider incorporating feedback in Project planning and design.

Communication objectives for the proposed Project include:

- Providing clear information about the Project and project-related activities;
- Communicating the potential benefits afforded to the local environment from the Project; and
- Creating and enhancing awareness in the community of VFPA's habitat enhancement work.

Community stakeholders for the proposed Project include relevant:

- Land owners;
- Adjacent residents;
- General public; and,
- Special interest groups.

Information about VFPA's HEP is shared with the public and stakeholders through VFPA's website, program email updates and VFPA's municipal engagement program, which includes updates to local government councils and staff. VFPA has and will continue to engage with all levels of government, regulators, Aboriginal groups and adjacent communities, as appropriate, during project definition, design and development.

5.2.2 Existing Services

There will not be an increased demand on fire protection, health facilities and emergency services arising from the Project.

6.0 REFERENCES

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WorleyParsons Ltd. 2015. Proposed Conversion of an Area Alongside the South Arm Jetty, Steveston, BC. Prepared for Hemmera Envirochem Inc.

APPENDIX A
Qualified Environmental Professional Assisted Assessment

MEMORANDUM

Date:	August 30, 2017
To:	Gord Ruffo, P.Eng. Program Manager, Vancouver Fraser Port Authority Habitat Enhancement Program
From:	Jim Roberts, B.Sc., R.P.Bio. Hemmera Scott Northrup, R.P.Bio. Hemmera
File:	302-035.05
Re:	VFPA's Habitat Enhancement Program - South Arm Jetty Tidal Marsh Project QEP Assisted Assessment, in accordance with DFO Fisheries Protection Program Guidance

1.0 INTRODUCTION

The South Arm Jetty Tidal Marsh Project (the Project) is located on the right (north) bank of the South Arm of the Fraser River in the Steveston Bend reach. It is near the City of Richmond, BC, immediately north of Steveston North Jetty (**Figure 1**). The Project is being developed by the Vancouver Fraser Port Authority (VFPA) as part of its Habitat Enhancement Program. The Project is being undertaken in accordance with the 2012 working agreement between VPFA and Fisheries and Oceans Canada (DFO) entitled "Working Agreement Concerning Procedures for Development and Operation of the Port Metro Vancouver Habitat Bank". The agreement acknowledges the mutual benefits of a habitat bank to both parties and provides guidelines for the establishment of habitat enhancement sites.

This self-assessment of Serious Harm is guided by information presented in DFO's Projects Near Water web site[1] and the Fisheries Productivity Investment Policy (DFO 2013). Consistent with the approach taken for other VFPA habitat enhancement projects and subject to guidance from Qualified Environmental Professionals (QEPs), please consider this memo an assisted assessment for the South Arm Jetty Tidal Marsh Project.

This assessment is also based on consideration of DFO's "Science Advice for Managing Risk and Uncertainty in Operational Decisions of the Fisheries Protection Program" (DFO 2014).

2.0 SITE LOCATION AND EXISTING CONDITIONS

The Project site is located immediately north of the Steveston North Jetty, which separates it from the South Arm of the Fraser River (**Figure 1**). The site is located in a dynamic environment in which sediments are transported by a combination of wind generated waves, tidal currents and discharge from the Fraser River.

[1] http://www.dfo-mpo.gc.ca/pnw-ppe/index-eng.html

The site predominantly consists of an unvegetated intertidal sandflat (**Photos 1** and **2**). Some of the sand deposits at the site originate from the placement of approximately 40,000 m^3 of dredged material as part of an attempted marsh habitat creation project in 1980 (Envirocon 1980). The deposited dredged material was planted with 718 plugs of *Carex lyngbei* and 1,366 *Scirpus americanus*, and remained vegetated for a period of time, however significant vegetation is no longer present at the transplant locations. Creosote-wood pilings, navigation towers and concrete pilings are scattered throughout the site. The concrete pilings were part of previous marsh habitat creation efforts, placed in an attempt to dampen wave energy at the site and stabilize the shifting dredge material placed in 1980. The Project site is submerged at medium to higher tides and is situated to the west of an intertidal mudflat (at approximately -0.35 m geodetic datum (GD)) and a developing tidal marsh bench running east-west along the north side of the Steveston North Jetty (0.2 m to 0.9 GD).

Productivity at the site is currently limited due to its lack of vegetation and the presence of elevated, rapidly drained sand features, and it is of low value as fish habitat. The Project will involve converting the existing un-vegetated intertidal sandflat into a more productive tidal brackish marsh, thereby improving the productivity and habitat value for fish (**Figure 2**). This will be accomplished through construction of a containment berm, placement of fill material to the appropriate elevation for the establishment of intertidal marsh vegetation and installation of nursery stock marsh species.

3.0 QEP ASSISTED ASSESSMENT

This section outlines the methodologies employed in conducting an assisted assessment for the South Arm Jetty Tidal Marsh Project. The assisted assessment was conducted by QEPs Jim Roberts, B.Sc., R.P.Bio. and Scott Northrup, B.Sc., R.P.Bio., and assesses the Project's potential to cause Serious Harm to fish.

3.1 MANAGING RISK AND UNCERTAINTY IN THE FISHERIES PROTECTION PROGRAM

DFO's science advisory report entitled "Science Advice for Managing Risk and Uncertainty in Operational Decisions of the Fisheries Protection Program" (DFO 2014) provides direction for self-assessments (completed by proponents) or assisted assessments (prepared by QEPs). Assessments of this type are used to determine if a proposed project requires DFO review and/or approval. For a project to proceed under a self- or assisted assessment, both the death of fish and residual adverse habitat effects need to be avoided. Furthermore, the project should be designed in such a way that there will be no loss of local productivity which would otherwise result in the need for offsetting.

By design, the South Arm Jetty Tidal Marsh Project is habitat enhancement that will result in an overall net benefit to fish and fish habitat. This Project will not result in any residual adverse effects on habitat and is, in fact, expected to result in a net increase in local productivity. Furthermore, it is noted that fish mortality (including fish that contribute to commercial, recreational and aboriginal (CRA) fisheries) can be avoided during construction through application of appropriate best management practices and mitigation measures.

The DFO advisory report also states that assessments of this type need to provide appropriate consideration for risk. For a project to proceed under a self- or assisted assessment and without DFO review/approval, low likelihood and low uncertainty needs to apply to both the death of fish and any net residual habitat impacts.

3.1.1 Consideration of Uncertainty and Risk

In assessing the South Arm Jetty Tidal Marsh Project, both uncertainty and risk need to be properly considered to ensure compliance with DFO's science advisory report (DFO 2014). This assisted assessment finds that there is a low likelihood of potential death of fish or net negative residual habitat impacts and that there is strong confidence in this conclusion.

Regarding the conclusion of low likelihood, the death of fish can be avoided during construction through application of appropriate best management practices and construction mitigation. In particular, application of an appropriate low risk inwater work window will protect downstream migrating juvenile Pacific salmon and other CRA fish.

There is high certainty that this Project will result in an overall net benefit for fish and fish habitat. Tidal marsh construction is a well-established enhancement technique in the lower Fraser River and past experience indicates that construction can be successfully undertaken with appropriate mitigation measures in place. There is no notable uncertainty in the ability of the Project to avoid the death of fish in the short-term. Furthermore, residual habitat benefits will apply over the long-term.

3.2 PROJECTS NEAR WATER WEB PAGE GUIDANCE

DFO's "Projects Near Water" website guides proponents to either self-assess a project, submit a Request for Review to DFO or to apply for a *Fisheries Act* Authorization. Projects that do not require a review can include "Habitat Restoration" projects:

- **Habitat Restoration**
  - Habitat restoration projects including riparian planting, bank stabilization, bio-engineering and creation of in-stream structure do not require DFO review if:
    - No new temporary or permanent fill is placed below the High Water Mark; and,
    - Works are undertaken in a manner such that any obstruction to fish passage will respect timing windows.

The South Arm Jetty Tidal Marsh Project will not result in "fill", which is defined as the creation of new land. Given this, it appears appropriate that this Project be assessed by a QEP to definitively confirm that there is no Serious Harm associated with the proposed works.

3.3 FISHERIES ACT AND SERIOUS HARM TO FISH

The *Fisheries Act* requires that proposed projects avoid Serious Harm to fish that contribute to CRA fisheries, unless authorized. VFPA is committed to following appropriate measures to avoid harm and ensure compliance with the *Fisheries Act* for the South Arm Jetty Tidal Marsh Project, as well as all other projects which are advanced under VFPA's Habitat Enhancement Program.

Under the updated *Fisheries Act* (November 25, 2013) and associated policy guidance, proponents are asked to consider the following key project-related effects when making determinations about whether a project is likely to cause Serious Harm to fish:

1. **Impacts to fish and fish habitat caused by the project:** Existing fish habitat values at the Project site consist of unvegetated unconsolidated substrates. Fish habitat values will be enhanced through the conversion of sandflats to intertidal brackish marsh, a highly valued productive habitat for rearing juvenile salmonids.

   Based on more than 25 years of similar enhancement work undertaken within the lower Fraser River, including work conducted in support of previous VFPA habitat creation efforts, tidal marsh construction is understood to be a reliable, proven enhancement technique. Past experience suggests that construction can be undertaken with well-established mitigation measures in place, reducing the risk of any impacts to fish or fish habitat.

   Once the physical construction of the site is complete, marsh vegetation planting will be undertaken. Establishment of marsh vegetation by this pro-active planting program will facilitate a boost to site specific productivity during in the first year post-construction. By the first year of juvenile salmonid outmigration following the initial establishment of marsh plantings, a dramatic improvement to site productivity will be realized.

2. **The duration of the impacts:** Enhanced productivity associated with this new brackish tidal marsh will begin contributing to the fish habitat values of the site in a substantive way following its first season of growth. As a result, the Project will provide direct benefits to the next generation of rearing salmonids. Full productivity of the constructed brackish marsh habitats is expected within a three year period and will be confirmed by a monitoring program.

3. **The geographic scale of the impacts:** The Fraser River estuary sustains intertidal marsh, intertidal mudflat and subtidal areas that are utilized by fish. The geographic scale of any construction-related effects of the Project will be relatively small within the context of the extensive estuarine habitats present within the lower Fraser River including the South Arm. For example, the Sturgeon Bank Wildlife Management Area to the north of the Project site includes approximately 4,400 ha of intertidal habitat (GL Williams & Associates Ltd. and Northwest Hydraulic Consultants 2009), in contrast to the approximately 40 ha footprint of the Project.

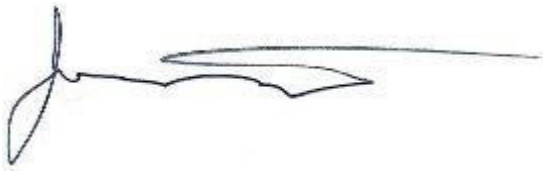
4. **The availability and condition of nearby fish habitat:** In the context of the fish habitat mosaic currently present within the Fraser River estuary, nearby intertidal habitats (including brackish tidal marshes in the immediately adjacent Sturgeon Bank Wildlife Management Area, in the South Arm Marshes Wildlife Management Area, and on the seaward edge of Westham Island) will continue to be available during and immediately after construction. Proposed Project works will enhance habitat values of the Project site and provide for an overall net gain in productivity, without impacting fish access or use of nearby habitats.

5. **Impact on the relevant fish:** No localized effect on fish populations or stocks (e.g., juvenile Pacific salmon, eulachon, and white sturgeon) will result from the proposed works. Works with the risk of impacts to fish will be undertaken during the appropriate low risk inwater work window. The potential for any direct injury to, or mortality of, fish will be minimized through construction mitigation measures. There will be no measurable effect to Pacific salmon or other CRA fish populations as a result of the physical works and the Project will result in enhanced productivity for these fish (including rearing salmonids).
6. **Proposed avoidance and mitigation measures:** Tidal marsh construction is a time-tested enhancement technique in the lower Fraser River estuary. Avoidance of potential fish impacts will be provided through the application of well-established mitigation measures, including low risk inwater work windows where warranted. These mitigation measures are considered to prevent Serious Harm, by avoiding CRA fish mortality or residual habitat impacts. The Project will be monitored through both construction and post-construction (effectiveness) monitoring to ensure its success as a habitat banking project under VFPA's Habitat Enhancement Program.

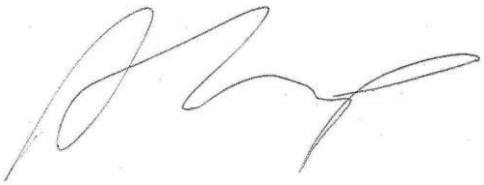
4.0 SELF-ASSESSMENT SUMMARY

Based on the above information, it is our professional opinion that the proposed Project will not result in Serious Harm to fish that are part of any CRA fisheries, or to any fish that support such fisheries, and that a Section 35(2)(b) Authorization is not required for this Project. We are also confident that both low likelihood and low uncertainty apply to the potential death of fish or net negative residual habitat impacts.

Prepared by:
Hemmera Envirochem Inc.



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Scott Northrup, R.P.Bio.
Fisheries Biologist/Advisor
250.619.2807
snorthrup@hemmera.com

5.0 REFERENCES

DFO. 2013. Fisheries productivity investment policy: A proponent's guide to offsetting. Accessed August 2017. Available at: http://www.dfo-mpo.gc.ca/pnw-ppe/offsetting-guide-compensation/index-eng.html

DFO. 2014. Science advisory report 2014/015: Science advice for managing risk and uncertainty in operational decisions of the fisheries protection program. Accessed August 2017. Available at: http://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2014/2014_015-eng.html

Envirocon. 1980. Fraser River estuary habitat development program; Addendum to the criteria summary report. Prepared for Departments of Supply and Services, Fisheries and Oceans, Canadian Wildlife Service, and Public Works Canada.

GL Williams & Associates Ltd. and Northwest Hydraulic Consultants. 2009. Roberts Bank and Sturgeon Bank Reach Overview – Backgrounder. Prepared for the Fraser River Estuary Management Program. Accessed August 2017. Available at: http://www.robertsbankterminal2.com/wp-content/uploads/Roberts-Bank-and-Sturgeon-Bank-Reach-Overview-Backgrounder.pdf.

FIGURES AND PHOTOS

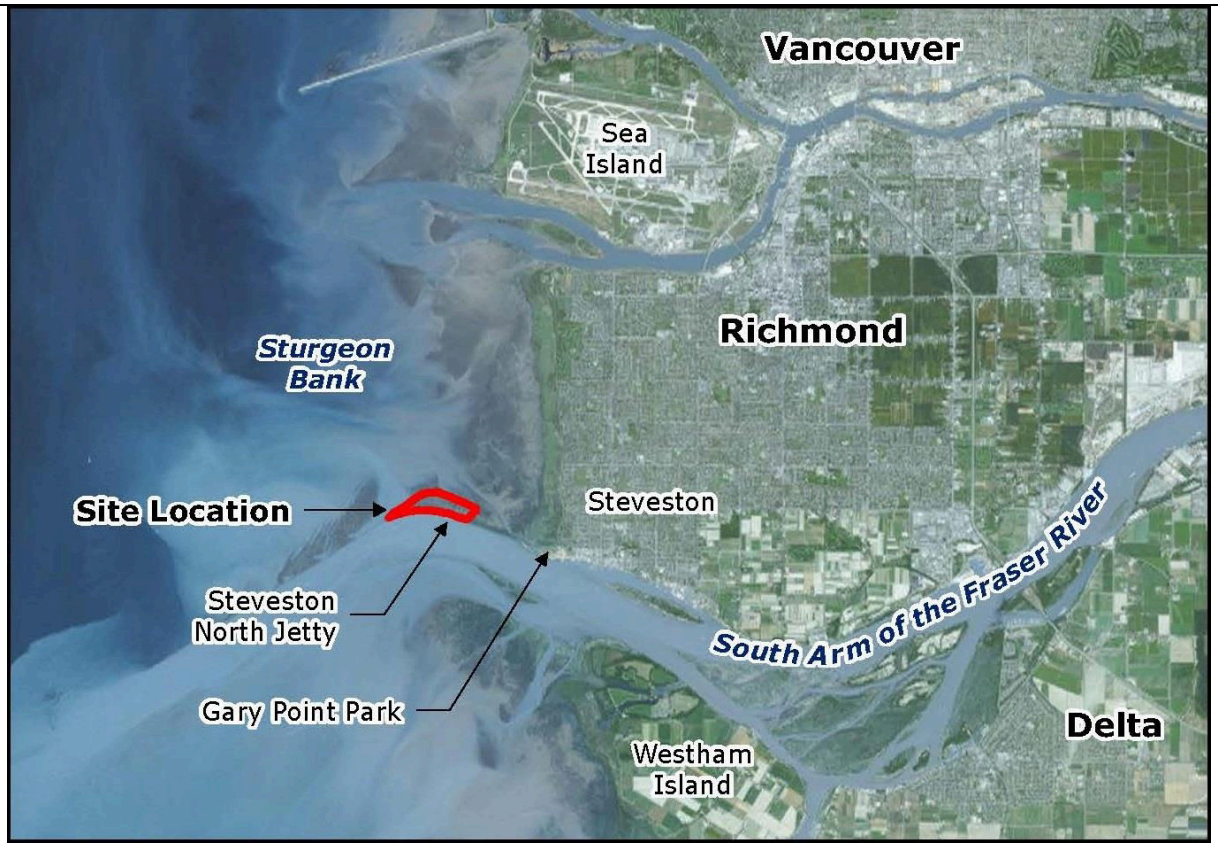


Figure 1 Regional Setting for the South Arm Jetty Tidal Marsh Project

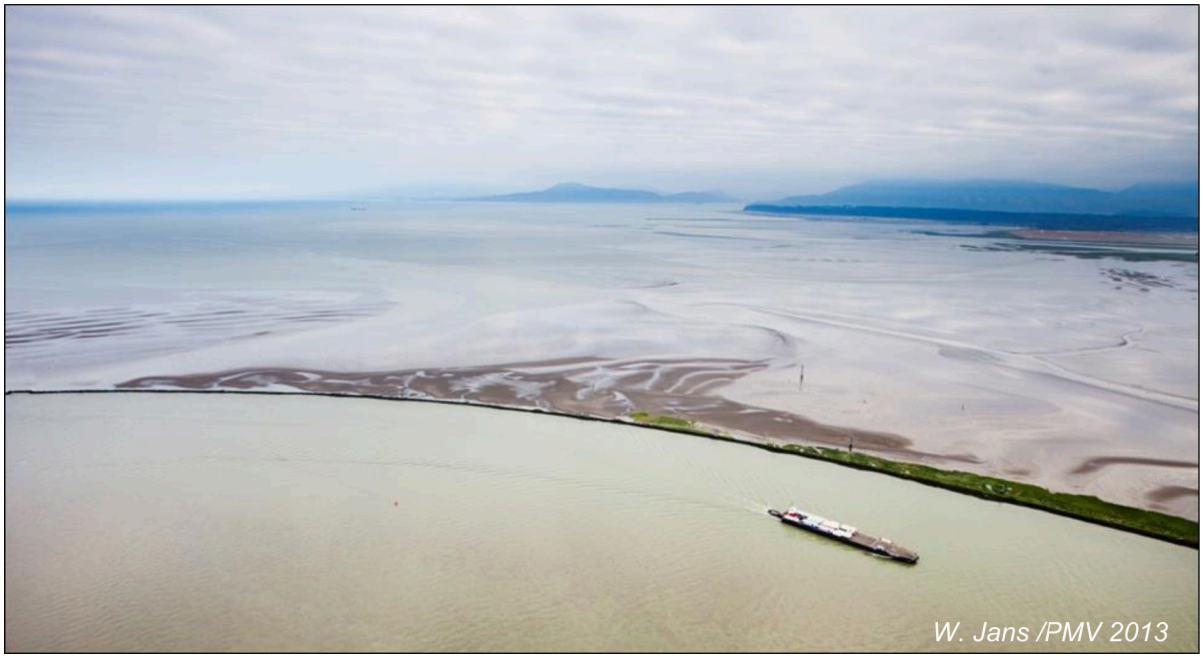
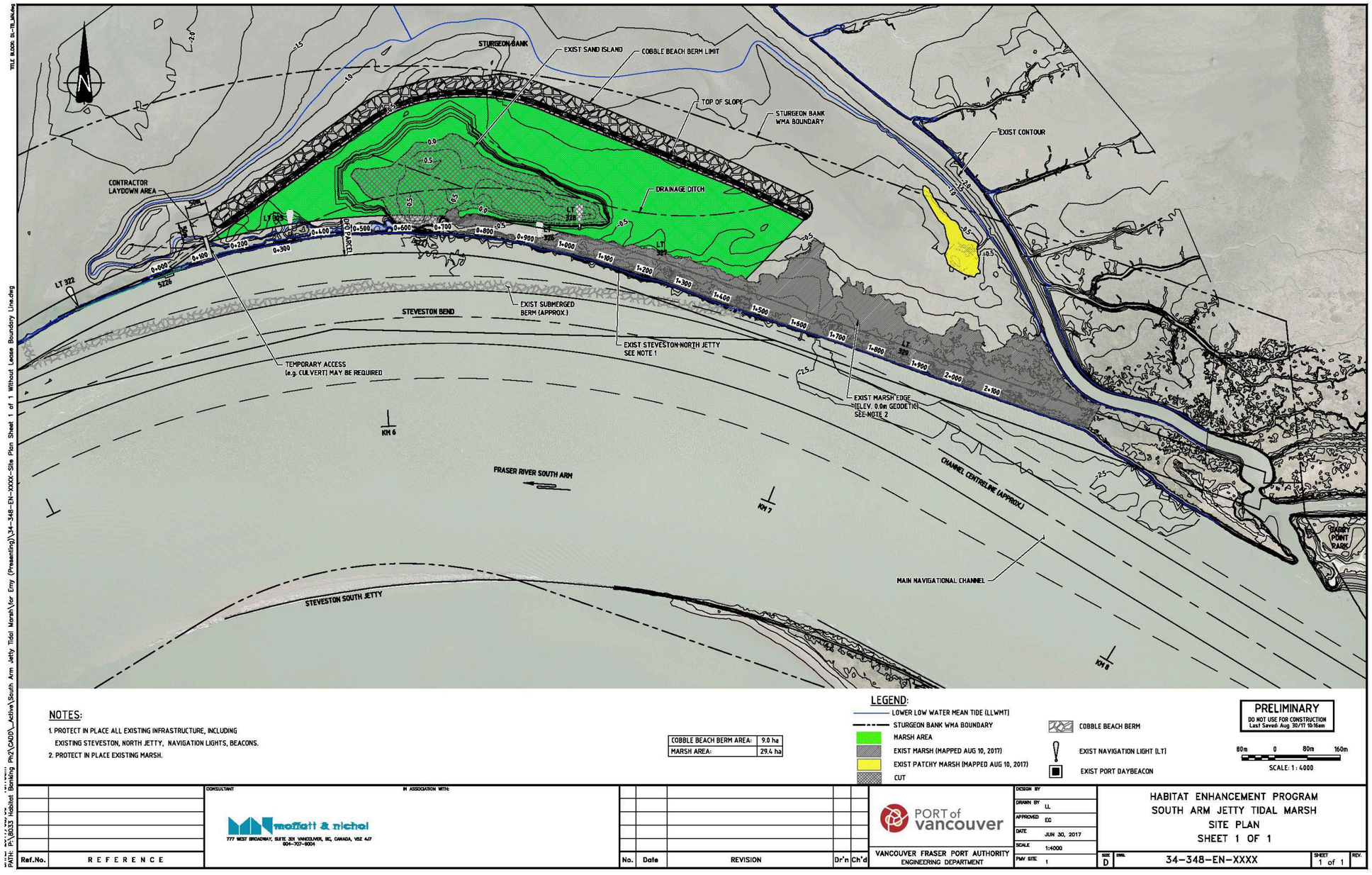


Photo 1 South Arm Jetty Tide Marsh site existing conditions – looking northwest



Photo 2 South Arm Jetty Tidal Marsh site existing conditions – looking west



NOTES:
1. PROTECT IN PLACE ALL EXISTING INFRASTRUCTURE, INCLUDING EXISTING STEVESTON, NORTH JETTY, NAVIGATION LIGHTS, BEACONS.
2. PROTECT IN PLACE EXISTING MARSH.

COBBLE BEACH BERM AREA:	9.0 ha
MARSH AREA:	29.4 ha

LEGEND:
- LOWER LOW WATER MEAN TIDE (LLWMT)
- STURGEON BANK WMA BOUNDARY
- MARSH AREA
- EXIST MARSH (MAPPED AUG 10, 2017)
- EXIST PATCHY MARSH (MAPPED AUG 10, 2017)
- CUT
- COBBLE BEACH BERM
- EXIST NAVIGATION LIGHT (LT)
- EXIST PORT DAYBEACON

PRELIMINARY
DO NOT USE FOR CONSTRUCTION
Last Saved: Aug. 30/17 10:16am

80m 0 80m 160m
SCALE: 1 : 4000

CONSULTANT: moffatt & nichol, 777 WEST BROADWAY, SUITE 301, VANCOUVER, BC, CANADA, V5Z 4J7, 604-707-9004
IN ASSOCIATION WITH:

PORT of vancouver
VANCOUVER FRASER PORT AUTHORITY
ENGINEERING DEPARTMENT

DESIGN BY	
DRAWN BY	LL
APPROVED	EC
DATE	JUN 30, 2017
SCALE	1:4000
PMV SITE	1

HABITAT ENHANCEMENT PROGRAM
SOUTH ARM JETTY TIDAL MARSH
SITE PLAN
SHEET 1 OF 1

SIZE D | DWG. 34-348-EN-XXXX | SHEET 1 of 1 | REV.

Ref.No.	REFERENCE

No.	Date	REVISION	Dr'n	Ch'd

PATH: P:\0633 Habitat Banking Ph2\CAD_Active\South Arm Jetty Tidal Marsh\For Emy (Presenting)\34-348-EN-XXXX-Site Plan Sheet 1 of 1 Without Lease Boundary Line.dwg
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Figure 2 South Arm Jetty Tidal Marsh Design – Site Plan

APPENDIX B
BC Environmental Assessment Office Decision Letter

BRITISH COLUMBIA

File: 30400-35/SAJTM-05-06

Reference: 300697

September 19, 2016

SENT VIA EMAIL

Gord Ruffo
Program Manager
Vancouver Fraser Port Authority
Habitat Enhancement Program
100 The Pointe, 999 Canada Place
Vancouver BC V6C 3T4
Gord.Ruffo@portmetrovancouver.com

Dear Mr. Ruffo:

On July 31, 2015, the Environmental Assessment Office (EAO) received a request from Vancouver Fraser Port Authority (VFPA) for a determination from the Executive Director that the South Arm Jetty Tidal Marsh Project (South Arm Jetty Project) does not require an environmental assessment certificate and that VFPA may proceed without an assessment pursuant to Section 10(1)(b) of the British Columbia *Environmental Assessment Act*.

EAO evaluated information provided by VFPA in support of this request, and referred the request and supporting information to an advisory working group comprised of representatives of First Nations, local governments, provincial governments and federal government agencies.

After considering VFPA's request and supporting documentation, and EAO's Exemption Assessment report, I have determined that an environmental assessment certificate is not required for the South Arm Jetty Project, and VFPA may proceed with the South Arm Jetty Project without an environmental assessment, provided that the Project is constructed and operated in accordance with Schedule A (Certified Exempted Project Description) and Schedule B (Table of Conditions) of the enclosed Section 10(1)(b) Order.

...2

Information regarding this decision is available on EAO's website at https://a100.gov.bc.ca/appsdata/epic/html/deploy/epic_project_home_438.html

If you have any questions, please contact Monica Perry, Executive Project Director, at Monica.Perry@gov.bc.ca, or by telephone at 250 387-2402.

With best regards,

Kevin Jardine
Associate Deputy Minister

Enclosures (2)

cc: Michelle Carr, Assistant Deputy Minister, Environmental Assessment Operations, Environmental Assessment Office

Monica Perry, Executive Project Director, Environmental Assessment Office

In the matter of the
ENVIRONMENTAL ASSESSMENT ACT
S.B.C. 2002, c.43
(the Act)

and

in the matter of a

Request for a determination pursuant to Section 10(1)(b) of the Act (Request)

by

THE VANCOUVER FRASER PORT AUTHORITY
(Proponent)

for the

SOUTH ARM JETTY TIDAL MARSH PROJECT
(Project)

ORDER UNDER SECTION 10(1)(b)

Whereas:

A. The Proponent proposes to construct the Project described in Schedule A to this Order;

B. The Project is reviewable pursuant to Part 5 of the Reviewable Projects Regulation (B.C. Reg. 370/02), because it is a new shoreline modification project that entails dredging, filling or other direct physical disturbance of two or more hectares of foreshore or submerged land, or a combination of foreshore and submerged land, below the natural boundary of a stream, marine coastline or estuary;

C. On July 31, 2015, the Proponent submitted a Request for a determination from the Executive Director, pursuant to section 10(1)(b) of the Act, that an environmental assessment (EA) certificate is not required for the Project, and that the Proponent be allowed to proceed with the Project without an assessment on the basis that the Project would not result in any significant adverse effects;

D. Environmental Assessment Office (EAO) established an advisory working group (Working Group) consisting of the federal Environment and Climate Change Canada, BC Ministry of Forests, Lands and Natural Resource Operations, City of Richmond, Corporation of Delta, and the following First Nations: Cowichan Tribes, Lyackson First Nation, Semiahmoo First Nation, Tsawwassen First Nation, and Tsleil-Waututh Nation, to support EAO in its evaluation of the Request;

E. EAO evaluated the Request from October 21, 2015 to November 18, 2015, in consultation with the Working Group;

F. Compliance with this Order, including its conditions, will be monitored by the staff of the Environmental Assessment Office, partner agencies and others who have been authorized to inspect under the Act;

G. The undersigned have considered the Exemption Assessment report prepared by EAO, the undersigned considers that the Project will not result in significant adverse environmental, economic, social, heritage or health effects, taking into account practical means of preventing or reducing to an acceptable level, any potential adverse effects; and

H. The Project is subject to future approvals under the *Canadian Environmental Protection Act, 1999,* and the Vancouver Fraser Port Authority`s Project and Environmental Review Process under the *Canadian Environmental Assessment Act, 2012*.

Now Therefore,

Pursuant to section 10(1)(b) of the Act, I order that:

(i) an EA certificate is not required for the Project; and

(ii) the Proponent may proceed with the Project without an assessment, provided that the Project is constructed as described in the Certified Exempted Project Description (Schedule A), subject to the conditions set out in Schedule B.

Kevin Jardine
Associate Deputy Minister and Executive Director
Environmental Assessment Office

Issued this 19th day of September, 2016

SCHEDULE A

Certified Exempted Project Description

SOUTH ARM JETTY TIDAL MARSH PROJECT

(PROJECT)

The Project must be constructed and operated as shown in figures 1 and 2. The total gross area of created marsh habitat is up to 48 ha.

Construction activities include the construction of a containment structure and perimeter berm, followed by the placement of suitable fill material located adjacent to (south of) the Sturgeon Bank Wildlife Management Area. The containment structure will be up to 190 m in length, with the crest at an elevation of 1.5 m geodetic datum. The perimeter berm will be up to 60 m wide and up to 2.4 km in length.

Following establishment of the marsh substrate, establishment of marsh vegetation must be undertaken either by transplantation, natural spread or a combination of these methods.

Figure 1 Location of South Arm Jetty Tidal Marsh Project (Regional Context)

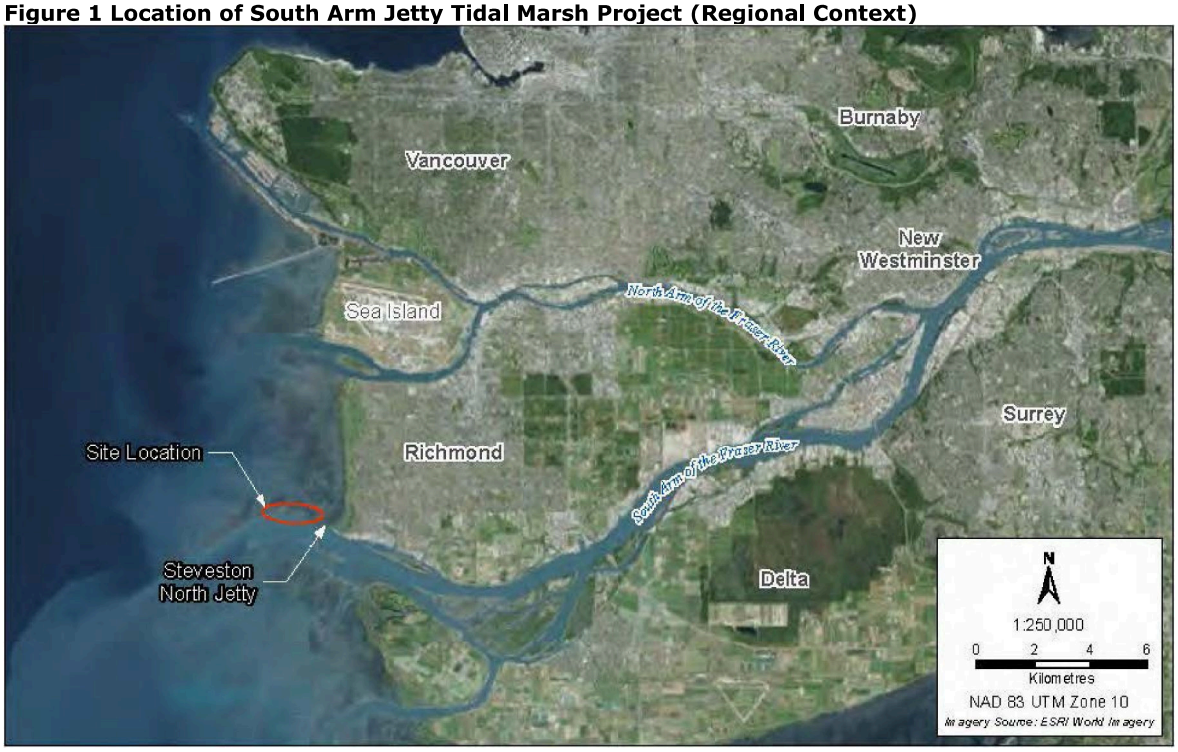
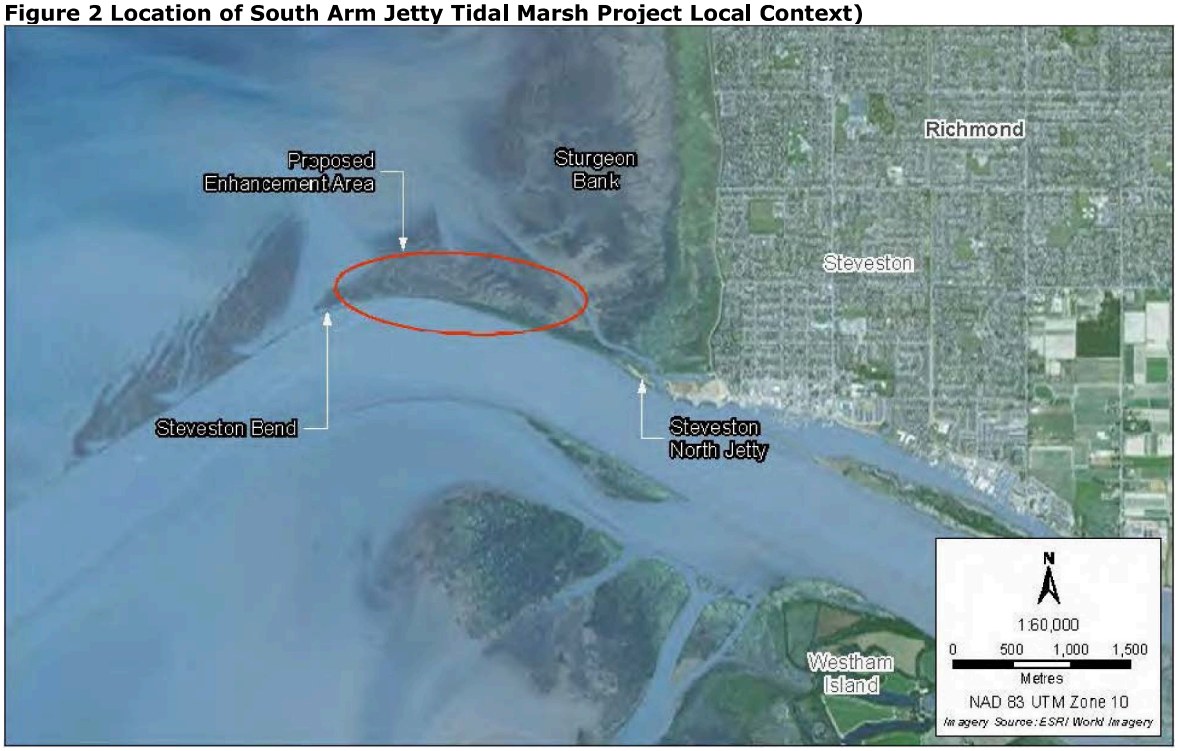


Figure 2 Location of South Arm Jetty Tidal Marsh Project Local Context)



SCHEDULE B

SOUTH ARM JETTY TIDAL MARSH PROJECT

TABLE OF CONDITIONS FOR ORDER UNDER SECTION 10(1)(b)

INTERPRETATION

In this Schedule, Column 3 (Project Phase), in the table below is for convenience of reference only, and does not form a part of the condition.

DEFINITIONS

Aboriginal Groups	Cowichan Tribes, Lyackson First Nation, Semiahmoo First Nation, Tsawwassen First Nation, and Tsleil-Waututh Nation.
Aboriginal Interests	Asserted or determined Aboriginal rights, including title.
Construction	The phase of the Project during which physical alteration of land, vegetation or any other aspect of the natural environment, occurs. For the purposes of this Schedule B, Construction: (i) does not include any activities conducted solely for investigative purposes under a valid permit or authorization, and (ii) includes upgrading, repairing, replacing, or removing, any existing work or infrastructure.
Proponent	Vancouver Fraser Port Authority.
Post Construction	The phase of the Project following the establishment of the marsh substrate during which planting, maintenance and monitoring activities are implemented.
Qualified Professional	A Person who has training, experience and expertise in a discipline relevant to the field of practice set out in the condition, and who is registered with the appropriate professional organization in British Columbia, is acting under that organization's code of ethics and is subject to disciplinary action, if determined to be necessary by that organization.
Order	Order pursuant to Section 10(1)(b) of the *Environmental Assessment Act.*

Request	Request from the Vancouver Fraser Port Authority, dated July 31, 2015, to the Environmental Assessment Office pursuant to Section 10(1)(b) of the *Environmental Assessment Act*, for an Environmental Assessment Certificate exemption, and accepted for review on September 30, 2015.

Acronyms

DFO	Department of Fisheries and Oceans Canada
EAO	Environmental Assessment Office
EM	Environmental Monitor
EPP	Environmental Protection Plan
PCMP	Post Construction Monitoring Plan
VFPA	Vancouver Fraser Port Authority

No.	Condition
1.	**Compliance Verification** The Proponent must provide any document, data or information requested by EAO for the purposes of compliance inspection and verification.
2.	**Project Status Notification** The Proponent must notify EAO Compliance and Enforcement, in writing, at least 14 days prior to commencing Construction. Should the primary contact person for the Project change, the Proponent must notify EAO (to the attention of EAO Compliance and Enforcement), in writing, within 30 days of such change and provide the physical address, email address and phone number(s) of the new primary contact person.
3.	**Compliance Notification** The Proponent must notify EAO: a) as soon as practical; and b) In any event, no more than 72 hours, after the Proponent determines that the Proponent has not, or may not have, fully complied with this Order.
4.	Prior to commencing Construction, the Proponent must ensure that the services of a Qualified Professional as the Environmental Monitor (EM) are retained. The purpose of the EM will be to assist in identifying and mitigating potential adverse effects of the Project to environmental, health, economic, social or heritage values and maintaining compliance with this Order. The EM must have a minimum five years demonstrated experience and knowledge of environmental monitoring for major construction projects in British Columbia. The EM must be retained throughout the Construction and for any follow-up maintenance activities involving physical works (if applicable). Prior to the start of Construction, the Proponent must develop terms of engagement between the Proponent and the EM and provide a copy of the terms of engagement to EAO. EAO may require changes to the terms of engagement related to items a) to e) below. Such terms of engagement must include, at a minimum, the following: a) roles and responsibility of the EM; b) required monitoring frequency;

	c) required reporting to the Proponent, EAO, Aboriginal groups, and other regulatory agencies, on the Proponent's compliance with this Order and, where mitigation measures are required, the effectiveness of the Proponent's mitigation measures carried out by the Proponent pursuant to this Order; d) the types of situations in which the EM will have the authority to stop work on part or all of the Project if the EM determines that: i) the Proponent has not, or may have not, complied fully with the requirements of this Order; and ii) stopping work is necessary to prevent or reduce adverse effects caused by that non- compliance; and e) the types of situations in which the EM will have the authority to require mitigation or corrective actions be taken by the Proponent and report on the effectiveness of the mitigation or corrective actions. Reports by the EM must be provided in a format, frequency, and level of detail that is to the satisfaction of EAO. The EM must notify EAO: a) as soon as practical; and b) in any event, no more than 72 hours, after the EM determines that the Proponent has not, or may not have, fully complied with this Order.
5.	Prior to the start of Construction, the Proponent must develop a site-specific Environmental Protection Plan (EPP) that includes requirements for: • Mitigation for conducting any high-risk in-water works that pose unacceptable risk, as determined by the Qualified Professional, to protect juvenile salmonids and eulachon (i.e., least risk work window of August 16 and February 28); • Ensuring that construction would be undertaken with mitigation and monitoring in place, to the satisfaction of a Qualified Professional, to minimize any potential Construction-related effects on fish species that may currently use the site; and • Specific actions and monitoring to prevent spills of deleterious substances including mitigation in the case of any spills. The EPP must be implemented throughout Construction and Post-Construction under the direction of a Qualified Professional.
6.	The Proponent must complete pre-Construction survey(s) to detect the presence of active nests if Construction works are conducted during the bird breeding period (March 15 to August 15 unless otherwise determined by a Qualified Professional) and within 30 m of vegetated habitats or other potential nesting areas. Construction may occur during the bird breeding window within 30 m of potential nesting areas, if a Qualified Professional determines there is a low risk of adverse effects on nesting birds or if bird nest surveys (conducted by a Qualified Professional) indicate that there are no active bird nests present within the potential zone of adverse effect, as determined by a Qualified Professional. If active nest(s) are observed within 30 m of construction works, the Proponent must implement site-specific mitigation measures to avoid adverse effects to breeding birds, as determined by a Qualified Professional.
7.	If active raptor nests are detected, the Proponent must avoid or mitigate potential disturbances under the direction of a Qualified Professional and in accordance with the BC Raptor Conservation Guidelines (MOE, 2013 or as amended or replaced from time to time).
8.	Within 24 months of Construction completion, the Proponent must establish marsh vegetation through transplantation, natural spread or a combination of these methods within a timeframe

	and manner as directed by a Qualified Professional. The Proponent must consult with DFO in the development of a planting plan. The Proponent must include, or provide a rationale for why the Proponent is not including, in the planting plan plant species of cultural, spiritual and medicinal significance, as identified to the Proponent following the Proponent's May 2014 request for input from Aboriginal groups.
9.	The Proponent must implement a formal monitoring program Post-Construction in accordance with the Post-Construction Monitoring Plan (PCMP) for VFPA's Habitat Enhancement Program.
10.	The Proponent must develop and implement a Chance Find Protocol during construction, and provide opportunities for Aboriginal Groups to be involved in the monitoring and protection of any artefacts discovered during Construction.
11.	The Proponent must implement atmospheric noise mitigation measures, including potentially limiting hours of operation as determined by a Qualified Professional as appropriate.
12.	Prior to the start of Construction, the Proponent must undertake a public and community engagement program (as described in the VFPA July 31, 2015 project description application) for the Project that invites input from the City of Richmond, Aboriginal groups and adjacent communities. Prior to the start of Construction, the Proponent must develop and post online a summary report describing the engagement program, input received and how the input was incorporated, or not, in the design of the Project.

APPENDIX C
Letters of Support

MUSQUEAM INDIAN BAND
6735 SALISH DRIVE
VANCOUVER, B.C.
CANADA V6N 4C4
TELEPHONE: 604 263-3261
FAX: 604 263-4212

July 29, 2015

Jemma Scoble
Infrastructure Development, Aboriginal Consultation
Port Metro Vancouver
100 The Pointe, 999 Canada Place
Vancouver, BC, V6C 3T4 (Sent Via Email: Jemma.Scoble@portmetrovancouver.com)

Dear Jemma,

Re: June 25 Habitat Enhancement Program Project Updates

Thank you for your letter dated June 30, 2015 regarding the Habitat Enhancement Program Project Updates.

Musqueam would like to advise the Port that we are supportive of some of the habitat enhancement projects (namely the South Arm Jetty Tidal Marsh, Steveston Tidal Marsh, Point Grey, and Tswwassen Eel Grass), which enhance important habitat within Musqueam's traditional territory in hopes of benefiting broad ranges of fish and wildlife species and support ecological functions. It is important to note that Musqueam supports these projects in principle and that our support is based on Musqueam's Aboriginal and proven rights being at the forefront of these projects.

Musqueam

Musqueam Indian Band is a thriving First Nation community engaged in economic development while protecting and ensuring future generations their collective rights to a healthy aquatic and land base. We are the inherent stewards of our traditional lands passed down to us through generations of protocols and practices founded in our customs, practices and our traditional laws. We regard our traditional territory from a collective communal perspective, keeping in our hearts and minds that our decisions and actions ripple through time affecting generations yet to come.

It is in the best interests of every proponent to pursue meaningful engagement directly with Musqueam. We are the stewards of our lands and keepers of our waters and all things within it. With this perspective we live and assert our traditional laws to ensure balance in our ecosystems and resources within our traditional territory. We must be consulted and have free, prior and informed consent of activities within in our territories especially of activities impacting our established rights as held by the

Supreme Court of Canada in the landmark *Sparrow*[1] decision that providing and ensuring constitutional protection our Aboriginal rights. Any infringement of those established rights must be justified. To Musqueam the right to fish is of fundamental importance to our members and all aspects of our culture and economy. The cumulative effects of industry activities in our territory are of great concern to Musqueam particularly those impacting our established rights.

Sparrow Test and the Constitution

In Musqueam's landmark case, *R. v. Sparrow* (1990), the Supreme Court of Canada found in our favour, recognizing we have a pre-existing right pre-dating confederation and the shaping of this county now called Canada. Any perceived activity in our traditional territory that infringes on our right to fish places a heavy justification onus on the Crown of satisfying the *Sparrow* test.

The *Sparrow* test asks if there is an infringement imposed by the proposed activity that interferes with an existing Aboriginal right. To determine if there has been such an interference, the following questions must be asked and answered:

1. Does it impose undue hardship on the First Nation?
2. Is it considered by the courts to be unreasonable?
3. Does it prevent the right-holder from their preferred means of exercising that right?

The threshold of showing an infringement is low and any interference other than trivial interference is sufficient. *Sparrow* also holds that a justification of an infringement places a heavy onus on the Crown requiring:

1. A valid legislative objective; this must be compelling and substantial and includes preservation and prevention of harm.
2. A link between the justification and the allocation of priorities so that the interests of Musqueam rank first subject only to conservation needs;
3. A consideration of whether there has been minimal infringement; adequate consultation and fair compensation.

In addition the Court's discussion of Section 35 of the *Constitution Act* 1982[2] concludes Musqueam have an existing right to fish that cannot be interfered with without consent or satisfaction of the justification test and calls for a "just settlement for aboriginal peoples".

Haida and the Duty to Consult

While the duty to consult is an obligation that rests with the Crown, proponents should also consult in a meaningful way and where appropriate accommodate for infringements. Consultation should always be conducted in a meaningful way when there is a real or constructive knowledge of a potential Aboriginal right. The spectrum of the duty to consult ranges from low to high, high end being 'deep consultation, participation in the decision making process and accommodation'. The requirement to justify an

[1] R. v. Sparrow (1990) S.C.R. 1071
[2] Constitution Act 1982

infringement of Musqueam's established aboriginal rights is greater than the threshold of deep consultation set out in *Haida*.

Tsilhqot'in and Aboriginal Title

Recently in another land mark decision the Supreme Court of Canada found in favour of the Tsilhqot'in Nation: *Tsilhqot'in* [2014][3]. This case reaffirms that First Nations have the legally enshrined right of use and control of our Aboriginal title land and to reap the benefits flowing from it. The *Tsilhqot'in* test for a justification of infringement of an Aboriginal right requires:

1. A valid compelling and substantive legislative objective;
2. Satisfaction of the Crowns fiduciary obligations imposing an obligation of proportionality including a requirement "that the incursion is necessary to achieve the government's goal [rational connection]; that the government go no further than necessary to achieve it [minimal impairment]; and that the benefits that may be expected to flow from that goal are not outweighed by adverse effects on the Aboriginal interest [proportionality of impact]"; .
3. The Crown must consult in all cases, and must do so in a meaningful way in accordance with rules set out in *Haida* (2004)[4] referencing *Guerin*[5] (1984).

The Court noted that allegations of infringement or failure to adequately consult can be avoided by obtaining consent of the Aboriginal group and that failure to obtain consent may lead to a project being cancelled.

In closing we confirm our commitment to engaging in future opportunities and economic development for our Nation's greater collective good benefiting future generations and Chief and Council Vision Statement:

> "Musqueam people, a proud and unified people, will as a self-governing nation, work together to ensure enhanced quality of life for all generations of our people to develop a sustainable, self-reliant, vibrant community that is built upon the historical and traditional values of our community."

Sincerely,

Richard Sparrow
Fisheries Manager
Musqueam Indian Band

[3] Tsilhqot'in Nation v. British Columbia, 2014 SCC 44 D
[4] Haida Nation v. British Comumbia (Minister of Forests), [2004] S.C.R. 511
[5] Guirin v. The Queen, [1984] 2 S.C.R. 335

From: Joanne Charles [semiahmoojoanne@gmail.com]
Sent: July-29-15 12:22 PM
To: Scoble, Jemma
Cc: Joanne Charles; Adam Munnings
Subject: SUPPORT OF ENHANCEMENT PROJECTS

Hello Jemma,

Further to our meeting today, I would like to confirm Semiahmoo's support for the following proposed projects:

1) Tsawwassen Eelgrass project;

2) Steveston Island Tidal Marsh Project; and

3) Proposed South Arm Jetty Tidal Marsh Project.

Semiahmoo's support is on the basis that Port Metro will provide:

1) training and employment opportunities for Semiahmoo to participate in with these habitat projects; and

2) input on the selection of the plants for some of the areas, specifically the inclusion of harvestable plants like the sea asparagus plant and some other medicinal plants in these areas.

Should you require any further information, please advise.

Thank you,
Councillor Joanne Charles

Appendix IR2020-1.1-A4

Archeological Overview Assessment – South Arm Jetty Tidal Marsh Project, Richmond, BC

Archaeological Overview Assessment

South Arm Jetty Tidal Marsh Project, Richmond, BC



Prepared for:
Port Metro Vancouver
100 The Pointe
999 Canada Place
Vancouver, BC V6G 3T4

Prepared by:
Stantec Consulting Ltd.
500 – 4730 Kingsway
Burnaby, BC V5H 0C6

Final

September 22, 2014

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Report Production
Nicole Bryer

Acknowledgements

Stantec Consulting Ltd. would like to thank Port Metro Vancouver for the opportunity to conduct a desk based archaeological overview assessment of the South Arm Jetty Tidal Marsh Project.

Management Summary

At the request of Port Metro Vancouver, Stantec Consulting Ltd. conducted an archaeological overview assessment for the proposed South Arm Jetty Tidal Marsh Project.

Available information concerning the location, nature and distribution of known prehistoric and historic resources in the vicinity of the Project was acquired using the Remote Access to Archaeological Data application maintained by the Archaeology Branch of the Ministry of Forests, Lands and Natural Resource Operations.

A review of background literature dealing with the ethnography, history, archaeology and paleoenvironment of the project region was conducted to place the Project in a cultural context.

Archaeological site types recorded in the general vicinity of the Project include shell middens associated with permanent villages and temporary campsites, lithic scatters from the tools of hunters and fishers, subsistence features relating to the many villages and resource extraction areas that once proliferated the Lower Mainland and historic sites and shipwrecks. The archaeological sites comprise of one or several of these components.

The Project is in a deltaic environment that has a complex pre-contact and historic record. Archaeological and ethnographic data demonstrate that the shorelines, foreshores, and intertidal areas throughout the Fraser River delta and beyond have been settled and used as marine resource harvest locations for millennia and the Project is near recorded ethnographic named places and archaeological and historic sites.

The Project is assessed as having archaeological potential. A preliminary field reconnaissance is recommended to further refine the assessment and determine if the development may potentially pose a risk of impacting heritage resources. Should the field assessment confirm archaeological potential within the project area, further archaeological work may be recommended prior to commencement of any construction activities.

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Abbreviations

AIA	Archaeological impact assessment
AOA	Archaeological overview assessment
BP	Before present
CWH	Coastal western hemlock
CMT	Culturally modified tree
FLNRO	Ministry of Forests, Lands, and Natural Resource Operation
HBC	Hudson's Bay Company
HCA	*Heritage Conservation Act*
PFR	Preliminary Field Reconnaissance
RAAD	Remote access to archaeological data

1.0 INTRODUCTION

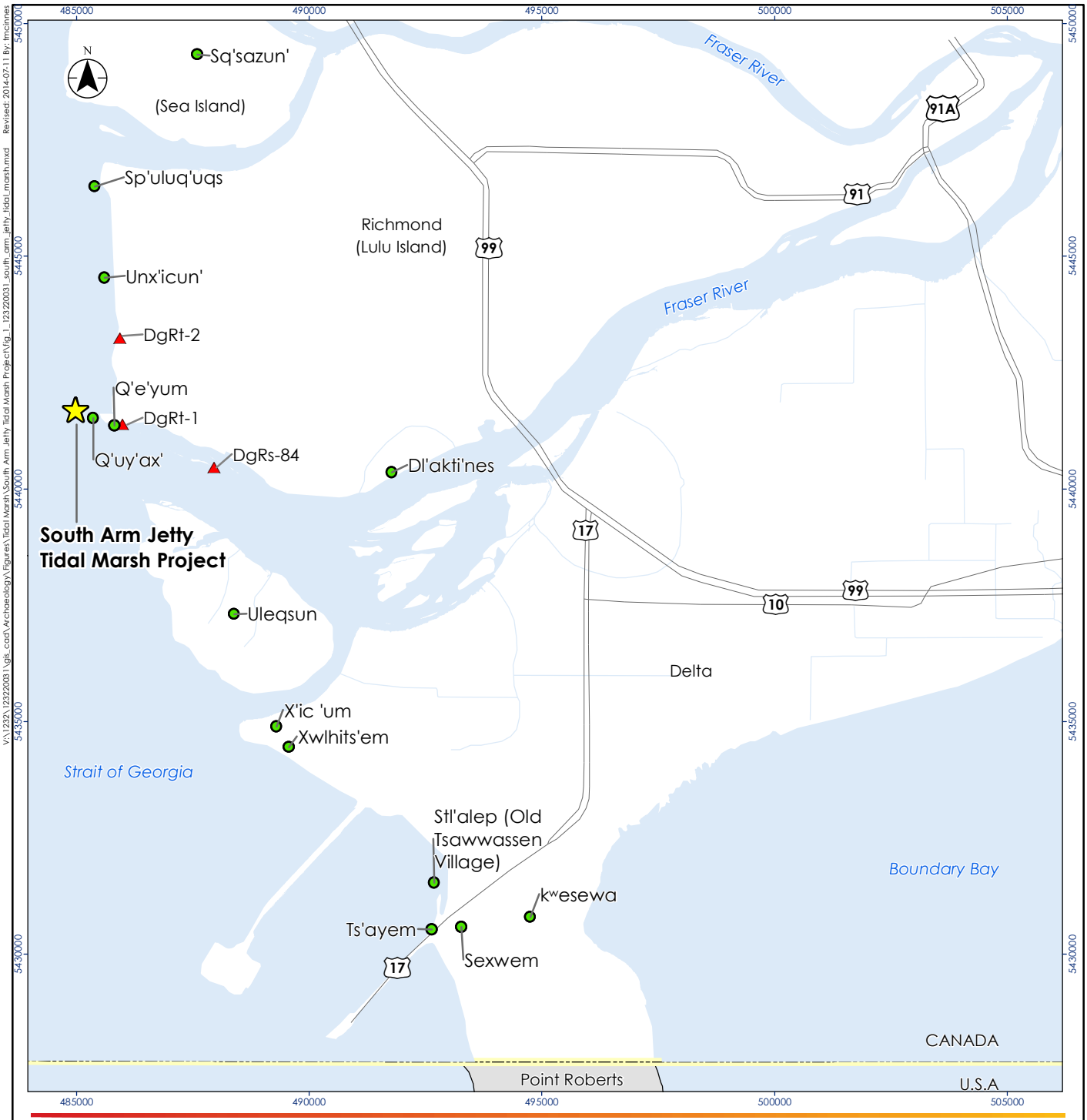
At the request of Port Metro Vancouver, Stantec Consulting Ltd. (Stantec) conducted an archaeological overview assessment (AOA) for the proposed South Arm Jetty Tidal March Project (the Project; Figure 1). The Project falls under federal jurisdiction and as such provincial heritage legislation is not applicable. However, this AOA was carried out to provincial standards under the terms and conditions of the *Heritage Conservation Act* (HCA).

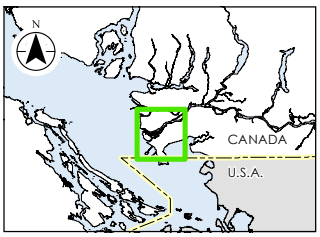
The general Project area comprises a minimum of approximately 3 ha of land located north of the Steveston Jetty at the mouth of the Fraser South Arm along the western shoreline of Lulu Island immediately west of Gary Point in Richmond, British Columbia (Figure 1 & Figure 2). According to the provincially maintained consultative areas database used to identify First Nations with treaty rights or asserted or proven rights to title, the Project falls within the asserted traditional territories of the Coast Salish member groups of the Hul'qumi'num Treaty Group, the Musqueam First Nation, the Semiahmoo First Nation, the Stó:lō Tribal Council, the Stó:lō Nation, the Tsawwassen First Nation, and the Tsleil-Waututh Nation.

Heritage resources can be precontact in age (the time before written records) or they can be historic. Historic sites can be of First Nations, Inuit, Metis, European, Euro-Canadian or another ethnic affiliation. Ethnographic heritage sites are locations reported as having been used or occupied by Aboriginal people in the past, which may or may not contain any physical evidence for such an occupation or use. A reported ethnographic site found to contain physical evidence changes the site to an archaeological site enhanced by ethnographic information. Ethnographic sites with no corroborative physical evidence are not treated as heritage sites according to present heritage legislation.

There are usually three stages to the heritage resource impact assessment and review process; an AOA, a detailed archaeological impact assessment (AIA), and an impact mitigation. The AOA is intended to identify and assess heritage resource potential, or the likelihood that sites are present. The objectives of the AIA are the identification and evaluation of heritage resources within a proposed development area, and also an assessment of possible impacts by the development on these sites. Impact mitigation is any course of action that results in the reduction or the elimination of the adverse impacts of a development. Mitigation, where required, usually involves site protection, project redesign or systematic data recovery, and normally involves archaeological excavation.

The present study was designed to satisfy the objectives of an AOA. The following results are based entirely on desktop analysis. The study was conducted without prejudice to First Nations treaty negotiations, aboriginal rights or aboriginal title.





- Ethnographic Named Places
- Proposed Tidal Marsh Project
- Archaeological Sites
- International Border
- Roads

0 1 2 3 4 Kilometres

1:125,000 (at original document size of 8.5x11)

Stantec

PORT METRO vancouver

Project Location
Steveston,
British Columbia, Canada

123220031
Prepared by TM on 2014-05-09
Technical Review by NP on 2014-05-27
Independent Review by RC on 2014-05-27

Client/Project
Port Metro Vancouver
South Arm Jetty
Tidal Marsh Project

Figure No.
1

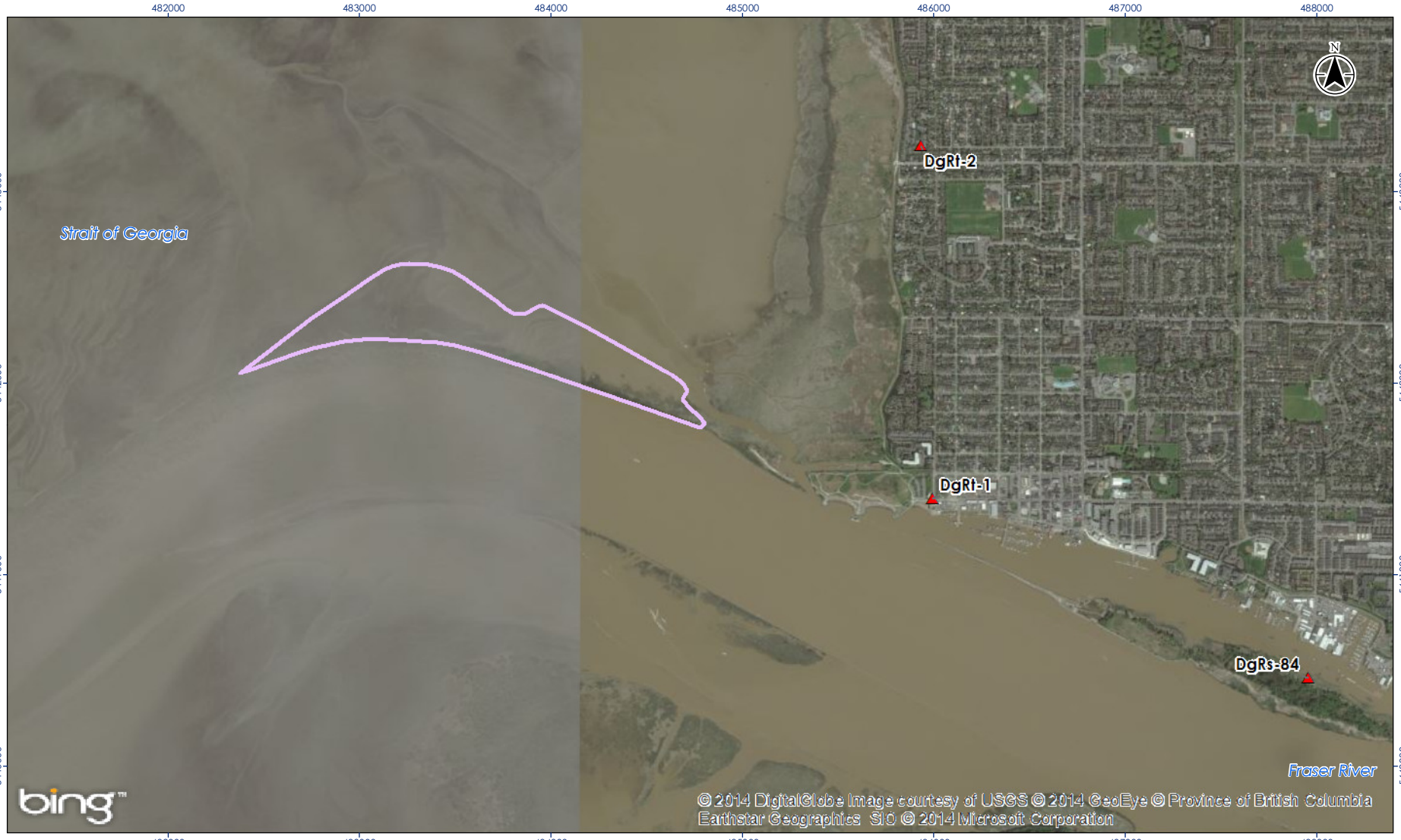
Title
General Project Location with nearby Ethnographic and Archaeological Sites

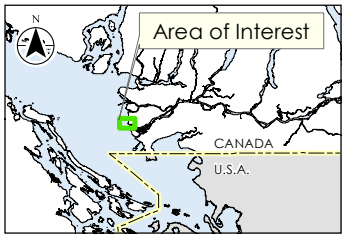
Notes

Coordinate System: NAD 1983 UTM Zone 10N
Base features produced under license with GovBC; GeoBC; DataBC; Canvec v12; CanVec v12, Government of Canada, Coast Salish Historical Atlas

Disclaimer: Stantec assumes no responsibility for data supplied in electronic format. The recipient accepts full responsibility for verifying the accuracy and completeness of the data. The recipient releases Stantec, its officers, employees, consultants and agents, from any and all claims arising in any way from the content or provision of the data.

V:\123220031\gis_cad\Archaeology\Figures\Tidal Marsh\South Arm Jetty Tidal Marsh Project.ch\fig_1_123220031_south_arm_jetty_tidal_marsh.mxd Revised: 2014-07-11 By: tmcinnes





▲ Archaeological Sites

Proposed South Arm Jetty Tidal Marsh Project

0 250 500 750 1,000 metres

1:30,000 (At original document size of 8.5x11)

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Base features produced under license with GeoBC; GovBC; Data BC
3. Orthoimagery © Bing, Microsoft product screen shot(s) reprinted with permission from Microsoft Corporation;

Stantec

PORT METRO vancouver

Project Location
Steveston, British Columbia, Canada

123220031
Prepared by TM on 2014-05-26
Technical Review by NP on 2014-05-27
Independent Review by RC on 2014-05-27

Client/Project
Port Metro Vancouver
South Arm Jetty
Tidal Marsh Project

Figure No.
2

Title
South Arm Jetty Tidal Marsh Project and nearby Archaeological Sites

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V:\123\123220031\gis\mxd\Archaeology\Figures\Tidal Marsh\South Arm Jetty Tidal Marsh Project\Fig. 2_123220031_tidal_marsh_south_arm_jetty.mxd Revised: 2014-07-11 By: tmcinnes

2.0 PROPOSED PROJECT

The Project is intended to restore or create fish and wildlife habitat in the intertidal zone. Construction will consist of creating artificial berms or the raising of surface elevations with fill to the approximate mean water level for the establishment of brackish marshes. The Project will cover approximately 3 ha of intertidal area (Figure 2).

3.0 METHODS

Available information concerning the location, nature and distribution of known prehistoric and historic resources in the vicinity of the Project was acquired using the Remote Access to Archaeological Data application maintained by the BC Archaeology Branch of the Ministry of Forests, Lands, and Natural Resource Operations (FLNRO).

A review of background literature dealing with ethnohistory and ethnography, history, archaeology and the paleoenvironment of the project region was conducted to place the Project in cultural contexts. A review of local and regional natural history can provide insight into past environmental conditions that may have influenced cultural adaptation and settlement. These palaeoecological studies, in concert with ethnographic, historical and archaeological data, help determine the likelihood that heritage resources are present within the development areas and the potential nature of those resources.

4.0 PROJECT AREA

The Project area is comprised of the western shoreline of Lulu Island immediately west of Gary Point in Richmond, British Columbia (Figure 1 & Figure 2).

4.1 PALAEOENVIRONMENT

The Project is located within the Fraser Lowland, a region characterized by low-lying and gently rolling hills of glacial drift separated by wide alluvium filled valleys. The Fraser Lowland is bounded by the Coast Mountains to the North, the Cascade Mountains to the east and southeast and the Strait of Georgia to the west. The Fraser River is the dominant watercourse which assumed its modern channel approximately 10,800 BP (before present). Since then, alluvial deposits have created more than 625 km^2 of new land at the mouth of the Fraser River. The Fraser River annually delivers an estimated load of 17 by 10^6 tonnes of sediments to the Fraser River Delta (McLean & Tassone 1991). There are a variety of habitats in and around the Fraser River delta. This diversity includes the freshwaters of the Fraser, Nicomekl and Serpentine Rivers, the brackish marshes of Sturgeon and Roberts Banks and the salt marsh at Tsawwassen, as well as the salt water environments of the Strait of Georgia and Boundary Bay (Groulx & Mustard 2004; Adams & Williams 2004).

The Project is situated within the Coastal Western Hemlock (CWH) zone. On average, the CWH zone is the rainiest biogeoclimatic zone in British Columbia with typically cool summers, with some hot spells and generally mild winters. The CWH zone tends to be dominated by western hemlock (*Tsuga heterophylla*) with western red cedar (*Thuja plicata*) and Douglas fir (*Pseudotsuga menziesii*) also being widespread. The poorly to moderately developed shrub layer consists mostly of salal (*Gaultheria shallon*), dull Oregon grape (*Mahonia nervosa*) and red huckleberry (*Vaccinium parvifolium*). The well-developed moss layer consists of Oregon beaked moss (*Kindbergia oregana*), step moss (*Hylocomium splendens*), lanky moss (*Rhytidiadelphus loreus)* and wavy-leaved cotton moss, which is also known as flat moss *(Plasiothecium indulatum*) (Pojar et al. 1994). Pojar et al. (1991) provide a comprehensive list of avian and mammalian species that are commonly found in the project area.

During the Pleistocene, the area was overridden by glacial ice. The resulting isostatic depression resulted in relative sea-levels of approximately 200 m above present (Clague et al. 1982). By about 13,000 BP the deglaciation of the area was in effect and relative sea-levels had begun to fall (Armstrong 1981; Mathewes 1973). By 11,000 BP, the Fraser River had stabilized (Mathews et al. 1970). Relative sea-levels continued to fall, reaching an early Holocene lowstand of about 12 m at approximately 8,000 BP. Relative sea-levels subsequently rose to modern levels by about 5,000 BP (Clague et al. 1982).

4.2 ETHNOGRAPHY

The central Coast Salish groups described in this report are speakers of Halq'eméylem dialects, (Smith 2001; Suttles 1990; Thompson & Kinkaid 1990).

Prior to European contact, the Coast Salish used rectangular cedar plank houses as permanent dwellings with villages consisting of one or more of these houses as well as a number of smaller buildings. Permanent plank or bark-covered houses were constructed at well-established resource procurement locations. Temporary shelters of rush mats were used in areas utilized for shorter periods of time (Barnett 1955; Suttles 1974, 1979, 1990).

A wide variety of objects including woodworking tools, weapons and hunting and fishing gear were manufactured by flaking stone, grinding slate and working bone, antler and shell. Plant materials were extremely important, with red cedar (*Thuja plicata*) being used for houses, canoes, boxes, clothing, bags, baskets and mats. Blankets and clothing were sometimes woven from materials which included the hair of dogs (*Canis familiaris*) and mountain goats (*Oreamnos americanus*) (Schulting 1994; Wells 1966).

Fishing, particularly of salmon (*Oncorhynchus* sp.), was the principal economic activity among the Coast Salish. Both land and sea mammals were taken by a variety of methods. Birds were also taken. Plant foods, particularly blueberry (*Cyanococcus*), cranberry (*Vaccinium oxycoccus*) and braken ferns (*Pteridium aquilinum*), were also gathered for subsistence (Pojar & Mackinnon 1994; Suttles 1990; Turner 1974).

The contact period between Europeans and First Nations on the central and south coast commenced with the arrival of the *Spanish Quimper Expedition* in 1790 and the *Navarez Expedition* in 1791. Direct contact within the Project area began the following year with the Spanish ships of Galiano and Valdez, and the English ships of Captain Vancouver. A chance meeting occurred between their ships at Punta de Langara (Point Grey) in June 1792. The ships' logs for this period contain the earliest ethnographic descriptions of the local Salish peoples. Galiano described his first encounter with the Musqueam at Punta de Langara and the ship's artist Jose Cardero captured the first images of the local peoples from the Project area.

> They displayed an unequalled affability together with a war-like disposition. They traveled provided with many good arms such as iron pointed spears half a yard long, quivers full of arrows with tips of the same metal and of flint, bows and clubs, and hold the latter in such high esteem that it is not possible to get one in exchange for knives of Monterrey shells. They also brought in their canoes some boxes and baskets with stone harpoons, spear heads, seaweed lines, and other instruments and requisites for fishing (Wagner 1933: 260).

At the project location, Galiano noted, "satisfied that there was water in the mouth which the Punta de Langara forms the coast, we bore up and ran in to anchor on the east of the point where we knew there was a sand flat." His first observations of the Fraser River revealed the difficulties of navigating the Fraser River against its powerful currents, "… we had information that the current in the place where we were going to anchor ran 4.5 miles an hour, and would probably be much more rapid in the interior of the channel. We were already in water almost fresh, and saw great logs floating, these signs confirming us in the idea that the inlet we called Floridablanca was the mouth of some large river" (Wagner 1933: 262).

At the same time, as Captain Vancouver sailed north around the western point of Boundary Bay he became aware of the shallow waters and debris-choked shoals in the Fraser River delta between Point Roberts and Point Grey.

> …our progress along the eastern shore materially impeded by a shoal that extends from Point Roberts N. 80 W. seven or eight miles, then stretches N. 35 W. about five or six miles further, where it takes a northerly direction towards a low bluff point (Point Grey). Along the edge of this bank we had soundings from ten to one fathom, as we increased or decreased our distance from the eastern shore; to approach which all our endeavors were exerted to no purpose… (Vancouver 1801:187).

Village structures were observed in some detail by the earliest visitors to the area. At Point Roberts in June 1792, Captain Vancouver's botanist, Archibald Menzies described a large deserted village that was in ruins. "Each house appeared distinct and capacious of the form of an oblong square, and they were arranged in three separate rows of considerable length; the beams consisted of huge, long pieces of timber placed in notches on the top of supporters

14 feet above the ground… three supporters stood at each end for the longitudinal beams and an equal number were arranged on each side for the support of smaller cross beams in each house" (Menzies 1792:148).

In 1808, Simon Fraser canoed down the Fraser River, past the site of the Project. Although his contact with the local peoples within the general Project area was brief, he described something of how the people lived.

> On the right we noticed a village called by the natives Misquiame (Musqueum)… here we landed, and found but a few old men and women; the others fled into the woods upon our approach. The fort is 1,500 feet in length and 90 feet in breadth. The houses, which were constructed as those mentioned in other places, are in rows, besides some that are detached (Lamb 1960: 106).

Sustained contact between Europeans and local First Nations within the general Project area did not commence until nearly two decades later when Hudson's Bay Company (HBC) employees arrived with the intention of establishing a trading fort. Fort Langley was built in 1827 on the Fraser River approximately 50 km from the Fraser River delta. Prior to this construction, small groups of HBC employees would occasionally travel down the river to the delta. In 1824, HBC employee John Work canoed down the north arm of the Fraser River, which he described:

> … there are two other channels on the south side and a large one supposed to be on the north side. The channel through which we came was sounded in several places towards its discharge and found to be from 7 to 3.5 fathoms about high water. The land at the entrance of the river is very low and swampy with some few scattered pines of small size and bushes (Elliot 1912: 223).

Perhaps the darkest entries in the early journals and ships' logs were descriptions of evidence for a smallpox epidemic that devastated the Coast Salish in the 1770s. On the lower Fraser near present-day Lulu Island, HBC traders were approached by four canoes that contained seventeen Coast Salish, about which John Work wrote, "the old chief seems to be marked with the small pox…" (Elliot 1912: 222). Also in 1824 John Scouler, ship's surgeon aboard the HBC ship *William and Anne,* observed smallpox scars on the Indians on the south and central Salish coasts. As they sailed northward it was apparent that the disease lived on in the memories of the Indians in Puget Sound who, "speak about it with horror…" At Point Roberts, Scouler met a Cowichan chief who, "had in his retinue an Indian deeply marked with smallpox…" (Scouler 1905: 203).

Ethnographic researchers arrived relatively late on the south coast. It was not until the late 1890s with Franz Boaz and early 1900s with Charles Hill-Tout that the first professional ethnographers began to look at Salish culture at a time when they believed that traditional Indigenous knowledge would soon be extinguished under the sprawling weight of European settlement. By mid-20th Century, more dynamic approaches to participatory ethnography by Homer Barnett (1938), Wilson Duff (1952), Diamond Jenness (1974) and Wayne Suttles (1987) have yielded more balanced and insightful research on Coast Salish society.

For the peoples who resided within the general Project area, the marine and riverine environments provided most of their resources. Fishing was a paramount activity. Seasonal salmon runs provided the mainstay of the people's diet, while sturgeon, halibut and eulachon were also important. For the Musqueam, Tsawwassen and Semiahmoo villages on the coast, shellfish were also an important dietary addition. The Fort Langley journals provided descriptions of large movements of people following the huge salmon runs from the Fraser River delta up the canyon rapids as far as Yale. There were summer villages at Point Roberts where large congregations of Saanich from Vancouver Island, Lummi from present-day Washington State and local Semiahmoo groups established reef net fishing locations. Galiano described the Point Roberts fishery in 1792 as a location with, "an incredible quantity of rich salmon and numerous Indians" (Wagner 1933: 186-187). There were large Cowichan summer villages on the banks on the south arm of the Fraser River on Lulu Island, while large groups of Musqueam joined Cowichan, Nanaimo and Squamish people camped near Fort Langley.

In the vicinity of the project area, Point Roberts was the most important reef net fishing location in the south Strait of Georgia. The Fort Langley journals described Point Roberts where, "the quantity of salmon now caught there is immense and that all the Indians on the coast southward have resorted to the Point Roberts villages" (Maclachlan 2000:123). Barnett's research on the Tsawwassen reflected the importance of salmon to the seasonal subsistence strategies of the people living at old Tsawwassen village at Point Roberts.

> Much of the summer fishing and gathering was done from this base, but the people of Tswasan also had a camping ground on Lulu Island (*Dl'akti'nes*; Figure 1) where they caught sturgeon from May until July. At still another place... (*kikayt*; near New Westminster) sockeye were dried during the latter month. According to my Tswasan informant, near-by sites were visited by the Cowichan and Nanaimo people in the summer (Barnett 1955: 34).

There were several other options for catching salmon, as different species of salmon were harvested through different methods. Large quantities of salmon could be caught in fish weirs by barring up part of a shallow stream or creek. According to Suttles (1990: 457), "In the channels near the mouth of the Fraser, the Musqueam and Tsawwassen had tidal ponds made of long rows of stakes driven into the bottom, in which they took larger salmon and sturgeon." Suttles described a Musqueam sturgeon trap as a tidal pond that was harvested at low tide. These massive fish could also be gaffed or harpooned in the bays around the mouth of the Fraser. Suttles (1987: 243) reported the Semiahmoo and Musqueam traditions that the man who caught the sturgeon, "always gave his paddler the rear portion." Chinooks and Cohoes were also caught in the sea from winter through spring by trolling. Trawling nets resemble purses fixed to long poles and dragged between two canoes. Dip nets were fastened to the ends of poles and used in back eddies away from the strong currents on the Fraser. Fish racks dotted the shoreline in areas where fish could be easily taken. Fish split and dried in the wind and sun could then be stored for winter (Suttles 1987).

The importance of shellfish to the Musqueam is underscored by the immense shell midden deposits found in their villages on the coast. The traditional village cəsna?əm, which was labeled as the "Great Fraser Midden" by early investigators was described as 1,400 feet in length and 300 feet wide, with an average depth of between 5 and 15 feet, covering nearly 4.5 acres. The midden was mainly comprised of the remains of clam and mussel shells (Maud 1978: 21).

The local Coast Salish also hunted deer, elk, bear and other animals to supplement their marine diets. Plants were vital, both for food and as the raw material for clothing, shelter, containers, watercraft and many tools. A wide range of plants provided edible sprouts and stems, berries and nuts, and bulbs and roots were harvested. Starchy bulbs such as brake ferns, camas, wapato and wild carrots were a popular supplement to the marine diet (Bouchard & Kennedy 1998; Turner 1974).

During winter, many families would come together in large villages comprising of wooden plank houses. Some of these structures were small single family dwellings while others were massive, multi-family houses. Other, very large structures were the site of ceremonies and community feasts. Each spring, people left the villages for summer camps and resource sites. Sometimes they took the planks from the winter houses, lashed them across two canoes, and transported them to their summer homes (Barnett 1955).

Ethnographic researchers recorded stories from First Nations peoples, who had vivid memories through the stories of their Elders, of the many diseases that decimated their communities. Their narratives which describe smallpox devastation resound throughout the lower Fraser River watershed. Hill-Tout's account of a large communal burial pit in a village midden at present-day Stanley Park described his consultants' beliefs that these mass burials were the result of some pestilence or epidemic. "The tribe inhabiting this district was almost decimated with small-pox. So terrible was the scourge that they abandoned their village site after burying all their dead in a big hole" (Maud 1978: 54). Wayne Suttles' Elder consultants recalled stories of entire villages along the lower Fraser that were severely depopulated due to smallpox. A village near the mouth of the Fraser River, whose name translated into English as "Hazelberries" disappeared after the 1770s smallpox epidemic (Suttles 1955).



Photo 1 Fish Drying Racks at Point Roberts

SOURCE: Retrieved on 20 April 2014 from: http://www.surreyhistory.ca/activities.html

The Fort Langley Journals have yielded important ethnographic information from the first permanent European settlement in Coastal Salish territory, which was a magnet for trade for the people of the Fraser River delta. According to these journal entries, armed, hostile village raids and slave taking were rampant among the Coast Salish. On 11 August 1828, Chief factor McMillan wrote that a Musqueam chief had, "just arrived from the Yeukeltas (Lekwiltok) where he went to try to recover his wife and daughter, who were taken along with 30 or more women and children in the last attack. He did not get them as they were already sold to Indians farther to the northward" (Maclachlan 2000: 71). Mitchell's research (1984: 44) into the slave trade on the North Pacific in the 1800s related that it was the usual practice for the Lekwiltok to "trade their prisoners to the Quaghcuils (Fort Rupert Kwakwaka'wakw) who trade them to the Heiltsuk."

According to one ethnographer's research, a protective bunker was a prominent feature of coastal village life. Homer Barnett (1938:128) wrote that:

> Of distinct interest from a wider point of view is the presence of semi-subterranean defensive (retreats) west of the Coast Range. They were known from Langara to Butte Inlet and were used as refuges in time of war. Furthermore, the Muskwium on Point Grey built underground dwellings of exactly the same type as those farther up the valley. They existed side by side with the plank shed roofed habitations already described, and were a luxury for those who could afford them.

The shores of Point Grey have a long history of defense. According to Musqueam sources, lookout stations were established behind what is now the Museum of Anthropology facing the Strait of Georgia. The Musqueam band used this site as a lookout for approaching northern tribes who were intent on looting and kidnapping, in particular the Lekwiltok from Johnstone Strait. If approaching war canoes were observed, fleet-footed runners were sent along established trails to alert their friends and relatives at the Kwantlen and Katzie villages on the lower Fraser. The Musqueam could then counter the aggressor by embarking their war canoes or by retreating to their defensive village positions (Norman, n.d.).

4.3 ARCHAEOLOGY

A large number and variety of archaeological studies have been conducted in the Fraser Lowland. A summary and review of these studies can be found in Kristensen et al. (2009).

The most important archaeological site unearthed in the vicinity of the Project area is called cəsna?əm or the "Marpole Midden" which shows continuous occupation for at least 4000 years, up to about 200 years ago. Harlan Smith, who worked for the Jessup North Pacific Expedition from 1897 to 1911, collected ancestral remains for his comparative collection for the American Museum of Natural History. Several decades later, Charles Hill-Tout excavated portions of the site for the Art, Historical and Scientific Association of Vancouver. In the 1950s UBC professor Charles Borden undertook salvage excavations at the site ahead of the construction of the Fraser Arms Hotel, which destroyed a portion of the site. During excavations at the site in 2012, Musqueam First Nation members and their supporters staged protests against the construction of a proposed condominium development within the site to prevent any further impact.

The First Nations groups in whose asserted traditional territories the Project area is situated are Coast Salish. A great deal of archaeological research has focused on the Coast Salish and a generally accepted culture history has been formulated. The following generalized sequence is based primarily upon the works of Borden (1970,1975,1976); Ham (1982); Ham et al. (1984); Matson (1976,1992) and Mitchell (1971,1990).

The earliest culture type identified is variously referred to as Old Cordilleran (Matson 1976;1992), the Lithic culture type (Mitchell 1971), the Pebble Tool Tradition (Carlson 1990) or the Proto-western Tradition (Ham 1982). This little known period, which extends from about 8,500 to 5,500 BP, is characterized by an artifact assemblage consisting of abundant chipped stone artifacts, including cobble tools and leaf-shaped bifaces, along with bone and antler tools (Carlson 1990; Matson 1992). Faunal remains from the Old Cordilleran component at the Glenrose Cannery site (**DgRr-6**), located on the South Arm of the Fraser River, south of Annacis Island, reflected an economic pattern directed towards the hunting of land mammals with deer (*Odocoileus hemionus*) and wapiti (*Cervus elaphus*) being the two most important. Seals, salmon (*Oncorhynchus* sp.), sticklebacks (*Gasterosteus aculeatus*), eulachon (*Thaleichthys pacificus*), flatfish and bay mussel (*Mytilus edulis*) were also present (Matson 1976, 1992).

The Charles Culture and the Locarno Beach and Marpole phases form a construct known as the Proto-Coast Salish Tradition (Ham 1982), a series of archaeological cultures directly ancestral to the ethnographic Coast Salish culture.

The Charles Culture type (5,500–3,300 BP) may be the earliest archaeological phase that is directly ancestral to the ethnographically documented Northwest Coast pattern. This period saw a continuation of some tool types from the previous culture type and the introduction of new types. New tool types included chipped stone scrapers, drills, stemmed bifaces as well as ground slate, bone and antler implements (Ham et al. 1984). A well-developed woodworking technology is inferred from the presence of adzes and wedges and the remains of several large residential structures located along the Fraser River at Agassiz and Hatzic, and possibly at Fort Langley (James 1990; LeClair 1976; Matson 1994). Pratt (1992) suggests that Charles Culture faunal remains are indicative of a mixed economy where land and sea mammals were exploited.

Although salmon were exploited to some extent, specialization had not yet begun (Pratt 1992; Matson 1992). Thus, Pratt (1992) views the Charles Culture as essentially a hunting population. Mason (1994) has argued that the presence of several large residential structures at sites located along the Fraser River suggests that specialized salmon exploitation had occurred by this period. It is doubtful that a hunting population would have required, or invested the necessary time and energy into the large structures found at the Hatzic Rock (**DgRn-23**) and Maurer (**DhRk-8**) sites (Mason 1994; LeClair 1976).

Eldridge (1991) argues for intensive salmon harvesting, processing and storage at the mouth of the Fraser River by 4,600 BP based on the presence of intertidal stakes at the Glenrose Cannery site thought to represent the remains of fish weirs. Eldridge further suggests that the Northwest Coast pattern was likely well established during the Charles Culture, and elements such as massive architecture, wealth accumulation, hereditary status and social ranking were in place at this time. Cannon (1993) has argued for the presence of salmon specialization and storage technology at Namu on the central coast prior to 6,000 BP suggesting that similar data are waiting to be uncovered along the Fraser River. Ham et al. (1984) suggest a broader economic base may have led to stratification in social status as evidenced by burial practices, use of labrets and possibly cranial deformation. In contrast, Pratt (1992) suggests the existence of an egalitarian society despite the possible presence of status differentiation reflected in burial remains at Tsawwassen and possibly Pender Canal.

The Locarno Beach phase or culture type (ca. 3,500/3,300–2,500 BP) is typified by a varied resource base showing a greater reliance on shellfish, birds and sea mammals, although land mammals and fish still are of prime importance. Tool types show continuity from earlier periods but reflect changing styles and different relative frequencies. Evidence of cordage, basketry and other wood items has been recovered from water saturated sites in the Lower Mainland (Archer & Bernick 1990; Borden 1976). Evidence of large residential structures is lacking, but these dwellings likely existed based on the nature of tools found in artifact assemblages and the evidence of large Charles Culture dwellings.

The Marpole phase (Burley 1980; Clark 2013; Mitchell 1971) spans the period between 2,000 and 1,500/1,100 BP and is characterized by an emphasis on a pecked and ground stone industry. There is also a noticeable rise in (non-lithic) bone and antler industries and increasing reliance on composite tools. Fishing becomes even more important though the economy is still broadly based. Important artifact types are hand mauls, unilaterally barbed non-toggling harpoons, pecked stone zoomorphic bowls and thin ground slate knives. During Marpole, a rich artistic tradition develops which is expressed in stone and antler sculpture, slate and shell disc beads and decorated items of native copper.

Marpole settlements are relatively well known. Large house platforms have been discovered at Garrison (Kornbacher 1989), Beach Grove (Matson et al. 1980), False Narrows (Burley & Knüsel 1989), Whalen Farm (Matson & Coupland 1995), Dionisio Point (Mitchell 1971), and possibly Tualdad Altu (Chatters 1989). Site distribution generally shifts to riverine locations, many of which are located on the Fraser River.

Conversely, elevated inland shell midden sites have been identified on the Gulf Islands and on the mainland that contain artifacts commonly associated with Marpole assemblages. This move to inland locations could be attributed to increased warfare and raiding, or other population pressures that influenced small groups to move inland to less desirable locations (Wilson 1988). Archaeological studies at inland shell midden sites have been conducted at **DeRu-44** on Saltspring Island (Wilson 1988) and on Gabriola Island at **DgRw-200** and **DgRw-196** (Wilson 1987). Wilson offers another explanation for inland shell middens during the Marpole phase; the zoomorphic bowl found at **DiRw-16**, clearly dating to the Marpole phase, is identified as part of a shaman's retreat–offering yet another explanation for elevated inland shell midden sites (Wilson 2000).

Past studies (Burley 1980; Clark 2013; Matson et al. 1980) have shown significant geographic and temporal variation within the Marpole culture type. Two subphases of Marpole have been proposed to explain this diversity. These subphases have been interpreted as a result of unequal access to the Fraser River fishery (Clark 2013).

Ascribed status differentiation is clearly present with the rise of cranial deformation around 2,000 B.P. (Burley & Knüsel 1989). Rich burial inclusions are also present during the Marpole phase (Burley & Knüsel 1989; Matson 1976).

The *Developed Coast Salish Tradition* at around 1,400 BP to European contact (Borden 1954; Ham 1982) is directly ancestral to present Coast Salish culture and contains a single culture type, though several regional variants have been proposed. These include Late Marpole (Fladmark 1982; Matson 1976, 1992), San Juan (Carlson 1960), Strait of Georgia (Mitchell 1971, 1990), Gulf of Georgia (Ham 1982) and Stselax (Borden 1954). This culture type is characterized by a marked decrease in chipped stone and a concomitant increase in ground stone and bone artifacts.

4.4 HISTORY

The written record of the general Project area that illustrates the historical events along the shoreline between Point Grey and Steveston shares an interesting historical continuity with the archaeological past, as this coastal landscape has continued to attract peoples from distant places. Today these lands hold some of the most expensive real estate in North America, including the Province's first University, an international airport and one of the most prestigious golf courses in western Canada.

The early historical period was recorded through the journal entries of various Hudson's Bay traders who occasionally travelled through the Project area, but by the 1850s, European immigration on a large scale began to make lasting alterations to the Indigenous landscape on the lower mainland. Additional pressures were placed on the local aboriginal communities when another smallpox epidemic struck the west coast in 1862 to 1863, and in 1865, a 21 year timber lease at Point Grey was granted to the Vancouver Island Spar, Lumber and Sawmill Company. The landscape was further divided with the government survey of the Musqueam Reserve in 1870 and over the next several years (1876 to 1877) three reserves were granted to the Musqueam people, two of which border the Project area. The city grew rapidly following completion of the Canadian Pacific Railway transcontinental line from Eastern Canada, allowing for continuous rail service in the late 1880s. The Point Grey lands set aside for the new University of British Columbia were first cleared in 1912. Several batteries of heavy guns were positioned along strategic points at Point Grey in 1914 to defend the city against assaults from the German navy. During WWII in 1942, several defenses were constructed across the Lower Mainland, including gun stations at Point Atkinson, Stanley Park, and Steveston, with Point Grey acting as a pivotal defense location (Norman n.d.)

The Fraser River delta is the entrance to one of the most important salmon rivers in North America and much of the historical record centres around the salmon fishery. Steveston was originally a small town founded in 1880 by William Herbert Steves, although the Steveston waterfront had served for centuries before European arrivals as salmon fishing and processing locations where countless generations of Coast Salish women have cleaned and prepared salmon. European owned fish canneries on the Fraser River were well established by the turn of the 20th century. Built in 1894, the Gulf of Georgia Cannery was the largest cannery in British Columbia until 1902. It gained notoriety as the "Monster Cannery" for packing more than 2.5 million cans of salmon in 1897. By 1905, 14 canneries were operating in Delta and an additional 21 canneries in Steveston along the Fraser River (Yesaki et al. 2005). The canning industry declined by the mid-20th century, with only 16 canneries remaining out of 97 that had been operating during World War I.

4.5 SITE TYPES

A variety of archaeological site types are commonly found throughout the Lower Mainland and some of these site types have been located near the project area. The descriptions of the site types provided below is intended to provide a more thorough understanding of the sites identified near the Project as well as those that could be potentially within or near the project area but yet unidentified.

4.5.1 Shell Midden

Shell midden is typified by the presences of shellfish (clam, mussel, scallop, etc.) shells discarded after the consumption of shellfish. Shell midden also commonly contains charcoal, ash and burnt sediments, fire-broken rock, and stone, bone, antler, and shell artifacts. Shell midden deposits vary from small pockets to very large sites many hundreds of metres long. They are usually but not only found along or near marine and riverine shorelines. Shell midden sites often represent villages or seasonal encampments where shellfish were consumed in quantity. Shell midden deposits are unique inasmuch as the shells neutralize soil acidity, such that archaeological materials that usually degrade quickly are preserved. Artifacts of bone and antler, faunal remains, and human bone all preserve in shell midden.

4.5.2 Wet Sites

Organic material is rarely preserved in British Columbian archaeological sites and only a few "wet sites" are known across the entire Northwest Coast from Alaska to northern California. Although rare, a description of this site type is included since the project area has the conditions for preservation of organic material. Ordinarily, bacteria and fungi cause the rapid decay of virtually all organic materials in a brief time. In wet sites, the pores between soil particles where bacteria and fungi are normally found are filled with water instead. This creates an oxygen-free environment which greatly inhibits natural decay. The preservation of organic material is a unique but highly important aspect of Northwest Coast archaeology given its importance in reflecting ethnic identity. Whereas stone, bone, antler and shell industries often reflect some range of past activities, basketry, cordage and wooden items provide insight in to the full range of those activities.

4.5.3 Lithic Scatters and Isolated Lithic Finds

Lithic scatter sites consist of surface and/or subsurface scatters of stone tools and/or flakes, the result of lithic raw material processing and tool production or tool maintenance. Isolated lithic artifact finds consisting of single artifacts are included in this category. These sites lack structural remains and often reflect little diversity in their artifact assemblages, the result of less intensive and more specialized activities than are reflected at village sites. Lithic scatters are frequently identified in surface exposures, although archaeological subsurface testing is required to establish their boundaries and depths. They can reflect activities such as procurement and/or processing of food or raw minerals. They can also reflect seasonal or short-term campsites, hunting lookouts or various other activities.

4.5.4 Subsistence Features

Subsistence features are related to the collection, processing or storage of food, and are often found in the vicinity of water sources and are often a component of larger, multi-function sites such as village and defensive locations. Subsistence features may also be associated with

temporary hunting or fishing camps away from principal habitation sites. Subsistence features can include roasting areas and shellfish processing areas, intertidal fish weir complexes, and other ancient ground-altering disturbances that indicate a wide variety functions.

4.5.5 Human Burials

This category includes sites which contain material remains and features associated with prehistoric mortuary practices. Interments in the historic period can also be reported in association with recorded archaeological sites. Information about historic cemeteries or individual or family interments can often be acquired through documentary research and consultation with local residents. Prehistoric burials are difficult to identify because of their generally unmarked nature, although cairns and other visible related structures can be associated with burials.

4.5.6 Trails

Trails are transportation corridors frequently following well-traveled game trails around and to lakes, rivers, creeks and other geographical features. Because of their typically ambiguous nature, trails are rarely identified as archaeological sites, but instead are noted as historic and/or traditional land use features. It is assumed that historic and traditional use trails were present in the project region although disturbances due to industrial development would have obscured most, if not all, physical evidence of trail locations.

4.5.7 Historic Sites

Historic sites relate to human activities during the time period documented by written records. Historic sites in the project region relate primarily to resource extraction such as logging and agriculture, but also include ranching and small scale hunting and fishing. Sites can range from large complex sites which represent a wide range of activities to task specific sites which evidence little diversity in activity. Thus, the scientific, historic, and ethnic significance of this site type varies greatly and should be assessed on an individual basis. Such research should take into account archaeological remains, standing structures, documentary evidence, historic significance (links to important events, individuals and developments in local, regional and national history), ethnic and economic significance.

Current British Columbia legislation requires archaeological evaluation of all sites older than AD 1846 and allows added flexibility with more recent resources. However, post-1846 sites may also require archaeological work and may be protected by legislation depending on the nature and significance of the site.

4.5.8 Heritage Wreck Sites

Thousands of ship wrecks are submerged in the ocean off the British Columbian coasts, while many more lay wrecked in interior lakes and rivers. The *Canada Shipping Act* (R.S. Can. 1985, c.S-9, Part VI) prohibits removal of any artifacts from heritage wreck sites without a permit.

Damaging or altering a heritage wreck or the removal any heritage object from a heritage wreck is also contravenes the British Columbia's *Heritage Conservation Act* [RSBC 1996]. A "heritage wreck" means the remains of a wrecked vessel or aircraft if…

1. Two or more years have passed from the date that the vessel or aircraft sank, was washed ashore or crashed
2. The vessel or aircraft has been abandoned by its owner and the government has agreed to accept the abandonment for the purposes of this *Act*

5.0 RESULTS

5.1 NEARBY ARCHAEOLOGICAL AND HISTORIC SITES

No archaeological sites are within 500 m of the Project. However, two archaeological sites and one historic site are located within 2 km of the Project (Figure 1 & Figure 2)

- **DgRt-1**: This site is located on Lulu Island at Gary Point, on a recent part of the Fraser River Delta. It has been disturbed through construction of two dykes and a few canneries. The site is described as a historic building and a precontact habitation feature (Bouchard & Kennedy 1988).
- **DgRt-2**: This shell midden and lithic scatter measuring 100 m x 50 m is located on the west end of Lulu Island. The site is considered destroyed (Bouchard & Kennedy 1988).
- **DgRs-84**: This is a historic shipwreck site found near the north shore of Steveston Island. This is described in the site report as a large wrecked barge and a log boom ground at the island. The site form does not cite a reference (RAAD 2014).

5.2 TRADITIONAL USE SITES

A number of traditional use sites have been documented in Metro Vancouver. Tobias (2000:3) defines traditional use as follows:

> Use refers to activities involving the harvest of traditional resources; things like hunting, trapping, fishing, gathering of medicinal plants and berry picking, and travelling to engage in these activities. For any given community or nation, use occurs over a specific geographic area. Occupancy refers to the area which a "particular group regards as its own by virtue of continuing use, habitation, naming, knowledge and control." These two geographic areas are usually

different in extent. Use mapping documents the locations where activities like hunting, fishing and travelling occur. Occupancy mapping, by contrast, records the following types of information: stories and legends about places; indigenous place names; habitation sites like cabins and burial grounds.

These types of sites can also be defined as ethnographic heritage sites although this term is more commonly associated with sites identified with specific place names or documented ethnohistoric sources.

There are 13 recorded place names along the shorelines and between 8 km and 1.4 km from the Project (Figure 1). Table 5-1 provides the names, significance and location of the recorded ethnographic heritage sites (information summarized from Carlson 2001; Bouchard & Kennedy 1991).

Table 5-1 Place Names, Significance, and Location In Relation to the Project

Place Name	Significance	Location
Sq'sazun'	Geographic location	On Sea Island
Q'úy'ax'	Habitation feature	On the Sturgeon Bank Jetty
Q'é'yum	Unknown	On the Steveston Jetty
Uléqsun	Unknown	Westham Island
Dl'akti'nes	Cowichan fishing camp/berry harvest location	South shore of Lulu Island
Unx'icun'	Unknown	West shoreline of Lulu Island
Sp'úluq'uqs	Unknown	West shoreline of Lulu Island
X'ic'um	Unknown	On mainland/south of Westham Island
Xwlhits'em	Unknown	On mainland/south of Westham Island
Kʷə's əwa	Fishing camp	On Point Roberts
Stl'álep	Old Tsawwassen Village	On Point Roberts west coast
Ts'áyem	Fishing camp	On Point Roberts
Sexwém	Unknown	On Point Roberts

*NOTE: this list is not exhaustive

5.3 EVALUATION OF ARCHAEOLOGICAL POTENTIAL

The known archaeological sites and traditional place names fringing the project area (Figure 1 and Figure 2; Table 5-1) demonstrate a long history of settlement and use of the area, and the potential for archaeological resources to be present. The ethnohistoric literature also indicates that this locality was heavily used by many Coast Salish groups during their seasonal subsistence activities, further raising the potential for archaeological deposits to be present within the project area. Specifically, the project area may contain inter-tidal wet-sites such as fish weirs or other resource extraction features.

6.0 RECOMMENDATIONS

A Preliminary Field Reconnaissance (PFR) is recommended prior to development to further refine the desktop assessment. The PFR is recommended to evaluate the full extent and nature of previous impacts within the development area, identify any visible heritage resources, and further determine the likelihood of buried heritage resources. Should the field assessment confirm archaeological potential in the project area, further archaeological studies may be recommended prior to the commencement of any construction activities.

These recommendations apply solely to physical archaeological evidence of past human activity and in no way attempts to encompass any heritage concerns of the various First Nations people with asserted traditional territories in the project area. Attempts will be made to include First Nation representatives in whose traditional territories the project is located as members of the PFR field crew.

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Appendix IR2020-1.1-A5

South Arm Jetty Tidal Marsh Preliminary Field Reconnaissance

Stantec Consulting Ltd.
500 - 4730 Kingsway, Burnaby BC V5H 0C6
Phone: (604)436-3014 | Fax:(604) 436-3752

April 2015 – Final Report
File: 123220031

Via Email: Gord.Ruffo@portmetrovancouver.com

Port Metro Vancouver
100 The Pointe
999 Canada Place
Vancouver, BC

Attention: Mr. Gord Ruffo
Program Manager, Habitat Enhancement Program

Dear Mr. Ruffo,

Reference: South Arm Jetty Tidal Marsh Preliminary Field Reconnaissance

At the request of Port Metro Vancouver, Stantec Consulting Ltd. (Stantec) conducted a preliminary field reconnaissance (PFR) of Port Metro Vancouver's proposed South Arm Jetty Tidal Marsh (Figure 1). According to the provincially-maintained Consultative Areas database used to identify First Nations with treaty rights or asserted or proven rights to title, the project area falls within the asserted traditional territories of the Coast Salish member groups of the Hul'qumi'num Treaty Group, the Musqueam Indian Band, the Semiahmoo First Nation, the Stó:lō, Tsawwassen First Nation, and the Tsleil-Waututh Nation. Based on an archaeological overview assessment (AOA) conducted by Stantec (2014), the project area was assessed as having archaeological potential based on proximity to known archaeological sites in the region, ethnohistorical descriptions of Aboriginal land use of the project area and traditional placenames. Stantec recommended a PFR be conducted to further evaluate the potential for archaeological sites.

PROPOSED CONSTRUCTION

Port Metro Vancouver intends to restore valuable fish and wildlife habitat in the intertidal zone of Sturgeon Bank. The project area is located due west of Steveston on the northern side of Steveston North Jetty. The proposed project, which extends over an area of approximately 166 m by 2,317 m (384,622 m^2), will consist of removing approximately 0.5 m of sand from the existing sand island in the central portion of the development area and building out the existing marshes by placing 0.2 m to 0.5 m of sand atop of the existing sediments.

Reference: South Arm Jetty Tidal Marsh Preliminary Field Reconnaissance



Photo 1 View of Sturgeon Bank across the Steveston North Jetty at low tide, facing north

PRELIMINARY FIELD RECONNISSANCE

The PFR was conducted on February 23, 2015 by Sean P. Connaughton of Stantec, Wayne Point of Musqueam Indian Band, and Don Welsh representing Semiahmoo First Nation. The PFR was conducted at low tide (1.4 m).

The PFR involved visual inspection of Sturgeon Bank from a small boat (water taxi) as it was not possible to safely access the bank on foot from land. Inspection focused on the marsh, sand island, and mudflats exposed at low tide for evidence of archaeological remains and/or terrain likely to correspond with past cultural use and which would support archaeological site preservation, if present.

Reference: South Arm Jetty Tidal Marsh Preliminary Field Reconnaissance

Results

During the PFR, the water taxi made two passes along the south shore of Sturgeon Bank from which the project area was visually inspected (Figure 2). The project area could not be directly accessed on foot by boat due to both personal and boat safety that precluded a safe landing. An alternative attempt to access Sturgeon Bank via Scotch Pond (also known as Hole-in-the-wall) also proved unsafe as the depths were too shallow for the water taxi to navigate. Examination of exposed bank deposits confirmed the presence of thick, recently deposited sediments throughout the area (Photo 2). Historical air photos from 1954 to 2009 show significant sediment build-up throughout the project area and extensive dredging along the eastern edge of the project area, closest to the shoreline near Steveston.



Photo 2 View of Scotch Pond at low tide with access precluded due to shallow water and dry land, facing west

Reference: South Arm Jetty Tidal Marsh Preliminary Field Reconnaissance

SUMMARY AND RECOMMENDATIONS

No further archaeological work is recommended for the proposed project area. The PFR was undertaken to refine the desktop AOA and further evaluate the full extent and nature of previous impacts within the development area, identify any visible heritage resources, and determine the likelihood of buried heritage resources. Visual examination of the general area confirmed thick deposits of recently accumulated sediments north of the Jetty and extensive dredging near the shoreline. From these observations this project area is subsequently assessed as having low potential for archaeological resources. In the unlikely event that archaeological resources are identified during construction, work should cease in the immediate vicinity and the Archaeology Branch of British Columbia should be contacted for direction.

Please don't hesitate to contact the undersigned should you have any questions or concerns.

Regards,

STANTEC CONSULTING LTD.

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Rob.Commisso@stantec.com

Attachment: Figure 1 South Arm Jetty Tidal Marsh Overview Map
Figure 2 South Arm Jetty Tidal Marsh Project Area Map

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Stantec Consulting Ltd. 2014. Archaeological Overview Assessment. South Arm Jetty Tidal Marsh Project. Prepared for Port of Metro Vancouver.





Legend

- City
- International Boundary
- Contour (100 m)
- Pipeline
- Railway
- Highway
- Road
- Transmission Line
- Watercourse
- Waterbody
- Park, Protected Area, Ecological Reserve or Conservancy
- Indian Reserve
- Treaty Land
- United States
- South Arm Jetty Project Area

0 2.5 5 7.5 10 km

1:250,000 (at original document size of 8.5x11)

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Base features: Government of Canada, Government of British Columbia

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Stantec

PORT METRO vancouver

Project Location
Greater Vancouver, British Columbia

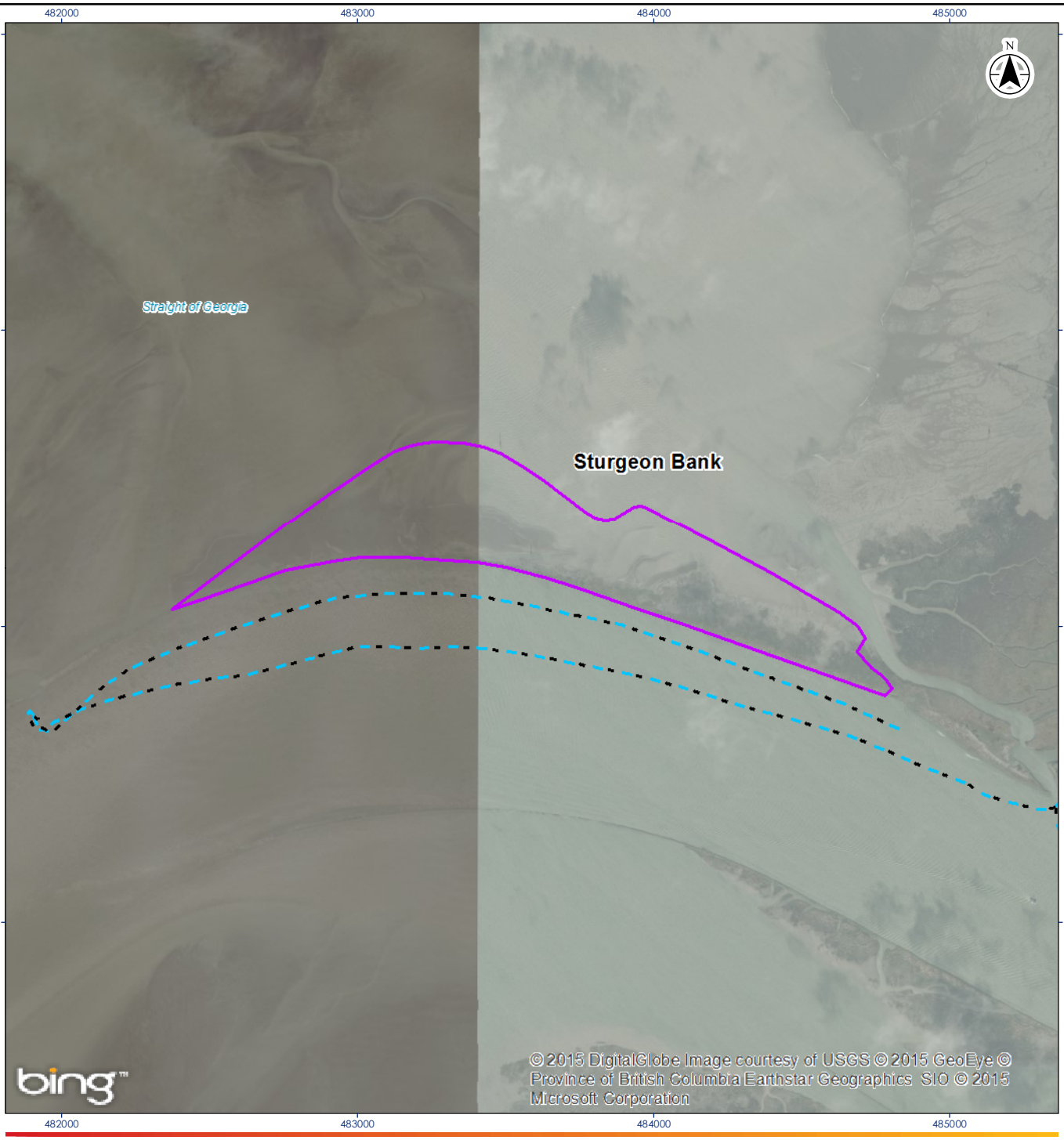
123220031
Prepared by LLT on 2015-03-04
Technical Review by SC on 2015-03-05
Independent Review by ABC on 2015-03-05

Client/Project
Port Metro Vancouver
South Arm Jetty Tidal Marsh Habitat Banking

Figure No.
1

Title
South Arm Jetty Tidal Marsh Overview Map

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Legend

- Places
- Highway
- International Boundary
- Water Taxi Tracks
- South Arm Jetty Project Area

0 100 200 300 400 500 m

1:20,000 (at original document size of 8.5x11)

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Base features: Government of Canada, Government of British Columbia

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Stantec

PORT METRO vancouver

Project Location
Greater Vancouver, British Columbia

123220031
Prepared by LLT on 2015-03-04
Technical Review by TC on 2015-03-05
Independent Review by SC on 2015-03-05

Client/Project
Port Metro Vancouver
South Arm Jetty Tidal Marsh Habitat Banking

Figure No.
2

Title
South Arm Jetty Tidal Marsh Project Area Map

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Appendix IR2020-1.1-A6

Supplemental Hydrodynamic and Salinity Analysis by Incorporating Phase 2 Breaching into the South Arm Jetty Tidal Marsh Project

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MEMORANDUM

To: Michael Cho, P.Eng., M&N

From: Cheng-Feng Tsai, P.E., & Dilip Trivedi, P.E., M&N

Date: May 28, 2020

Subject: Supplemental Hydrodynamic and Salinity Analysis by Incorporating Phase 2 Breaching into the South Arm Jetty Tidal Marsh Project

EXECUTIVE SUMMARY

The purpose of this memo is to analyze potential changes in the South Army Jetty (SAJ) Tidal Marsh project area following the introduction of Raincoast Conservation Foundation (RCF) Phase 2 breaches in the Steveston North Jetty east of the SAJ project. The hydrodynamic modeling results suggest that current speeds and salinity within the project area are similar or slightly lower in magnitude compared to the without-breaches condition. Therefore, the breaches of the RCF Project do not present any adverse effects in the SAJ project area. In addition, results show that the effects of the proposed SAJ breaches located to the west of the SAJ site are limited and therefore not recommended to be included as part of the SAJ project.

BACKGROUND

The Vancouver Fraser Port Authority (VFPA) has developed the Habitat Enhancement Program (HEP) to create and improve fish and wildlife habitat in advance of port development projects, to make certain that any impacts to existing habitat can be offset. As part of the HEP, the South Arm Jetty Tidal Marsh (SAJ) project is a proposed intertidal marsh located along the north side of Steveston North Jetty (SNJ). Moffatt & Nichol (M&N) has been retained by VFPA for the design of the SAJ Project, which included a cobble beach berm, general raising of site grades with sand fill, drainage channels suitable for marsh planting (by others). M&N completed wave exposure and hydrodynamic/salinity analyses to support the design in Dec. 2017[1].

In 2018, RCF proposed the Fraser River Estuary Connectivity Project that consists of breaching sections of the SNJ surrounding the SAJ project. Tetra Tech Inc. was retained by the RCF to investigate the impacts of the proposed project on navigation and on sedimentation processes in the vicinity, and two reports were prepared (a Phase 1 report in Feb. 2018[2], and a Phase 2

[1] Moffatt & Nichol, 2017. Coastal Processes & Salinity Modeling, South Arm Jetty Tidal Marsh Project. Draft Report.

[2] Tetra Tech, 2018. Investigation of the Hydrodynamic and Sedimentation Impacts in the Fraser River from the Proposed Openings along the Steveston North Jetty. Technical Memorandum.

report in Jan. 2019[3]). The VFPA and M&N provided review comments on both reports. At present, Phase 1 of breaches east of the SAJ project (hereafter referred as RCF breaches) has been implemented and the formation of natural channels have been occurring. Phase 2 of breaches is scheduled to potentially proceed in 2020.

A supplemental analysis of tidal hydrodynamics and salinity was conducted to assess whether the RCF breaches have potential impacts to the SAJ Project. In addition, two proposed SAJ breaches west of the SAJ project (hereafter referred to as SAJ breaches) were evaluated to examine if there are any benefits by incorporating the SAJ breaches in the future project footprint. This addendum report is intended to supplement the 2017 M&N main report. **Figure 1** shows the SAJ Project footprint and the locations of three RCF breaches and two proposed SAJ breaches.

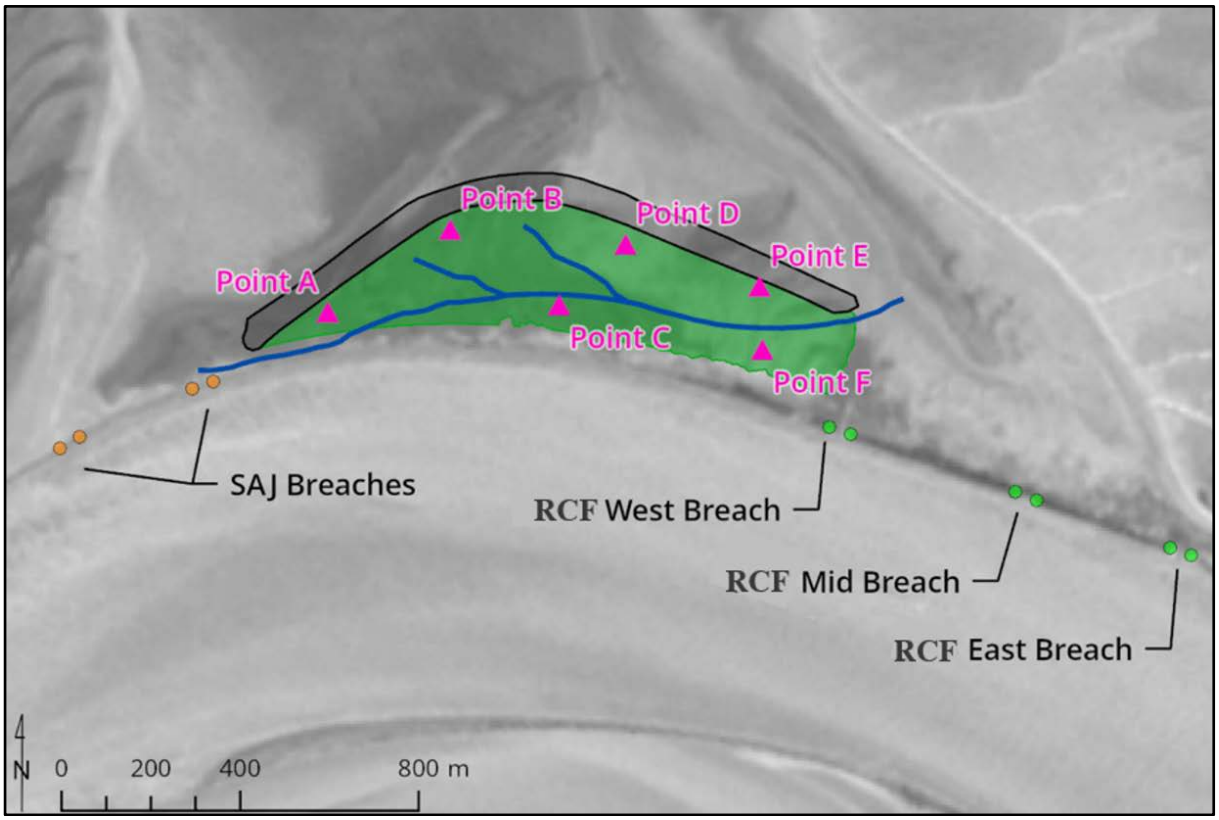


Figure 1: The SAJ Project Footprint, Locations of Three RCF Breaches and Two Proposed SAJ Breaches, and the Six Model Data Extraction Points (Point A-F Triangles).

MODELING APPROACH

[3] Tetra Tech, 2019. Phase 2 Report - Hydrodynamic and Sedimentation Study for the Proposed Breaches on Steveston North Jetty in the Fraser River. Presented to Raincoast Conservation Foundation.

The modeling approach and model performance characteristics (e.g. model development, calibration) are addressed in the main report of the 2017 M&N modeling work and are therefore not reiterated here. The only changes are to introduce the breaches and to incorporate the latest 2019 LiDAR data in the vicinity of the RCF breaches.

The latest LiDAR data was collected for the RCF Project in summer 2019 by McElhanney Consulting Ltd[4]. The survey was conducted at low tide and covers eastern half of the project area as well as the parcel to the east. Elevations were in the range from -2.3 m GD to +4.5 m GD.

Two additional scenarios were developed in the supplemental analysis to assess the effects of breaches on the SAJ Project. The first scenario incorporates the RCF breaches, while the second scenario incorporates both the RCF breaches and the proposed SAJ breaches. The existing condition (without any breaches and without the SAJ project) and the with-SAJ project scenarios developed in 2017 were also included for comparison purposes. Six model data extraction points were used to analyze the effects of the breaches in the SAJ project area. The extraction points are denoted by the triangles shown in **Figure 1**, Point A-F.

Three discharge flow conditions in the Fraser River were investigated in the supplemental analysis to allow direct comparison to the 2017 modeling results. The low flow of 2,000 m^3/s represents the base flow condition. The high flow was set to 8,000 m^3/s, an average peak discharge during the freshet. The medium flow of 5,500 m^3/s represents a transition from the low to the high flow.

MODEL SCENARIOS

The associated tidal channel will form and evolve naturally after a breach is created. A desktop analysis of tidal channel geometry was performed based on the literature to identify the extent of tidal channels connecting the RCF breaches.

Hydrodynamic model results found that the peak discharge through the RCF west breach (most impacting the SAJ project) is approximately 40 m^3/s. Friedrichs (1995[5]) and some other studies suggest the existence of a relationship between cross-sectional area and peak discharge for sheltered tidal channels. **Figure 2** presents the observed relationship. Using this relationship, an equilibrium cross-sectional area for the RCF tidal channel at peak discharge is estimated to around 60 m^2, which further indicates a RCF tidal channel width of around 20 to 25 m. Similarly, the peak discharge through the SAJ marsh channel is approximately 10 m^3/s, corresponding to a channel with an estimated cross-sectional area of 30 m^2 and a channel width of 10 to 15 m.

While there is great variability within tide-dominated systems, the channel width-to-depth ratio can be split into two discrete groups of tidal channels: vegetated channels and channels on bare

[4] McElhanney Consulting Services Ltd. (2019). LiDAR for Raincoast Conservation Foundation 2019.

[5] Friedrichs, C. T. , 1995. Stability Shear Stress and Equilibrium Cross-Sectional Geometry of Sheltered Tidal Channels. Journal of Coastal Research (11), p1062-1074.

flats (Hughes, 2011[6]). Aerial photographs and LiDAR data were used to estimate the width-to-depth ratios for vegetated channels around Sturgeon Bank and the results are shown in **Figure 3**. Also shown in the figure is the estimated RCF breach channel (a width of 20 m and a depth of 1.5 m at MWL) and the SAJ marsh channel geometry (a width of 10 m and a depth of 0.7 m). The estimated channel geometries are aligned well with the surrounding vegetated channels.

Two additional model scenarios were developed using these estimated channel geometries. They were then incorporated into the earlier with-SAJ Project scenario, which adds a rock berm, a marsh channel, and raising of site grades to support marsh habitat.

The first scenario, "RCF Breaches", adds the three RCF breaches and associated tidal channels to the with-SAJ Project scenario. The second scenario, "All Breaches", adds the two proposed SAJ breaches to the first scenario. The bathymetry of four model scenarios are shown in **Figure 4.**

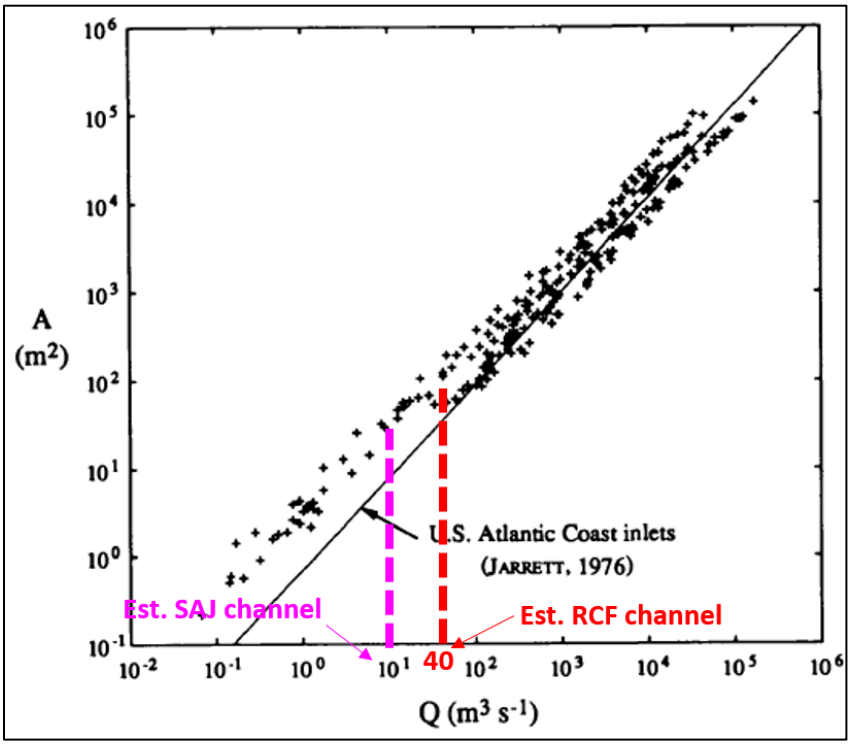


Figure 2: Cross-Sectional Area vs. Peak Discharge for Tidal Channels (Friedrichs, 1995)

[6] Hughes, Z. J. , 2011. Chapter 11: Tidal Channels on Tidal Flats and Marshes, Principles of Tidal Sedimentology. Editors: Davis Jr. , R. A. and Dalrymple, R. W. Publisher: Springer Netherlands.

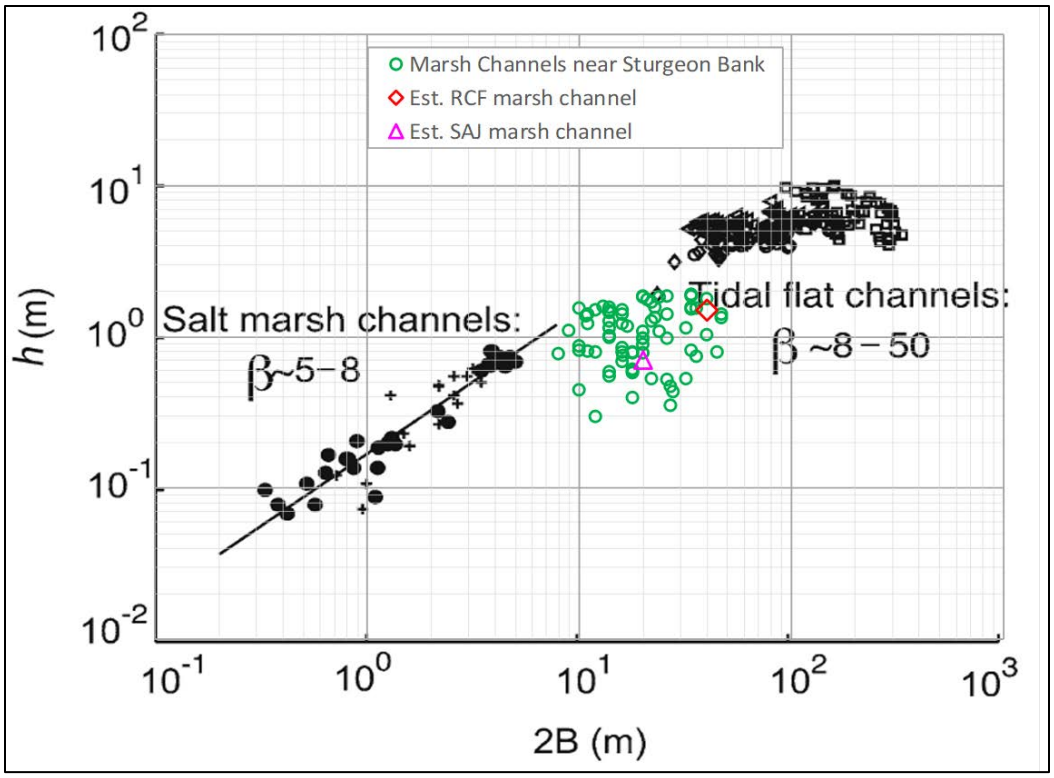


Figure 3: Width-to-Depth Ratio for Tidal Channels (Revised from Hughes 2011)

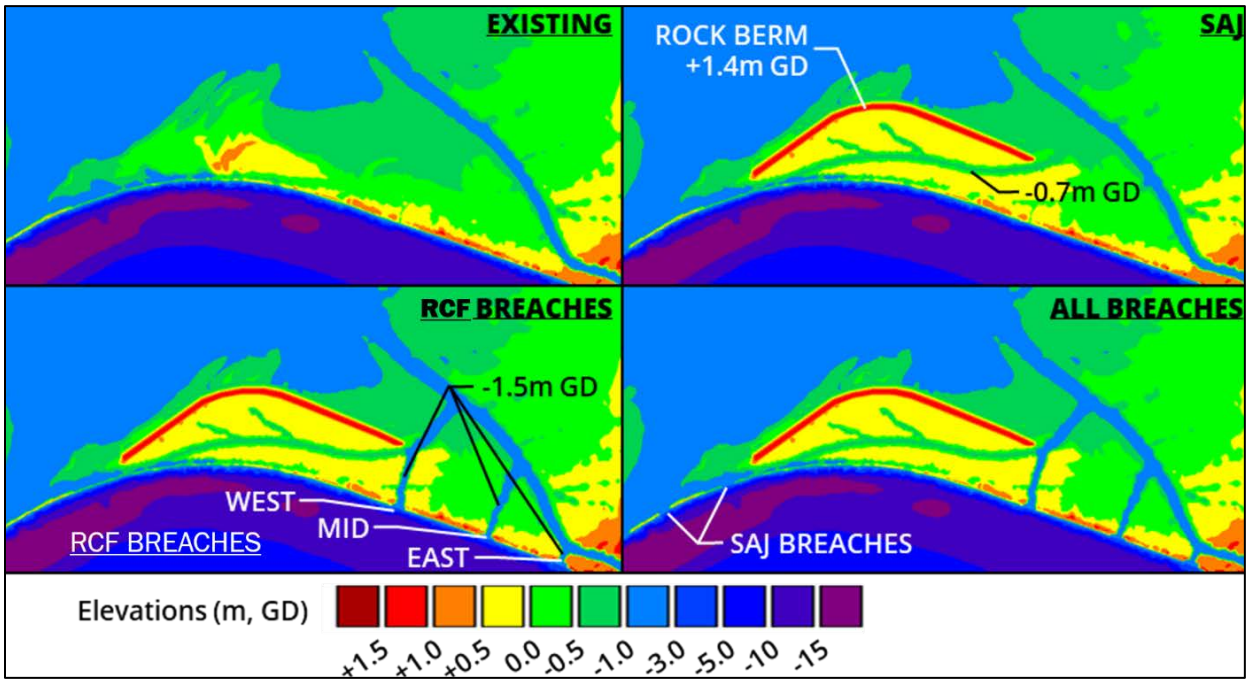


Figure 4: Bathymetry for Model Scenarios

MODEL RESULTS

Figure 5 and **Figure 6** show current speeds and surface salinities at Point "A" and Point "F", respectively. Points "A" and "F" were chosen because they are on the opposite ends of the project area and the results at the other four locations mostly fall between Points "A" and "F". All three conditions: high flow (8,000 m^3/s), medium flow (5,500 m^3/s), and low flow (2,000 m^3/s) were investigated in the supplemental analysis. Results show that there are no discernible differences with the addition of the RCF breaches or SAJ breaches under all flow conditions. Only the low flow condition is presented in the figures for illustrative purposes.

Results indicate that the current speeds within the SAJ project area are not substantially affected by the addition of the RCF breaches or the SAJ breaches. At all extraction points, the range of current speeds during the simulation period are similar as long as the SAJ project elements such as the cobble berm and raising the site grades, are implemented (e.g. "SAJ", "RCF Breaches", and "All Breaches") and are generally less than 0.3 m/s. However, a substantial reduction of current speeds can be seen between the scenarios with the SAJ project elements and the existing condition, in which the current speed could reach around 0.7 m/s at Point A. Therefore, it confirms the positive effects with the proposed SAJ project elements. At the eastern portion of the SAJ project area (Point "E" and Point "F"), a slight reduction of the current speed can be observed with the addition of the RCF breaches, though the reduction is minor.

The maximum current speed in the RCF west breach is about 1.2 m/s. Because the channel flow and waves present in the channel may potentially erode the eastern edge of the marsh area, slope protection is recommended along the sides of the channel.

Similarly, surface salinity in the project area does not change significantly with the breaches. Although the overall salinity range (e. g. 0 to 29 PSU) during the simulation period is indiscernible between the scenarios with the SAJ project elements and the existing condition, the former may show lower daily variations in salinity (e. g. 3 to 15 PSU at Point "A" on 12/26) than the existing condition (e.g. 3 to 26 PSU), indicating a modest fresher environment when the SAJ project elements are implemented. At Point "F", occasional reduction in salinity is observed during certain flooding tide stage with the addition of the SAJ breaches. This is because less saline water flows to the eastern end of the project area (Points "E" and "F") when the flow conveyance through the SAJ breaches is provided. However, the lower salinity state is fairly short (an hour per day). Therefore, the benefits of the SAJ breaches are considered limited.

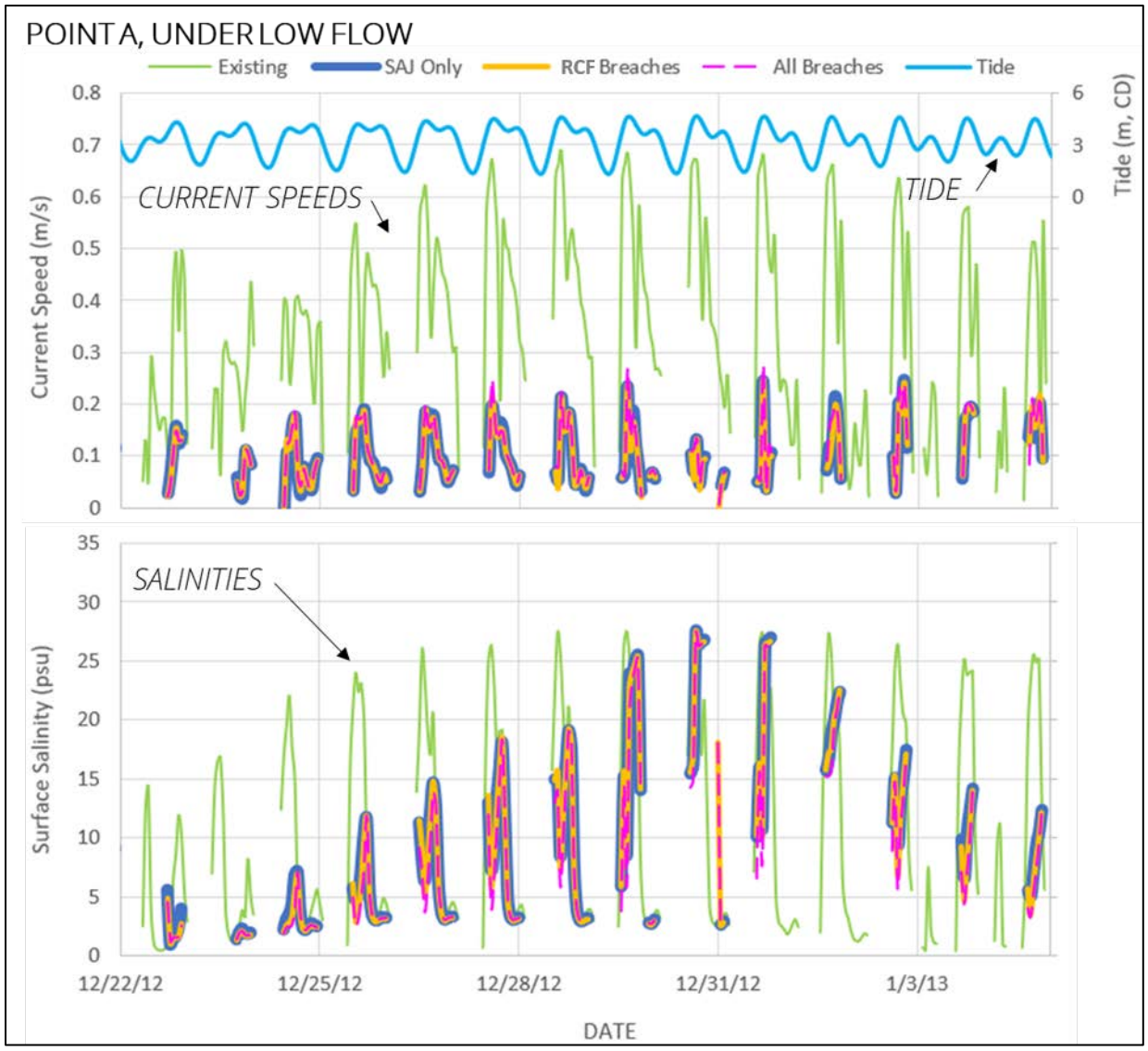


Figure 5: Current Speed and Surface Salinity at Point A, Under Low Flow.

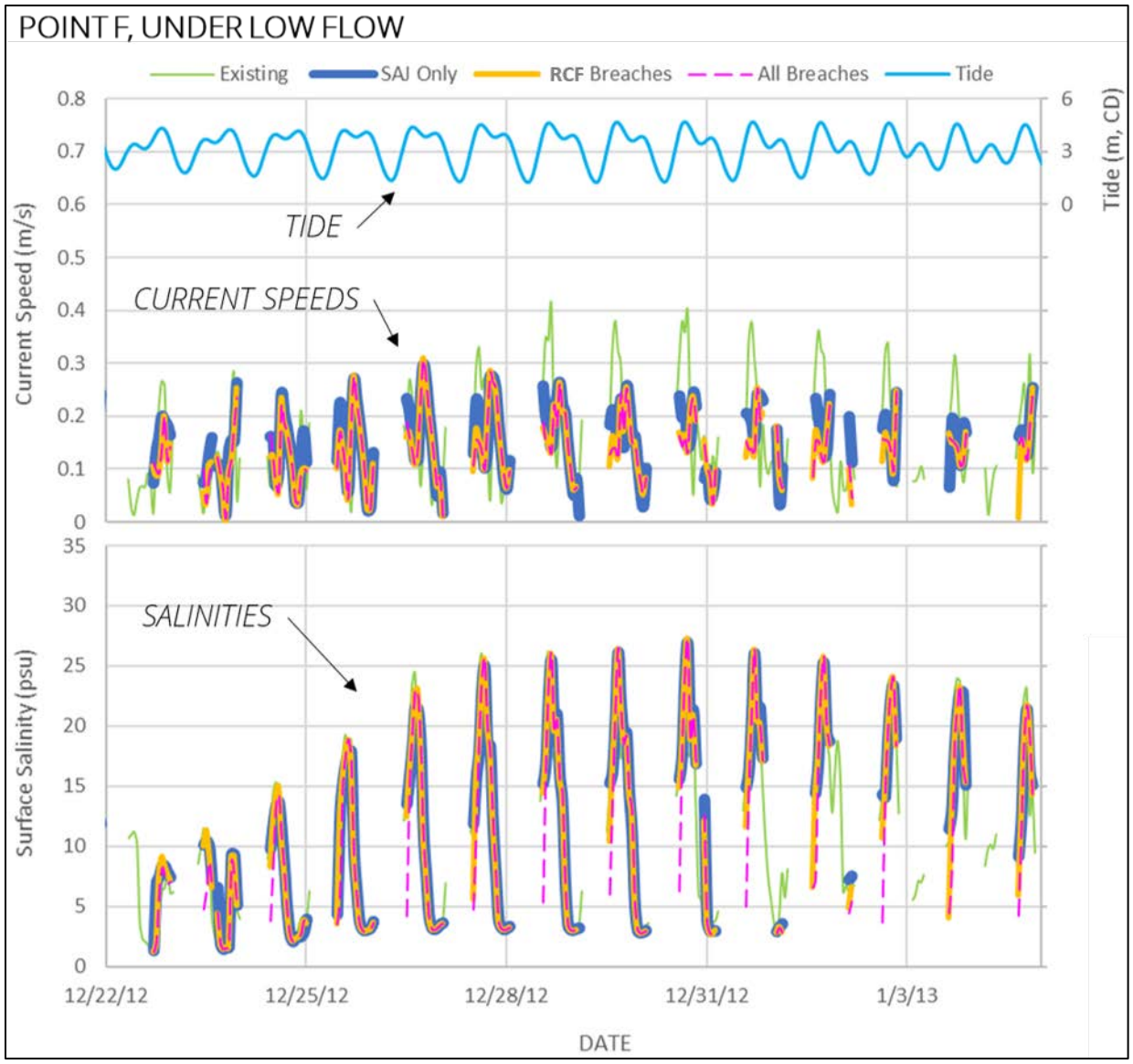


Figure 6: Current Speed and Surface Salinity at Point F, Under Low Flow.

CONCLUSIONS & RECOMMENDATIONS

The main conclusions from this supplemental analysis are:

- The current speeds within the SAJ project area are not substantially affected by the RCF breaches or SAJ breaches.
- The current speeds could be substantially higher in the project area without the SAJ project elements (e. g. cobble berm and raising site grades).
- The maximum current speed in the RCF west breach is about 1.2 m/s. Because the channel flow and waves present in the channel may erode the eastern edge of the SAJ marsh area, slope protection (0.3 m median rock size) is recommended along the sides of the channel.
- Salinity in the SAJ project area does not change significantly with the breaches and the overall salinity range is similar.
- The benefits of the proposed SAJ breaches are limited from a hydrodynamics and salinity perspective and therefore are not recommended for incorporation into the SAJ Project.

Appendix IR2020-1.1-A7

Habitat Enhancement Program – South Arm Jetty Tidal Marsh Coastal Processes and Salinity Modeling

moffatt & nichol

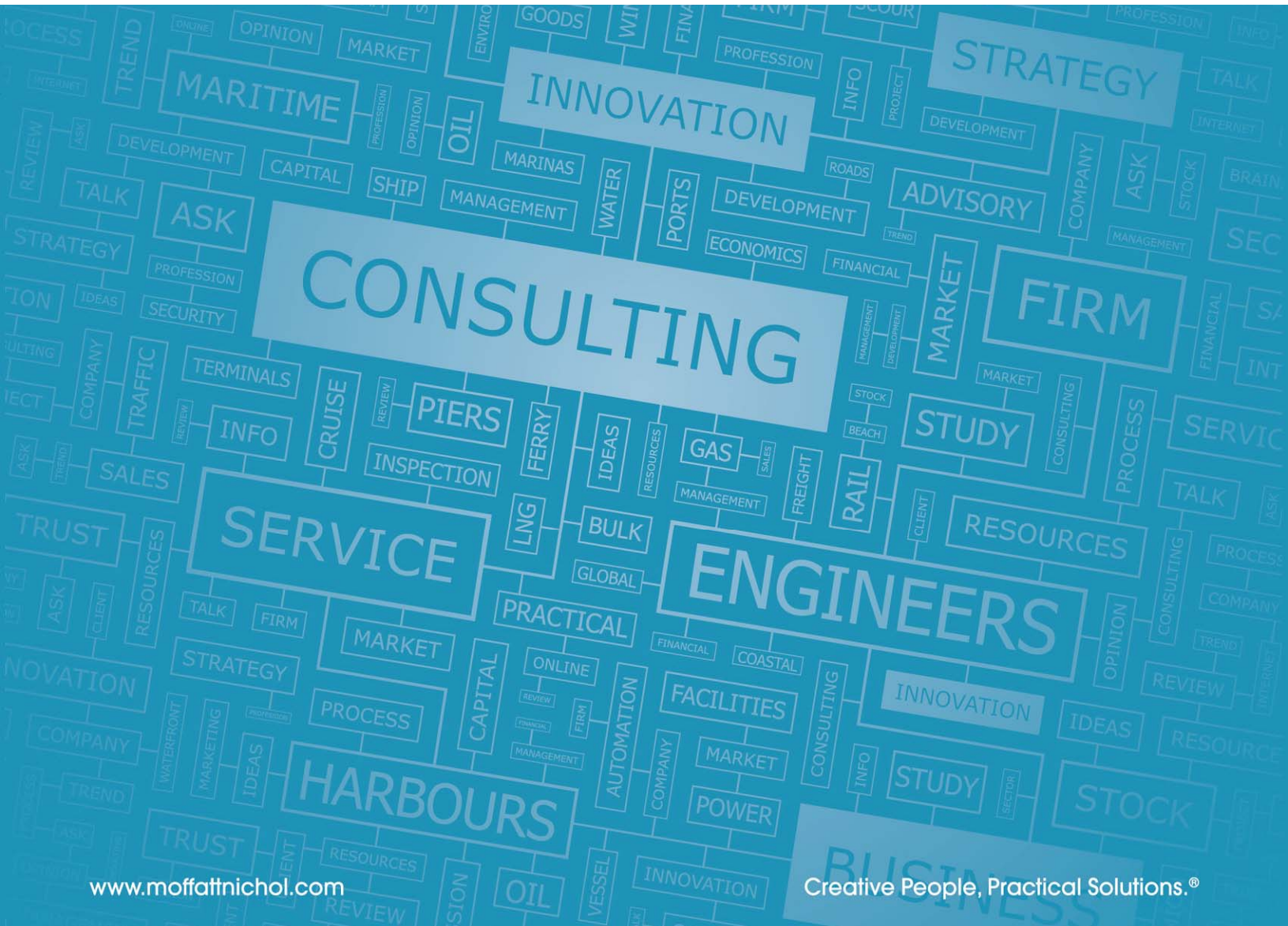
HABITAT ENHANCEMENT PROGRAM

South Arm Jetty Tidal Marsh
Coastal Processes & Salinity Modeling

PRODUCED FOR

PORT of vancouver

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Glossary

Ah	Ampere-hour
AIS	Automatic Identification System
CD	Chart Datum
CHS	Canadian Hydrographic Service
CTD	Conductivity, Temperature and Depth
CGVD2013	Canadian Geodetic Vertical Datum of 2013
d_{50}	Average Particle Size (50% Finer by Weight)
d_{75}	Quartile Particle Size (75% Finer by Weight)
DC	Direct Current
DO	Dissolved Oxygen
DHI	Danish Hydraulic Institute
FHWA	Federal Highway Administration
GD	Geodetic Datum
GLW	GL Williams & Associates Ltd
HD	Hydrodynamic
HEP	Habitat Enhancement Program
HHW	Higher High Water
HHWLT	Higher High Water Large Tide
HHWMT	Higher High Water Mean Tide
kt	Knot
LiDAR	Light Detection and Ranging
LL	Liquid Limit
LLW	Lower Low Water
LLWLT	Lower Low Water Large Tide
LLWMT	Lower Low Water Mean Tide
m	metres
M&N	Moffatt & Nichol
MWL	Mean Water Level
NRCS	National Resources Conservation Service
PI	Plasticity Index

PCB	Polychlorinated Biphenyl
PBDE	Polybrominated Diphenyl Ether
PAH	Polycyclic Aromatic Hydrocarbon
ppt	Parts Per Thousand (‰)
PSU	Practical Salinity Unit
PWGSC	Public Works and Government Services Canada
RCF	Raincoast Conservation Foundation
SAJ	South Arm Jetty
SW	Spectral Wave
τ_{max}	Maximum Bed Shear Stress (N/m^2)
US	United States
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
VFPA	Vancouver Fraser Port Authority
WQ	Water Quality

Executive Summary

Moffatt & Nichol (M&N) has been retained by the Vancouver Fraser Port Authority (VFPA) to conduct numerical modelling in support of their Habitat Enhancement Program (HEP), and the design and construction of the South Arm Jetty (SAJ) tidal marsh. The SAJ project includes construction of a cobble beach berm, raising the site grades with dredged sandy materials, and marsh planting. M&N developed spectral wave and hydrodynamic models for the Lower Fraser River and the Strait of Georgia.

Two main analyses were performed with the objectives of: *1)* Quantifying the distribution of wave-induced shear stresses at the surface of the proposed marsh substrate for existing and proposed project conditions (spectral wave simulations); and *2)* Determining the distribution of salinity between the Fraser River and Sturgeon Bank for existing and proposed project conditions (hydrodynamic simulations). A summary of the findings from both analyses is presented below.

Wave Induced Bed Shear Stress Evaluation

Introduction of the cobble berm at Sturgeon Bank can achieve the objective of reducing wave-induced bed shear stresses in the proposed marsh area and promote favorable conditions for marsh growth.

Overall, results clearly show that the cobble berm effectively reduces wave-induced bed shear stresses. Although it is noted that under extreme storm conditions, above-threshold values occur over the majority of the marsh area with or without the presence of the cobble berm, the berm does promote favorable conditions for development of the proposed marsh growth consistently throughout most of the year (e.g. 99th percentile).

Vulnerable areas, where the 99th percentile τ_{max} exceeding the threshold value, were identified in the south and southwest portions of the marsh. This is because the cobble berm provides only limited sheltering from waves in this area, and there is a more direct exposure to waves from southerly directions.

In addition, it was found that the cobble berm crest elevation is the most influential factor for reducing bed shear stresses. Shear stress values were reduced for the cases where the berm crest elevation is at +1.9 m GD. Preliminary results suggest that a short cobble berm could be implemented and still provide favorable conditions for the marsh growth. However, a more thorough investigation would be required to determine the feasibility of this option.

Salinity Distribution Analysis

Overall, model results suggest that the cobble berm will bring salinities in the proposed marsh area closer to those of the existing marsh.

During low discharge periods (e.g. winter months), the cobble berm promotes somewhat lower salinity levels in the proposed marsh area. This suggests that the fresh water retained in the marsh can be improved approximately 50% of the time during the year.

During medium discharge periods, the cobble berm also aids in a significant reduction of the salinity in the proposed marsh area.

During high discharge periods (e.g. freshet), fresh water is dominant in the proposed marsh area almost always throughout the tidal cycle, and hence the cobble berm does not affect salinity levels.

Incorporation of the Phase 2 Raincoast Project

A supplemental analysis of tidal hydrodynamics and salinity was conducted in spring 2020 to assess potential effects in the SAJ project area following the introduction of Raincoast Phase 2 breaches in the Steveston North Jetty. The hydrodynamic modelling results suggest that current speeds and salinity within the project area are similar or slightly lower in magnitude compared to the without-breaches condition. In addition, results show that the effects of the proposed SAJ breaches are limited in the project area. Therefore, the breaches of the Raincoast Project do not present any adverse effects in the SAJ project area and the proposed SAJ breaches do not provide significant benefits to the project area from a hydrodynamics and salinity perspective.

1. Introduction

1.1. Project Background

The Habitat Enhancement Program (HEP) from the Vancouver Fraser Port Authority (VFPA) has been developed to create and improve fish and wildlife habitat in advance of port development projects, to make certain that any impacts to existing habitat can be offset. Typical examples of habitat that could potentially be affected by port development include eelgrass beds, saltwater marshes and intertidal marshes. The HEP endeavors to improve or create these types of habitats, to offset any future loss.

The HEP includes the construction of the proposed South Arm Jetty (SAJ) Tidal Marsh, an intertidal marsh located on the South Arm of the Fraser River along the north side of Steveston Jetty. The site lies in Sturgeon Bank offshore of Steveston Village in Richmond, British Columbia (see Figure 1-1). In general, the project consists of a cobble beach berm, raising of site grades with sand fill, and marsh planting.

Moffatt & Nichol (M&N) was retained by VFPA to conduct wave exposure and hydrodynamic/salinity analyses in support of the design in 2017. The draft revision of the current report was submitted to VFPA on December 22, 2017.

In 2018, the Raincoast Conservation Foundation (RCF) proposed the Fraser River Estuary Connectivity Project that consists of breaching sections of the Steveston North Jetty. Tetra Tech Inc. was retained by RCF to investigate the impacts of the proposed project on navigation and on sedimentation processes in the vicinity. At present, the Phase 1 of breaches had been implemented and the Phase 2 of breaches is scheduled to proceed in spring 2020.

As a result of the RCF Project, supplemental analyses of tidal hydrodynamics and salinity were conducted to assess if the breaches implemented by the RCF could have potential impacts to the SAJ Project. The findings of these supplemental analyses are included in Appendix A of this updated report.

1.2. Project Site

The proposed South Arm Jetty Tidal Marsh is located along the north side of the Steveston Jetty within the Steveston Bend Reach of the Fraser River South Arm (Figure 1-2). This area is adjacent to the maintained deep-sea shipping channel. A large strip of marsh currently exists along the north side of the jetty.

The proposed tidal marsh site is on a shallow portion of Sturgeon Bank with elevations ranging from -0.75 m to +0.75 m Geodetic Datum (GD), with low spots at the west end of the site as low as -1.5 m GD. There is an area with higher elevation which is referred to as the “sand island.” This area is a remnant of dredge material disposal activities in the early 1980s. The adjacent Steveston North Jetty is permeable and constructed of piled rock and concrete debris. There are several low points along the jetty which allow flow to pass over the jetty and onto Sturgeon Bank (Figure 1-2).

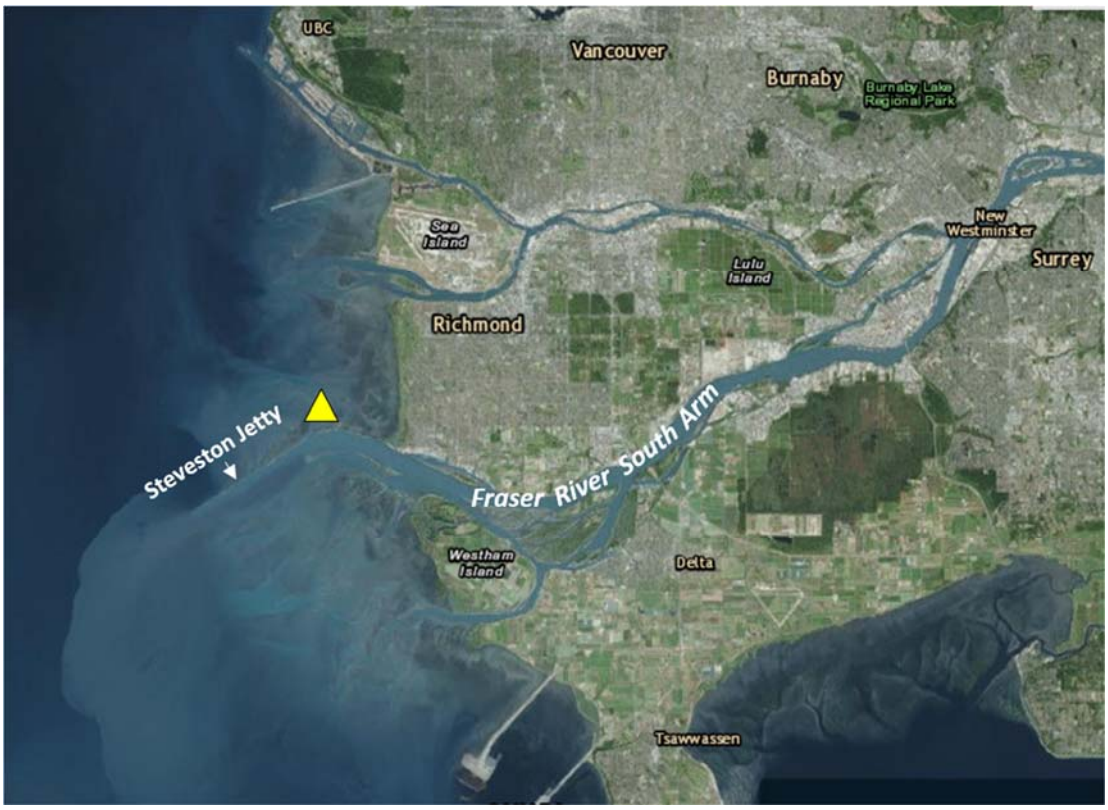


FIGURE 1-1: LOCATION OF PROJECT SITE AT FRASER RIVER SOUTH ARM



FIGURE 1-2: LOCATION OF PROPOSED SAJ TIDAL MARSH AREA

1.3. Scope of Work

The objectives of this study are to:

1. Quantify the changes of wave-induced shear stresses at the surface of the proposed marsh substrate for existing and with-project scenarios;
2. Quantify the changes of salinity for existing and with-project scenarios; and
3. Assess if the breaches implemented by the RCF Project have any potential impacts to the SAJ project area.

Two primary analyses were investigated, wave exposure and salinity analysis.

Wave exposure analysis included the following tasks:

- Simulate wave exposure for existing conditions, for a range of wind speeds, directions, and tides;
- Estimate wave-induced bed shear stress distribution over a storm cycle, as well as for dominant conditions;
- Compare to naturally colonizing areas and establish target shear stress criteria for proposed marsh; and
- Simulate wave exposure for with-project scenario, and estimate changes of wave-induced bed shear stress distribution.

Salinity analysis included the following tasks:

- Develop a coupled hydrodynamic and salinity model for tides & salinity, using the recent Light Detection and Ranging (LiDAR) bathymetry and observations of tides, river flow, and salinity;
- Simulate circulation and salinity processes for existing conditions, for a sufficient length of time (at a minimum a full spring-neap cycle);
- Compare to naturally colonizing areas and establish target criteria for proposed marsh; and
- Evaluate salinity changes for with-project scenario by using proposed marsh elevations, based on discussions with the project team and Fisheries and Oceans Canada.

2. Basis of Analysis

2.1. Topographic Data

Topographic data at the project site consists primarily of LiDAR data acquired by Stantec in 2013 and 2017. In addition, the RCF Project surveyed eastern half of the project site as well as the parcel to the east in 2019.

2.1.1. LiDAR Topography in 2013

Topographic data for the project site and vicinity was collected on October 24, 2013 using airborne LiDAR data collection. The survey was conducted at low tide and covers the area of Sturgeon Bank and Roberts Bank. Elevations were in the range from -2.6 m GD to +7.2 m GD.

Vertical datum is the Canadian Geodetic Vertical Datum of 2013 (CGVD2013, short as GD), which represents the coastal mean sea level in North America.

2.1.2. LiDAR Topography in 2017

Topographic data for the project site and vicinity was collected on August 9, 2017 using airborne LiDAR data collection. The survey was conducted at low tide and covers the areas of Sturgeon Bank, Roberts Bank, and Steveston. Elevations were in the range from -2.5 m GD to +5.7 m GD.

2.1.3. LiDAR Topography in 2019

Topographic data for the RCF Project was collected in summer 2019 by McElhanney Consulting Ltd. The survey was conducted at low tide and covers eastern half of the project site as well as the parcel to the east. Elevations were in the range from -2.3 m GD to +4.5 m GD. This latest topographic information was incorporated in the supplemental analyses (Appendix A).

2.1.4. Bed Level Changes at Project Site

Figure 2-1 shows bed level changes at the project site between the 2013 and 2017 LiDAR data. The proposed cobble beach berm is shown for reference.

Shades of red indicate lowering of the grade (erosion), shades of blue indicate an increase in elevation (accretion), and white color represents neutral, unchanged conditions. In general, Sturgeon Bank was subject to both accretion and erosion between 2013 and 2017. West of the proposed marsh area, alternating blue and red patterns indicate migration of bed forms (i.e. sand waves and dunes). The marsh area exhibits mild erosion (indicated by faint shades of red), although somewhat higher erosion occurred around the Sand Island (depicted in darker red); closer to the Richmond shoreline, blue color is more typical, indicating an increase in elevations.

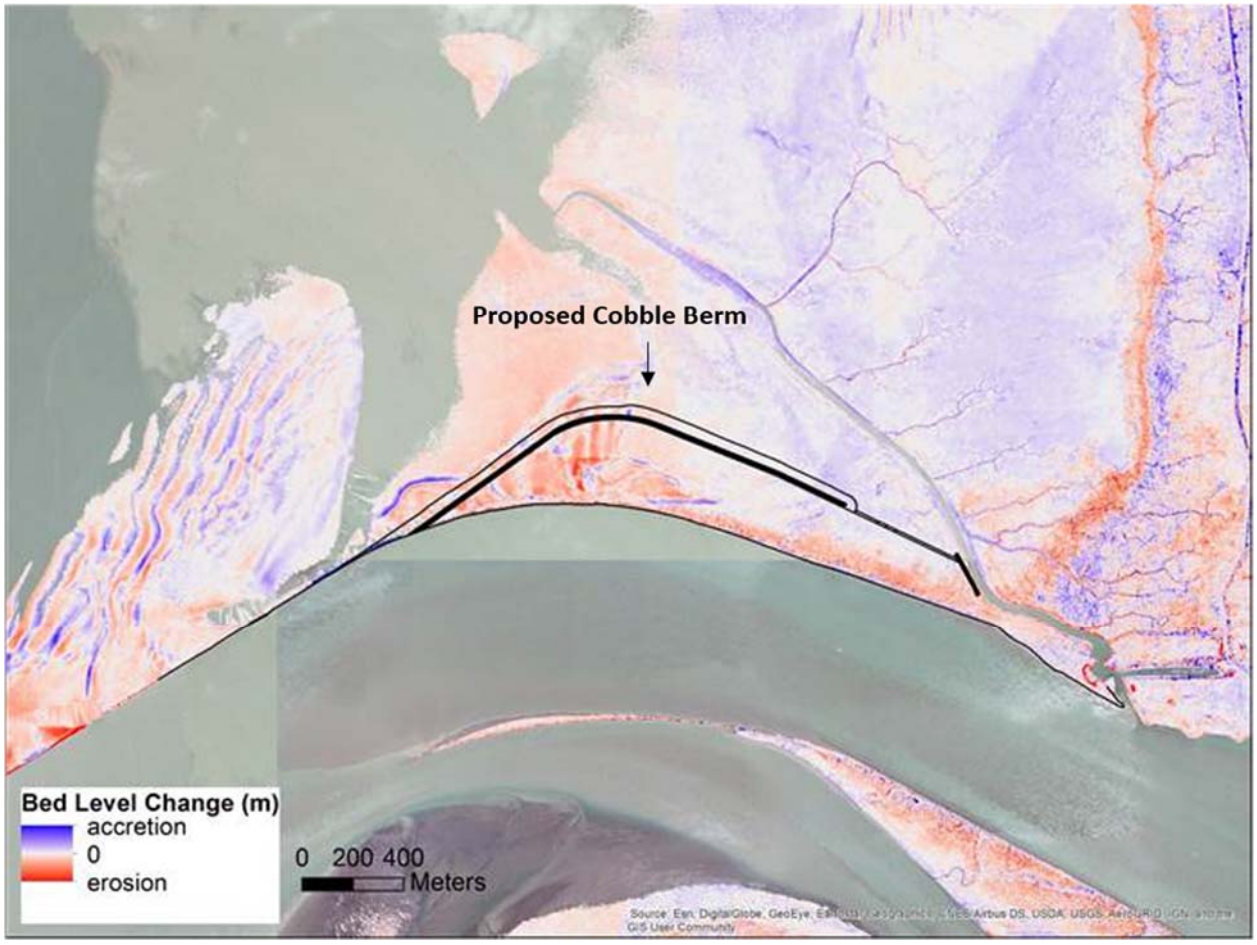


FIGURE 2-1: BED LEVEL CHANGES BETWEEN 2013 AND 2017 (*STANTEC, 2017*)

2.2. Bottom Conditions

A characterization of materials over the mudflat in the vicinity of the project site is provided in *Hemmera (2017)*. Figure 2-2 provides the location and logging of samples taken. Sample material characterization was subsequently used to develop the shaded areas in the figure depicting surficial sediments in the form of marsh (blue), mud (pink), sand (yellow), and sand/mud mix (orange).

Golder (2014) conducted a site reconnaissance, and characterizes the bottom material as overbank Fraser River sediments comprising of silty to silt clay loam, normally less than 2 m thick; overlying deltaic and distributary channel fill of interbedded fine to medium sand.

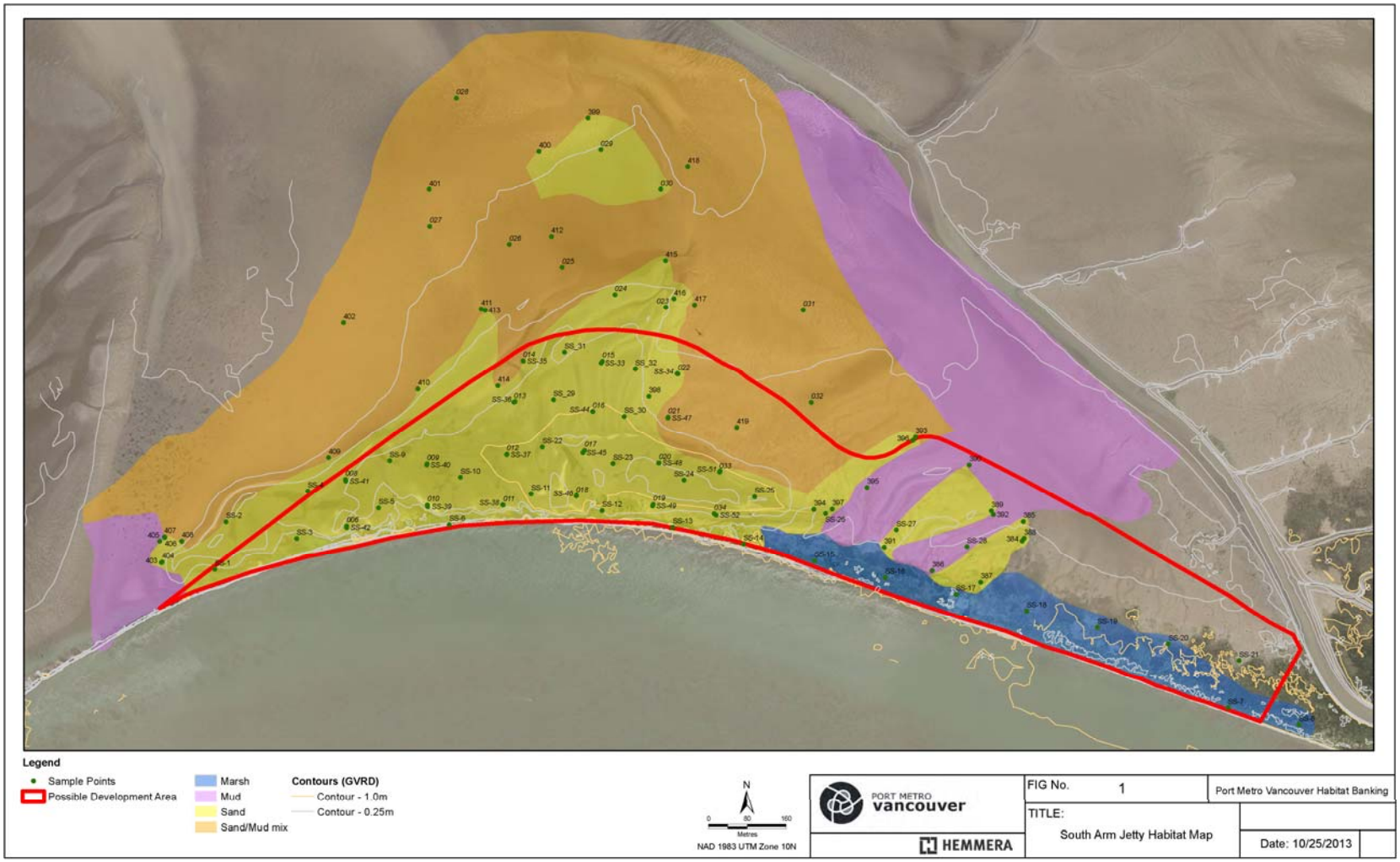


FIGURE 2-2: CHARACTERIZATION OF BOTTOM MATERIALS *(HEMMERA, 2017)*

2.3. Tidal Datums

Tidal datums for Sand Heads from published Nautical Chart *(CHS, 2005)* are provided in Table 2-1.

TABLE 2-1: TIDAL DATUMS AT SAND HEADS

Datum	m CD	Description
HHW-LT	4.9	Higher High Water – Large Tide
HHW-MT	4.3	Higher High Water – Mean Tide
MWL	3.1	Mean Water Level
LLW-MT	1.3	Lower Low Water – Mean Tide
LLW-LT	0.2	Lower Low Water – Large Tide
CD	0.0	Chart Datum

In navigable waters, Chart Datum is the common vertical datum reference. In inland waters, Geodetic Datum is more commonly used. Figure 2-3 shows how tidal datums at Point Atkinson and Sand Heads relate to water level datums for the Fraser River at Steveston. Tidal datums at Point Atkinson and at Sand Heads (left side of the figure) are purely astronomical. Tidal datums for the Fraser River, however, are affected by the amount of outflow from the river *(CHS, 2014)*. The figure shows how the tidal datums vary with reference to Geodetic Datum depending on discharge as measured at Hope. Geodetic Datum (GD) at Steveston is located at +2.2 m CD per *CHS (2005)*. It can be seen that the elevations of higher high water mean and large tides remain fairly constant. Elevations of lower low tides (mean and large) increase with increasing discharge.

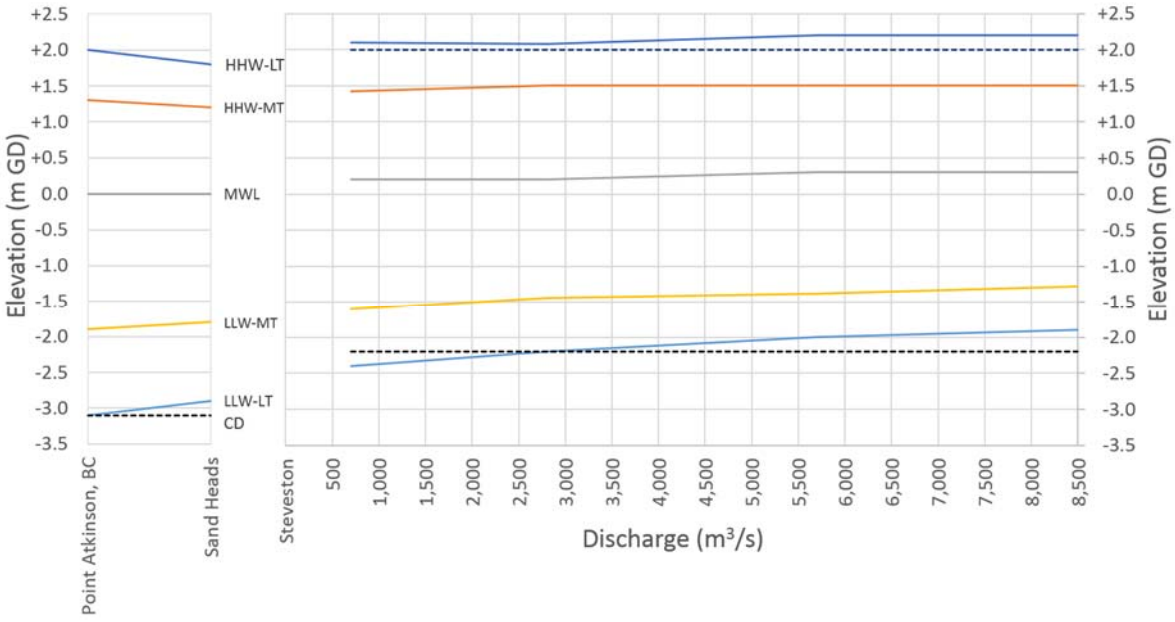


FIGURE 2-3: VARIATIONS OF TIDAL DATUMS AT STEVESTON VS. FRASER RIVER DISCHARGE

2.4. Fraser River Discharge

The gross drainage area of the Fraser River is approximately 217,000 km^2. Hydrometric data, including water levels and discharge data has been measured at Hope (Figure 4-1) since 1912, capturing a period of record of 106 years.

Figure 2-4 summarizes the maximum, minimum, and mean discharge data recorded at Hope. Additionally, the year 1991 is shown, taken as representative of average conditions.

It can be seen that outflow from the river remains fairly constant over the months from January to mid-April, and increases rapidly through mid-June. Over the months of July to October, the outflow decreases pronouncedly, followed by a more gradual decrease in October and November, until a somewhat constant discharge is reached around December.

The rapid increase of outflow over the spring and summer months (freshet) is due to melting of snow accumulated in the mountains over the winter months.

The annual peak discharge around mid-June can range from approximately 4,000 m^3/s (blue curve) to 15,000 m^3/s (green curve). The average peak discharge is around 7,000 m^3/s (brown curve). In dry years, the base outflow can be lower than 1,000 m^3/s, increasing to 2,000-4,000 m^3/s in wet years.

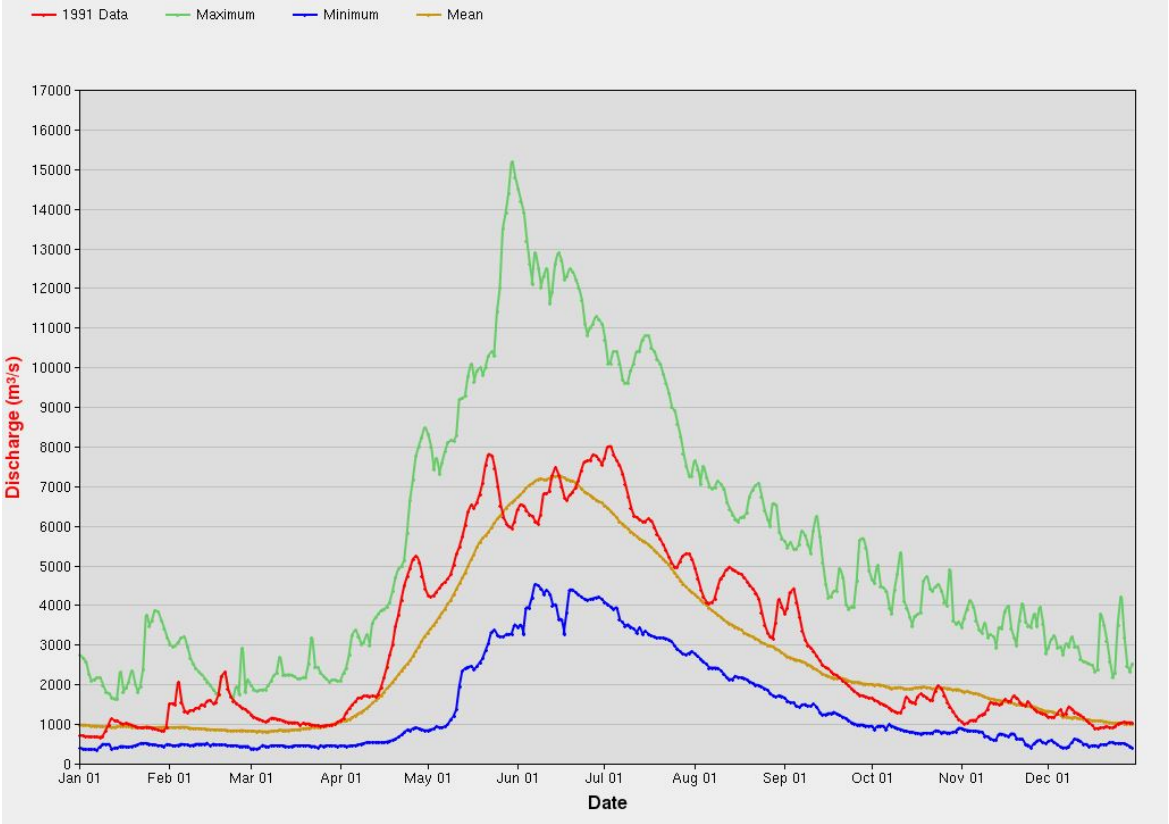


FIGURE 2-4: FRASER RIVER DISCHARGE (*EC, 2017*)

2.5. Fraser River Salinity Data

Water is drawn from the Fraser River for consumption, industrial, and agricultural uses. The salinity of the water depends on how far upstream the water is sourced. The extent of salinity intrusion up the Fraser River is strongly dependent on the river outflow (discharge), which varies annually. The salinity intrusion is greater in years with low river discharge.

Salinity data was acquired from *ENVIRODAT (2017)* for the Fraser River Water Quality Buoy. The buoy provides continuous real-time sampling of surface water quality parameters utilized to assess the quality of Fraser River. The location of the buoy is shown in Figure 2-5, which is near Tilbury at Gravesend Reach, at Latitude/Longitude 49.1484°N, 123.0392°W.

The buoy provides continuous real-time tracking of dissolved oxygen (DO) content, water pH value, conductivity, turbidity, water velocity, and water temperature. Levels of trace metals, nutrients, major ions, and coliforms are logged bi-weekly. The buoy also has the ability to track levels of a range of organic contaminants, including pesticides, nonylphenols, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and polybrominated diphenyl ether (PBDEs).

Additional instrumentation on the buoy captures wind speed, wind direction, air pressure, relative humidity, water depth, and buoy position and heading.

The buoy is also outfitted with an Automatic Identification System (AIS) transmitter and amber flashing navigational light, which enables vessels on the river to track and identify the buoy location.

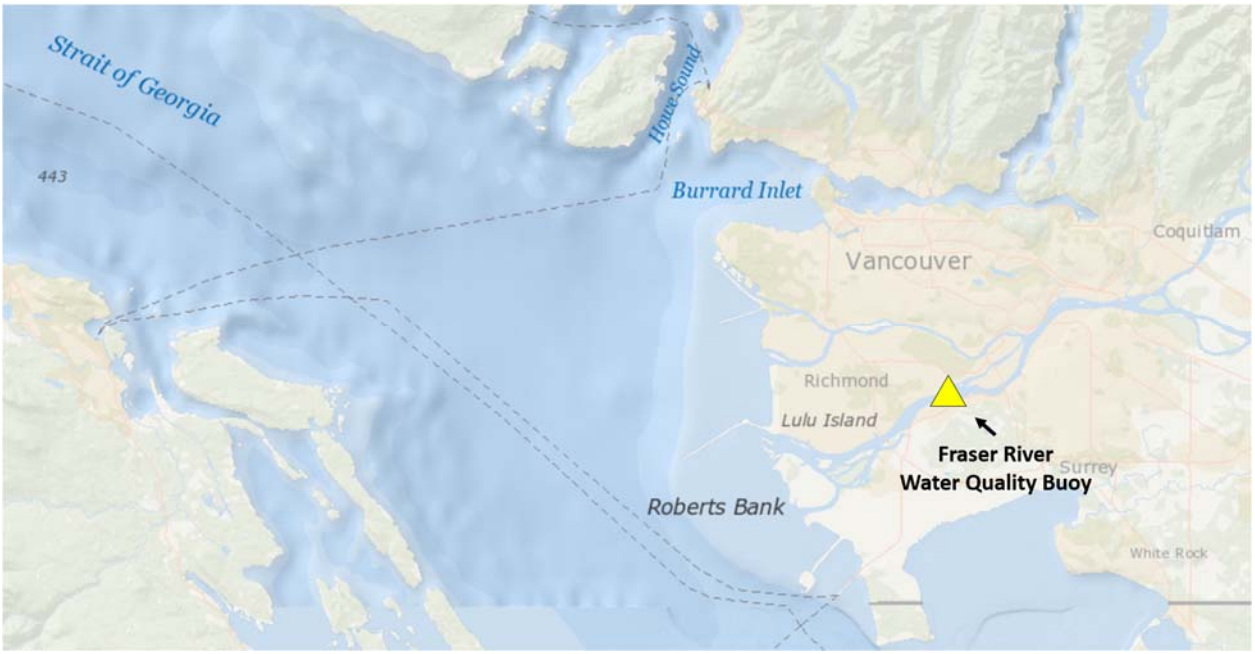


FIGURE 2-5: LOCATION OF FRASER RIVER WATER QUALITY BUOY

Figure 2-6 provides a summary of water temperature and salinity over the range of years from 2008 through 2017. Water temperature is indicated by the blue and grey curves according to the scale on

the left side of the figure. Salinity levels are indicated by the yellow to red curves per the scale on the right side of the figure.

It can be seen that the water temperature variation falls within a fairly narrow range, progressively increasing from 2-4°C in January to 18-22°C peaking in August, followed by a steady decrease through December.

Salinity levels through the year are inversely related to outflow from the Fraser River. Salinities of up to 15-18 ppt are recorded in the months from September to December through April (low discharge months). Over the summer months from May through August, i.e. the peak discharge months, the water is fresh.

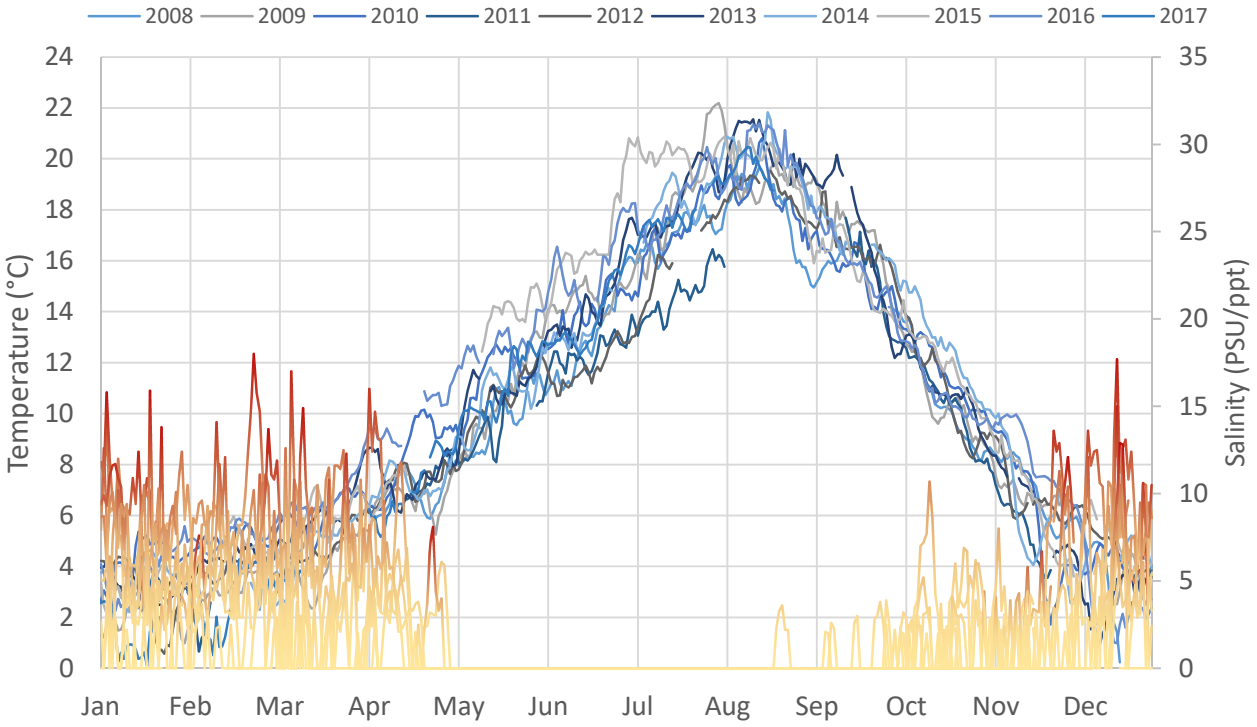


FIGURE 2-6: WATER TEMPERATURE AND SALINITY DATA FROM FRASER RIVER WQ BUOY *(ENVIRODAT, 2017)*

Figure 2-7 shows an example of the intertidal variation of salinity levels. The dark blue curve indicates the tide stage recorded at the buoy in meters relative to the scale on the left side. The green curve shows the corresponding flow velocities in meters per second, measured on the same scale. Flood tides are denoted by positive values and ebb tides by negative values. It can be seen that the tidal currents oscillate around a mean of around -0.4 m/s, which represents the steady outflow from the river.

The variation of the salinity level is indicated by the orange/red curve, with units in PSU/ppt per the scale on the right side of the figure. It can be seen that the variation of the salinity follows each tidal cycle, increasing on flood tides as saltwater propagates inland, and decreasing on ebb tides where more freshwater flows out.

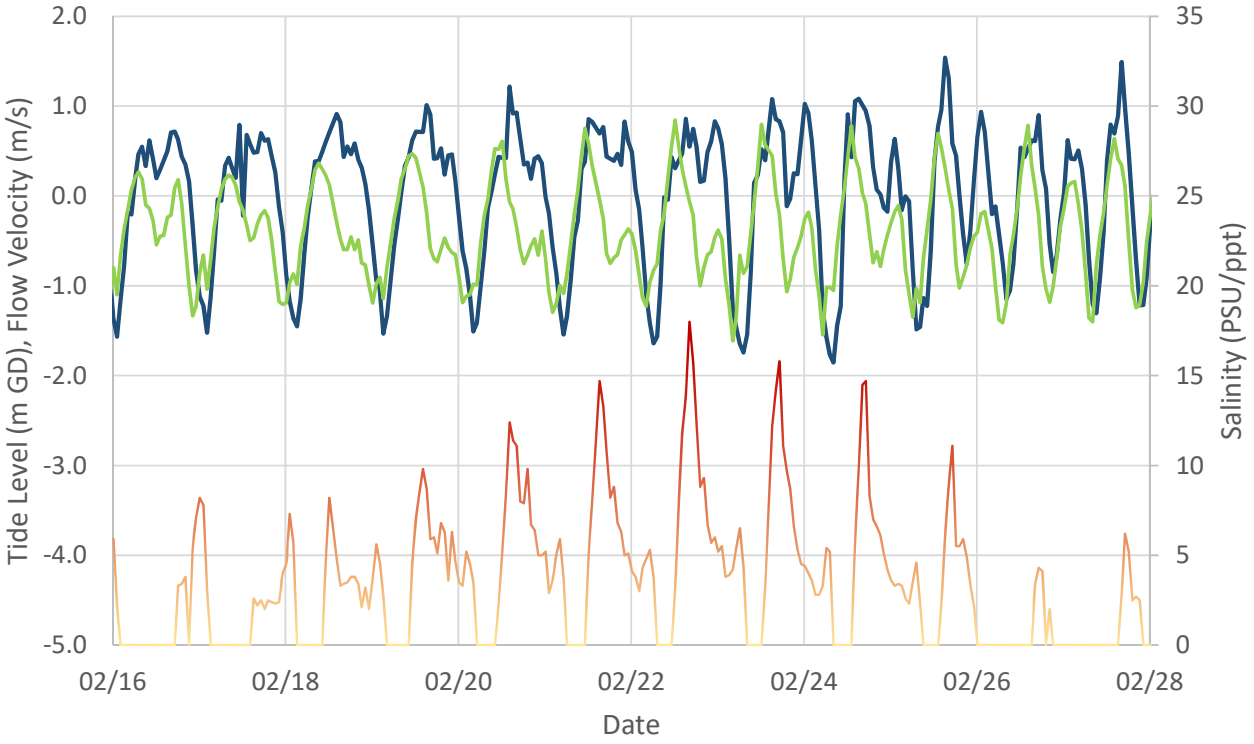


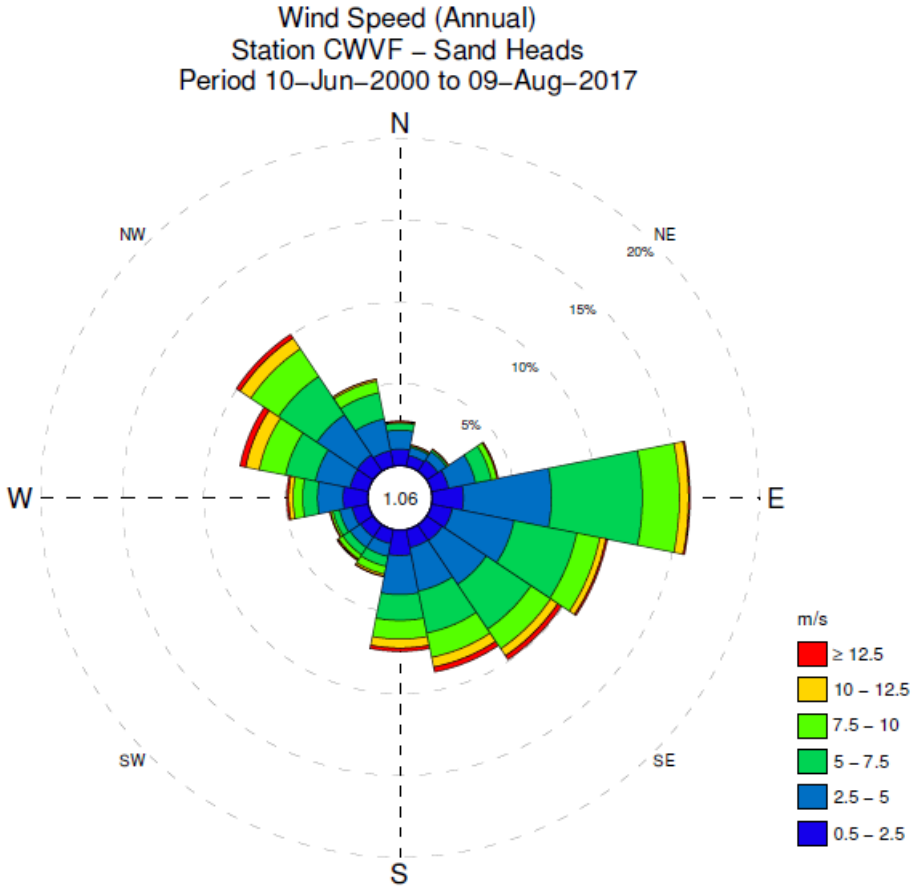
FIGURE 2-7: VARIATIONS OF SALINITY DURING FLOOD AND EBB TIDE *(ENVIRODAT, 2017)*

2.6. Wind Statistics

A metocean gauge located at Sand Heads has collected wind data since 2000. The location of the gauge (labeled as CWVF) is shown in Figure 4-1. Wind statistics for the station are summarized in Figure 2-8. The distribution of wind direction shows that predominant wind directions are from west-to-northwest sector, and from south-to-east sector.

These directions reflect the open-water configuration in the Strait of Georgia, having a great expanse to the northwest. The winds from easterly directions are representative of overland conditions. The topography of the inland area and mountain ranges to the north have the effect of generally funneling winds from east over the Vancouver area. The effect is consistent and the Vancouver Airport runways are therefore aligned approximately east-west orientation.

The table in Figure 2-8 summarizes the occurrence of wind speeds by direction. It can be seen that extreme wind speeds can exceed 12 m/s, but winds are more commonly below 10 m/s. The distribution of the highest winds shows that storm systems entering the Strait of Georgia can generate high winds from virtually any direction at Sand Heads, but less frequently from north-easterly direction.



Percentage of Occurrence

Wind Speed, m/s	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	2.71	1.30	1.58	4.12	15.77	10.97	9.91	8.87	7.40	2.92	2.63	2.36	4.93	7.99	10.05	5.42	98.94
12.5						0.11	0.27	0.31	0.20				0.11	0.35	0.26		1.81
10					0.57	0.37	0.52	0.61	0.55	0.14			0.27	0.84	0.80	0.12	5.01
7.5				0.35	2.27	1.44	1.45	1.52	1.15	0.49	0.32	0.15	0.59	1.65	2.03	0.73	14.27
5	0.43	0.10	0.14	0.99	5.57	3.91	3.29	2.62	1.58	0.62	0.54	0.41	0.90	1.87	2.82	1.63	27.43
2.5	1.16	0.50	0.62	1.68	5.38	3.85	3.24	2.71	2.40	0.79	0.77	0.78	1.56	2.16	2.96	1.98	32.55
0.5	0.99	0.65	0.80	1.04	1.89	1.27	1.13	1.10	1.53	0.87	0.90	0.98	1.49	1.12	1.16	0.95	17.88
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total

FIGURE 2-8: ANNUAL WIND ROSE AT SAND HEADS

2.7. Wave Statistics

Wave data for Station C46146 Halibut Bank (see Figure 4-1) is summarized in Figure 2-9. The data shows the annual percentage of occurrence. The majority (87%) of the waves recorded at the buoy have wave periods in the range from 2 to 10 seconds, which is representative of wind-waves dominated in the Strait of Georgia. The remaining longer-period waves in the form of remnant swell wave components may enter Strait of Georgia from the Pacific Basin.

During storm events, wind-generated wave heights can reach up to 2.1 meters in magnitude. This is expressed as the significant wave height, which is the average of the 1/3 of the largest waves. As a rule-of-thumb, the highest waves can be estimated around 1.8 times the significant wave height, and therefore on the order of 4 m (1.8×2.1). For reference, the height of an individual wave is measured from the trough to the crest.

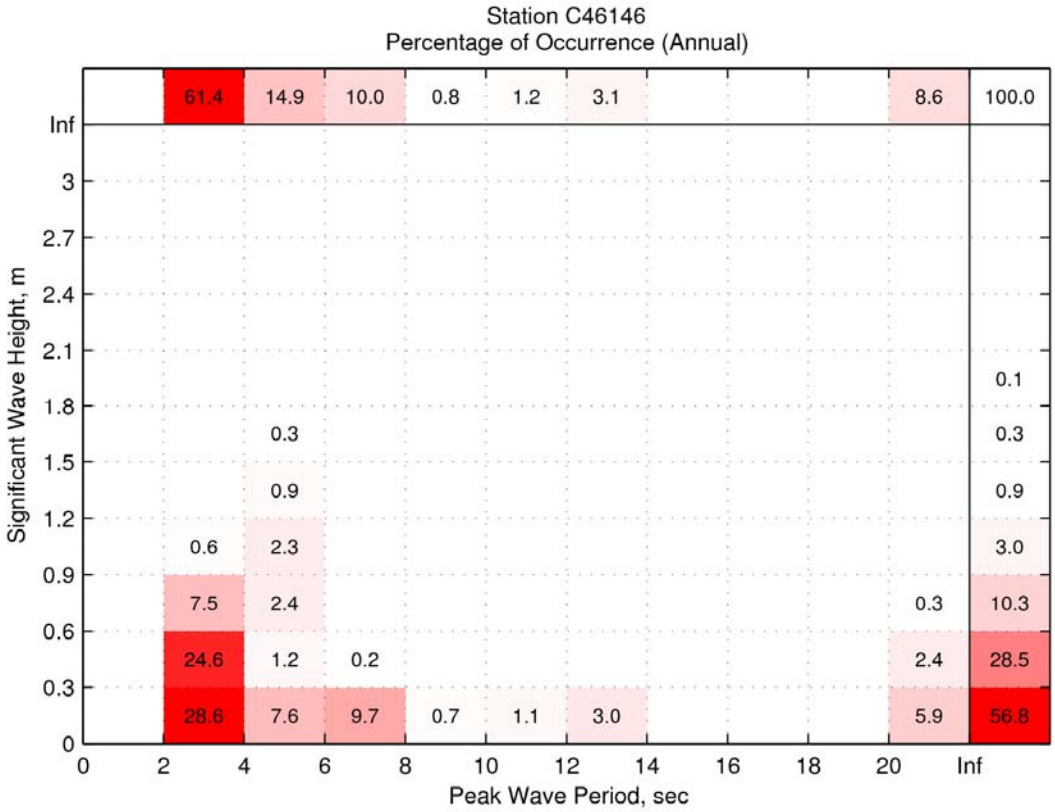


FIGURE 2-9: WAVE STATISTICS FOR HALIBUT BANK BUOY

3. Tidal Marsh Ecological Criteria

3.1. Soils

A characterization of surficial soils at the site is summarized in Figure 2-2. In addition to materials existing at the site, new fill material will be introduced in order to develop the grade at the site to the level appropriate for marsh vegetation.

In the following, information is provided on the permissible shear stress for material types such as those existing and planned for the site.

Table 3-1 summarizes typical permissible shear stresses for channels in bare soil to rock with linings across the range from non-cohesive to cohesive materials. Shear stress is defined as the force per unit area (expressed in N/m^2) applied parallel to the surface of a material.

TABLE 3-1: TYPICAL PERMISSIBLE SHEAR STRESS, REPRODUCED FROM *FHWA (2005)*

Material Category	Material Type	Permissible Shear Stress (N/m^2)
Bare Soil (PI = 10)	Clayey sands	1.8 to 4.5
	Inorganic silts	1.1 to 4.0
	Silty sands	1.1 to 3.4
Bare Soil Cohesive (PI ≥ 20)	Clayey sands	4.5
	Inorganic silts	4.0
	Silty sands	3.5
	Inorganic sands	6.6
Bare Soil Non-cohesive (PI < 10)	Finer than coarse sand d_{75} < 1.3 mm	1.0
	Fine gravel d_{75} = 7.5 mm	5.6
	Gravel d_{75} = 15 mm	11.0
Gravel Mulch	Coarse gravel d_{50} = 25 mm	19.0
	Very coarse gravel d_{50} = 50 mm	38.0
Rock riprap	d_{50} = 0.15 m	113.0
	d_{50} = 0.30 m	227.0

Permissible shear stress for non-cohesive material depends on the submerged weight of the material relative to the tractive force. The submerged weight is commonly described by a characteristic material grain size. The angularity of the material also affects its stability, but to a lesser degree when the material is placed horizontally or near-horizontally.

The grain sizes of cohesive materials are typically so small that the diameter does not affect the stability of the materials. The permissible shear stress for cohesive materials is therefore more complex and depends primarily on the plasticity index (PI) of the material, the void ratio, and to a lesser extent the angularity of the grains.

Details on permissible shear stress for non-cohesive and cohesive soils are provided in the following.

3.1.1. Non-Cohesive Soils

Figure 3-1 shows the allowable effective stress for non-cohesive materials for the range from fine sand to coarse gravel (solid black line). The theoretical threshold of mobility is indicated by the yellow line. This relation arises from the following relations:

$$\theta_c = \frac{U_{fc}^2}{(s-1)gd}$$

Where θ_c is the dimensionless critical Shield's Parameter, g is the gravitational acceleration, d is the sediment grain diameter, and s is the relative density of the sediment defined as:

$$s = \frac{\rho_s}{\rho_w}$$

Where ρ_s is the density of the sediment, and ρ_w is the density of the water.

The critical bed friction velocity, U_{fc}, is defined as:

$$U_{fc} = \sqrt{\frac{\tau_b}{\rho_w}}$$

Where τ_b is the critical bed shear stress.

The theoretical threshold of sediment mobility indicated by the yellow line in Figure 3-1 arises following introduction of the Shields-Rouse equation for the threshold of incipient motion (critical Shields Parameter), given by:

$$\theta_c = \frac{0.23}{d_*} + 0.054 \cdot \left(1 - exp\left(-\frac{d_*^{0.85}}{23}\right)\right)$$

Where d_* is the dimensionless sediment grain diameter, defined as:

$$d_* = \left(\frac{(s-1)g}{\nu^2}\right)^{\frac{1}{3}} d$$

Where ν is the kinematic viscosity of water.

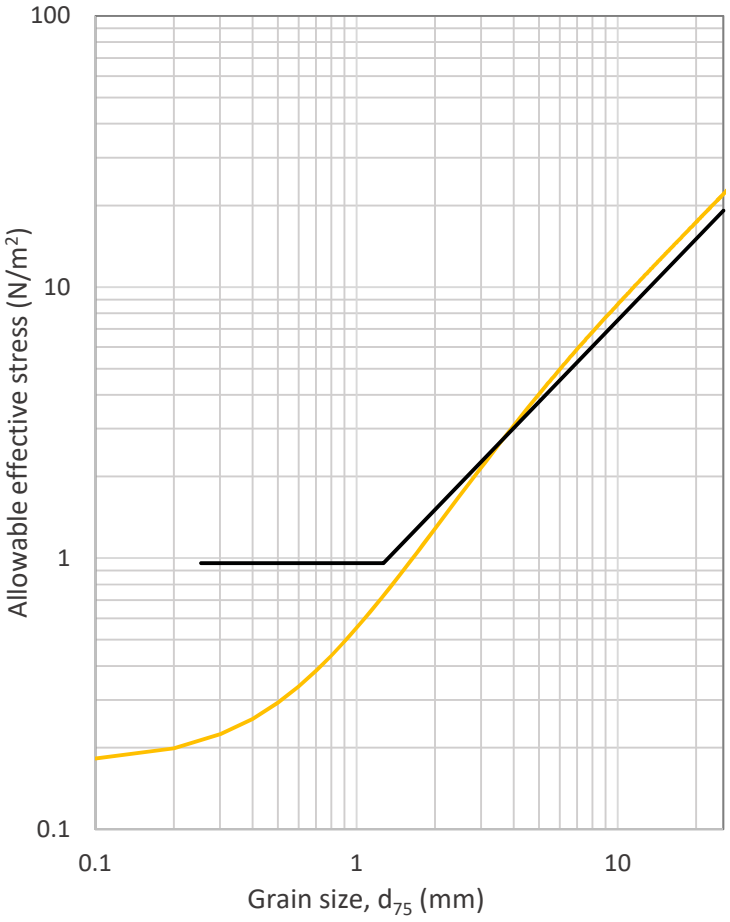


FIGURE 3-1: ALLOWABLE STRESS FOR NON-COHESIVE SOILS (*USDA, 2007*)

3.1.2. Cohesive Soils

Allowable stress for cohesive soils is summarized in Figure 3-2. The data covers selected material types as categorized per the Unified Soil Classification System (USCS) summarized in Table 3-2. The materials include clayey gravel (GC), fat clay (CH), silty gravel (GM), lean clay (CL), clayey sand (SC), elastic silt (MH), organic clay and organic silt (OH) with LL≥50, silt (ML), organic clay and organic silt (OL) with LL<50, and silty sand (SM).

TABLE 3-2: UNIFIED SOIL CLASSIFICATION SYSTEM (ABBREVIATED)

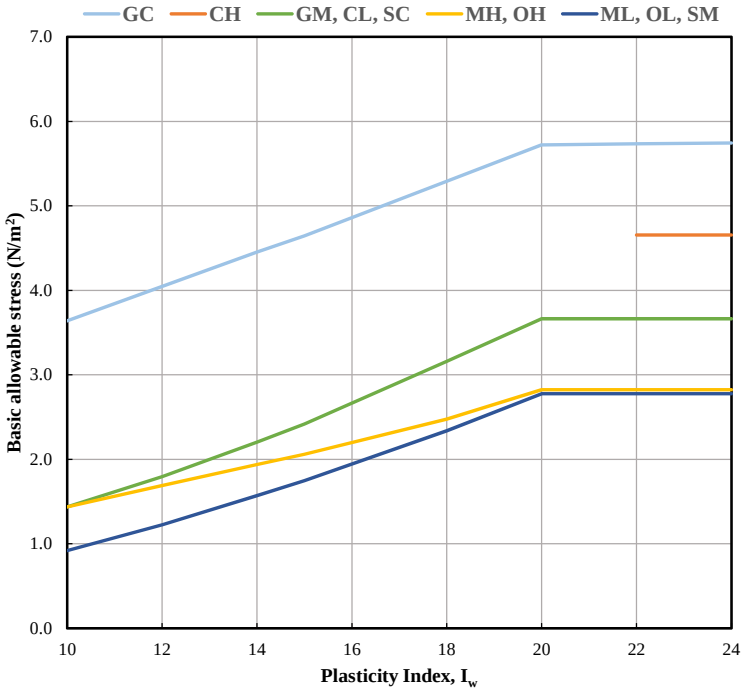
Classification		ID	Description
Gravels	Clean	GW	Well graded gravels
		GP	Poorly graded gravels
	With Fines	GM	Silty gravels
		GC	Clayey gravels
Sands	Clean	SW	Well graded sands
		SP	Poorly graded sands
	With Fines	SM	Silty sands
		SC	Clayey sands
Silts and Clays LL 50% or less		ML	Inorganic silts
		CL	inorganic clays
		OL	Organic silts or clays
Silts and Clays LL greater than 50%		MH	Inorganic silts
		CH	inorganic clays
		OH	Organic silts or clays
Highly Organic Soils		Pt	Peat

The graph on the left side of Figure 3-2 provides the basic allowable shear stress as a function of the plasticity index. The figure on the lower right provides an adjustment factor, which can range from 0.8 to 1.2 dependent on the void ratio of the material,

The void ratio of the material is the ratio of the volume of voids to the volume of the solids. The void ratio, e, also relates to porosity, n, as follows:

$$e = \frac{n}{1-n}$$

And is thus a measure of the compactness of the material, e.g. in non-cohesive materials the level of compaction from loose (n = 0.4) to dense (n = 0.3). In broadly graded materials such as glacial till, where smaller particles can be enclosed in the pores between larger grains, the void ratio can be as low as 0.3 (n = 0.2). Conversely, organic soils can have a very loose structure, e.g. loess having a void ratio of 0.9 ($n \approx 0.5$). Void ratios for cohesive soils are usually on the higher side with e = 0.9 to 3.2 (n = 0.47 to 0.76).



Soil Type	Void ratio, e
Loose angular-grained silty sand	0.65
Dense angular-grained silty sand	0.4
Stiff clay	0.6
Soft clay	0.9–1.4
Loess	0.9
Soft organic clay	2.5–3.2
Glacial till	0.3

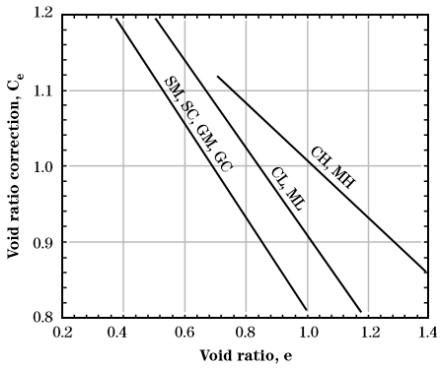


FIGURE 3-2: ALLOWABLE STRESS FOR COHESIVE SOILS *(USDA, 2007)*

3.1.3. Characteristics of Soils at Project Site

Hemmera (2014) and *GLW (2014)* summarized soils data for the habitat site and a wide range of dredge material source locations along the Fraser River and offshore.

Figure 3-3 characterizes soil types at the project location determined from samples taken at the South Arm Marsh site, *Hemmera (2014)*. The data is indicated by the crosses (×) in the figure, and shaded so that material with high sand content (left side of figure) is yellow, and transitions across orange to red with increasing amount of fines and organic content. The figure also shows soils data for source (dredge) material from Sand Heads Reach, which was determined by *GLW (2014)* to be the most suitable fill material for the site restoration. The data for this material is indicated by the circles (○) in the figure.

It can be seen that soils of the area characterize as: *sand, loamy sand, sandy loam, loam, and silt loam*.

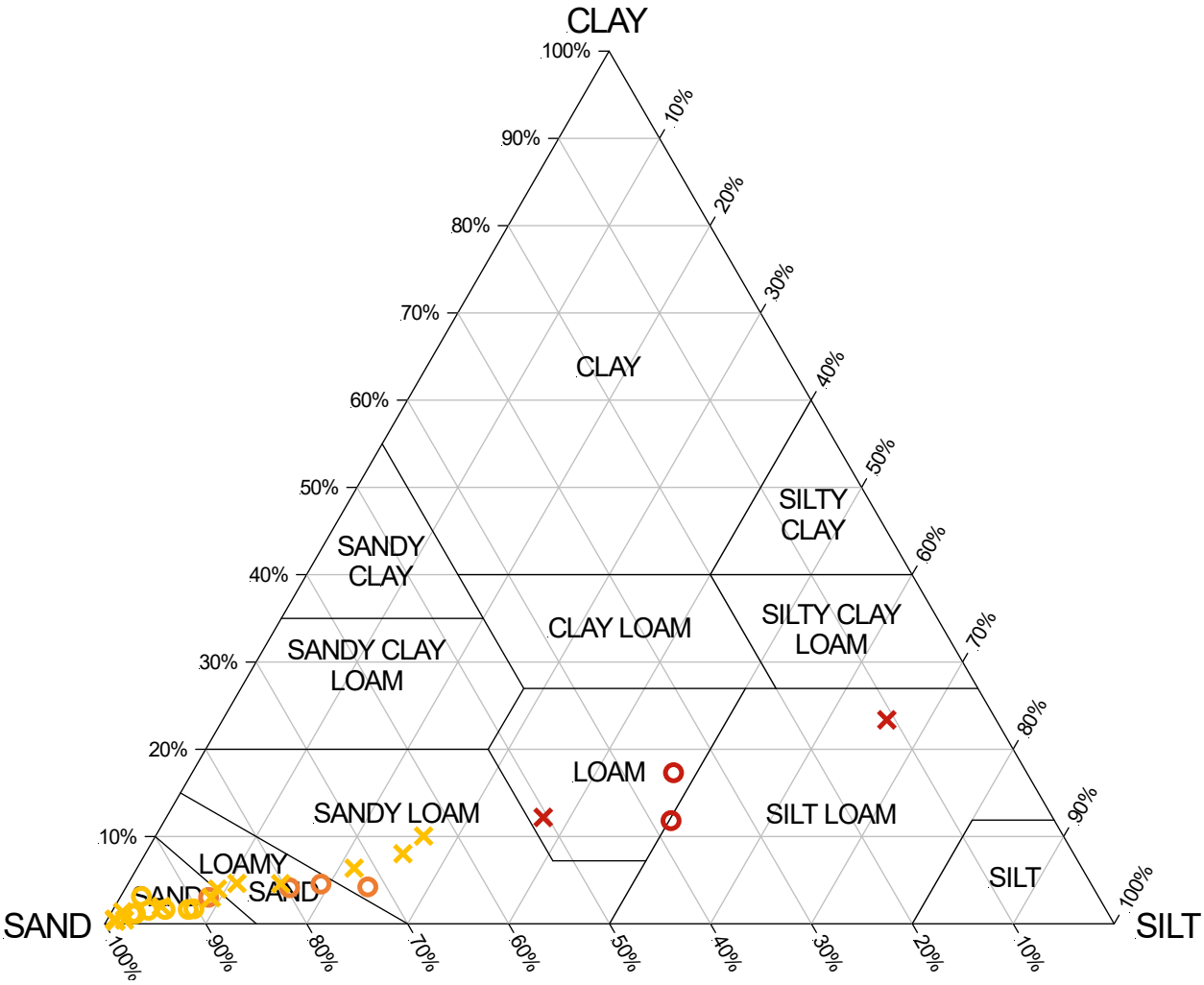


FIGURE 3-3: SOIL TYPES CHARACTERISTIC OF SOUTH ARM MARSH SITE AND SAND HEADS REACH

In order to assess the level of erodibility of materials, Figure 3-4 shows the corresponding mapping of soils characteristics per the USCS classification, which enables a characterization of the threshold of erodibility of materials via Figure 3-1 for non-cohesive sediments, and Figure 3-2 for cohesive materials.

Per the USCS classification, the South Arm Marsh and Sand Heads Reach materials generally characterize as: Well-graded sand (SW), silty sand (SM), sandy silt (MS), lean silt (ML), and clay of low plasticity, lean clay (CL).

Based on the information provided above regarding permissible shear stress and soil characteristics at Sturgeon Bank, it can be concluded that 1 N/m^2 is a reasonable and conservative target for bed shear stress in the proposed marsh area.

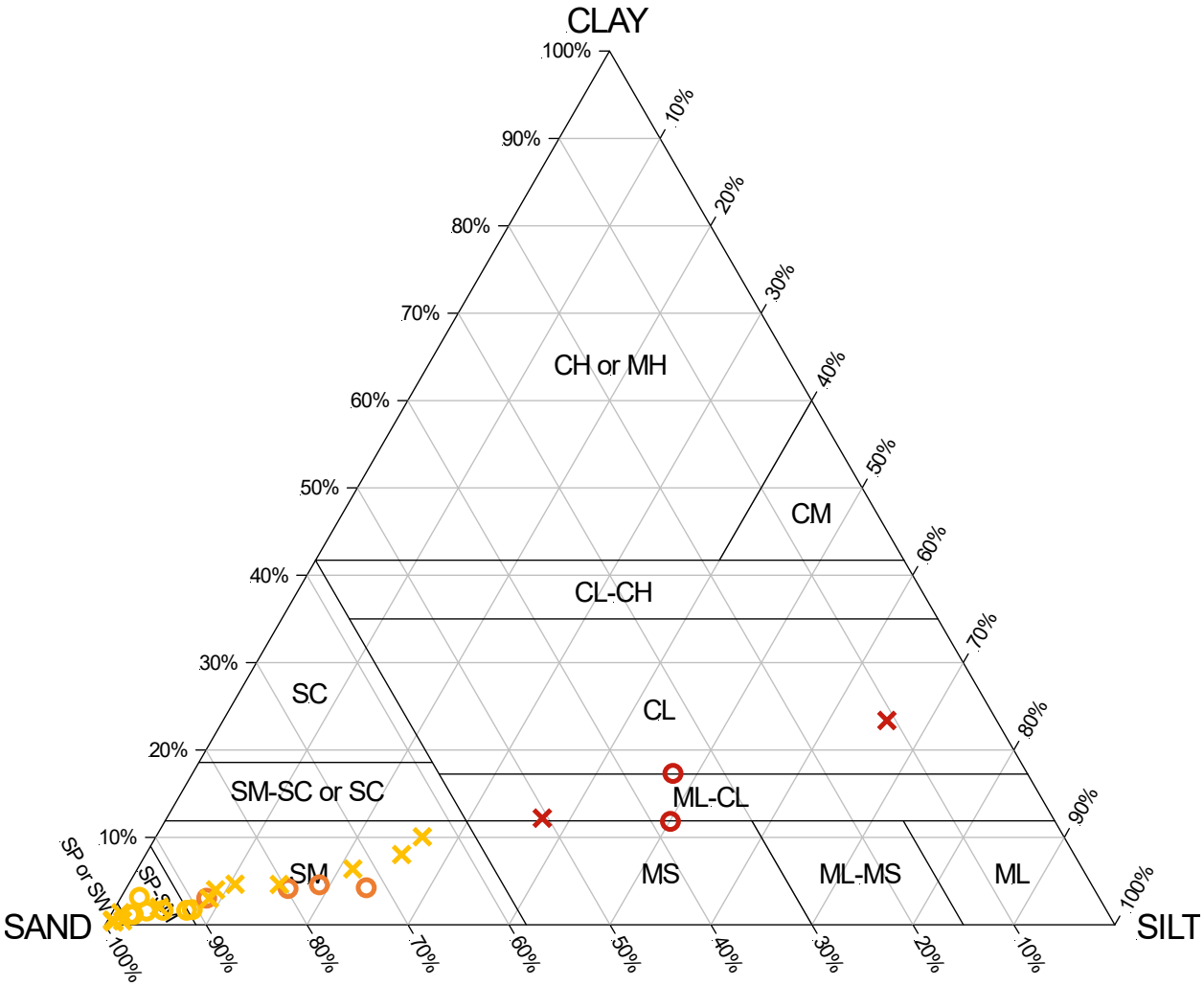


FIGURE 3-4: USCS SOIL CLASSIFICATION OF SOUTH ARM JETTY RESTORATION MATERIALS

3.2. Marsh Vegetation

3.2.1. Existing Marsh

An area of existing marsh vegetation has developed along a portion of the South Arm North Jetty, consisting of a 40-120 m wide band of marsh vegetation consisting of baltic rush, lyngbye's sedge, three-square bulrush and seacoast bulrush, *GLW (2017a)* and *M&N (2017)*. The vegetation is characterized by healthy stands of bulrush and adjoining rills 0.3 to 0.5 m deep (1 to 1½ feet). Other areas feature isolated patches of emerging stands of bulrush.

Observations from site visits indicate that the establishing marsh vegetation is likely affected by factors such as: elevation, bottom shear stress, soil organic content, salinity changes, and drainage patterns.

Sediment surface water salinities measured at the marsh platform during field visits were on the order of 4-5 PSU. Surface water salinities measured further north on the outer mudflat were 8-15 PSU.

Table 3-3 summarizes elevation ranges of plant species identified in field surveys at the South Arm Jetty and adjoining Roberts Bank.

TABLE 3-3: PROJECT AND REGIONAL PLANT ELEVATION RANGES

Plant Species	Elevation Range (m CD)		
	South Arm Jetty [1]	Roberts Bank [2]	DeltaPort Causeway [2]
Seacoast Bulrush	3.0 – 3.2	3.0 – 3.8	3.4 – 4.0
Lyngbye's Sedge	3.1 – 3.9	*3.1 – 4.2*	
Saltgrass		*3.8 – 5.0*	3.8 – 5.0
Baltic Rush	3.2 – 4.0	*3.0 – 3.4*	
Pacific Silverweed		*3.0 – 4.2*	
Pickleweed		*3.6 – 4.5*	3.6 – 4.7
Three-Square Bulrush	2.8 – 3.3	2.6 – 3.8	3.2 – 3.9
Softstem Bulrush		*3.1 – 4.3*	
Arrowgrass		*3.6 – 4.0*	3.6 – 4.0

References:

1) *GLW (2017a)*
2) *GLW (2009)*

3.2.2. Candidate Marsh Vegetation

Classification and characterization of proposed marsh vegetation is provided in the following. Candidate plants are based on existing vegetation identified during field visits *(GLW, 2017a)*, and the planting scheme proposed by GL Williams *(GLW, 2017b)*.

The taxonomy of the marsh vegetation considered is provided in Table 3-4 along with a guide to identification.

TABLE 3-4: TAXONOMY

Common Name *Scientific Name*	Clade	Family	Identification
Seacoast Bulrush *Bolboschoenus maritimus*	Monocot	Cyperaceae	
Lyngbye's Sedge *Carex lyngbyei*	Monocot	Cyperaceae	

Common Name *Scientific Name*	Clade	Family	Identification
Saltgrass *Distichlis spicata*	Monocot	Poaceae	
Baltic Rush *Juncus arcticus*	Monocot	Juncaceae	
Pacific Silverweed *Potentilla anserina*	Dicot	Rosaceae	
Pickleweed *Sarcocornia pacifica*	Dicot	Chenopodiaceae	
Three-Square Bulrush *Schoenoplectus pungens*	Monocot	Cyperaceae	
Softstem Bulrush *Schoenoplectus tabernaemontani*	Monocot	Cyperaceae	
Arrowgrass *Triglochin maritima*	Monocot	Juncaginaceae	

Table 3-5 summarizes the phytomorphology of the marsh vegetation considered. Data summarized based on information from *USDA (2017)* and *Baye (2007)*.

TABLE 3-5: PHYTOMORPHOLOGY

Common Name	Description	Foliage Color	Height (m)	Growth Form	Root Depth (m)
Seacoast Bulrush	Graminoid	Green	1.50	Rhizomatous	0.75
Lyngbye's Sedge	Graminoid	Green	1.00	Bunch	0.36
Saltgrass	Graminoid	Green	0.34	Rhizomatous	0.05
Baltic Rush	Graminoid	Green	0.70	Rhizomatous	0.40

Common Name	Description	Foliage Color	Height (m)	Growth Form	Root Depth (m)
Pacific Silverweed	Forb/herb/subshrub	Gray-Green	0.50	Multiple Stem	0.10
Pickleweed	Forb/herb/subshrub	Green	0.30	Multiple Stem	0.15
Three-Square Bulrush	Graminoid	Green	1.00	Rhizomatous	0.15
Softstem Bulrush	Graminoid	Green	2.00	Rhizomatous	0.41
Arrowgrass	Graminoid	Green	0.80	Tufted	0.20

Plant life cycle data, growth periods, growth rates, and lifespan is summarized in Table 3-6. A short lifespan is considered 1-3 years, a moderate life span 3-10 years and a long lifespan 10-20 years.

TABLE 3-6: GROWTH AND DEVELOPMENT

Common Name	Life Cycle	Active Growth Period	Lifespan
Seacoast Bulrush	Perennial	Spring, Summer	Long
Lyngbye's Sedge	Perennial	Spring, Summer	Long
Saltgrass	Perennial	Spring, Summer, Fall	Long
Baltic Rush	Perennial	Spring, Summer	Moderate
Pacific Silverweed	Perennial	Spring, Summer	Moderate
Pickleweed	Perennial	Spring, Summer	Short
Three-Square Bulrush	Perennial	Summer, Fall	Moderate
Softstem Bulrush	Perennial	Spring, Summer, Fall	Long
Arrowgrass	Perennial	Spring, Summer	Long

The salinity tolerance of marsh vegetation can be categorized as shown in Table 3-7 *(GLW, 2017b)*.

TABLE 3-7: MARSH TYPES

Marsh Type	Salinity Range (PSU)
Freshwater marsh	< 0.5
Brackish marsh	0.5 to 18
Saltmarsh	18 to 30

The pH scale shown in Table 3-8 ranges from 0-14, with neutral in the middle. Values below 7 indicate increasing acidity, while values above 7 indicate increasing alkalinity. The tabled pH values indicate that the candidate plants generally tolerate somewhat acidic to somewhat alkaline conditions. This is in line with the range expected for a saltwater marsh environment. The normal range of stream water has pH around 6 to 8, and seawater approximately pH 8.

TABLE 3-8: SALINITY AND PH TOLERANCE

Common Name	Salinity (PSU)	pH	Substrate
Seacoast Bulrush	2 - 20	4.3 - 9.0	Fines to sand
Lyngbye's Sedge	0 - 15	4.0 - 7.5	Fines to sand
Saltgrass	4 - 35	6.4 - 10.5	Fines to sand
Baltic Rush	2 - 15	7.8 - 9.1	Fines to sand
Pacific Silverweed	0 - 15	4.0 - 7.5	Fines
Pickleweed	18 - 35	6.0 - 10.0	Fines to sand
Three-Square Bulrush	0 - 20	6.0 - 7.0	Fines to sand
Softstem Bulrush	0 - 11	5.4 - 7.5	Fines
Arrowgrass	0 - 30	6.7 - 8.7	Fines



Figure 3-5 summarizes preferred water depths and salinity tolerance for the candidate marsh vegetation species. Each species is identified by its common name and its scientific name. The vertical scale on the left side of each figure provides a measure of the height of mature plants relative to ground level. Similarly, the approximate root depth is indicated below grade. The aquamarine horizontal lines indicate the preferred water level range for propagation of plant seedlings. The range indicated is typically quite narrow, but for most species fluctuating water levels will promote propagation of new shoots. The darker blue horizontal lines indicate the range of water depths preferred by the distinct types of vegetation. The lower line reflects the limit of desiccation, which is however approximate as it depends on the depth of the root system. The extent of the root system is in turn dependent on the characteristics of the substrate. The upper line can be taken as the maximum level of periodic inundation. It should be noted that some species, e.g. bulrushes prefer an environment with their root mass permanently submerged, whereas other species tolerate only periodical immersion. The maximum level of inundation is indicated by the dark blue dotted line, which is mostly shown as a wavy line, indicating that the respective species is tolerant to tidal inundation.

The vertical bar in yellow on the right-hand side of the figures indicates the salinity levels in PSU tolerated by each species. Light blue shading at the lower portion of the scale indicates species that tolerate brackish and fresh water.

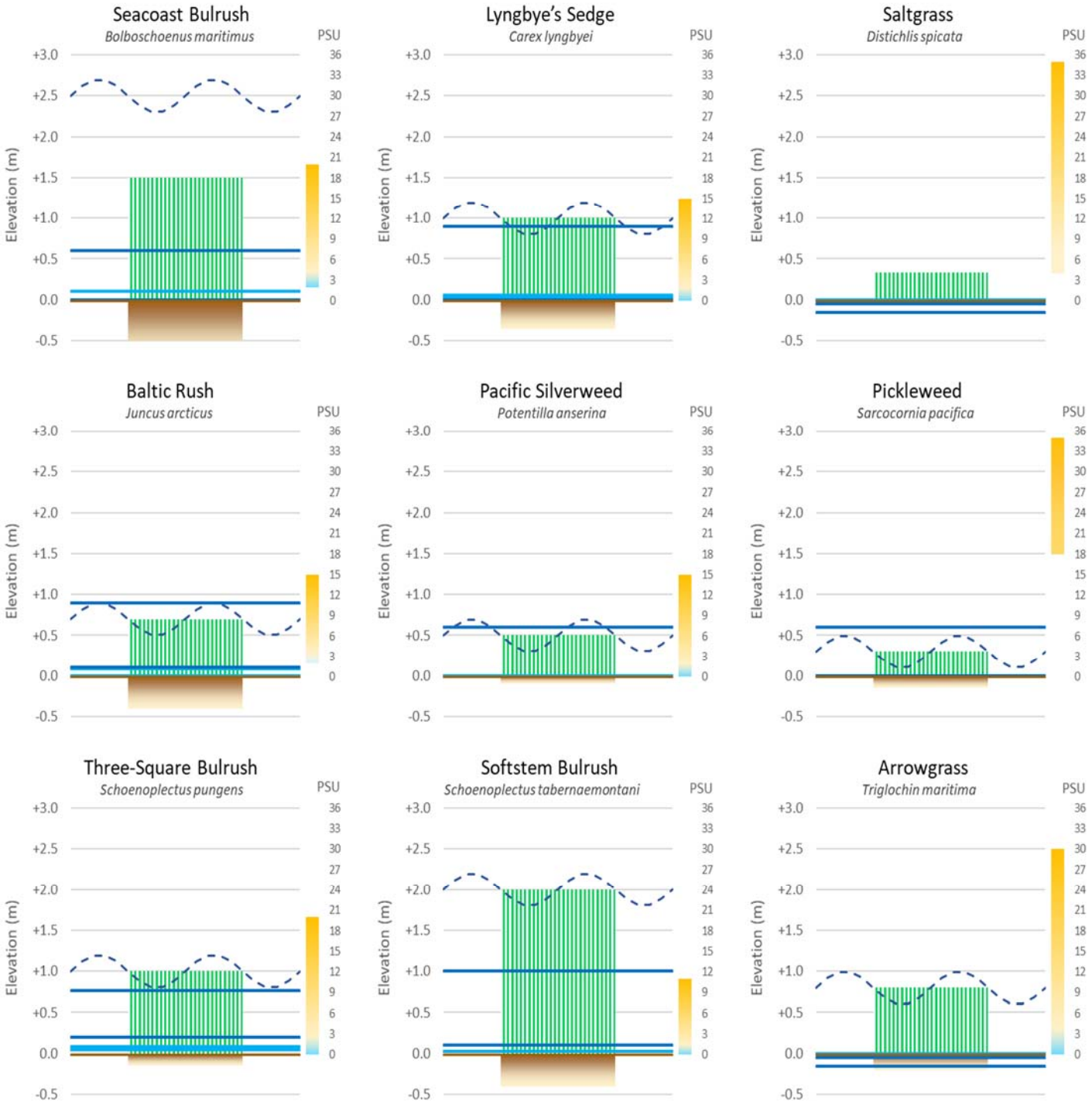


FIGURE 3-5: MARSH VEGETATION ELEVATION RANGE AND SALINITY TOLERANCE

4. Numerical Model Development

The Danish Hydraulic Institute MIKE-21 Spectral Wave (SW) and MIKE-21/3 Hydrodynamic (HD) models were developed for the Lower Fraser River and Strait of Georgia to carry out the relevant analyses and to determine engineering requirements for the proposed marsh. Both models were calibrated to ensure that wave, hydrodynamic, and salinity mixing processes were adequately reproduced. Figure 4-1 depicts the locations of the metocean data stations used in the model development.

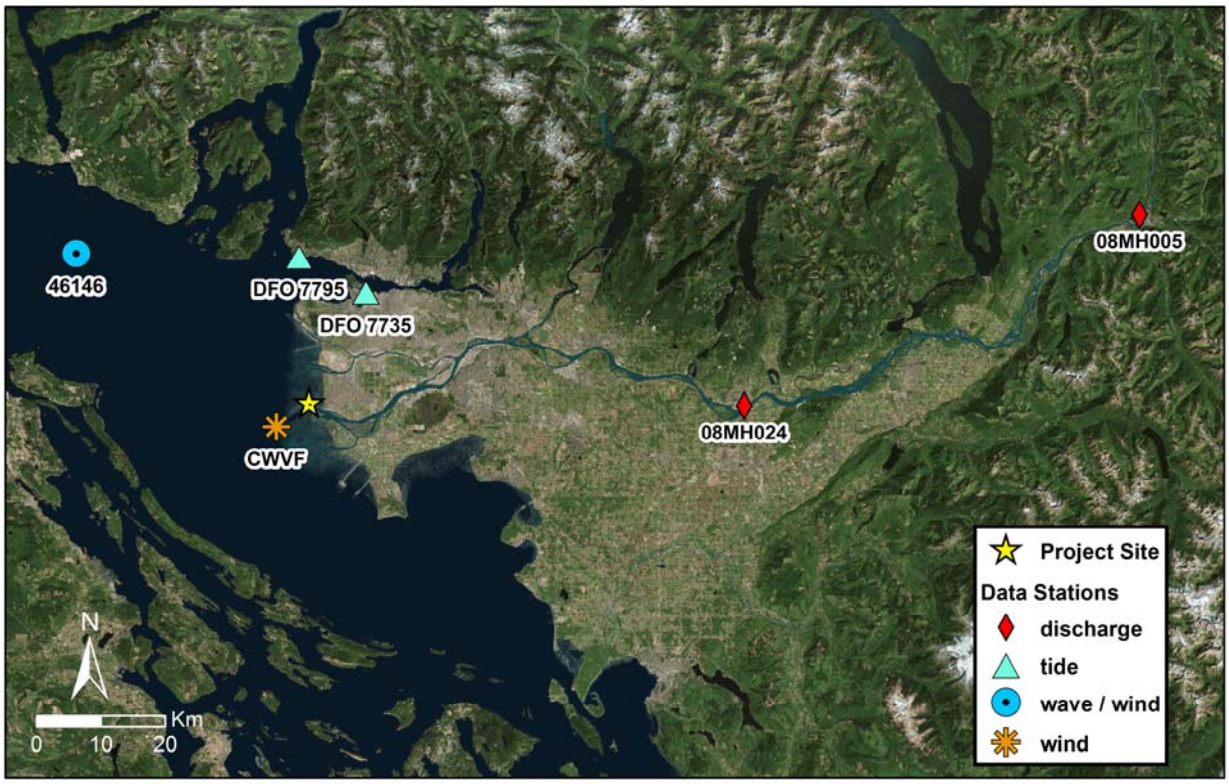


FIGURE 4-1: METEOCEAN DATA SOURCES

4.1. Model Description

MIKE is a modelling system developed by the Danish Hydraulic Institute (DHI) Water and Environment. It was selected for the project because of the flexibility and computational efficiency with its unstructured grid configuration. The unstructured grid makes it possible to resolve both large and small-scale flow and wave processes effectively. Finer resolution grid elements are used in the vicinity of the project area while coarser grid elements are used away from the areas of interest.

The two-dimensional SW model solves the wave action conservation equations and simulates the growth, decay, and transformation of wind-generated seas and long-period swells in offshore and coastal areas. The SW considers important physical processes, including wave growth by action of winds, shoaling and refraction due to depth variations, diffraction and reflection near structures, wave

breaking in the surf zone, wave dissipation (including bottom friction, white capping, and wave-wave interaction), and some non-linear wave-current interactions.

The HD model solves flow continuity, momentum, temperature, salinity and density equations and simulates water level variations and flows in response to a variety of forcing functions. Because of the complex variations in salinity mixing within the water column, the computational-demanding three-dimensional HD model was used in the study.

4.2. Model Grid and Bathymetry

For computational efficiency and accuracy purposes, different model grids were developed for the SW and HD model. To accurately reproduce wave processes such as growth and propagation to the SAJ project site, the computational domain for the SW model covers the Strait of Georgia Basin, extended around Texada Island to the northwest and Birch Bay to the south (orange polygon in Figure 4-2); while a smaller domain for the HD model (pink polygon in Figure 4-2) to resolve the complex circulation processes in the Fraser River Delta. The HD domain extends inland to Mission as the freshwater discharge source.

Figure 4-3 shows the unstructured grid elements near the project site. The finest element resolution along the SAJ North Jetty is approximately 10 m.

Bathymetry (or seabed elevations) for the majority of model domain was extracted from the C-Map Software of DHI, incorporating Jeppesen Norway's electronic database of global nautical charts (*DHI, 2008*). Figure 4-4 shows the average water depth in the Strait of Georgia is approximately 150 meters. The maximum depth can reach 400 meters, just south of Texada Island. Water depths in the Fraser River are largest on its South Arm (up to approximately 15 m) due to the presence of the navigation channel. Vertical datum reference is Geodetic Datum (GD).

A zoom-in view of the model bathymetry at Sturgeon Bank and the project site is provided in Figure 4-5. Noticeable bathymetric features in the view are the "Sand Island" shoal, with bed elevations of up to + 1.2 m GD, and the Scotch Pond and Scotch Pond Channel, dredged to elevations of around - 1.8 m GD.

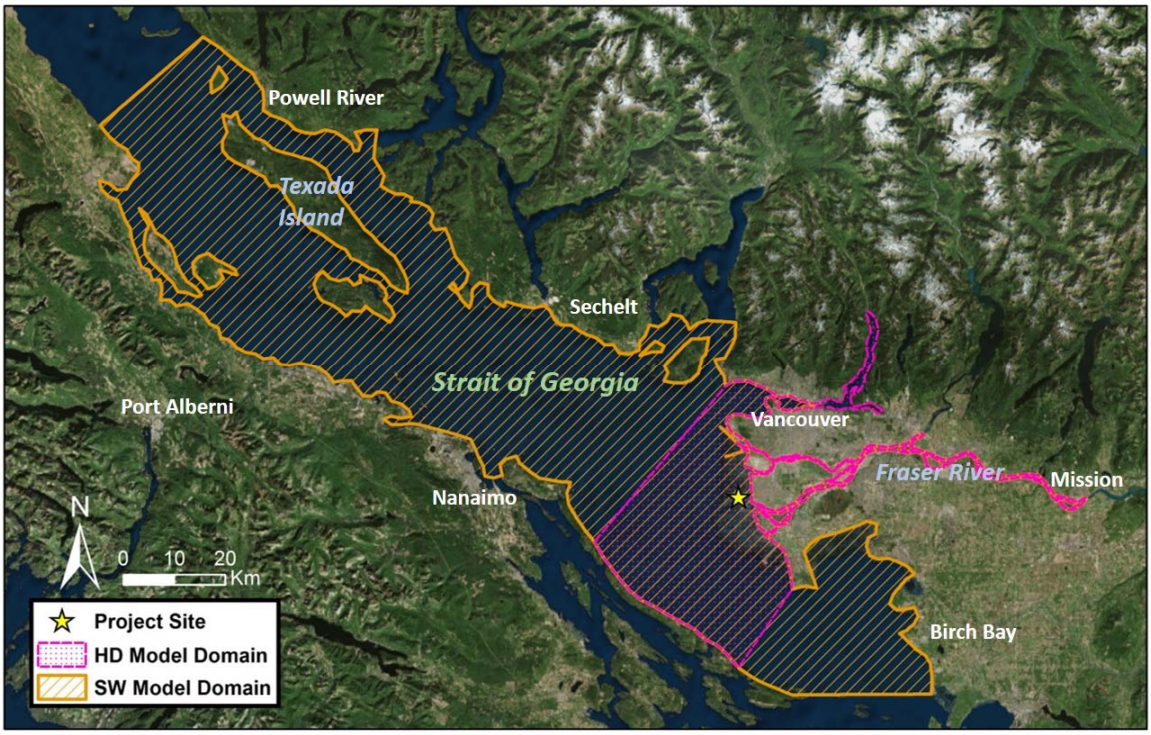


FIGURE 4-2: MODEL DOMAIN FOR SPECTRAL WAVE AND HYDRODYNAMIC MODELS

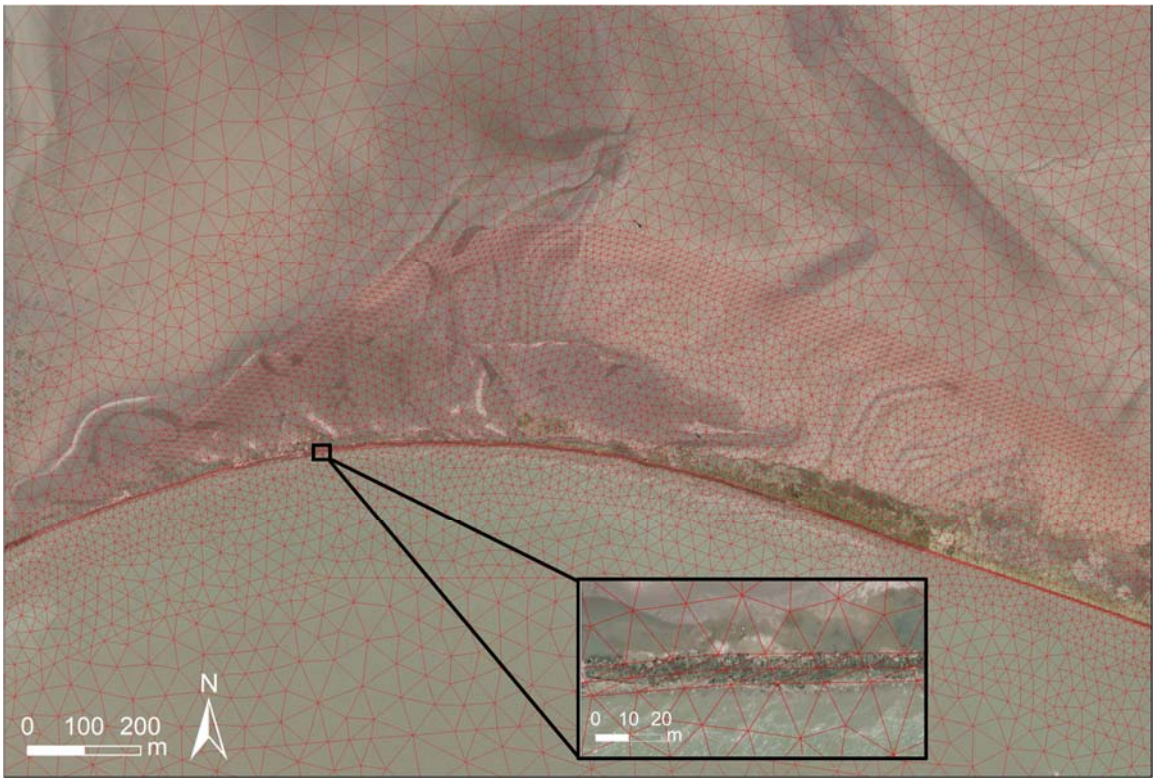


FIGURE 4-3: UNSTRUCTURED GRID ELEMENTS AT PROJECT SITE

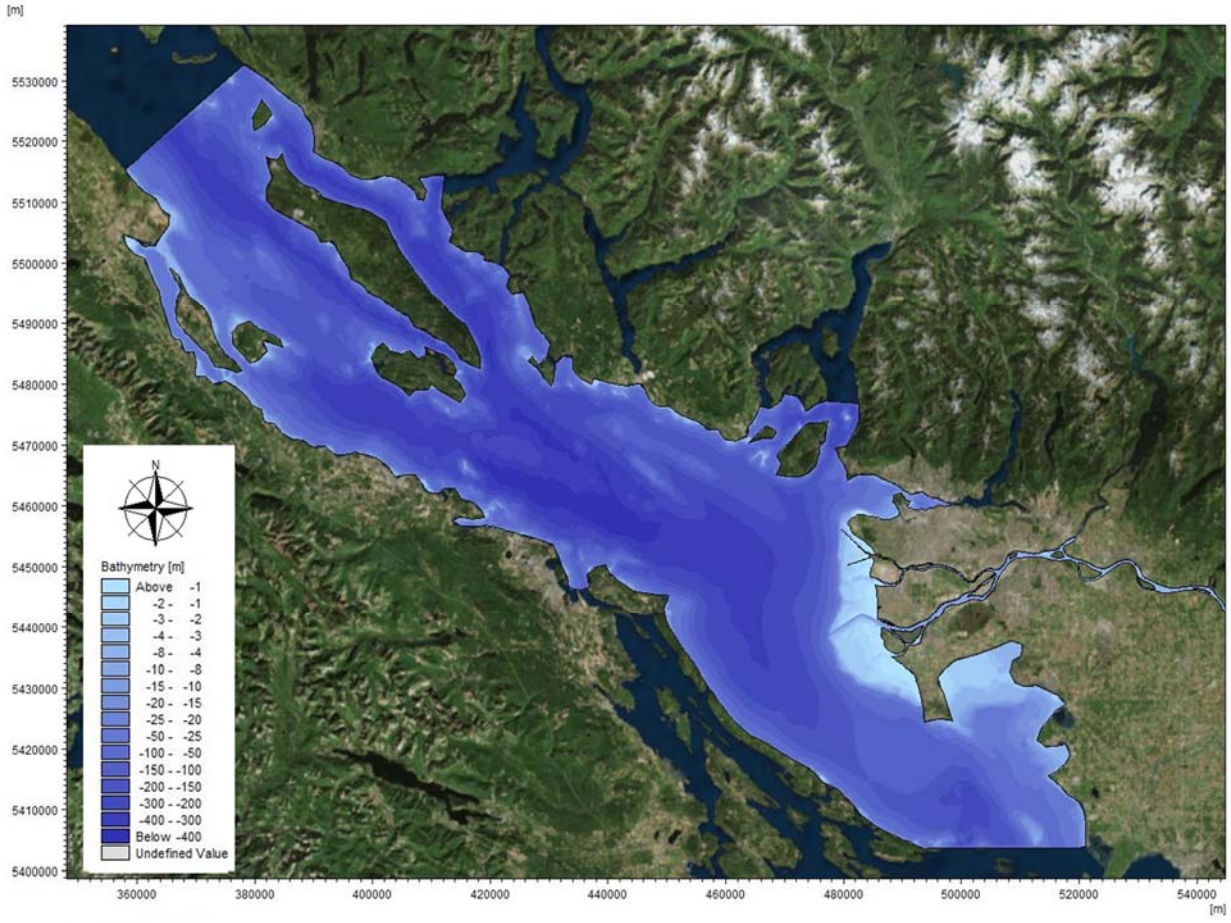


FIGURE 4-4: MODEL BATHYEMTRY (INCLUDING STRAIT OF GEORGIA)

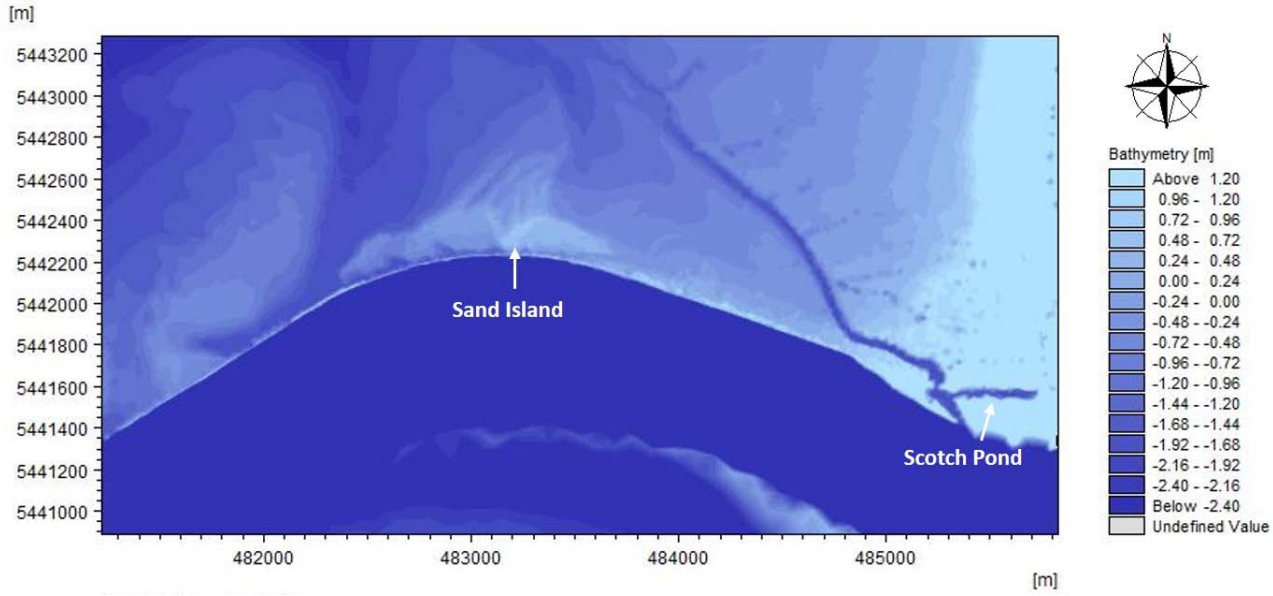


FIGURE 4-5: MODEL BATHYMETRY AT PROJECT SITE

4.3. SW Model Calibration

Typically, outputs from any numerical model need to be verified with field measurements, in order to show the model can reasonably reproduce the processes or environment of interest. This procedure is called model calibration.

The SW model was calibrated against hourly wave records at DFO Halibut Bank station (C46146, Figure 4-1), which include observations of significant wave height (H_s) and peak wave period (T_p) from 1996 to 2017.

A winter storm which occurred in Strait of Georgia in December 2001 was selected for SW model calibration because the storm had lasted more than 12 hours. Figure 4-6 shows the selected storm had retained a speed up to 40 knots (or 20 m/s) at Halibut Bank with predominant northwest-southeast directions.

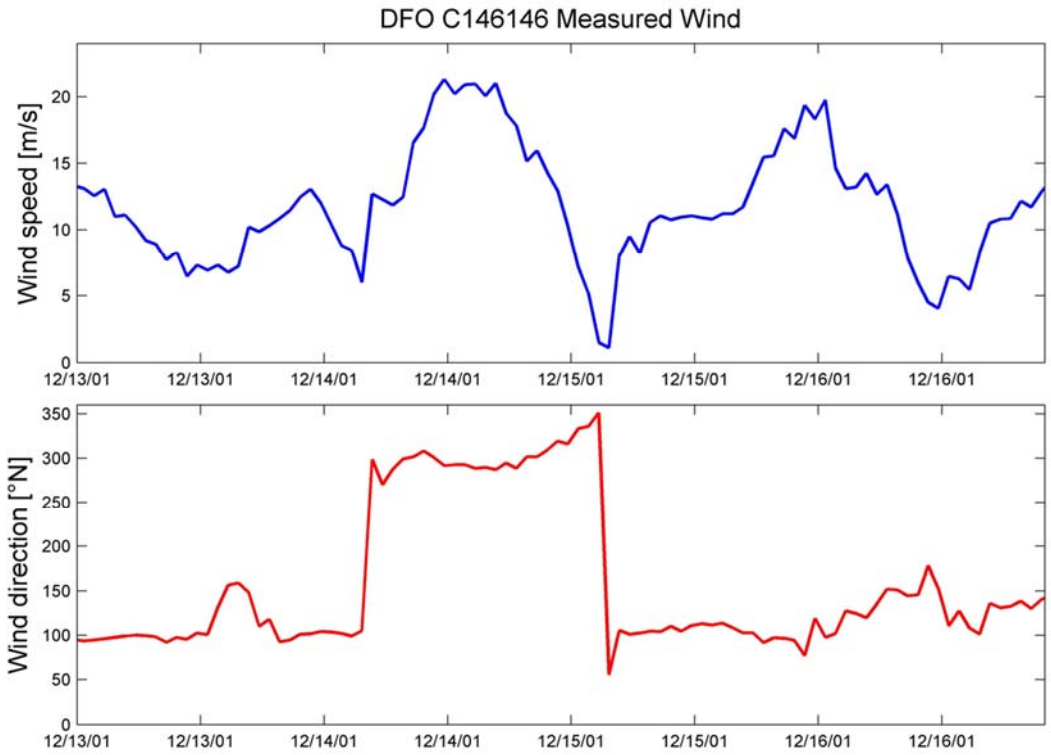


FIGURE 4-6: SELECTED WINTER STORM EVENT FOR WAVE CALIBRATION

Wave calibration was achieved by adjusting wave dissipation coefficients as well as spectral properties. In order to quantify the agreement between measured and model data, the following statistical parameters were determined.

- Root Mean Square Error (RMSE): $\varepsilon_{RMS} = \sqrt{\overline{(x-y)^2}}$
- Mean Absolute Error (MAE, m): $MAE = \overline{|x-y|}$

- Index of Agreement (d): $d = 1 - \frac{\sum (x-y)^2}{\sum \left(|x-\bar{x}| + |y-\bar{x}| \right)^2}$, $0 \le d \le 1$

Where, *x* and *y* represent the measured and modelled data, respectively. A comparison between measured and modelled wave statistical parameters is presented in Figure 4-7 and Figure 4-8, and shows that the model is in reasonable agreement with the measurements.

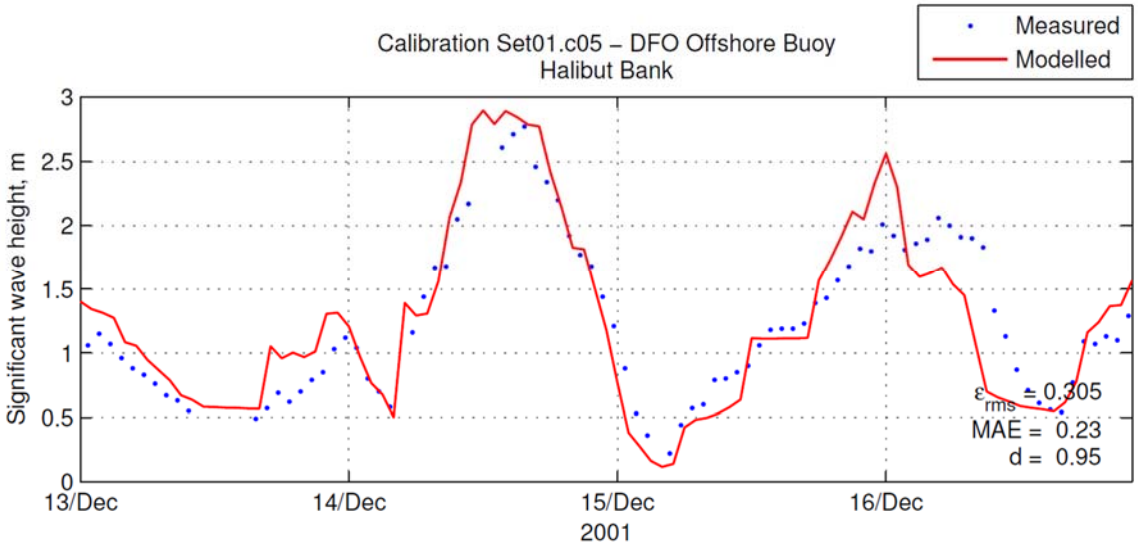


FIGURE 4-7: MEASURED VS. MODELLED H_S AT HALIBUT BANK

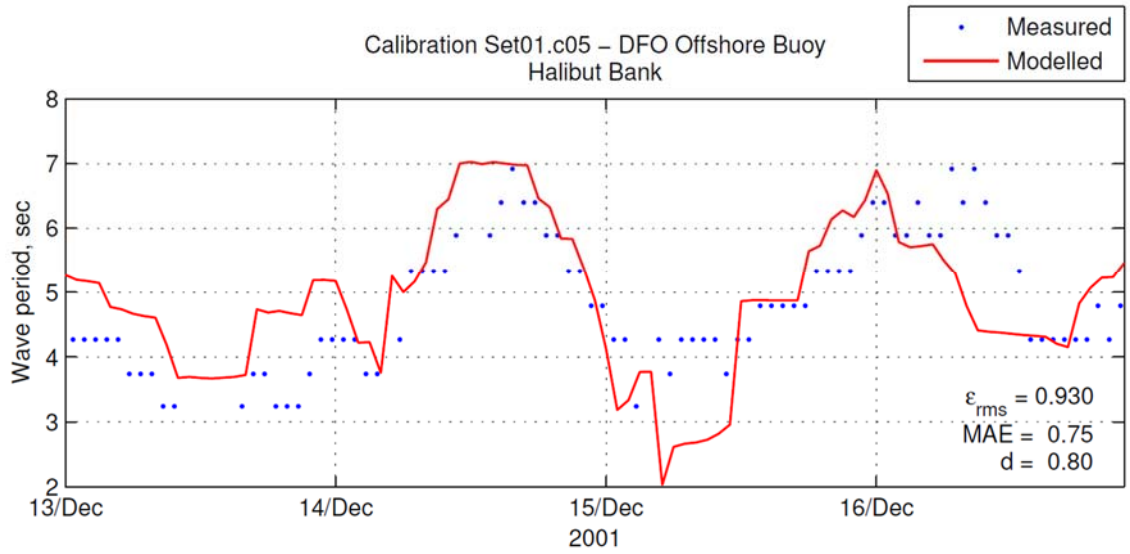


FIGURE 4-8: MEASURED VS. MODELLED T_P AT HALIBUT BANK

4.4. HD Model Calibration

The HD model was calibrated against water levels and flow split. Modelled water levels were compared with tides measured at two DFO tide gauges, namely Point Atkinson and Vancouver, labelled as DFO7795 and DFO7735 in Figure 4-1. Modelled flow split was compared to measurements as reported by North Hydraulic Consultants (NHC, 2006).

The HD model was forced with astronomical tides and tidal currents, derived from the tidal constituent global database developed from TOPEX/Poseidon altimetry data (Egbert & Erofeeva, 2010), along its offshore tidal boundaries. In addition, Fraser River discharge measured at Mission (station 08MH024 in Figure 4-1) was used as the inland freshwater boundary.

A two-month simulation period was conducted between June 1 and July 31, 2012, in order to capture the higher-than-average discharges observed during the 2012 freshet season. A graphical comparison between measured and modelled water levels is provided in Figure 4-9 and shows that the HD model closely reproduces observed water level variations. Model prediction capability indices (d) of 0.99 corroborate the accuracy of the modelled water levels at both tide gauges.

In addition, a comparison between the measured and modelled tidal constituents (i.e. the astronomical components of the tides) at both tide gauges was made. Figure 4-10 shows that the model adequately captures the amplitude of these constituents, with the M2 component amplitude being overpredicted by less than 7% and 3%, and the K1 component being overpredicted by 16% and 15%, respectively.

To confirm that the model correctly distributes flow into the North, Middle and South Arm of the Fraser river, modelled flow splits were also calculated. Flow split data collected by Public Works and Government Services Canada (PWGSC) from May 2005 to January 2006, was processed and reported by NHC in 2006. The blue and red boxes in Figure 4-11 indicate the measured and modelled flow splits, respectively. Overall, the model reproduces closely the flow distribution in the North, Middle and South Arm, with differences less than 1%. A slightly larger difference of 3% is found near Steveston.

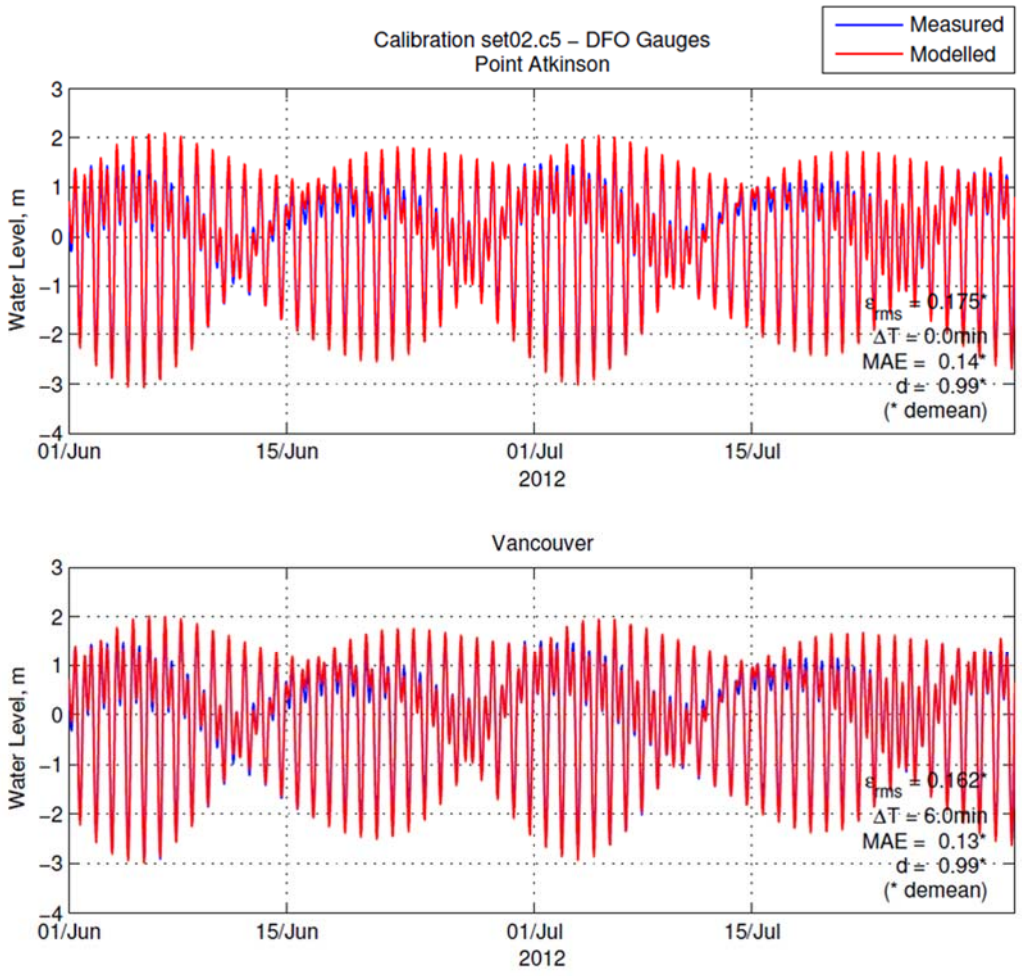


FIGURE 4-9: MEASURED VS. MODELLED WATER LEVELS AT DFO TIDE GAUGES

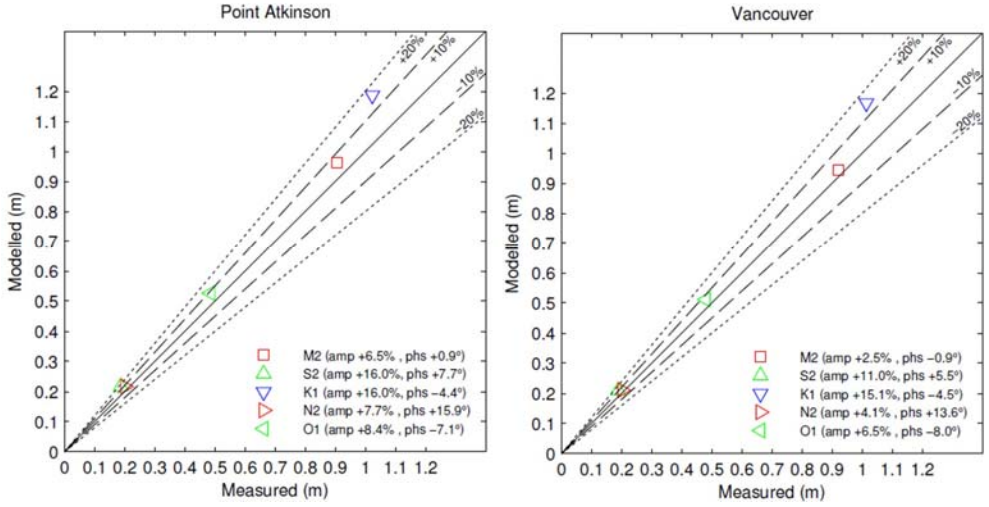


FIGURE 4-10: MEASURED VS. MODELLED TIDAL CONSTITUENTS AT DFO TIDE GAUGES

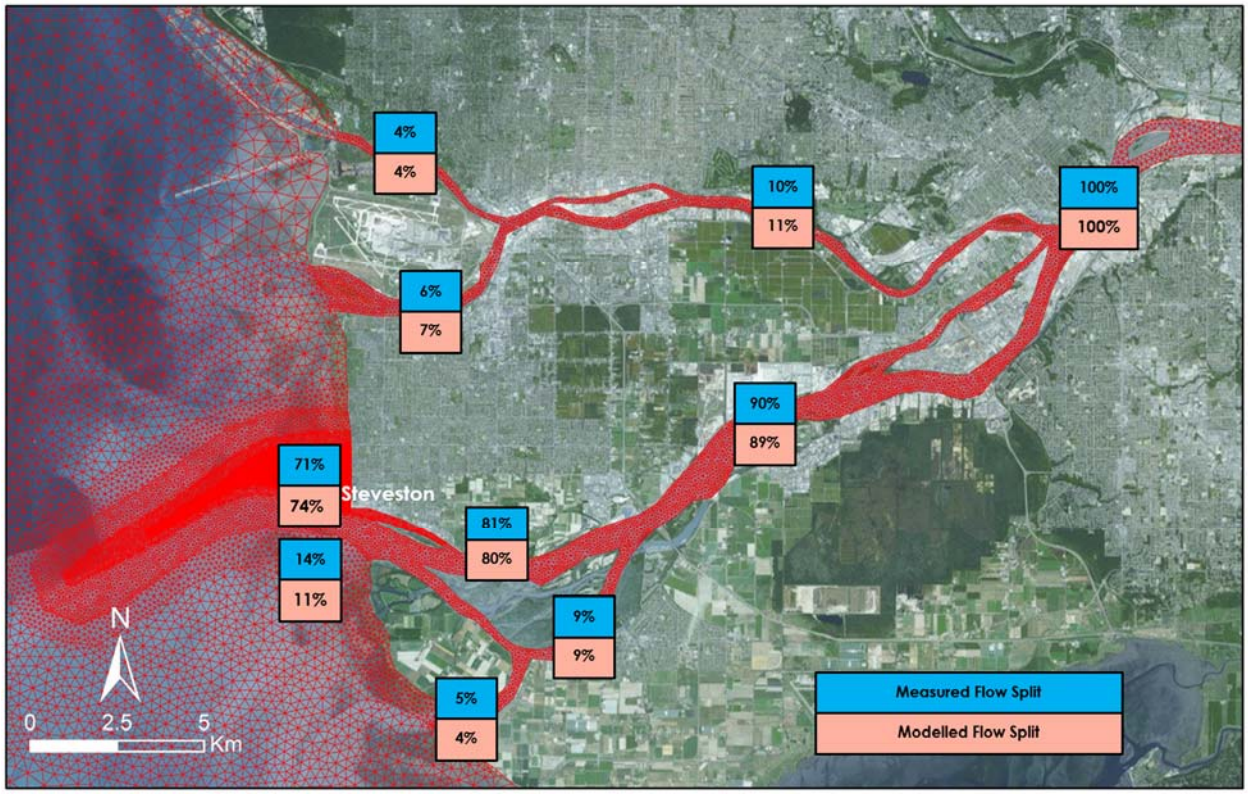


FIGURE 4-11: MEASURED VS. MODELLED FLOW SPLIT

4.5. Validation of Salinity Mixing

Once the comparison of water levels and flow split was deemed adequate, the salinity module within the HD model was activated to assess salinity mixing. The validation process compared the modelled salt wedge to findings reported in literature at locations in the South Arm.

Ages (1979), studied the salinity intrusion in the main South Arm of the Fraser River by conducting measurements under a range of discharges observed during 1976. Findings from the study indicate that the location of the salinity front varies within a single day in response to tidal fluctuations as well as seasonally in response to variations of river discharge.

The validation test was set up by imposing discharge recorded at Mission during the dates in which the measurements took place. A high and a low outflow condition were selected for the test. The focus of this validation was not to capture the exact location and shape of the salt wedge, but instead to ensure that the three-dimensional flows are adequately resolved in the model leading to a good representation of the salinity mixing in the Fraser River as well as in the intertidal zone of Sturgeon Bank, where the proposed marsh area is located.

Figure 4-13 to Figure 4-15 compare findings from the literature with model results. The literature, presented in the upper plot of each figure, depicts the distribution of salinity (with contour lines) along the main channel of the South Arm, under a specific discharge condition and tide stage. The lower plot of each figure represents the modelled salt wedge under the same tide and discharge conditions.

Four reference locations, including Sand Heads, Steveston, Deas Island, and Annacis Island, are used in comparison. Figure 4-12 shows the locations.



FIGURE 4-12: REFERENCE POINTS FOR VALIDATION OF MODELLED SALINITY

Under high discharge flow in Fraser River, the South Arm is primarily influenced by fresh outflows pushing saline water away. At a low tide stage, the salt wedge is typically kept out of the South Arm. Both measured and modelled data indicate that salinity is transitioning from saline to fresh in a narrow stretch close to Sand Heads (Figure 4-13). For the same high discharge flow but a higher tide stage, the salt wedge penetrates slightly into the South Arm. Intrusion of saline water (above 25 PSU, depicted in red in Figure 4-14) is shown halfway between Sand Heads and Steveston, while brackish waters (transitioning from saline to fresh) occur up to around Steveston.

Under low discharge flow in Fraser River, saline water intrudes further into the South Arm and can be observed halfway between Steveston and Deas Island, while the transition to fresh water occurs pass Deas Island (Figure 4-15).

Based on the similarity of measured and modelled salinity distributions, it is concluded that the salinity mixing processes in the HD model are captured satisfactorily and are capable of assessing potential changes in salinity distribution at the project site, where the proposed project elements are incorporated.

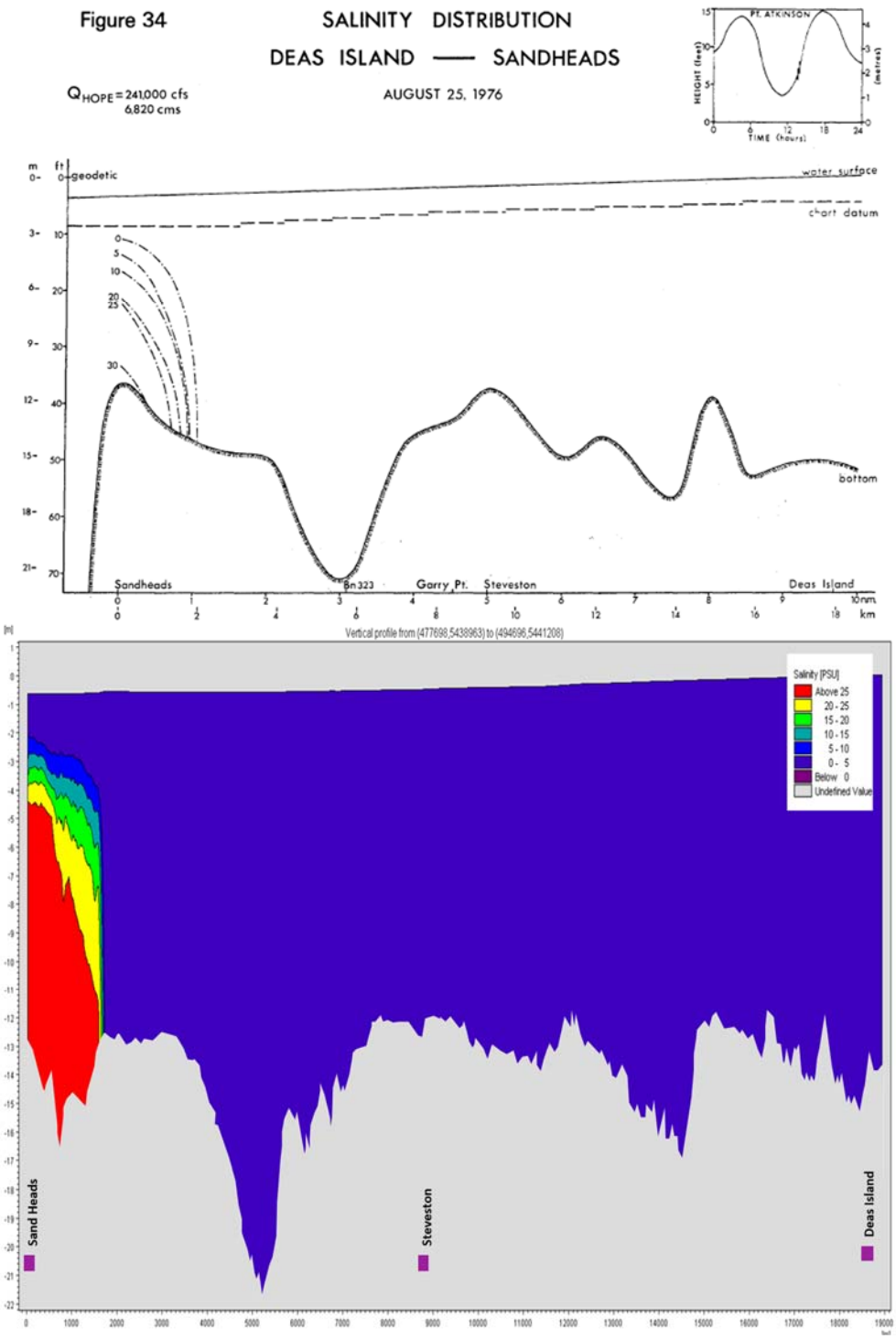


FIGURE 4-13: LOCATION OF SALT WEDGE UNDER HIGH DICHARGE FLOW AND LOW TIDE

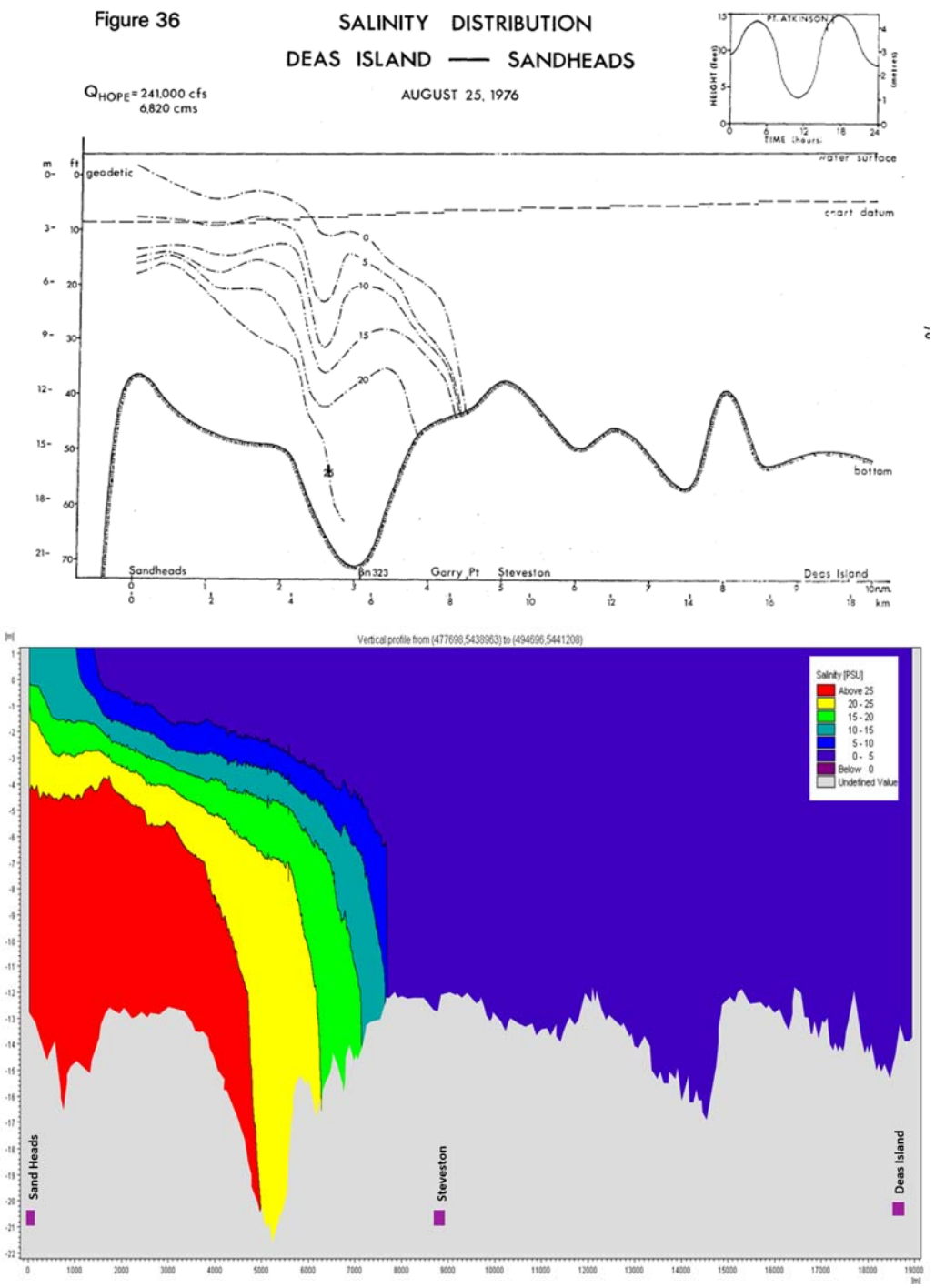


FIGURE 4-14: LOCATION OF SALT WEDGE UNDER HIGH DICHARGE FLOW AND HIGH TIDE

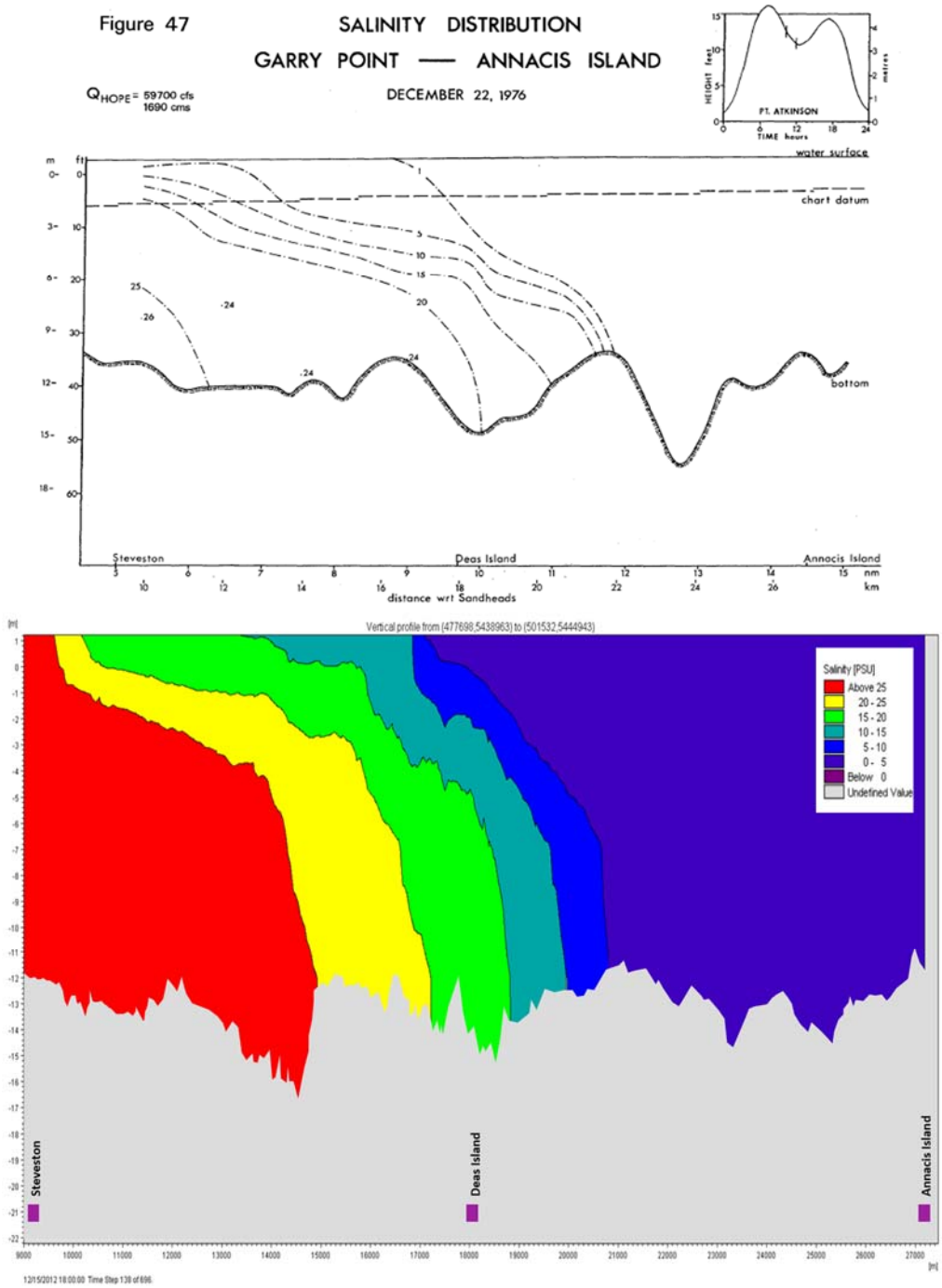


FIGURE 4-15: LOCATION OF SALT WEDGE UNDER LOW DICHARGE FLOW AND HIGH TIDE

5. Wave Exposure and Wave-Induced Bed Shear Stress Analysis

5.1. Introduction

Wave action represents a limiting factor for growth and development of the proposed marsh, as it affects the stability of the substrate. For a successful marsh establishment or restoration, evaluation of wave induced bed shear stresses at the site is necessary to determine the stability requirements for the new substrate. Values for allowable bed shear stresses for a range of substrate materials were provided in Section 3.1. As discussed, the existing substrate at Sturgeon Bank and the dredged material, proposed as new substrate, range from coarser well graded sands, to fine silts and clays. It was concluded that 1 N/m^2 (i.e. the permissible bed shear stress for finer sediments) is a reasonable and conservative target for allowable bed shear stress on the proposed marsh.

Evaluation of wave induced bed shear stresses was carried out for two scenarios, i.e. existing and with-project conditions, representing incident wave conditions at the project site in a typical year. Post-processing of the results was performed to compute the maximum bed shear stress τ_{max} according to *Fredsøe and Deigaard (1992)*, as well as its statistics during the entire simulation period.

For the with-project scenario, the bathymetry at the SAJ project area was adjusted to incorporate the proposed 1,500 m long cobble berm (crest elevation of +1.4 m GD) as well as raising of site grades in the lee of the cobble berm. Fill material slopes down from an elevation of +0.5 m GD at the toe to an elevation of approximately +0.3 m GD at the top of the proposed swale. This swale (invert at -0.7 m GD), running in the east-west direction approximately in the middle of the proposed marsh, is included to promote drainage and to enhance circulation in the project area. Figure 5-1 compares the bathymetry for the existing and with-project scenario. To emphasize the differences between them, the figure only depicts bed elevations of -1.4 m and higher. The proposed cobble berm footprint is depicted in orange to red shades in the lower plot of Figure 5-1. It is noted that the berm discontinues at its southwest corner (a gap of around 150 m), at the location of the swale.

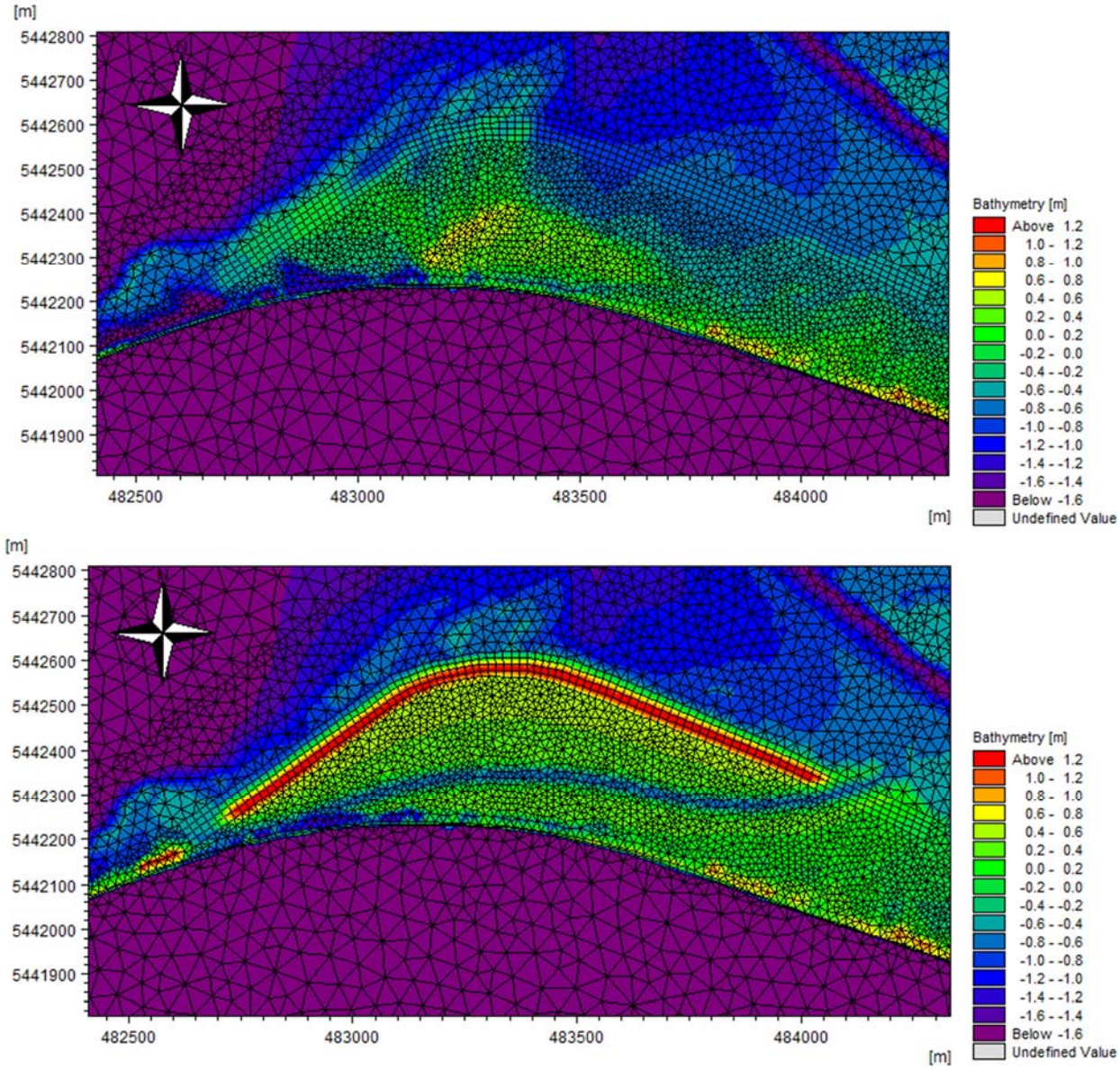
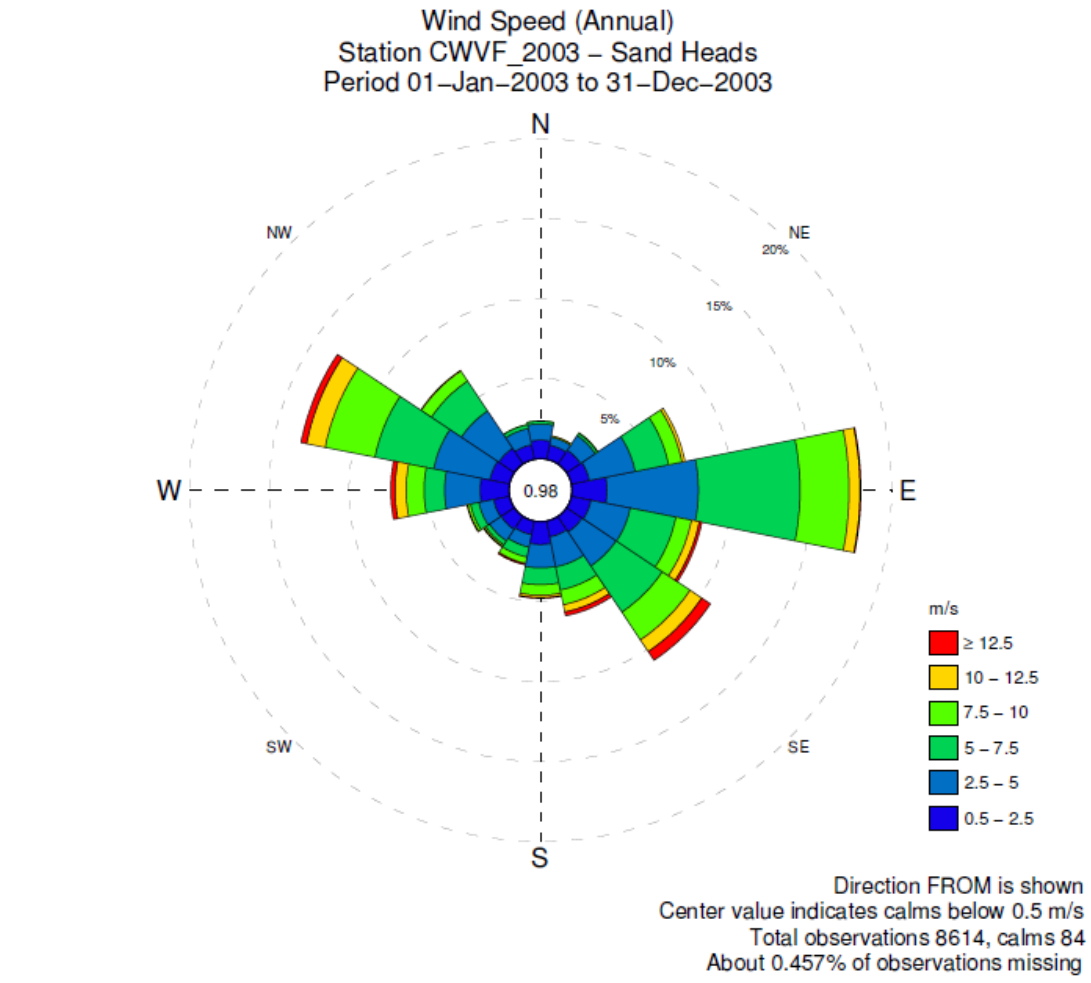


FIGURE 5-1: EXISTING VS. WITH-PROJECT BATHYMETRY

5.2. Imposed Wind Conditions

Wave exposure analysis in a typical year was conducted for year 2003 because it was found to be the most representative year in the full wind records at Sand Heads. Figure 5-2 presents the wind rose for year 2003. About 50% of the recorded wind speeds were at or below 5 m/s; while the predominant wind direction was East (approximately 18% of observations), higher wind speeds (i.e. above 12.5 m/s) were more frequently from the southeast and northwest sectors.

The hourly time series of wind speed and wind direction recorded at Sand Heads in 2003 was imposed in the SW model for the purpose of reproducing wave conditions that were observed during a typical year.



Percentage of Occurrence

Wind Speed, m/s	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	2.33	1.47	2.33	7.23	18.08	8.31	10.81	6.03	4.77	2.76	2.30	2.69	7.38	13.30	7.02	2.19	99.02
12.5						0.16	0.65	0.24					0.27	0.36			1.78
10				0.19	0.68	0.50	0.88	0.46	0.15				0.70	1.18			4.97
7.5				0.86	3.08	1.00	2.09	0.94	0.66	0.41	0.12	0.17	1.13	3.18	0.77		14.48
5	0.17		0.17	2.14	6.36	2.91	3.48	1.47	1.06	0.64	0.29	0.53	1.28	3.75	2.25	0.24	26.81
2.5	1.01	0.51	1.10	2.93	5.73	2.51	2.57	1.92	1.46	0.79	0.87	0.94	2.23	3.59	2.82	1.03	32.01
0.5	1.14	0.88	1.02	1.13	2.17	1.23	1.14	0.99	1.40	0.85	0.96	1.00	1.79	1.24	1.15	0.91	18.99

FIGURE 5-2: WIND ROSE FOR YEAR 2003

5.3. Results

The maximum bed shear stress (τ_{max}), computed from a series of waves (or called a wave train), is a function of the wave period and the horizontal wave orbital velocity near bed. τ_{max} was computed at each grid element for every time step for the existing and with-project conditions. Results are summarized in the following by means of τ_{max} statistics. As a reference, the footprint of the proposed cobble berm is depicted in pink in both figures.

Figure 5-3 compares the 99th percentile τ_{max} at the proposed marsh area for the existing (upper plot) and the with-project (lower plot) conditions. The 99th percentile value indicates that only 1% of the maximum bed shear stress would exceed the value (or equivalent to 88 hours per year).

As seen in the figures, the τ_{max} distribution follows the bathymetric contours closely. For the existing condition, the highest value (e.g. 2 N/m^2 depicted in yellow), is observed at the Sand Island, where bed elevations are higher. Around the Sand Island, τ_{max} values are consistently greater than the established threshold for sediment motion (e.g. 1 N/m^2).

For the with-project condition, the area surrounding the Sand Island as well as most of the marsh area are now depicted in blue shades, indicating a reduction of bed shear stresses (τ_{max} values between 0.3 and 0.8 N/m^2). The lowest values are observed at the location of the swale, where bed elevations are low. Higher values (e.g. 1 N/m^2) are observed at the south portion of the marsh area, between the swale and the Steveston North Jetty, or at the southwest corner, close to the cobble berm gap. Areas depicted in red, indicate the highest shear stress values over the cobble berm due to wave breaking, and do not impact the proposed marsh area.

Similarly, Figure 5-4 compares the statistical maximum of τ_{max} for the existing and the with-project conditions. These values represent the bed shear stresses reached only once per year (e.g. the highest within all τ_{max}). It is noted that the statistical maximum of τ_{max} values are higher than the threshold in most of the existing and the with-project conditions. For the existing condition, τ_{max} at the Sand Island and the surrounding area is now above 2.6 N/m^2 (depicted in red). For the with-project condition, τ_{max} above 2.6 N/m^2 is observed again in the south and southwest portions of the proposed marsh.

The bar plots in Figure 5-5 provide τ_{max} statistics for three selected points within the proposed marsh area. 75th Percentile (gray), 90th (yellow), 99th (green) and the maximum τ_{max} (blue) are compared for the existing and the with-project conditions. Locations for points A, B and C are depicted in Figure 5-3 and Figure 5-4. Points A and B represent areas where a considerable reduction in bed shear stresses is observed (τ_{max} decreases around 30%), as a result of wave sheltering from the cobble berm. In contrast, point C does not exhibit an obvious decrease in bed shear stresses (τ_{max} only decreases about 10%), since its location is farther away from the cobble berm and the area of influence. This area is more exposed and therefore more influenced by waves that approach from the south to south-southeast directions propagating over the Steveston North Jetty.

Overall, results clearly show that introduction of the cobble berm effectively reduces wave-induced bed shear stresses. It is noted that under extreme storm conditions, above-threshold values occur over the majority of the marsh area with or without the presence of the cobble berm, as shown in Figure 5-4. However, the berm does promote favorable conditions for development of the proposed marsh growth consistently throughout most of the year (e.g. 99th percentile).

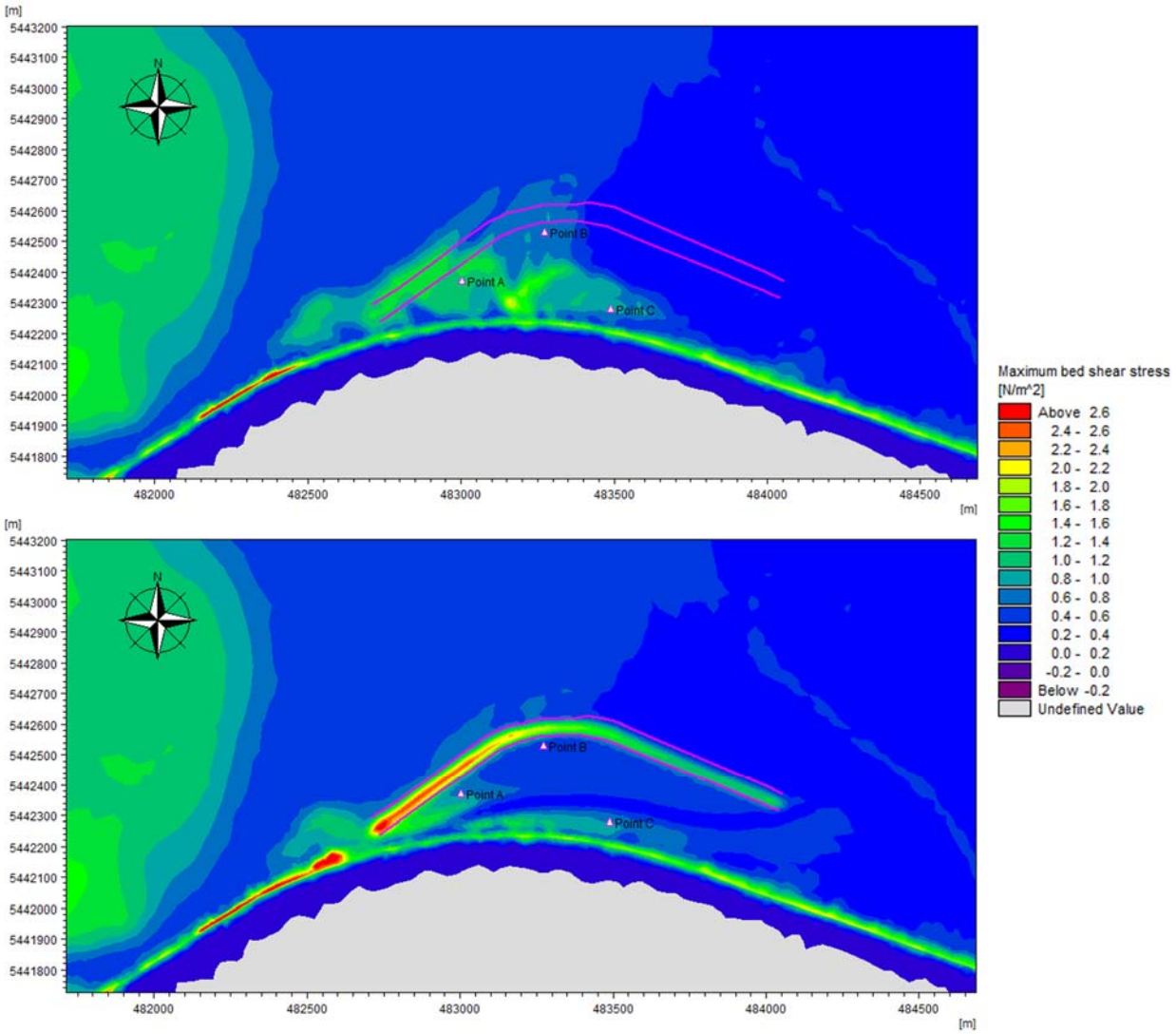


FIGURE 5-3: 99TH PERCENTILE BED SHEAR STRESS FOR EXISTING (TOP) AND WITH-PROJECT (BOTTOM) CONDITIONS

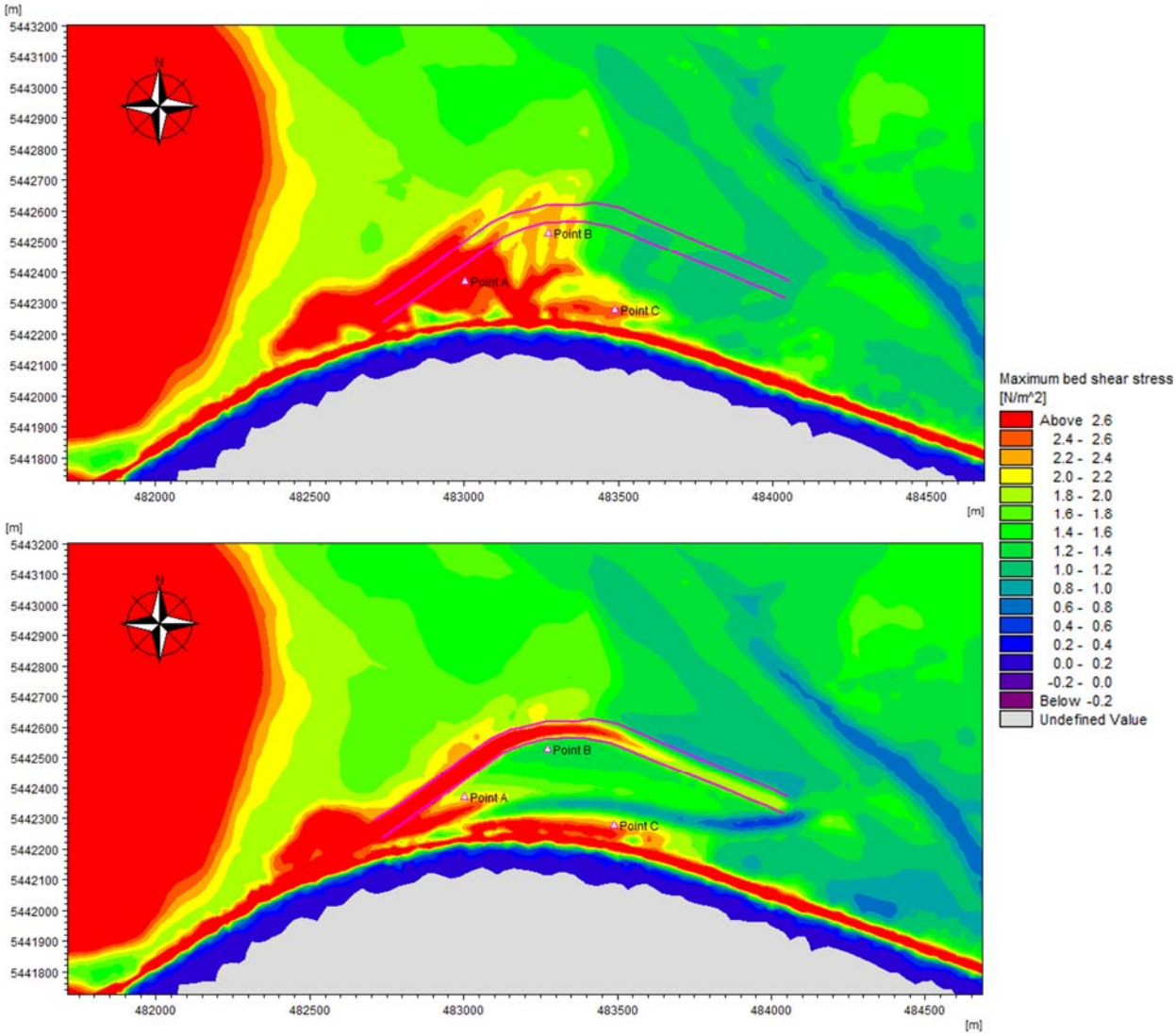


FIGURE 5-4: MAXIMUM BED SHEAR STRESS FOR EXISTING (TOP) AND WITH-PROJECT (BOTTOM) CONDITIONS

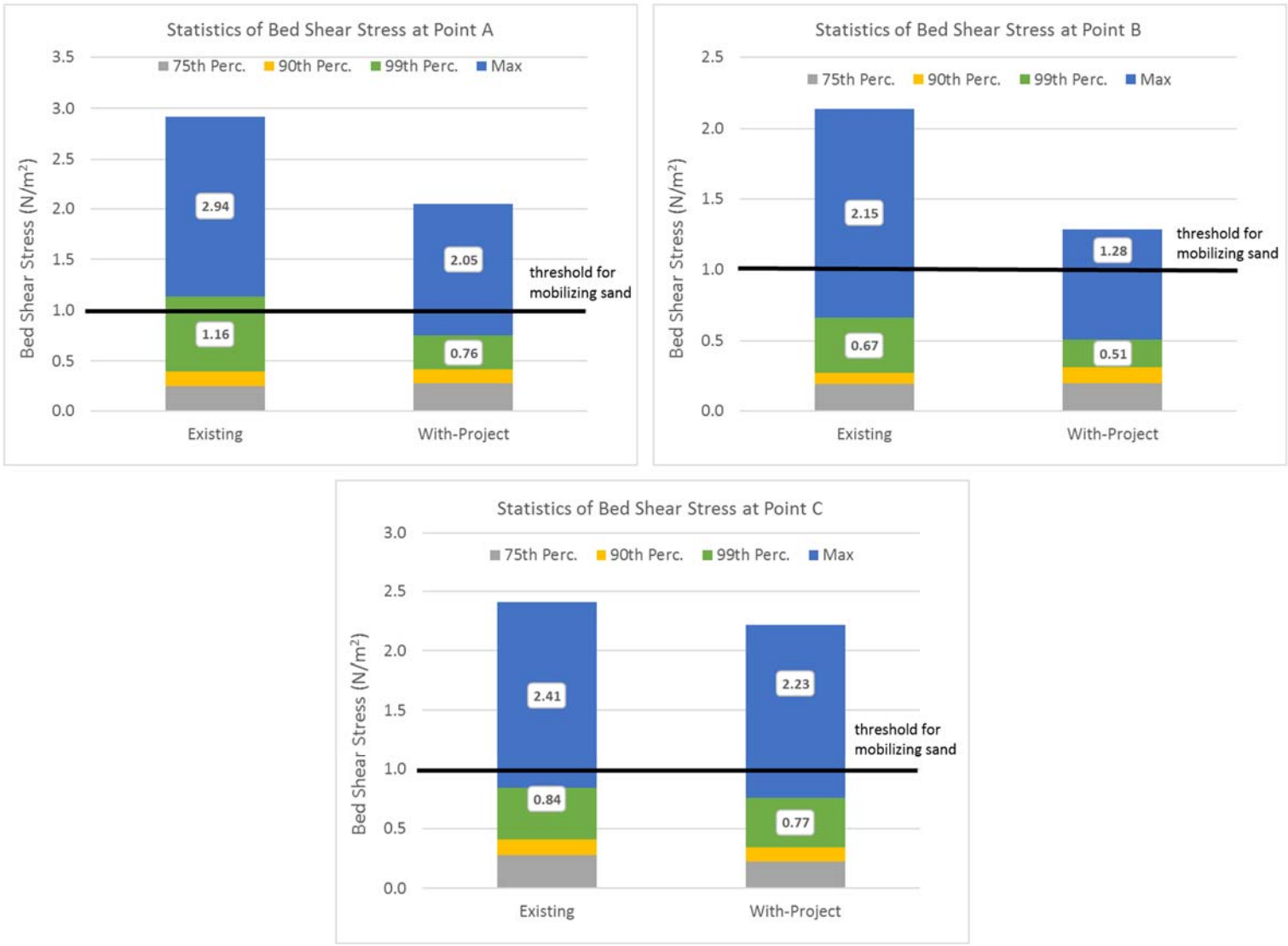


FIGURE 5-5: STATISTICS OF BED SHEAR STRESS AT POINTS A, B, AND C

5.4. Sensitivity to Project Modifications

In this section, sensitivity to the wave results were assessed for three project modifications.

- Case 1 (High Fill): This case changes the proposed grades to accommodate a steeper drainage slope. The grade slopes down from an elevation of +1.0 m GD (previously +0.5 m GD) at the interior toe of the cobble berm to an elevation of +0.3 m GD at the location of the swale.
- Case 2 (Berm Crest El. +1.9 m): For this case, the crest elevation of the cobble berm was raised from +1.4 m to +1.9 m GD. This corresponds to the crest elevation during construction (i.e. construction access road elevation).
- Case 3 (Short Cobble Berm): For this case, only the western reach of the cobble berm is incorporated in the model bathymetry. The shortened cobble berm length is approximately 900 m, and its crest elevation is +1.9 m GD. This layout corresponds to construction completed in Phase II.

Sensitivity cases were performed and the statistical maximum of τ_{max} was computed at the proposed marsh area, as described in Section 5.3. The simulation period (October 10 through November 3, 2003) was chosen to include the longest storm event recorded in 2003 (see Figure 5-6).

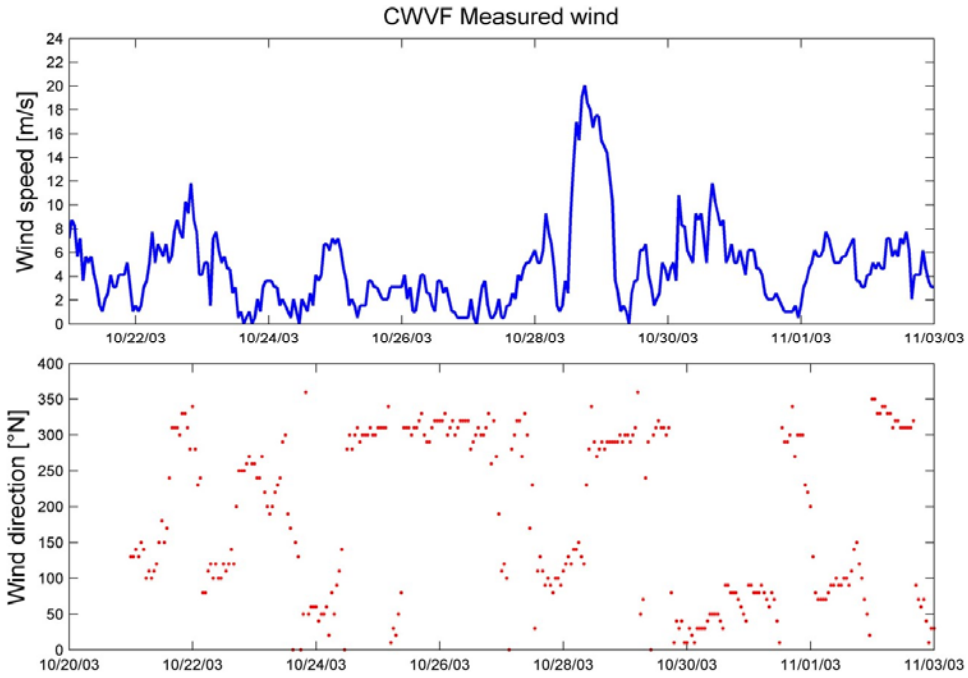


FIGURE 5-6: IMPOSED STORM EVENT FOR SENSITIVITY TESTS

To provide a direct comparison between the short sensitivity cases and the full year simulation, a normalized τ_{max} was computed as below.

$$Norm.\tau_{max} = \frac{\tau_{max}Case}{\tau_{max}base}$$

Where $\tau_{max}Case$ represents the statistical maximum for each sensitivity case, and $\tau_{max}base$ represents the base case without any project modifications. Figure 5-7 shows the normalized τ_{max} at Points A, B and C.

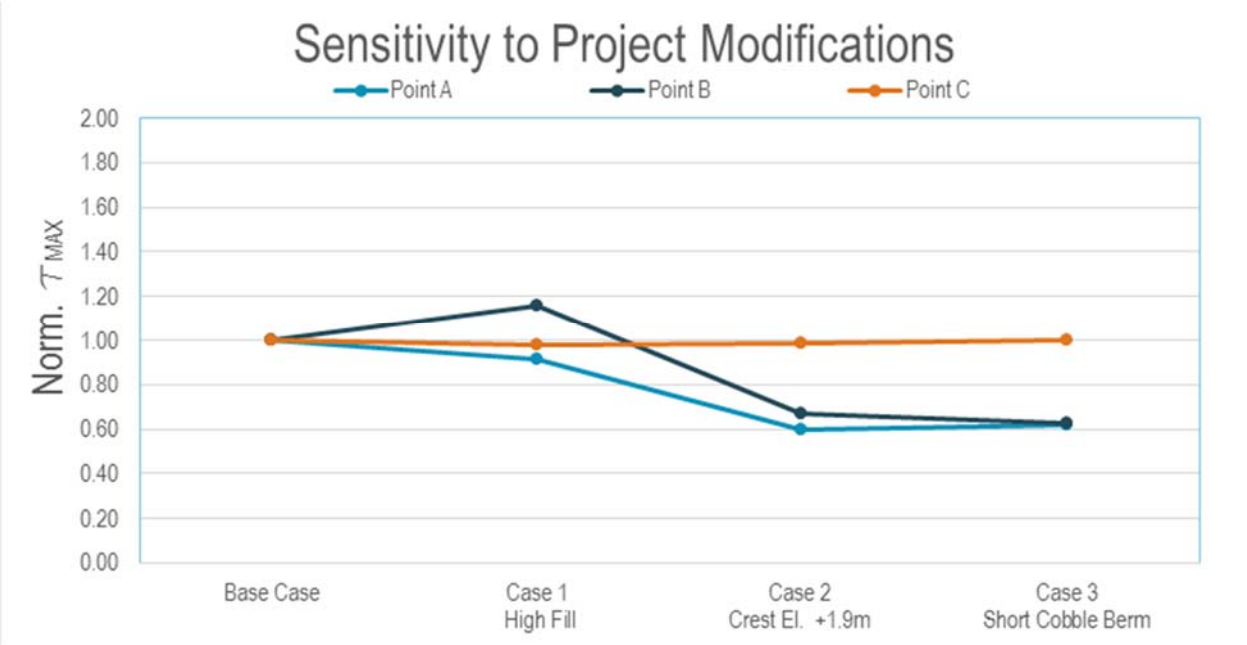


FIGURE 5-7: NORMALIZED T_{MAX} AT POINTS A, B AND C FOR SENSITIVITY CASES

τ_{max} sensitivity is somewhat similar at points A and B. For the high fill case (Case 1), bed shear stresses are comparable to the base case. Normalized τ_{max} values are 0.9 and 1.2 for Point A and B, respectively. These values do not represent a significant deviation in the resulting shear stresses, indicating low sensitivity to modification of the grades in the proposed marsh area.

Meanwhile, raising crest elevation of +1.9 m (Case 2) reduces to approximately 60% and 70% of the maximum shear stresses for points A and B, respectively. Result is similar for the short cobble berm case (Case 3). Normalized τ_{max} values of 0.6 for both A and B indicate that even for a shorter structure, with a crest elevation of +1.9 m provides sufficient sheltering from the predominant wave direction and hence can provide the area with favorable conditions for marsh development. However, a more thorough investigation would be required to determine the feasibility of this option.

For point C, normalized τ_{max} values are approximately one for all sensitivity cases. As mentioned before, point C is representative of an area in which the influence by the cobble berm is limited; therefore, no significant differences in wave-induced bed shear stresses are expected from project modifications.

5.5. Summary of Wave Exposure & Wave-Induced Bed Shear Stress Analysis

Introduction of the cobble berm at Sturgeon Bank can achieve the objective of reducing wave-induced bed shear stresses in the proposed marsh area and promote favorable conditions for marsh growth.

Overall, results clearly show that the cobble berm effectively reduces wave-induced bed shear stresses. Although it is noted that under extreme storm conditions, above-threshold values occur over the majority of the marsh area with or without the presence of the cobble berm, the berm does promote favorable conditions for development of the proposed marsh growth consistently throughout most of the year (e.g. 99th percentile).

Vulnerable areas, where the 99th percentile τ_{max} exceeding the threshold value, were identified in the south and southwest portions of the marsh. This is because the cobble berm provides only limited sheltering from waves in this area, and there is a more direct exposure to waves from southerly directions.

In addition, it was found that the cobble berm crest elevation is the most influential factor for reducing bed shear stresses. Shear stress values were reduced for the cases where the berm crest elevation is at +1.9 m GD. Preliminary results suggest that a short cobble berm could be implemented and still provide favorable conditions for the marsh growth. However, a more thorough investigation would be required to determine the feasibility of this option.

Changes in site grades in the marsh area were found to have limited to no impacts on bed shear stresses.

6. Salinity Distribution Analysis

6.1. Introduction

As discussed in Section 2.5, salinity distribution in the Fraser River is controlled primarily by the amount of outflow from the Fraser River, which varies significantly on a seasonal scale, and is controlled secondarily by the tidal phase, varying on an hourly to daily scale.

To evaluate the range of salinity at Sturgeon Bank and the proposed marsh area, three sets of simulations were performed to represent low, medium and high flow discharge in the Fraser River. For each flow discharge, simulations of the existing and with-project conditions were conducted to compare flow circulation and salinity distribution.

6.2. Imposed Boundary Conditions

The 27-year Fraser River discharge recorded at Mission (Station 08MH024, Figure 4-1) was analyzed to determine the river outflow that resemble the low, medium and high flow discharge occurring throughout the year. Figure 6-1 illustrates the daily and monthly averaged discharge for the full records at Mission.

A discharge of 2,000 m^3/s, representative of winter months, was selected for the low flow discharge. The high flow discharge was set to 8,000 m^3/s, an average peak discharge during the freshet. The medium flow discharge of 5,500 m^3/s represents a transition from the low to the high flow.

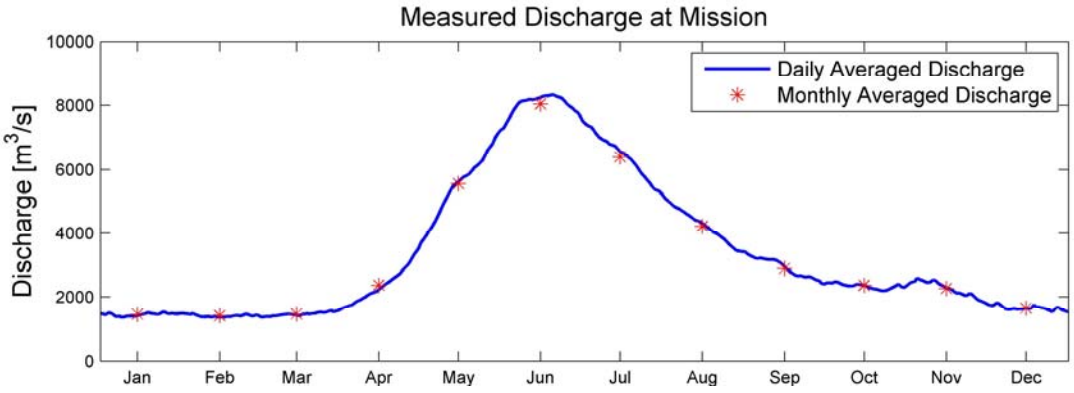


FIGURE 6-1: AVERAGE DAILY AND MONTHLY FRASER RIVER DISCHARGE AT MISSION

The three-dimensional hydrodynamic model with the salinity module was conducted for each discharge scenario for a spring-neap tidal cycle. Figure 6-2 depicts the tidal boundary conditions used to force the model, and illustrates the definition of terminologies used in the discussion. This figure shows how the tidal range varies with time; during neap tides (first and last days of the simulation), the offshore tidal range is around 2.5 m, and increases to approximately 4 m during spring tides (occurring halfway through the simulation period).

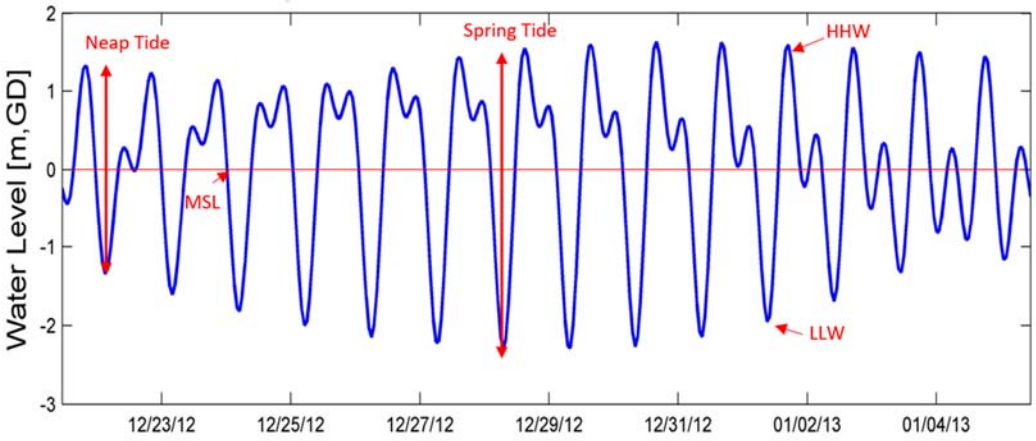


FIGURE 6-2: IMPOSED WATER LEVEL BOUNDARY CONDITIONS

6.3. Results

A comparison of salinity for the existing and the with-project conditions is provided in the form of snapshots at the surface (low discharge) or intermediate depth (medium and high discharge) at selected tide stages. Because the surface salinity becomes all fresh in the medium and high discharge scenario, salinity at the intermediate depth was analyzed instead. The footprint of the proposed cobble berm is depicted with a black solid line for the with-project condition, and with a dashed line for the existing condition (as a reference only). Vertical profiles along a transect are also provided in the figures and illustrate salinity stratification in the marsh area. Figure 6-3 indicates the transect location.

It is noted that some areas immediately adjacent to the Richmond shoreline are only active in the model computations when tidal elevations (i.e. high tides) are sufficient to inundate the areas. They should be disregarded from further interpretation. Better estimates of salinity values at the higher ground can be achieved with longer simulation run time.

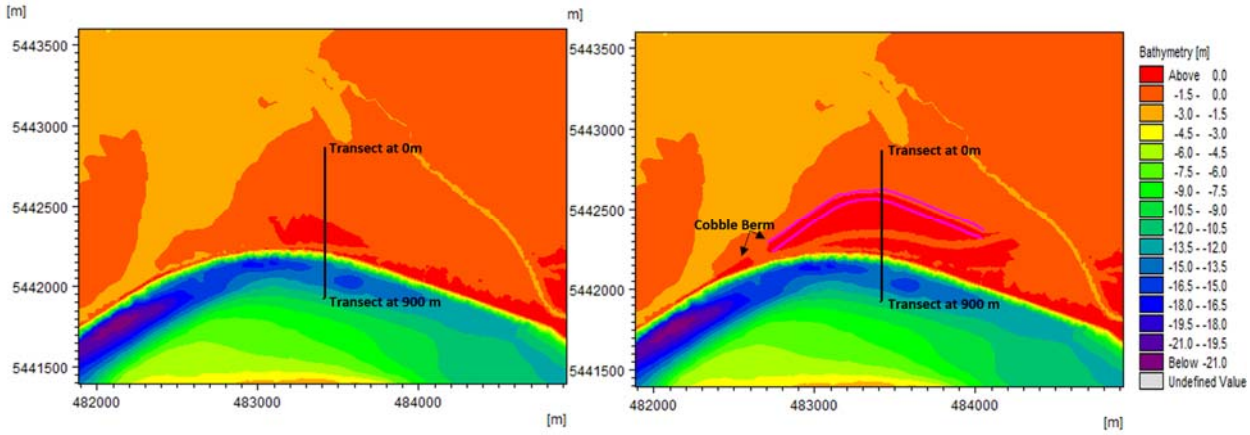


FIGURE 6-3: LOCATION OF SELECTED TRANSECT

6.3.1. Low Discharge Scenario

During low discharge periods, salinity in the Fraser River is primarily controlled by the tides. Brackish to salty sea water is predominant, and there is limited influence from the Fraser River in both fresh water input and circulation. Figure 6-4 depicts surface salinity distribution in the marsh area for the existing condition at low and high tide, respectively. Fresh water outflow reaches its maximum extent around Sand Heads (left plot), when the low tide is present. In the offshore areas, surface salinities are in the brackish range, depicted in green shades. At high tide (right plot), the intertidal areas of Sturgeon Bank exhibit higher salinity. In addition, higher salinity concentrations intrude into the South Arm, pushing freshwater upriver.

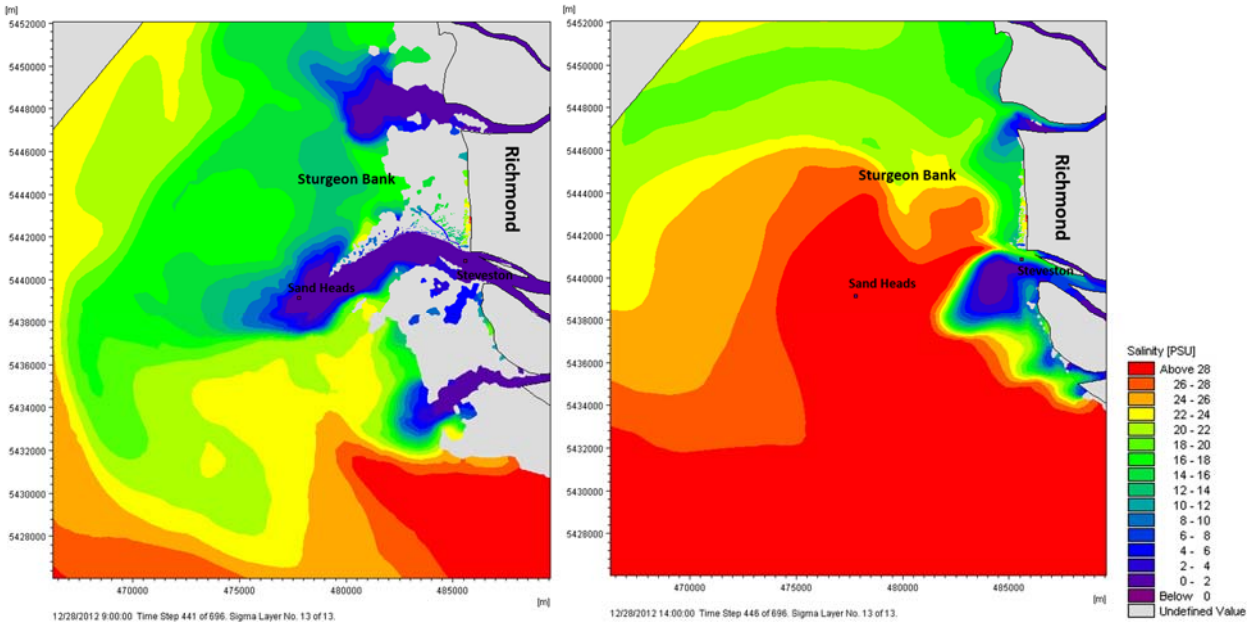


FIGURE 6-4: SURFACE SALINITY DISTRIBUTION UNDER LOW DISCHARGE AT LOW (LEFT) AND HIGH (RIGHT) TIDE, EXISTING CONDITION

The main effects of the cobble berm on the salinity are the following:

- Retention of fresh water overflowing the Steveston North Jetty or brought into the area from Scotch Pond.

  During low discharge, input of fresh water to the marsh area occurring by overflow of the Steveston North Jetty is limited to the time where salty sea water has not penetrated into the South Arm. Under the proposed project conditions, the flow pattern generated by the cobble berm, aids in retaining fresh water for a prolonged time.

- Obstruction of tidal flows that bring salty sea water to the proposed marsh area (Figure 6-7).

  This typically occurs as the tide rises between LLW and HHW. However, when HHW is reached, tidal elevations are high enough for salty sea water to overflow the cobble berm into

the marsh area (Figure 6-8). This effect could be mitigated by raising the crest elevation of the cobble berm.

- Retaining salty sea water (Figure 6-9).

  Mainly occurring after HHW, due to the overflow described above. As the tide retreats in Sturgeon Bank, the cobble berm retains salty sea water for a longer time when compared to existing conditions (where flow is not impeded).

Figure 6-5 provides a comparison of modelled depth-averaged salinity in the proposed marsh area for the existing (blue curve) and the with-project conditions (yellow curve). The upper and lower limits for both curves (representing highest and lowest salinity, which may occur at different times) are comparable, indicating that the salinity range in the area will not be altered by the project. However, with-project salinity will tend to be lower throughout the tidal cycle. For reference, salinity levels for the existing marsh area are depicted by the green dashed curve. When compared to the yellow curve (proposed marsh) it can be concluded that the cobble berm will promote a salinity range in the proposed marsh area which is comparable to that of the existing marsh.

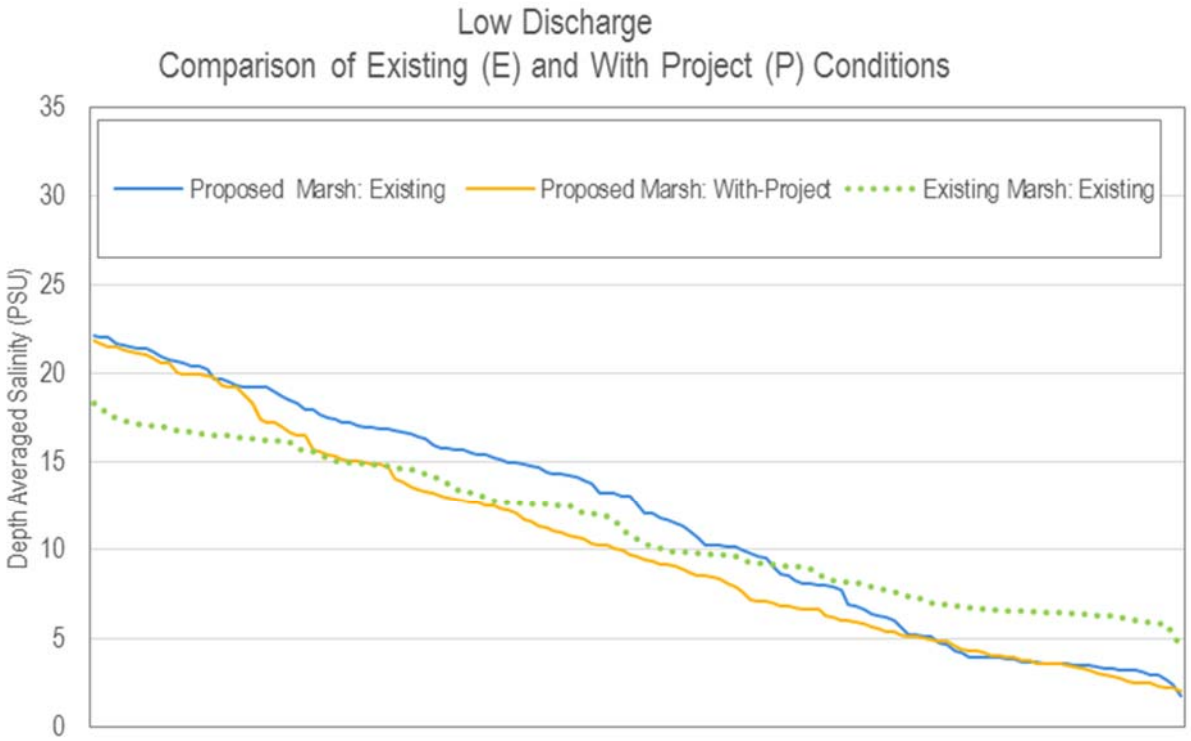


FIGURE 6-5: SALINITY VARIATIONS IN THE PROPOSED AND EXISTING MARSH AREA UNDER LOW DISCHARGE

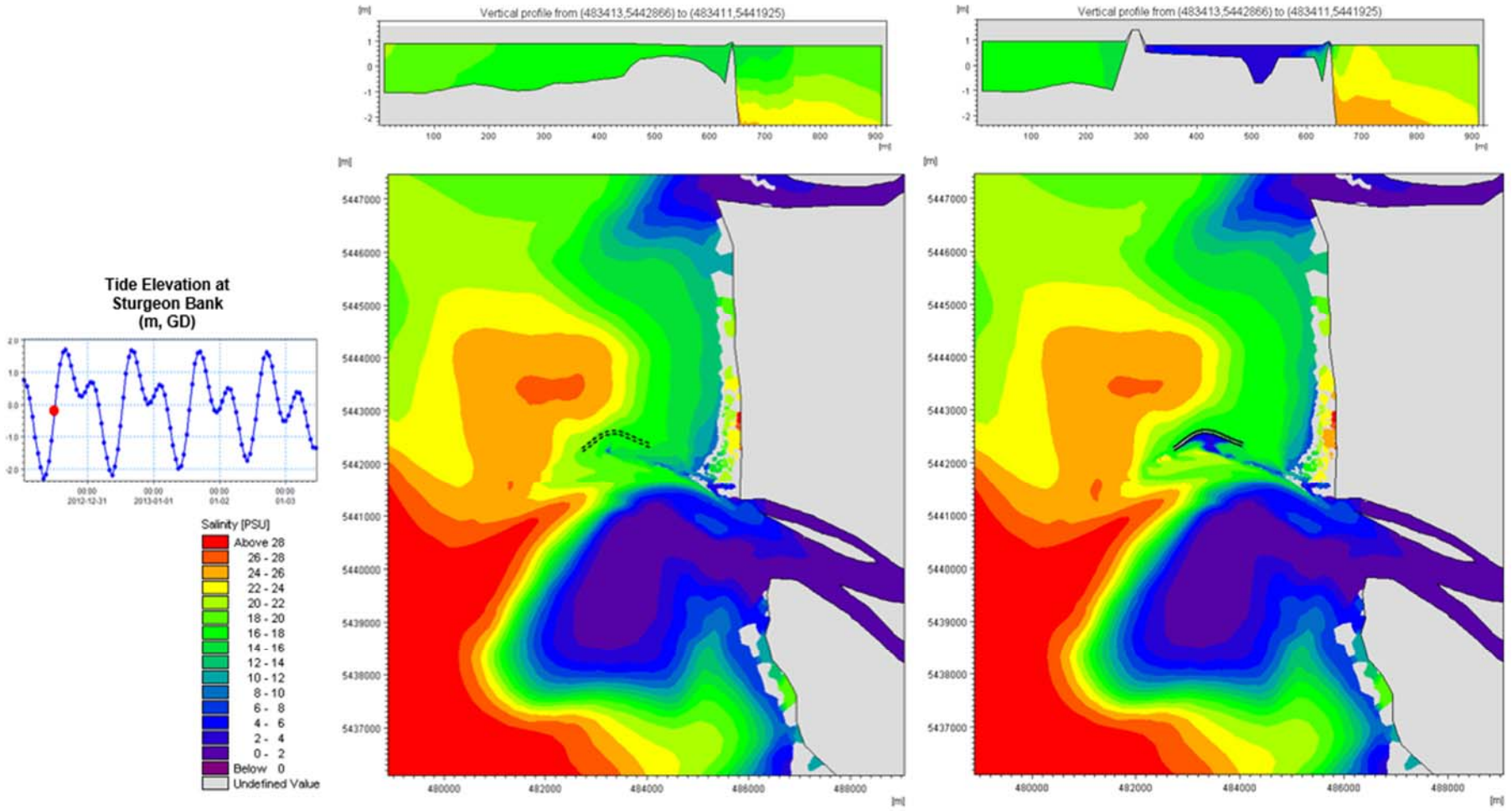


FIGURE 6-6: SALINITY PROFILE AND SURFACE SALINITY UNDER LOW DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS. TIDE EL. AROUND MSL

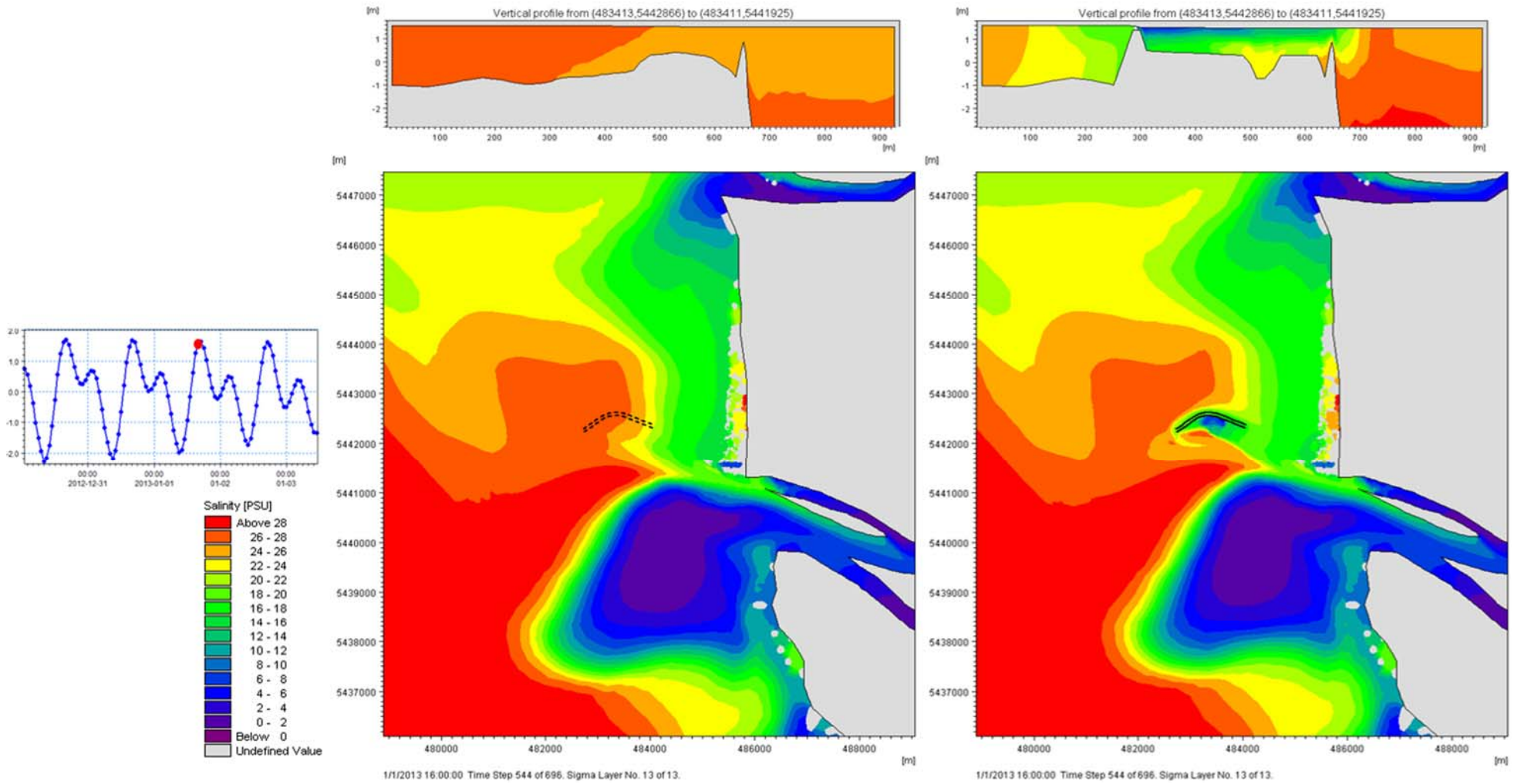


FIGURE 6-7: SALINITY PROFILE AND SURFACE SALINITY UNDER LOW DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS. TIDE EL. CLOSE TO HHW

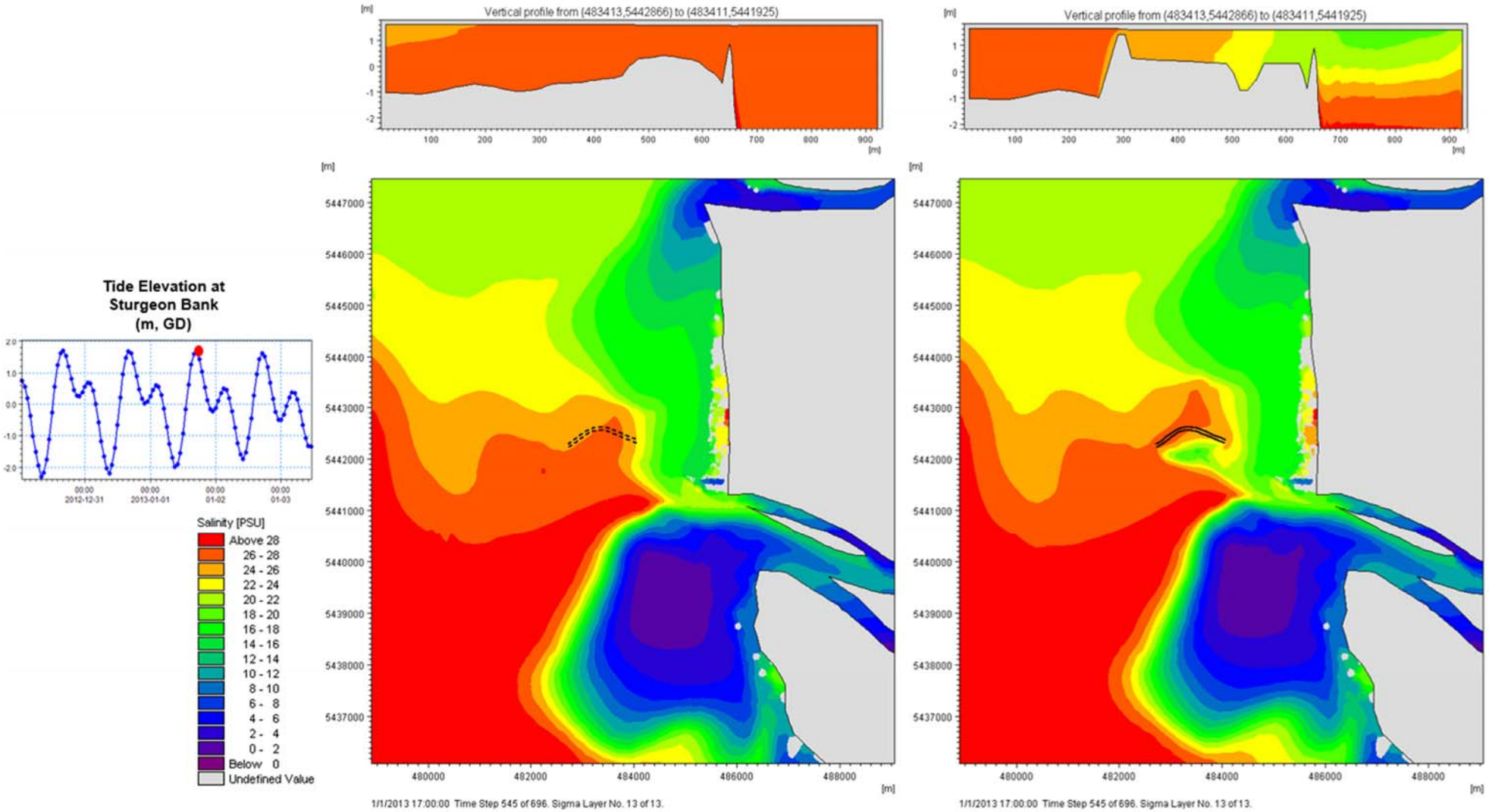


FIGURE 6-8: SALINITY PROFILE AND SURFACE SALINITY UNDER LOW DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS TIDE EL. AT HHW

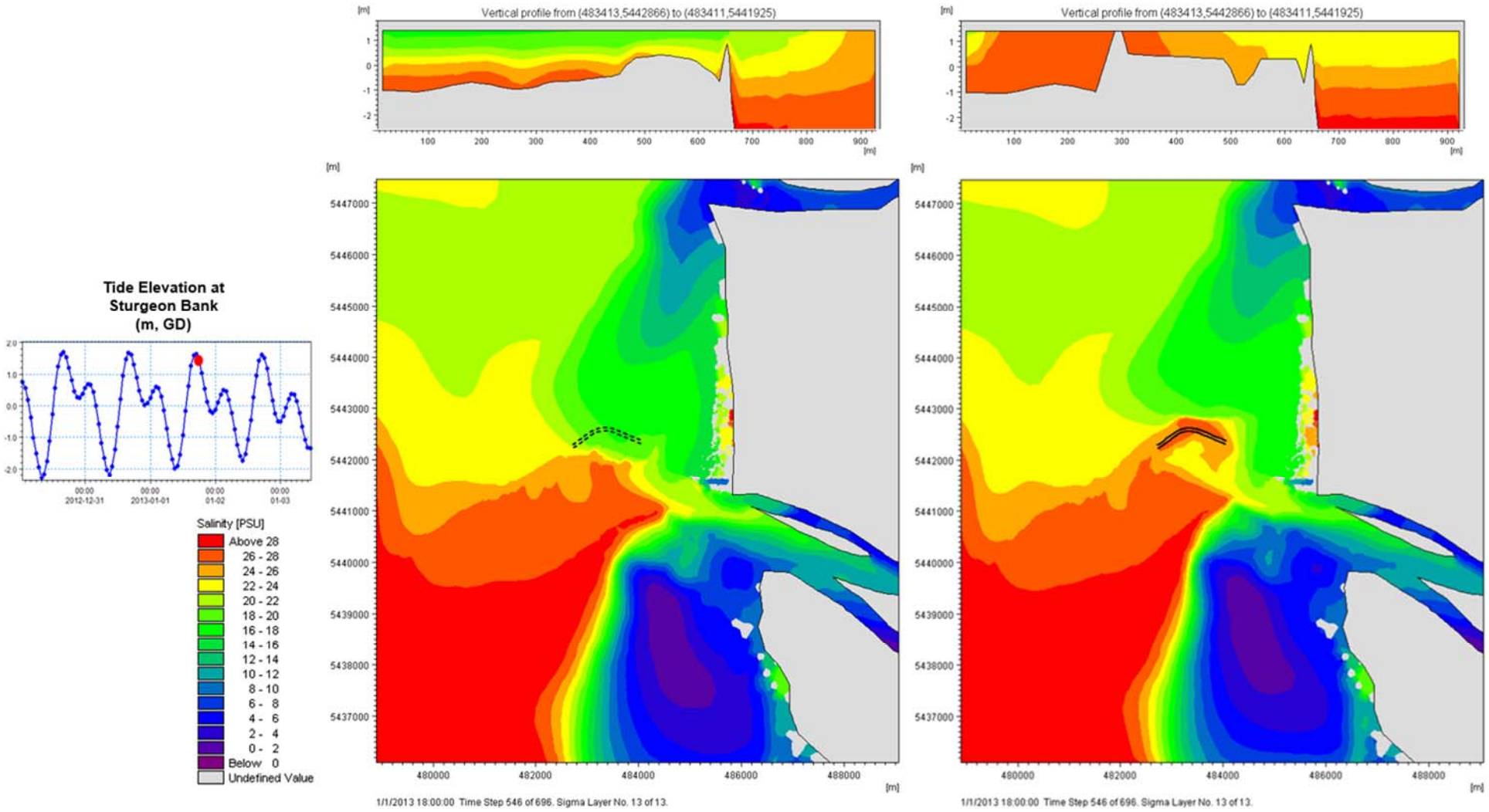


FIGURE 6-9: SALINITY PROFILE AND SURFACE SALINITY UNDER LOW DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS. TIDE EL. PASSED HHW

6.3.2. Medium Discharge Scenario

During medium discharge periods, the Fraser River has a larger influence on salinity and circulation in the area. As the tides retreat, fresh water pushes further into the ocean and spreads over a wider area, as depicted in the left plot of Figure 6-10, where blue shades are present in the offshore areas. Subsequently, Sturgeon Bank will be exposed to water of lower salinity during high tides, as depicted in the right plot of Figure 6-10 where brackish water (green shades) inundates the intertidal areas of Sturgeon Bank.

The stronger river flow in the South Arm starts to dominate over tidal flows, restricting salinity intrusion into the Fraser River.

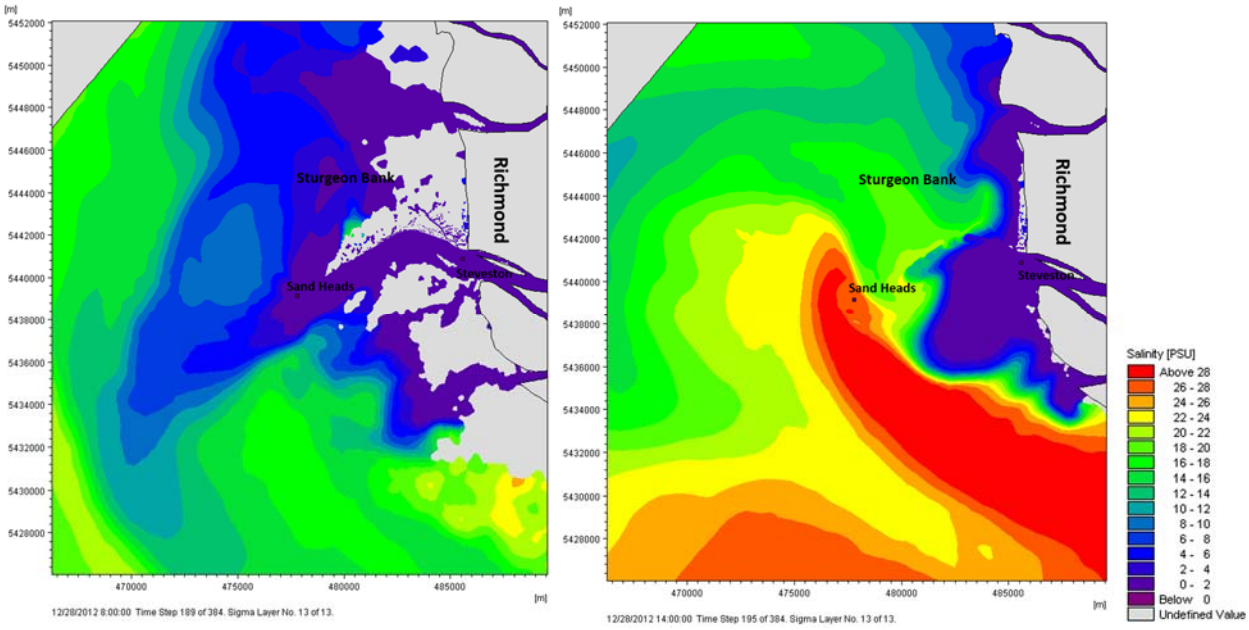


FIGURE 6-10: SURFACE SALINITY DISTRIBUTION UNDER MEDIUM DISCHARGE AT LOW (LEFT) AND HIGH (RIGHT) TIDE, EXISTING CONDITION

During times of medium discharge, there is a continuous supply of fresher water into the proposed marsh area flowing directly over the Steveston North Jetty or with the incoming tide for both the existing and the with-project conditions. For this reason, the main effect of the cobble berm on the salinity is:

- Obstruction of tidal flows that bring brackish water to the proposed marsh area.

Brackish waters are typically brought to Sturgeon Bank between LLW and HHW. The cobble berm effectively keeps brackish waters from coming into the marsh area (Figure 6-12). Even when the tide reaches HHW, flow from the river may overcome the tide (flowing in opposite directions), pushing brackish waters away from the marsh area (Figure 6-13). Exposure of the marsh area to brackish waters is therefore significantly reduced under the with-project condition.

The range of modelled depth-averaged salinities in the proposed marsh area for the existing and the with-project conditions is depicted with blue and yellow curves in Figure 6-11. Additionally, the range

of modelled salinities for the existing marsh area is depicted with the green dashed curve. This figure indicates that fresher waters are predominant through the tidal cycle in the area. However, the range of salinity in the proposed marsh area is considerably reduced for the with-project condition. The effect of the cobble berm is that salinities in the proposed marsh area are brought closer to the existing marsh.

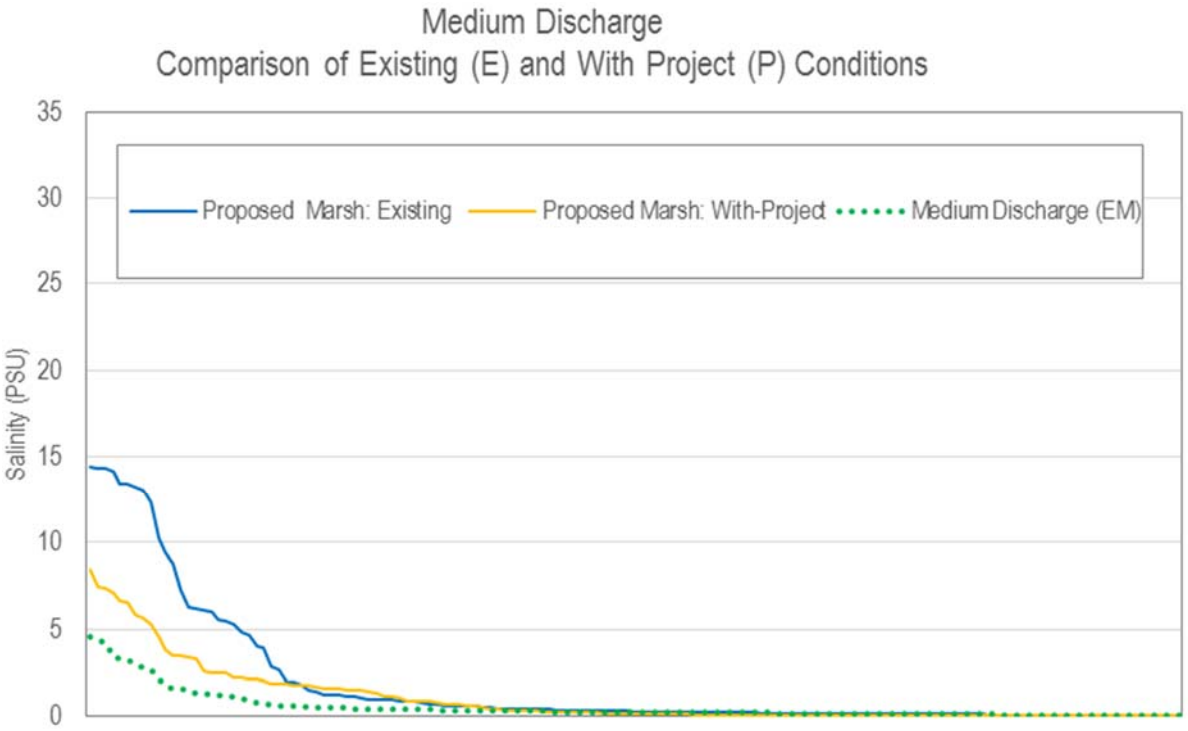


FIGURE 6-11: SALINITY VARIATIONS IN THE PROPOSED AND EXISTING MARSH AREA UNDER MEDIUM DISCHARGE

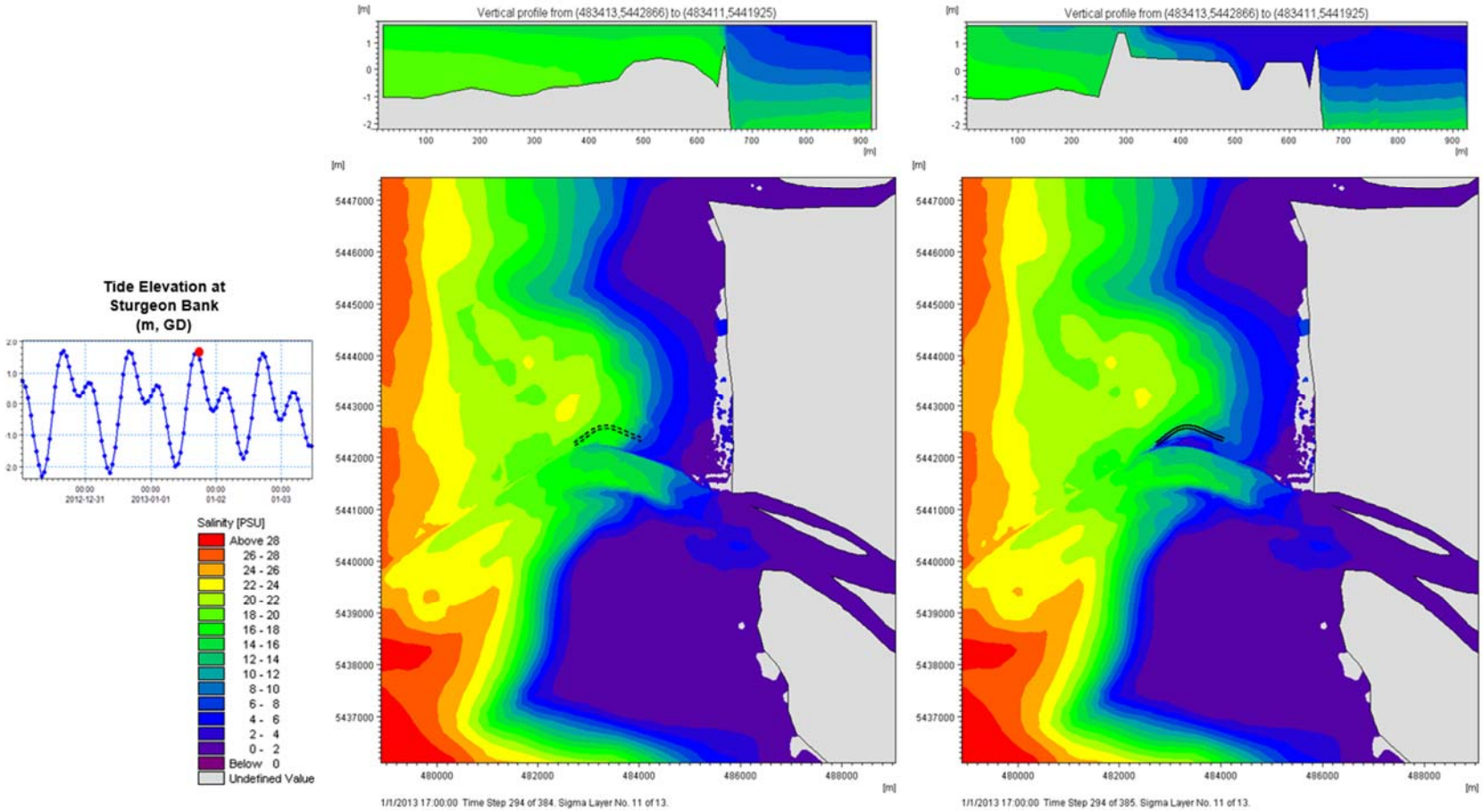


FIGURE 6-12: SALINITY PROFILE AND SALINITY AT INTERMEDIATE DEPTH UNDER MEDIUM DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS. TIDE EL. AT HHW

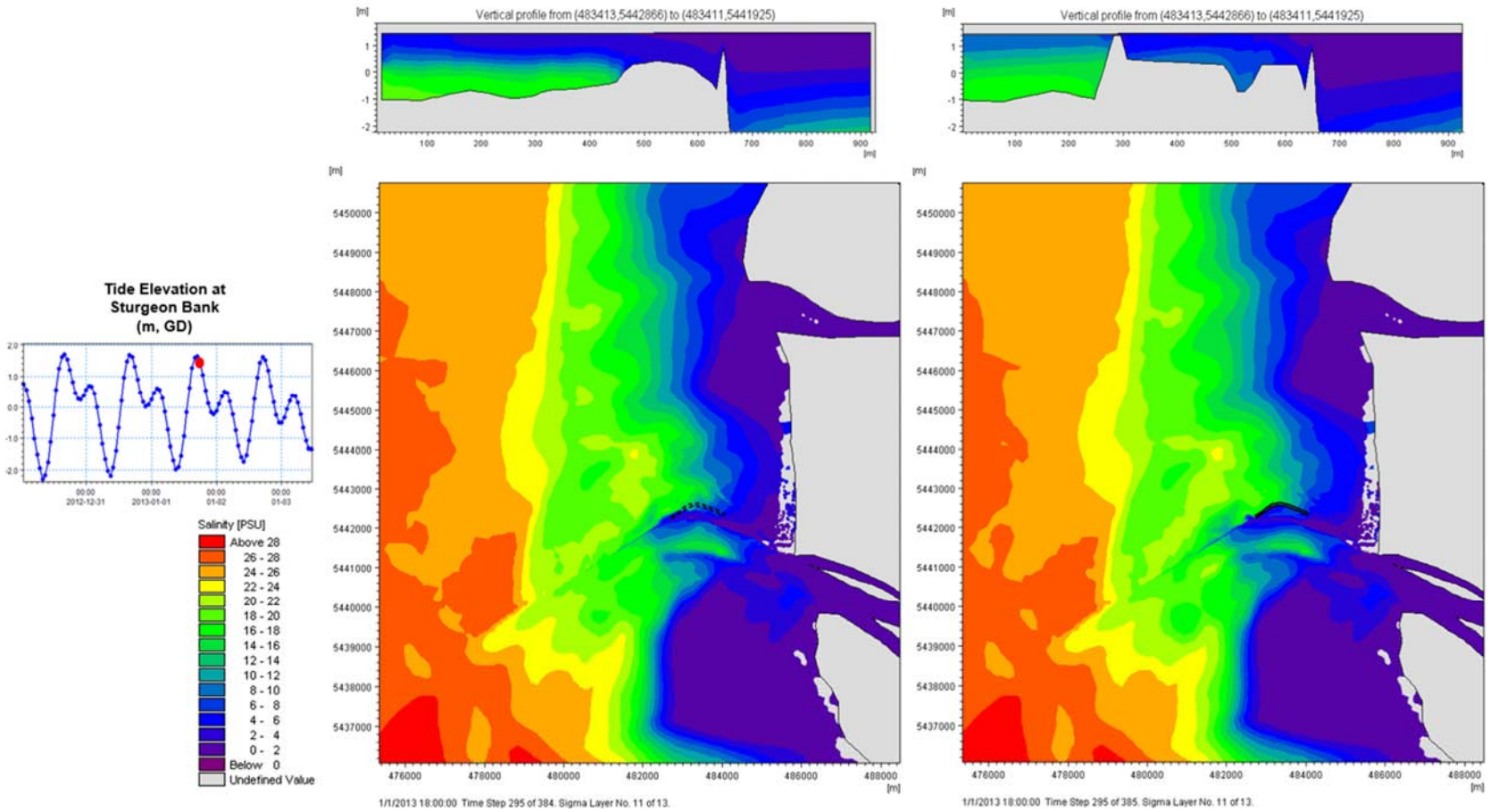


FIGURE 6-13: SALINITY PROFILE AND SALINITY AT INTERMEDIATE DEPTH UNDER MEDIUM DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS. TIDE EL. PASSED HHW

6.3.3. High Discharge Scenario

During freshet (high discharge) periods, salinities in the Fraser River are at the lowest levels. Fresh water is predominant, and intrusion of brackish water is limited at both Sturgeon Bank and the South Arm as illustrated in Figure 6-14, representing typical surface salinity distribution at low and high tide, respectively.

Maximum salinities within the marsh area are around 4-6 PSU and are limited to periods around Higher High Water (Figure 6-15). During the remaining time in the tidal cycle, salinities in the marsh area are close to 0 PSU.

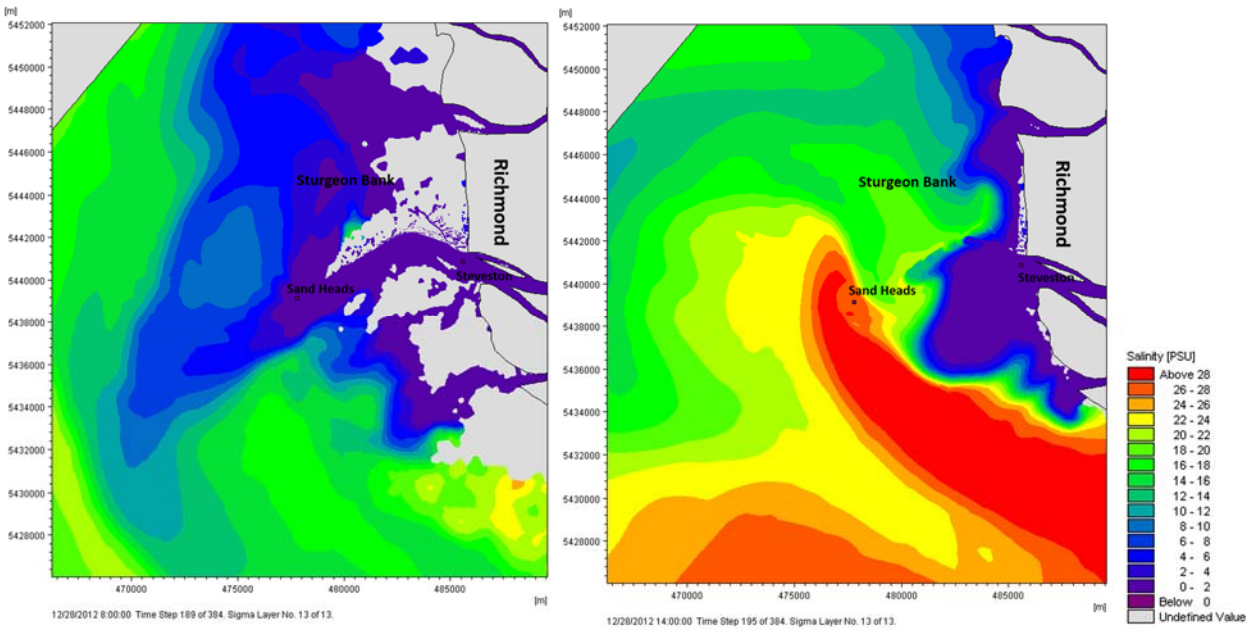


FIGURE 6-14: SURFACE SALINITY DISTRIBUTION UNDER HIGH DISCHARGE AT LOW (LEFT) AND HIGH (RIGHT) TIDE, EXISTING CONDITION

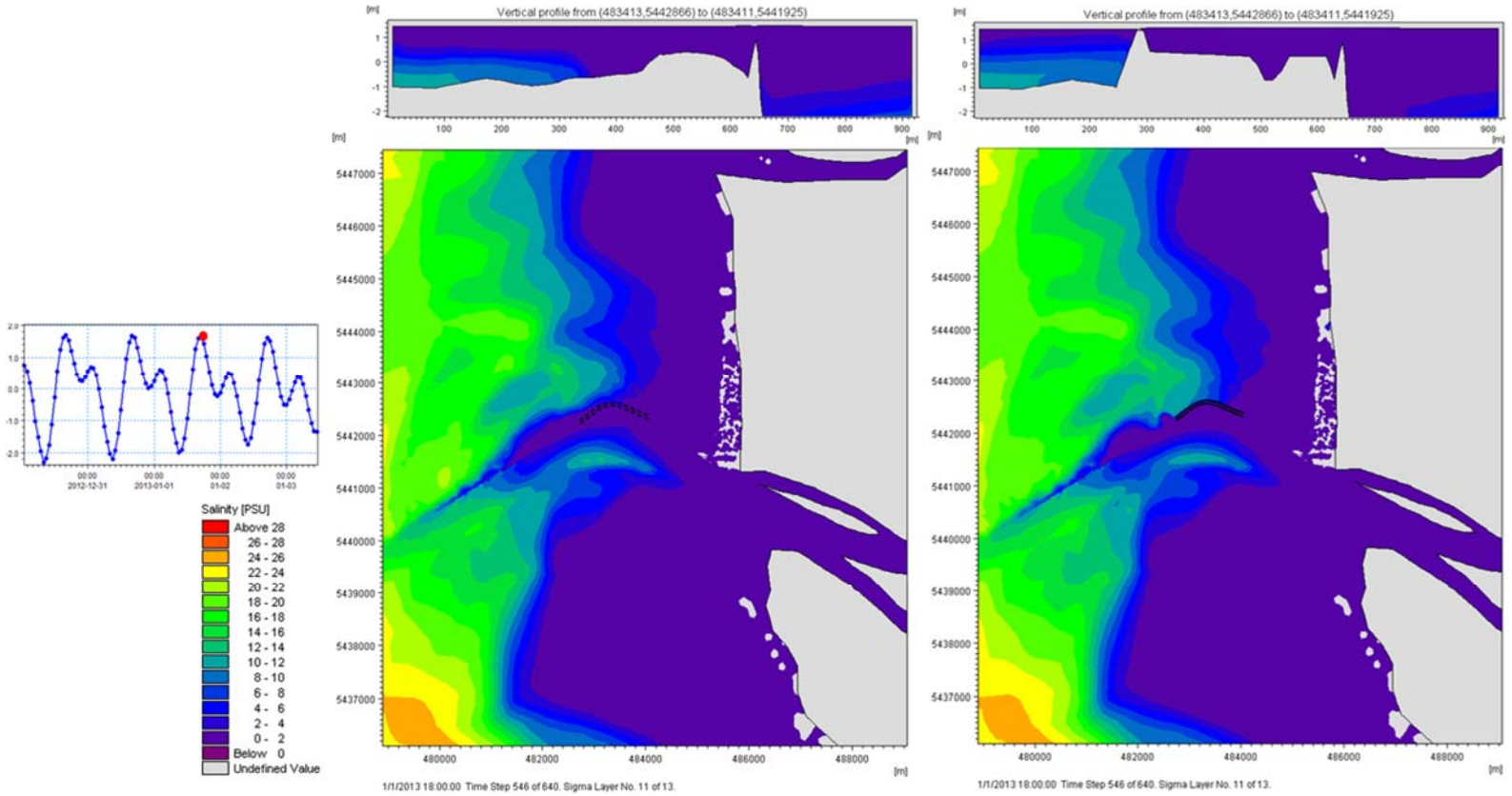


FIGURE 6-15: SALINITY PROFILE AND SALINITY AT INTERMEDIATE DEPTH UNDER HIGH DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS. TIDE EL. AT HHW

6.4. Summary of Salinity Distribution Analysis

Overall the modelled salinity ranges from 0 to around 22 PSU, for both the existing and the with-project conditions. Model results suggest that the cobble berm will bring salinities in the proposed marsh area closer to the existing marsh.

The range of salinity at the proposed marsh area varies primarily as a function of discharge from the Fraser River, which in turn varies throughout the year.

During low discharge periods (e.g. winter months), the cobble berm promotes somewhat lower salinity levels in the proposed marsh area. This suggests that the fresh water retained in the marsh can be improved approximately 50% of the time during the year.

During medium discharge periods, the cobble berm also aids in a significant reduction of the salinity in the proposed marsh area.

During high discharge periods (e.g. freshet), fresh water is dominant in the proposed marsh area almost always throughout the tidal cycle, and hence the cobble berm does not affect salinity levels.

7. Climate Change Impacts

The response of the marsh vegetation to sea level rise and climate change impacts depends on several factors, including the rate of sea level rise, the resiliency of the marsh vegetation, input of sediment/fines to the marsh area, flow circulation, and potentially other elements of climate change such as temperature and insolation.

A detailed study of the response of the proposed marsh to sea level rise is beyond the scope of the present study, but a cursory overview based on current research findings is provided in the following.

7.1. Sea Level Rise

The indication is that the marsh could be fairly resilient to sea level rise, having the ability to grow in parallel with a rise of the mean sea level, provided that a sufficient influx of sediment will continue to deposit and raise the marsh plain. Based on the experience to date, the Fraser River provides a substantial throughput of sediment and fines to Sturgeon Bank and Roberts Bank. If the marsh vegetation remains vigorous it will have the ability to trap sediment, raising the marsh plain. However, if the rate of sea level rise accelerates to a degree that rising ocean levels outcompete the raising of the marsh plain, then the marsh will gradually submerge.

Considering the Steveston North Jetty, sea level rise would have the effect of enabling more water to overtop the jetty, and more frequently. This could have the net effect of providing more freshwater inflow to the marsh area.

In terms of the cobble berm, sea level rise would have the effect of allowing more wave overtopping, and also allow increased saltwater inflow. Raising the crest elevation of the cobble would improve on both of these two aspects.

In terms of the Sturgeon Bank mudflats, if sea level rise outcompetes mudflat buildup (i.e. sediment input to the mudflat is insufficient to raise the bed elevation at the rate of the sea level rise), this could lead to larger water depths in the area of the cobble berm. Deeper water would in turn enable larger waves to impinge on the marsh area. The stability of the cobble berm should in this case potentially be re-evaluated.

7.2. Increases in Temperature

The indication is that increases in peak temperature or its frequency could present an adverse impact to marsh vegetation, resulting in a decrease in plant cover. This in turn may affect species utilizing the marsh as habitat. Temperature-related impacts may be ameliorated somewhat at Sturgeon Bank due to the pronounced flow exchange over tidal cycles which can aid in reducing peak temperature levels.

7.3. Changes in Salinity

In terms of potential changes in salinity due to changes in river outflow and/or ocean circulation patterns, the indication is that the marsh may well be able to accommodate small, gradual changes.

This is due to the typical marsh vegetation being tolerant to a wide range of salinity levels. A long-term effect may transition in terms of the type and species of marsh vegetation.

7.4. Marsh Resiliency

The long-term marsh resiliency is difficult to ascertain due to many factors affecting the health of the marsh. However, at the onset of the marsh restoration, the key factors that aid in establishment of the marsh vegetation are: 1) to reduce wave exposure; 2) to provide a terrain elevation that balances wetting and drying over tidal cycles; and 3) to improve salinity levels, in particular reduce exposure to very high salt concentrations.

8. Conclusions and Recommendations

From the analyses conducted for this study, the following can be concluded:

- Introduction of the cobble berm at the proposed marsh area will be effective in providing shelter from waves, reducing the amount of bed shear stresses, and promote favorable conditions for growth and development of the future marsh.
- The cobble berm will aid in reducing salinities in the proposed marsh area, and shift salinity ranges closer to those occurring in the existing marsh area.

M&N recommends further investigations on the efficacy of a higher cobble berm and its effect on reducing saline water exposure for the proposed marsh area. Additionally, simulations of salinities over longer periods would enable a better understanding of project impacts on salinities at Sturgeon Bank.

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Appendix A:
Supplemental Hydrodynamic and Salinity Analysis with Incorporation of Phase 2 Raincoast Project

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MEMORANDUM

To: Michael Cho, P.Eng., M&N

From: Cheng-Feng Tsai, P.E., & Dilip Trivedi, P.E., M&N

Date: May 28, 2020

Subject: Supplemental Hydrodynamic and Salinity Analysis by Incorporating Phase 2 Breaching into the South Arm Jetty Tidal Marsh Project

EXECUTIVE SUMMARY

The purpose of this memo is to analyze potential changes in the South Army Jetty (SAJ) Tidal Marsh project area following the introduction of Raincoast Conservation Foundation (RCF) Phase 2 breaches in the Steveston North Jetty east of the SAJ project. The hydrodynamic modeling results suggest that current speeds and salinity within the project area are similar or slightly lower in magnitude compared to the without-breaches condition. Therefore, the breaches of the RCF Project do not present any adverse effects in the SAJ project area. In addition, results show that the effects of the proposed SAJ breaches located to the west of the SAJ site are limited and therefore not recommended to be included as part of the SAJ project.

BACKGROUND

The Vancouver Fraser Port Authority (VFPA) has developed the Habitat Enhancement Program (HEP). HEP has been developed to improve fish and wildlife habitat in advance of port development projects, to offset impacts to existing habitat. As part of the HEP, the South Arm Jetty Tidal Marsh (SAJ) project is a proposed intertidal marsh located along the north side of Steveston North Jetty (SNJ). Moffatt & Nichol (M&N) has been retained by VFPA for the design of the SAJ Project, which included a cobble beach berm, general raising of site grades with sand fill, drainage channels suitable for marsh planting (by others). M&N completed wave exposure and hydrodynamic/salinity analyses to support the design in Dec. 2017[1].

In 2018, RCF proposed the Fraser River Estuary Connectivity Project that consists of breaching sections of the SNJ surrounding the SAJ project. Tetra Tech Inc. was retained by the RCF to investigate the impacts of the proposed project on navigation and on sedimentation processes in the vicinity, and two reports were prepared (a Phase 1 report in Feb. 2018[2], and a Phase 2

[1] Moffatt & Nichol, 2017. Coastal Processes & Salinity Modeling, South Arm Jetty Tidal Marsh Project. Draft Report.

[2] Tetra Tech, 2018. Investigation of the Hydrodynamic and Sedimentation Impacts in the Fraser River from the Proposed Openings along the Steveston North Jetty. Technical Memorandum.

report in Jan. 2019[3]). The VFPA and M&N provided review comments on both reports. At present, Phase 1 of breaches east of the SAJ project (hereafter referred as RCF breaches) has been implemented and the formation of natural channels have been occurring. Phase 2 of breaches is scheduled to potentially proceed in 2020.

A supplemental analysis of tidal hydrodynamics and salinity was conducted to assess whether the RCF breaches have potential impacts to the SAJ Project. In addition, two proposed SAJ breaches west of the SAJ project (hereafter referred to as SAJ breaches) were evaluated to examine if there are any benefits by incorporating the SAJ breaches in the future project footprint. This addendum report is intended to supplement the 2017 M&N main report. **Figure 1** shows the SAJ Project footprint and the locations of three RCF breaches and two proposed SAJ breaches.

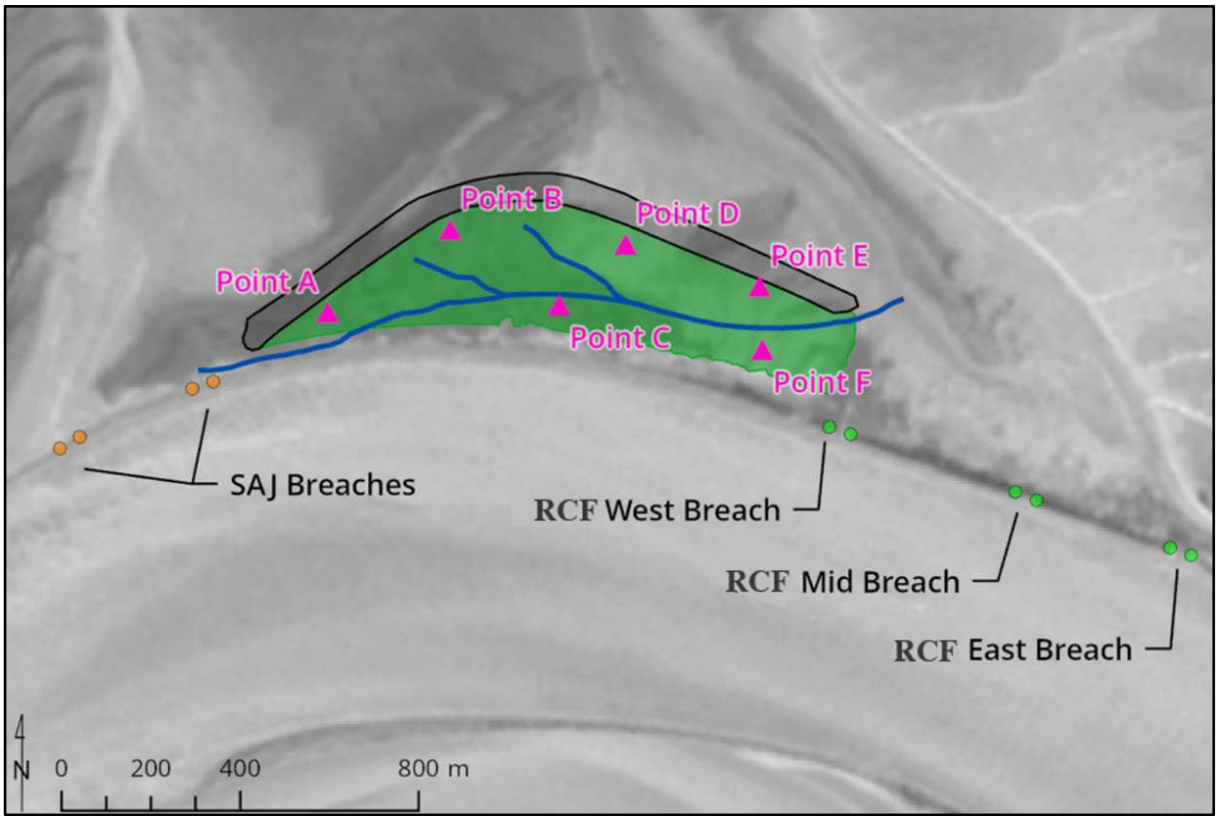


Figure 1: The SAJ Project Footprint, Locations of Three RCF Breaches and Two Proposed SAJ Breaches, and the Six Model Data Extraction Points (Point A-F Triangles).

MODELING APPROACH

[3] Tetra Tech, 2019. Phase 2 Report - Hydrodynamic and Sedimentation Study for the Proposed Breaches on Steveston North Jetty in the Fraser River. Presented to Raincoast Conservation Foundation.

The modeling approach and model performance characteristics (e.g. model development, calibration) are addressed in the main report of the 2017 M&N modeling work and are therefore not reiterated here. The only changes are to introduce the breaches and to incorporate the latest 2019 LiDAR data in the vicinity of the RCF breaches.

The latest LiDAR data was collected for the RCF Project in summer 2019 by McElhanney Consulting Ltd[4]. The survey was conducted at low tide and covers eastern half of the project area as well as the parcel to the east. Elevations were in the range from -2.3 m GD to +4.5 m GD.

Two additional scenarios were developed in the supplemental analysis to assess the effects of breaches on the SAJ Project. The first scenario incorporates the RCF breaches, while the second scenario incorporates both the RCF breaches and the proposed SAJ breaches. The existing condition (without any breaches and without the SAJ project) and the with-SAJ project scenarios developed in 2017 were also included for comparison purposes. Six model data extraction points were used to analyze the effects of the breaches in the SAJ project area. The extraction points are denoted by the triangles shown in **Figure 1**, Point A-F.

Three discharge flow conditions in the Fraser River were investigated in the supplemental analysis to allow direct comparison to the 2017 modeling results. The low flow of 2,000 m^3/s represents the base flow condition. The high flow was set to 8,000 m^3/s, an average peak discharge during the freshet. The medium flow of 5,500 m^3/s represents a transition from the low to the high flow.

MODEL SCENARIOS

The associated tidal channel will form and evolve naturally after a breach is created. A desktop analysis of tidal channel geometry was performed based on the literature to identify the extent of tidal channels connecting the RCF breaches.

Hydrodynamic model results found that the peak discharge through the RCF west breach (most impacting the SAJ project) is approximately 40 m^3/s. Friedrichs (1995[5]) and some other studies suggest the existence of a relationship between cross-sectional area and peak discharge for sheltered tidal channels. **Figure 2** presents the observed relationship. Using this relationship, an equilibrium cross-sectional area for the RCF tidal channel at peak discharge is estimated to around 60 m^2, which further indicates a RCF tidal channel width of around 20 to 25 m. Similarly, the peak discharge through the SAJ marsh channel is approximately 10 m^3/s, corresponding to a channel with an estimated cross-sectional area of 30 m^2 and a channel width of 10 to 15 m.

While there is great variability within tide-dominated systems, the channel width-to-depth ratio can be split into two discrete groups of tidal channels: vegetated channels and channels on bare

[4] McElhanney Consulting Services Ltd. (2019). LiDAR for Raincoast Conservation Foundation 2019.

[5] Friedrichs, C. T. , 1995. Stability Shear Stress and Equilibrium Cross-Sectional Geometry of Sheltered Tidal Channels. Journal of Coastal Research (11), p1062-1074.

flats (Hughes, 2011[6]). Aerial photographs and LiDAR data were used to estimate the width-to-depth ratios for vegetated channels around Sturgeon Bank and the results are shown in **Figure 3**. Also shown in the figure is the estimated RCF breach channel (a width of 20 m and a depth of 1.5 m at MWL) and the SAJ marsh channel geometry (a width of 10 m and a depth of 0.7 m). The estimated channel geometries are aligned well with the surrounding vegetated channels.

Two additional model scenarios were developed using these estimated channel geometries. They were then incorporated into the earlier with-SAJ Project scenario, which adds a rock berm, a marsh channel, and raising of site grades to support marsh habitat.

The first scenario, "RCF Breaches", adds the three RCF breaches and associated tidal channels to the with-SAJ Project scenario. The second scenario, "All Breaches", adds the two proposed SAJ breaches to the first scenario. The bathymetry of four model scenarios are shown in **Figure 4.**

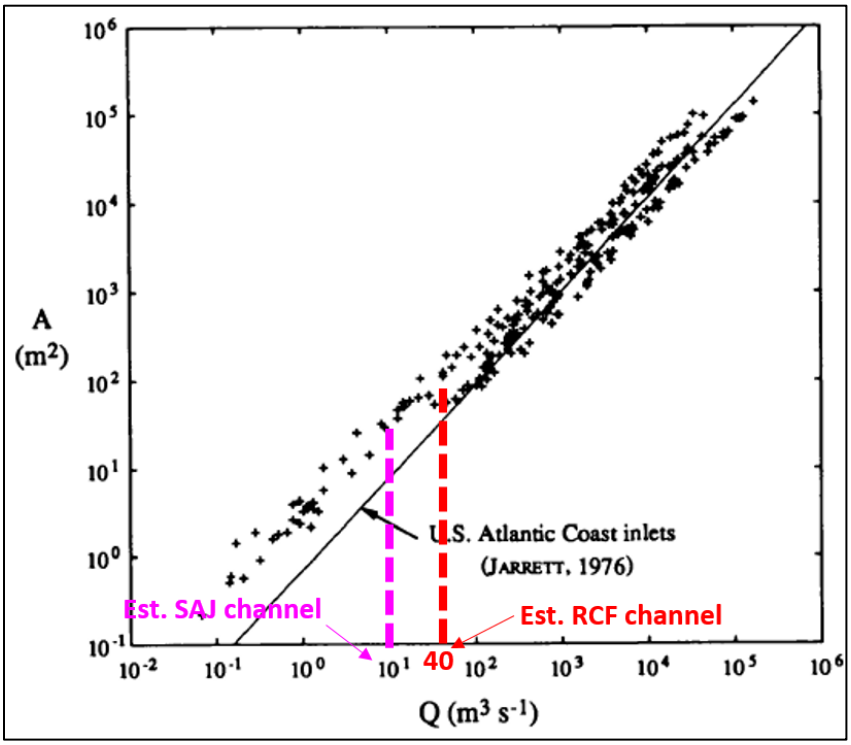


Figure 2: Cross-Sectional Area vs. Peak Discharge for Tidal Channels (Friedrichs, 1995)

[6] Hughes, Z. J. , 2011. Chapter 11: Tidal Channels on Tidal Flats and Marshes, Principles of Tidal Sedimentology. Editors: Davis Jr. , R. A. and Dalrymple, R. W. Publisher: Springer Netherlands.

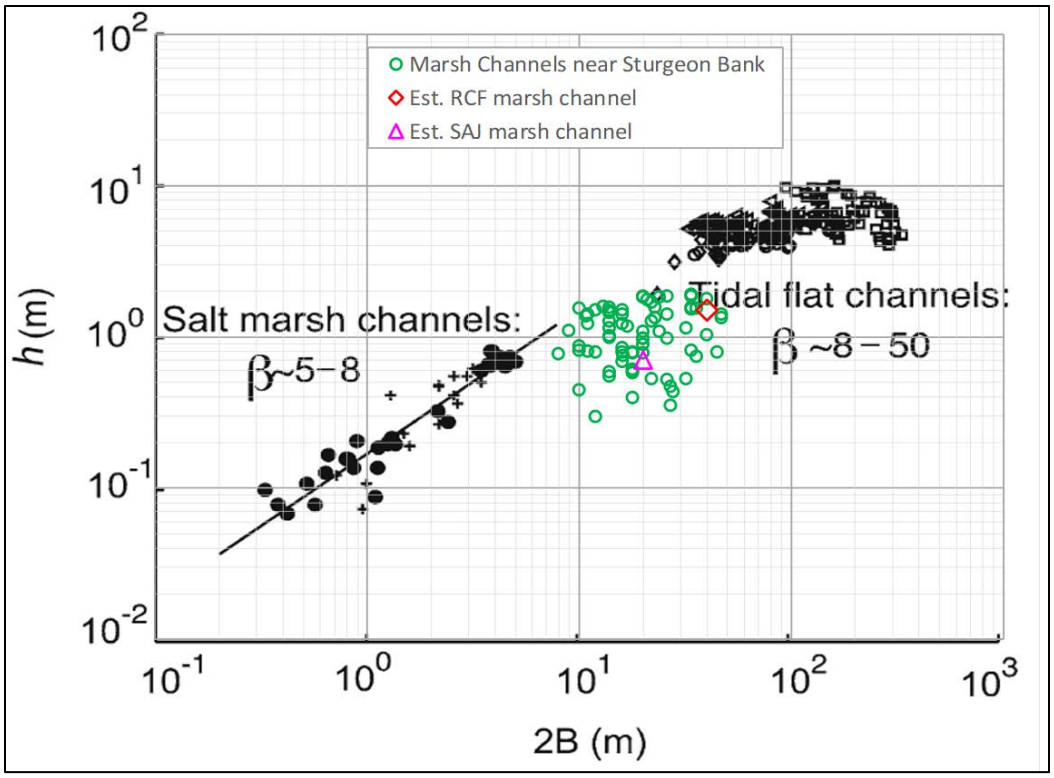


Figure 3: Width-to-Depth Ratio for Tidal Channels (Revised from Hughes 2011)

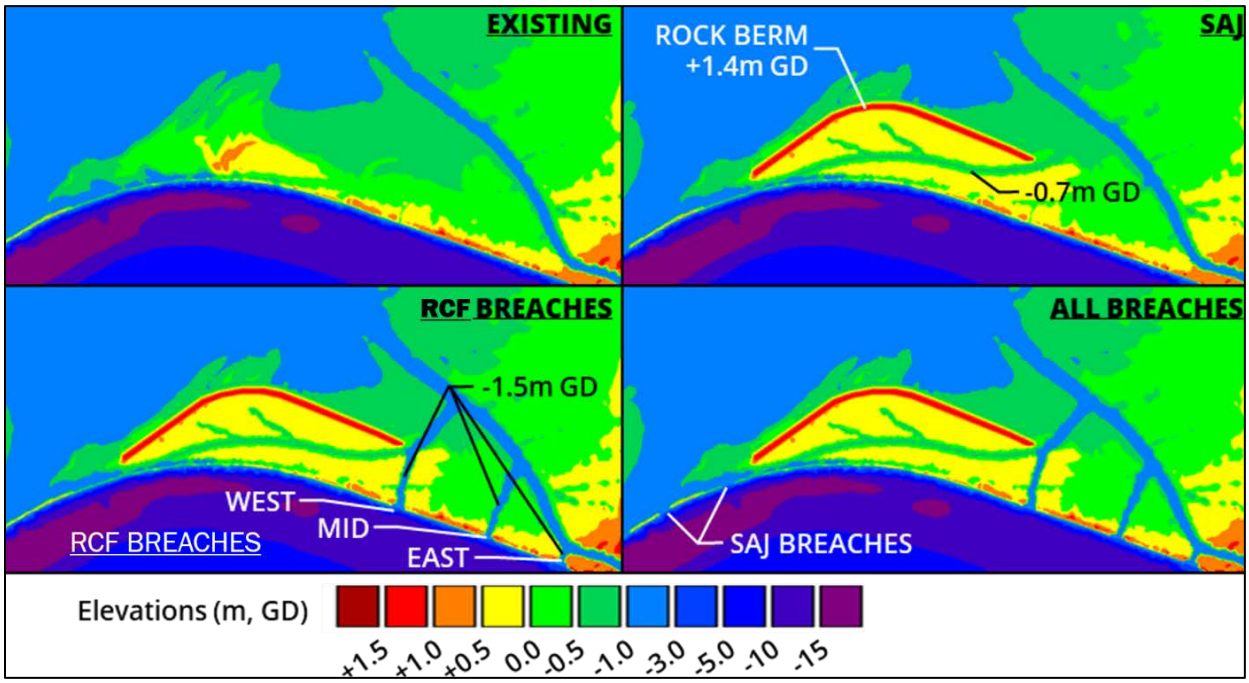


Figure 4: Bathymetry for Model Scenarios

MODEL RESULTS

Figure 5 and **Figure 6** show current speeds and surface salinities at Point "A" and Point "F", respectively. Points "A" and "F" were chosen because they are on the opposite ends of the project area and the results at the other four locations mostly fall between Points "A" and "F". All three conditions: high flow (8,000 m^3/s), medium flow (5,500 m^3/s), and low flow (2,000 m^3/s) were investigated in the supplemental analysis. Results show that there are no discernible differences with the addition of the RCF breaches or SAJ breaches under all flow conditions. Only the low flow condition is presented in the figures for illustrative purposes.

Results indicate that the current speeds within the SAJ project area are not substantially affected by the addition of the RCF breaches or the SAJ breaches. At all extraction points, the range of current speeds during the simulation period are similar as long as the SAJ project elements such as the cobble berm and raising the site grades, are implemented (e.g. "SAJ", "RCF Breaches", and "All Breaches") and are generally less than 0.3 m/s. However, a substantial reduction of current speeds can be seen between the scenarios with the SAJ project elements and the existing condition, in which the current speed could reach around 0.7 m/s at Point A. Therefore, it confirms the positive effects with the proposed SAJ project elements. At the eastern portion of the SAJ project area (Point "E" and Point "F"), a slight reduction of the current speed can be observed with the addition of the RCF breaches, though the reduction is minor.

The maximum current speed in the RCF west breach is about 1.2 m/s. Because the channel flow and waves present in the channel may potentially erode the eastern edge of the marsh area, slope protection is recommended along the sides of the channel.

Similarly, surface salinity in the project area does not change significantly with the breaches. Although the overall salinity range (e. g. 0 to 29 PSU) during the simulation period is indiscernible between the scenarios with the SAJ project elements and the existing condition, the former may show lower daily variations in salinity (e. g. 3 to 15 PSU at Point "A" on 12/26) than the existing condition (e.g. 3 to 26 PSU), indicating a modest fresher environment when the SAJ project elements are implemented. At Point "F", occasional reduction in salinity is observed during certain flooding tide stage with the addition of the SAJ breaches. This is because less saline water flows to the eastern end of the project area (Points "E" and "F") when the flow conveyance through the SAJ breaches is provided. However, the lower salinity state is fairly short (an hour per day). Therefore, the benefits of the SAJ breaches are considered limited.

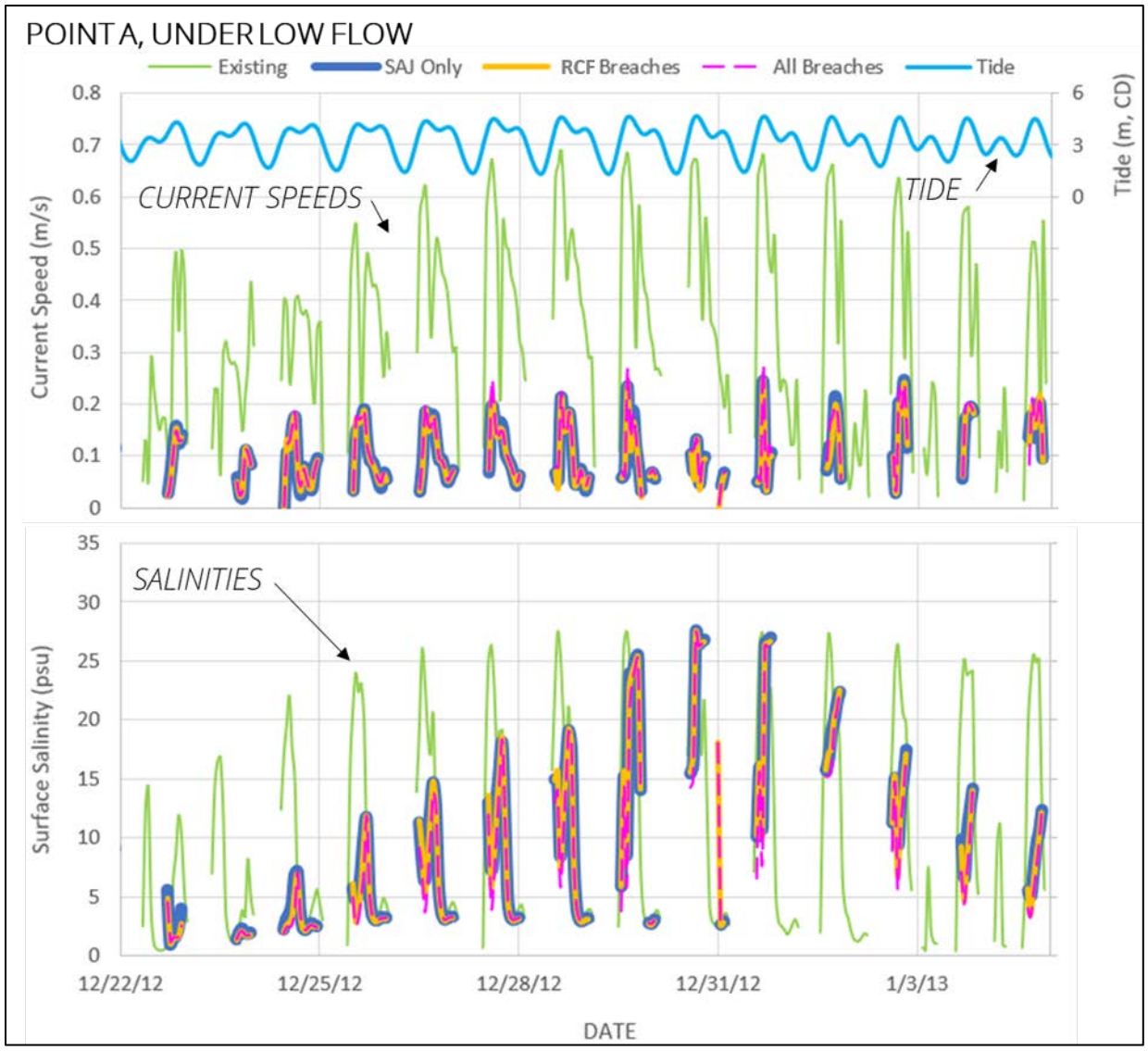


Figure 5: Current Speed and Surface Salinity at Point A, Under Low Flow.

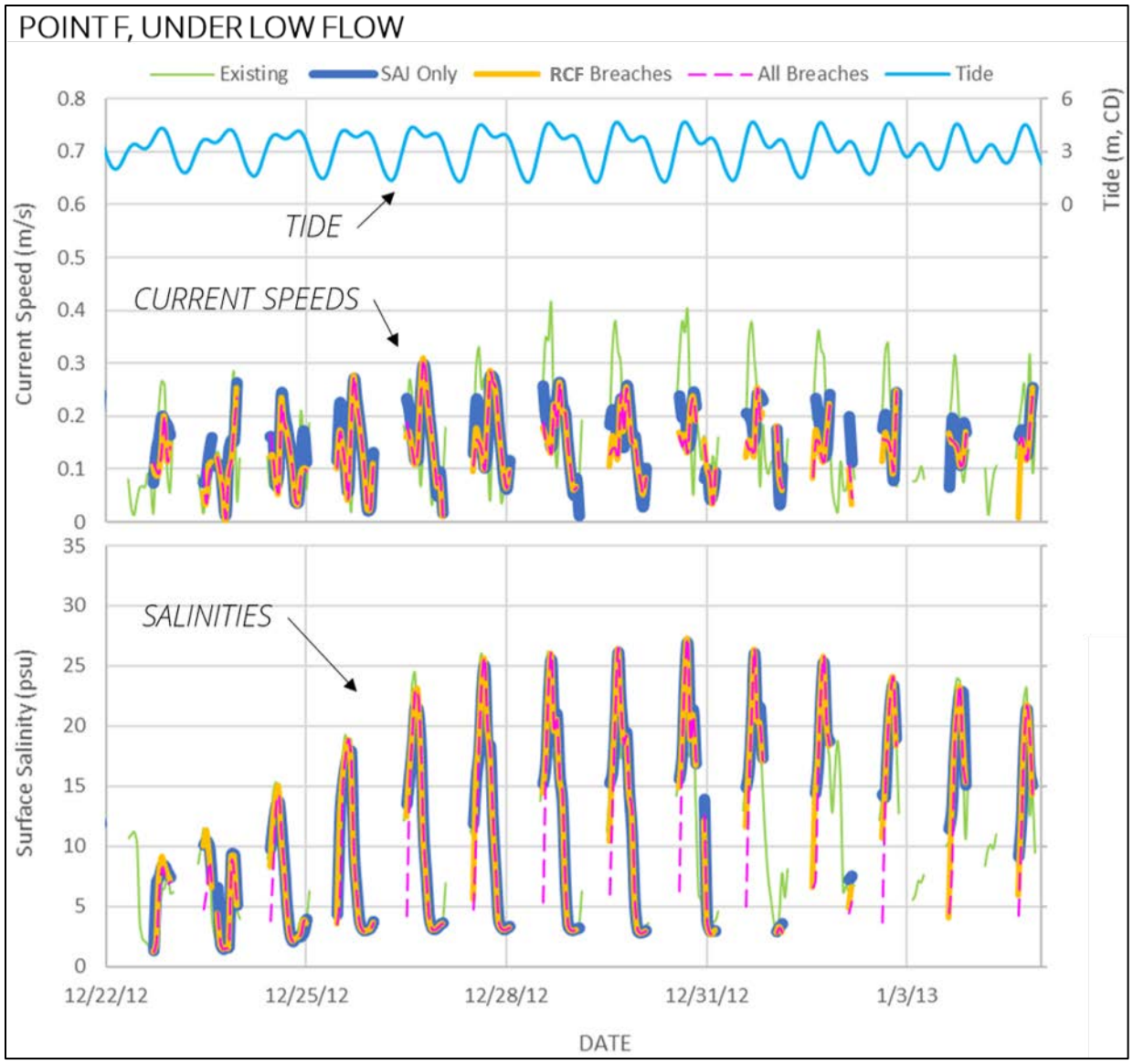


Figure 6: Current Speed and Surface Salinity at Point F, Under Low Flow.

CONCLUSIONS & RECOMMENDATIONS

The main conclusions from this supplemental analysis are:

- The current speeds within the SAJ project area are not substantially affected by the RCF breaches or SAJ breaches.
- The current speeds could be substantially higher in the project area without the SAJ project elements (e. g. cobble berm and raising site grades).
- The maximum current speed in the RCF west breach is about 1.2 m/s. Because the channel flow and waves present in the channel may erode the eastern edge of the SAJ marsh area, slope protection (0.3 m median rock size) is recommended along the sides of the channel.
- Salinity in the SAJ project area does not change significantly with the breaches and the overall salinity range is similar.
- The benefits of the proposed SAJ breaches are limited from a hydrodynamics and salinity perspective and therefore are not recommended for incorporation into the SAJ Project.



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Appendix IR2020-1.1-A8
South Arm Jetty Tidal Marsh Design Report

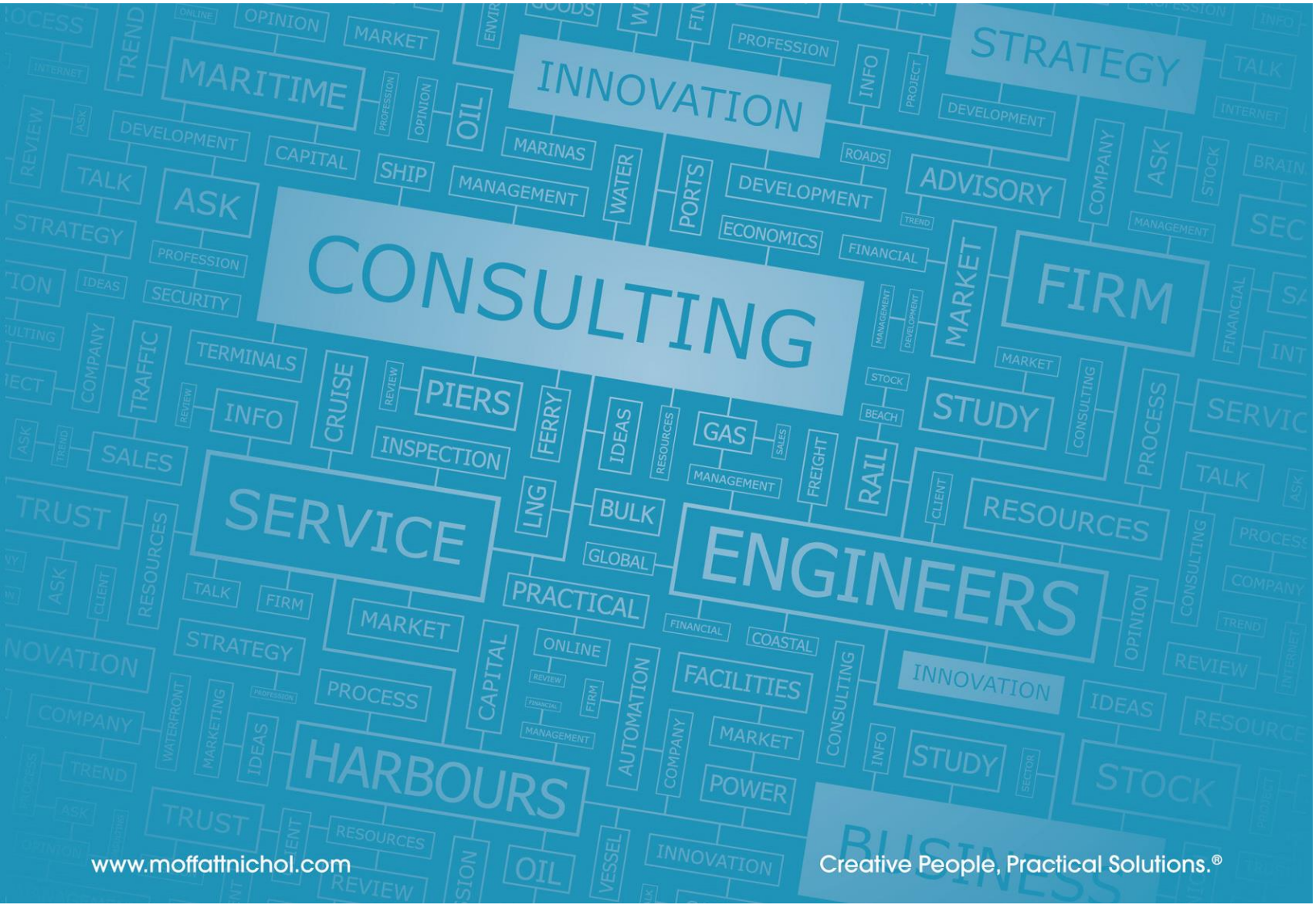
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South Arm Jetty Tidal Marsh Design Report

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This study is qualified in its entirety by, and should be considered in light of, these limitations, conditions and considerations.

1. Introduction

The Vancouver Fraser Port Authority (VFPA) is proposing to provide habitat restoration projects to offset impacts from construction of the Roberts Bank Terminal 2 project. One of the projects under investigation includes the South Arm Jetty Tidal Marsh, an intertidal marsh located on the South Arm of the Fraser River along the north side of Steveston Jetty within the Steveston Bend Reach (Figure 1-1) (km 5.5 to 7.5 of the navigation channel). The site lies on Sturgeon Bank offshore of Steveston Village in Richmond, British Columbia. In general, the project consists of a cobble beach berm, containment structure, raising of site grades with fill sand and then complemented with salt marsh planting.

This report provides the criteria that have been considered in developing the design for the South Arm Jetty Tidal Marsh. A characterization of the Fraser River and discussion of the existing site conditions are provided in Section 2. The design concept was developed through characterization of the existing conditions.

Subsequently, the criteria used to develop the design of the site are discussed in Section 3. Project design criteria also include a combination of the functional, physical and biological criteria (provided by others) as well as the applied engineering standards.

The construction details for the South Arm Jetty Tidal Marsh are discussed in Section 4. Following a general site description, the features of the project are presented, including: the cobble beach berm, containment structure, marsh, site access, construction methodology and construction schedule. Sections 5 provides details on the construction direct cost (CDC) estimate.

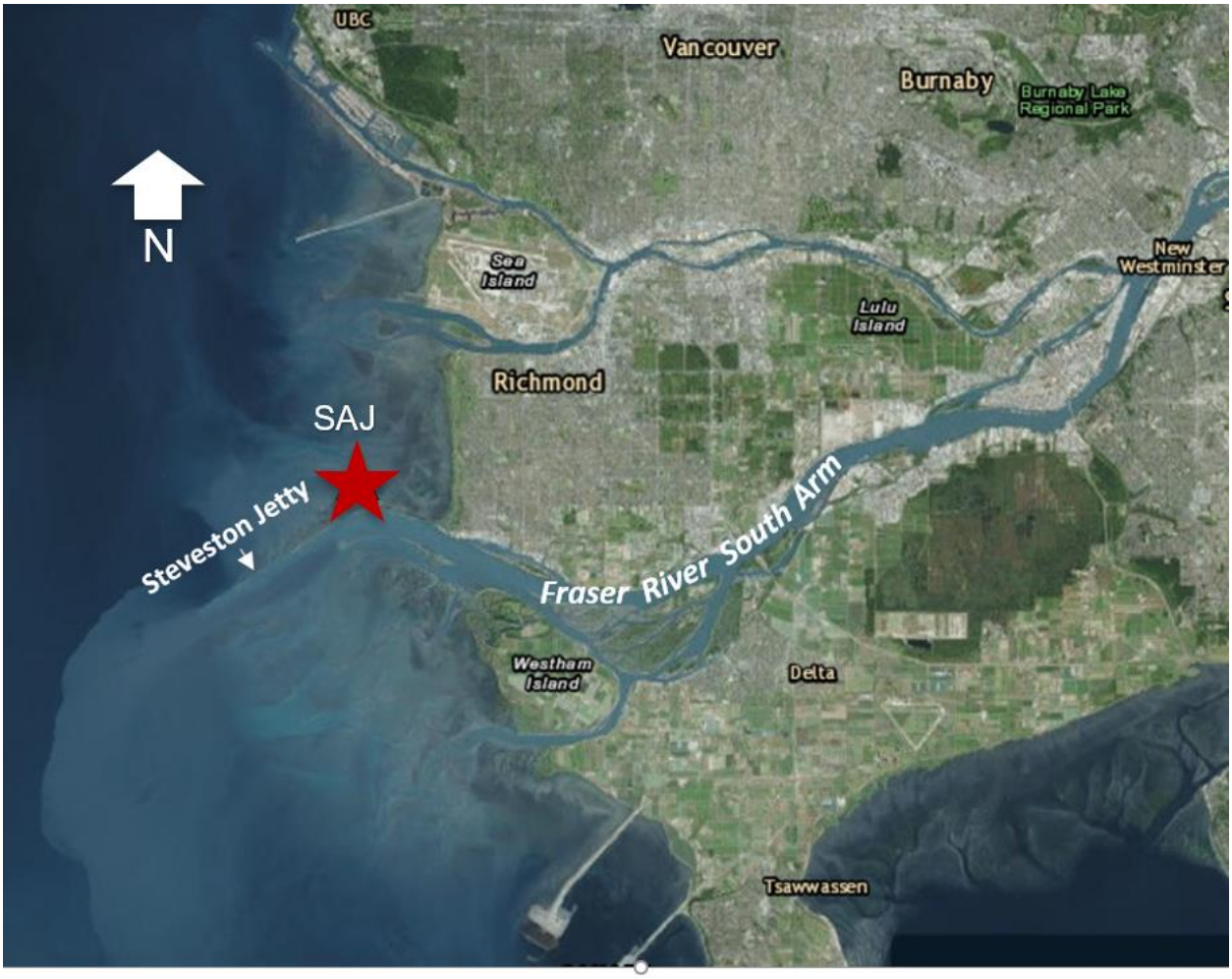


FIGURE 1-1: LOCATION OF PROJECT SITE AT THE STEVESTON JETTY, FRASER RIVER SOUTH ARM

1.1. Project Site

The proposed South Arm Jetty Tidal Marsh is located along the north side of the Steveston Jetty within the Steveston Bend Reach of the Fraser River South Arm (Figure 1-2). This area is adjacent to the maintained deep-sea shipping channel. A large strip of marsh currently exists along the north side of the jetty.

The proposed tidal marsh site is on a shallow portion of Sturgeon Bank with elevations ranging from -0.75 m to +0.75 m Geodetic Datum (GD), with low spots at the west end of the site as low as -1.5 m GD. There is an area with higher elevation which is referred to as the “sand island.” This area is a remnant of dredge material disposal activities in the early 1980s. The adjacent Steveston Jetty is permeable and constructed of piled rock and concrete debris. There are several low points along the jetty which allow flow to pass over the jetty and onto Sturgeon Bank (Figure 1-2).

Fisheries and Oceans Canada (DFO) and Raincoast Conservation Foundation (RCF) created three Breaches in 2019 in the jetty upstream of the proposed tidal marsh to improve fish access and sedimentation in Sturgeon Bank. Additional breaches downstream have been previously considered and described in the Tetra Tech 2019 report and will be addressed in this study.

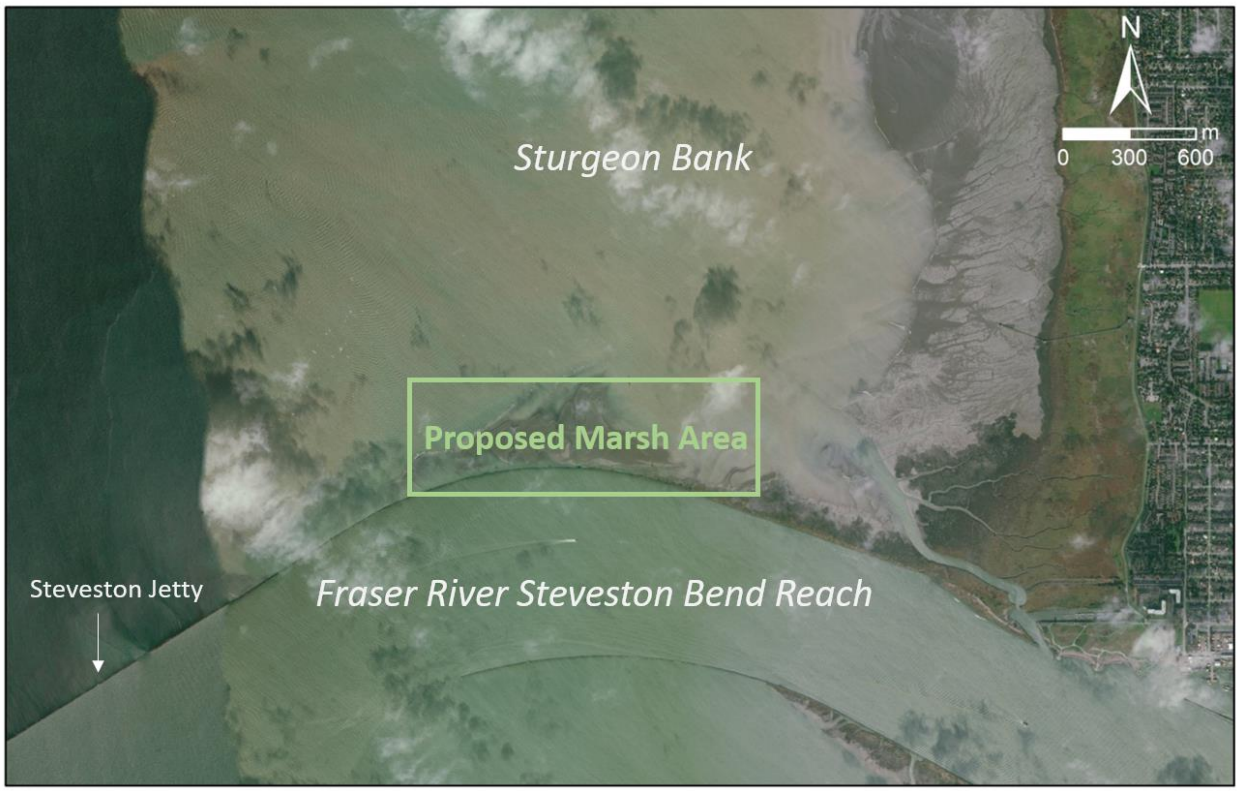


FIGURE 1-2: LOCATION OF PROPOSED MARSH AT STURGEON BANK

2. Coastal Analysis

2.1. General Overview

2.1.1. Background

The Fraser River is one of the largest rivers on the west coast of North America. Figure 2-1 shows the location of the South Arm Jetty site in the lower Fraser River (Ellis et al, 2004). The river crosses the urban area of Metro Vancouver and debouches into the Salish Sea connected to the Pacific Ocean through the Strait of Juan de Fuca.

Due to its commercial and economic importance, the Fraser River and associated system has been studied extensively (e.g. Thomson, 1981; Ferguson, 1991; McLean and Church, 1986; Miller and Barua, 1999; Morrison et al, 2002; Ellis et al, 2004; Williams et al, 2009 and CBA, 2010). The river is an important waterway for access to the Port and facilitates the transport of 50 million tonnes of coastal and deep sea cargo and supports some 650 million young salmon migrating downstream and 10 million spawning salmon (BIEAP-FREMP, 2006).

Important aspects of maintaining the port and navigation fairway that affects the hydro-morphologic setting of the river are diking, river training structures and annual dredging. Between 1975 and 1990, some 7 million m^3 of sand was dredged annually. Current guidelines limit dredging to 70% of the incoming bed-material load (BIEAP-FREMP, 2006), some 3.5 million m^3 annually.

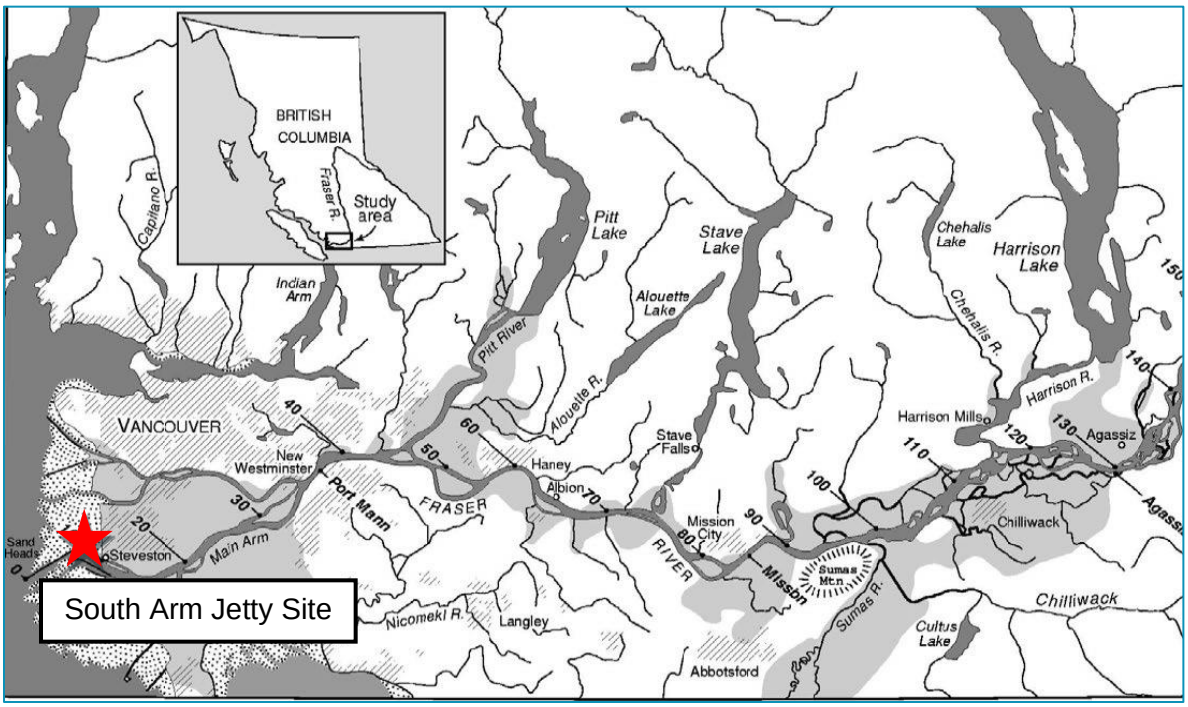


FIGURE 2-1: LOWER FRASER RIVER SYSTEM SHOWING THE SOUTH ARM JETTY SITE[1]

Several studies and research reports are available on the hydraulics and morphology of the Fraser River Estuary. These studies were mostly sponsored by public agencies such as the Burrard Inlet Environmental Action Program and Fraser River Estuary Management Program (BIEAP-FREMP), Environment Canada, Canadian Coast Guard and VFPA.

2.1.2. General Setting

The proposed project site is located in the Fraser River Estuary on the north side of Steveston Jetty within the Steveston Bend Reach, approximately 5.5 km upstream from Sand Heads. Section 2.3 describes the characteristics of the site. A brief review of the general physical setting of the Fraser River system is presented in this section.

[1] ★ represents the South Arm Jetty site on all figures



FIGURE 2-2: FRASER RIVER DELTA FRINGE PHYSIOGRAPHY

The gross drainage area of the Fraser River is approximately 217,000 km^2. Hydrometric data, including water level and discharge data has been measured at Hope since 1912, capturing a period of record of 106 years.

Figure 2-3 summarizes the maximum, minimum, and mean discharge data recorded at Hope. Additionally, the year 1991 is shown, taken as representative of average conditions.

It can be seen that outflow from the river remains fairly constant over the months from January to mid-April, and subsequently increases rapidly through mid-June to early July. Over the months of July to October, the outflow decreases pronouncedly, followed by a more gradual decrease of the outflow in October and November, until a somewhat constant discharge is reached around December.

The pronounced increase in outflow over the late spring and summer months (freshet) is due to melting of snow accumulated in the mountains over the winter months.

The peak annual discharge around mid-June can range from approximately 4,000 m^3/s (blue curve) to 14,000 m^3/s (green curve). The average peak annual discharge is around 7,000 m^3/s (brown curve). In dry years, the base outflow can be as low as 600-1,000 m^3/s, increasing to 2,000-4,000 m^3/s in wet years.

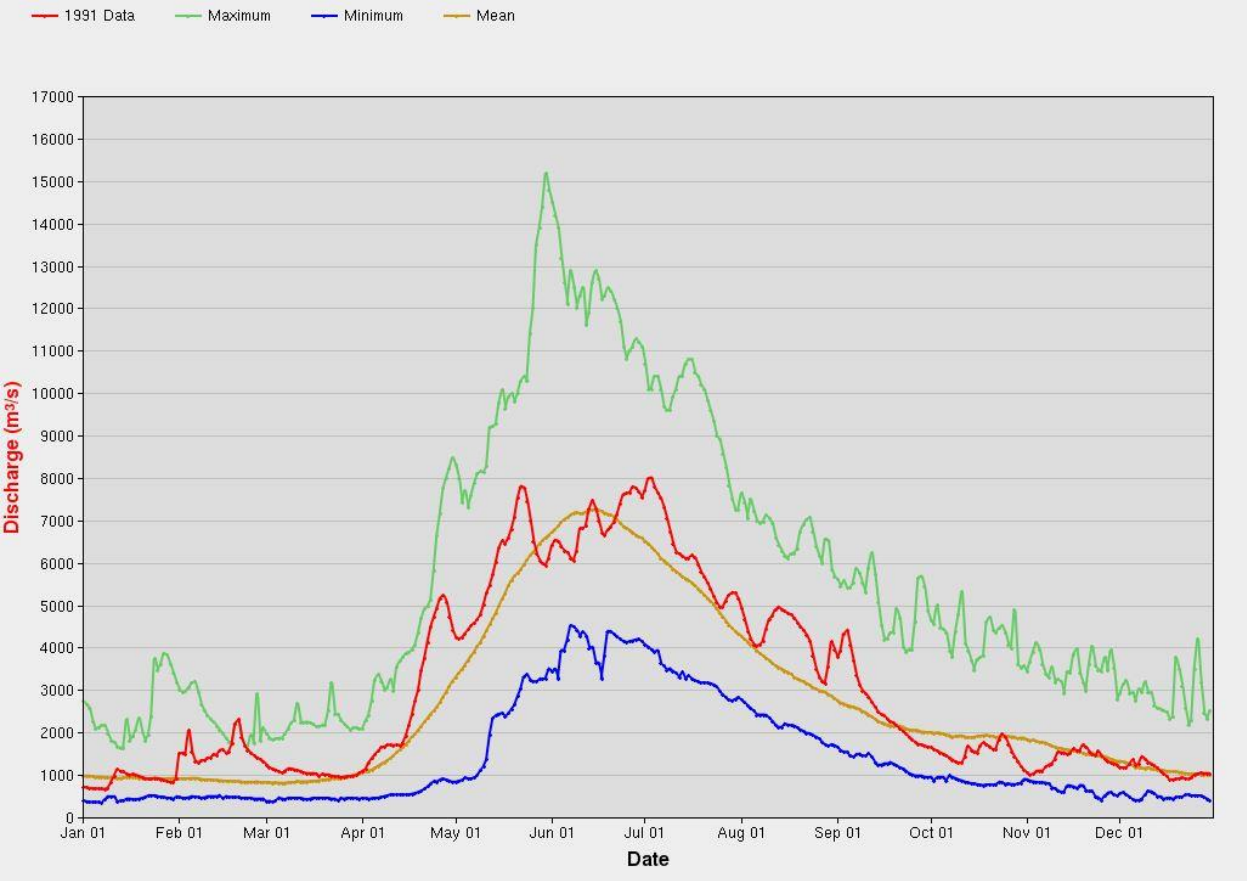


FIGURE 2-3: FRASER RIVER DAILY DISCHARGE, (EC 2017)

A summary of characteristic information on the Fraser River is provided in Table 2-1, including information about the mean, high, and low flow rates, distributary flow share, and sediment loads.

TABLE 2-1: FRASER RIVER CHARACTERISTICS

Description	Magnitude	Source
Flow at Hope:		
Mean flow	2,803 m^3/s	Morrison et al, 2002
Mean peak flow	8,705 m^3/s	
Mean minimum flow	687 m^3/s	
Lowest flow, January 8, 1916	340 m^3/s	
Highest flow, May 31, 1948	15,200 m^3/s	

Present distributary flow share	85% South Arm 5% Canoe Passage 10% North Arm	NHC-Triton, 2004 Chapter 2.5.1
Total sediment load at Mission and granular distribution	17.3×10^6 tonnes/year 35% sand 50% silt 15% clay	NHC-Triton, 2004 Chapter 2.1
*Bed-material load to sea	3.8×10^6 tonnes/year	Tetra Tech, 2019 Chapter 2.1.2.2
*Bed-material load is defined as medium to coarse sand (0.25 mm to 2 mm). sand (2 mm ≥ sand ≥ 0.063 mm); silt (0.063 mm ≥ silt ≥ 0.004 mm); clay (≤ 0.004 mm).		

The river delivers some 17.3 million tonnes of sediment annually to the Salish Sea, of which 35% is sand (2 mm ≥ sand ≥ 0.063 mm), 50% is silt (0.063 mm ≥ silt ≥ 0.004 mm) and the remaining 15% is clay (≤ 0.004 mm).

Due to the distributary flow share, the water levels along the south arm are affected by the freshets. Figure 2-4 shows the effects of freshets on water level in the reach starting from Sand Heads, in open water, to New Westminster (Ferguson 1991). The figure shows that mean water level rises by more than 1 m from Sand Heads to New Westminster during freshets.

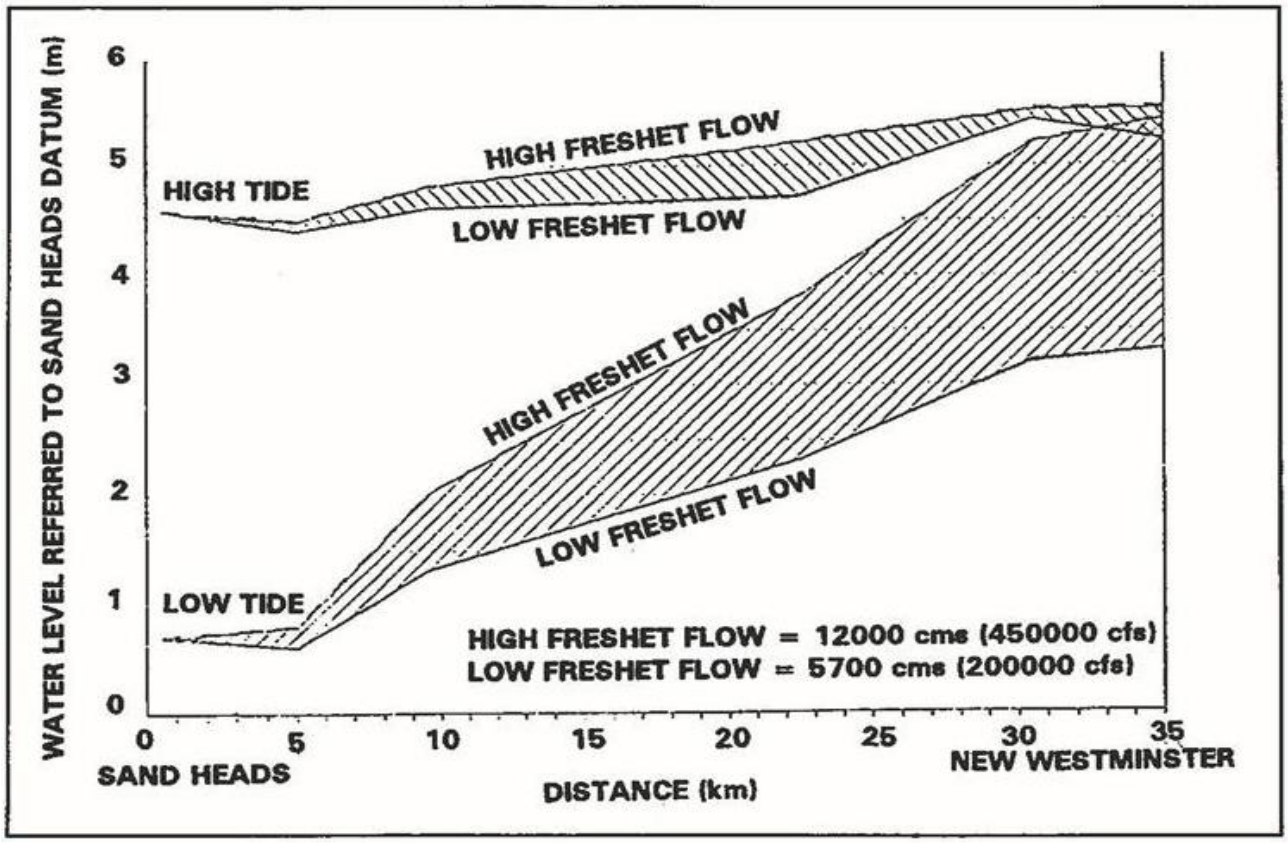


FIGURE 2-4: EFFECTS OF FRESHETS ON WATER LEVEL IN THE FRASER RIVER ESTUARY, BRITISH COLUMBIA

The history of changes of the Fraser River system is marked by human intervention in confinement of channels by protection works, diking, river training structures, navigation dredging and reclamation of delta fringes by dredgeate.

In their dredging management strategy report, BIEAP-FRMEP (2006) has delineated the Fraser River South Arm into three units: (1) the Sand Heads open tidal flat area, (2) the South Arm Tidal area and (3) the South Arm Meso-Tidal area. The South Arm Jetty site is part of the open tidal flat area.

Sturgeon Bank forms the marine foreshore of Lulu Island within the Fraser River delta. It is a highly dynamic environment in which sediments are transported by a combination of wind-waves, tidal currents and discharge from the Fraser River. Wind-waves can approach the project site from the northwest through southwest.

Other environmental factors which contribute to the transport of sediment within the project area include tidal currents and discharge of the Fraser River over and through existing shallow openings or gaps near the top of the Steveston North Jetty. The magnitude of tidal currents alone is expected to be weak; however, the impact of Fraser River discharge combined with tidal currents is expected to be a potential factor for mobilizing sediment.

2.2. Fraser River Salinity Data

Estuary is defined as where a river meets the sea, which creates a productive ecosystem for fish and wildlife. In the Fraser River, water is drawn for consumption, industrial, and agricultural uses. The salinity of the water depends on how far upstream the water is sourced. The extent of salinity intrusion up the Fraser River is strongly dependent on the river outflow (discharge), which varies annually. The salinity intrusion is greater in years with low river discharge.

Salinity data was acquired from ENVIRODAT (2016) for the Fraser River Water Quality Buoy. The buoy provides continuous real-time sampling of surface water quality parameters utilized to assess the quality of Fraser River fresh water. The location of the buoy is shown in Figure 2-5, which is near Tilbury at Gravesend Reach, at Latitude/Longitude 49.1484°N, 123.0392°W.

The buoy provides continuous real-time tracking of dissolved oxygen (DO) content, water pH value, conductivity, turbidity, water velocity, and water temperature. Levels of trace metals, nutrients, major ions, and coliforms are logged bi-weekly. The buoy also has the ability to track levels of a range of organic contaminants, including: pesticides, nonylphenols, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and polybrominated diphenyl ether (PBDEs).

Additional instrumentation on the buoy captures wind speed, wind direction, air pressure, relative humidity, water depth, and latitude/longitude position and heading.

The instrument platform consists of an aluminum superstructure mounted on a 3 m foam float buoy hull, anchored to the riverbed with mooring chain. Instruments are powered via six 55 Watts solar panels and an underwater generator, delivering 12 V DC to a battery pack consisting of eight 100 Ah batteries.

The buoy is also outfitted with an Automatic Identification System (AIS) transmitter and amber flashing navigational light, which enables vessels on the river to track and identify the buoy location.

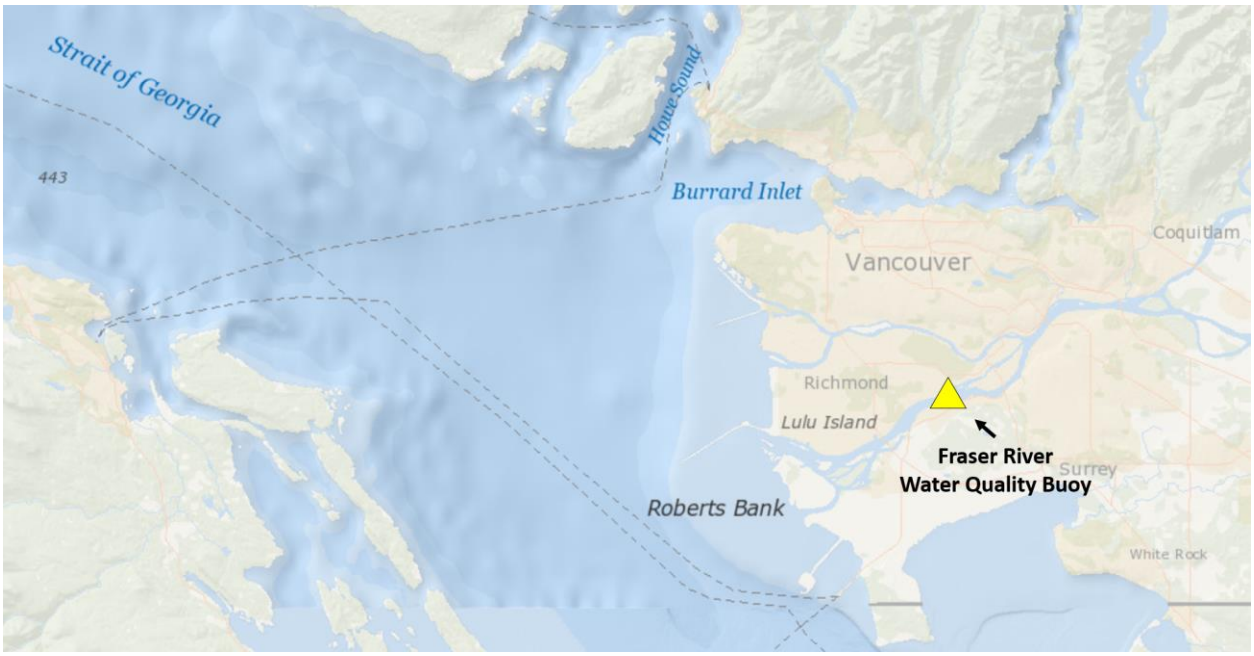


FIGURE 2-5: LOCATION OF FRASER RIVER WATER QUALITY BUOY

Figure 2-6 provides a summary of water temperature and salinity over the range of years from 2008 through 2017. Water temperature is indicated by the blue and grey curves according to the scale on the left side of the figure. Salinity levels are indicated by the yellow to red curves per the scale on the right side of the figure.

It can be seen that the temperature variation falls within a fairly narrow range, progressively increasing from 2-4°C in January to 18-22°C peaking in August, followed by a steady decrease in water temperature through December.

Salinity levels throughout the year are inversely related to outflow from the Fraser River. Salinities of up to 15-18 ppt are recorded in the months from September through April (low discharge months). Over the summer months from May through August, i.e. the peak discharge months, the water is fresh.

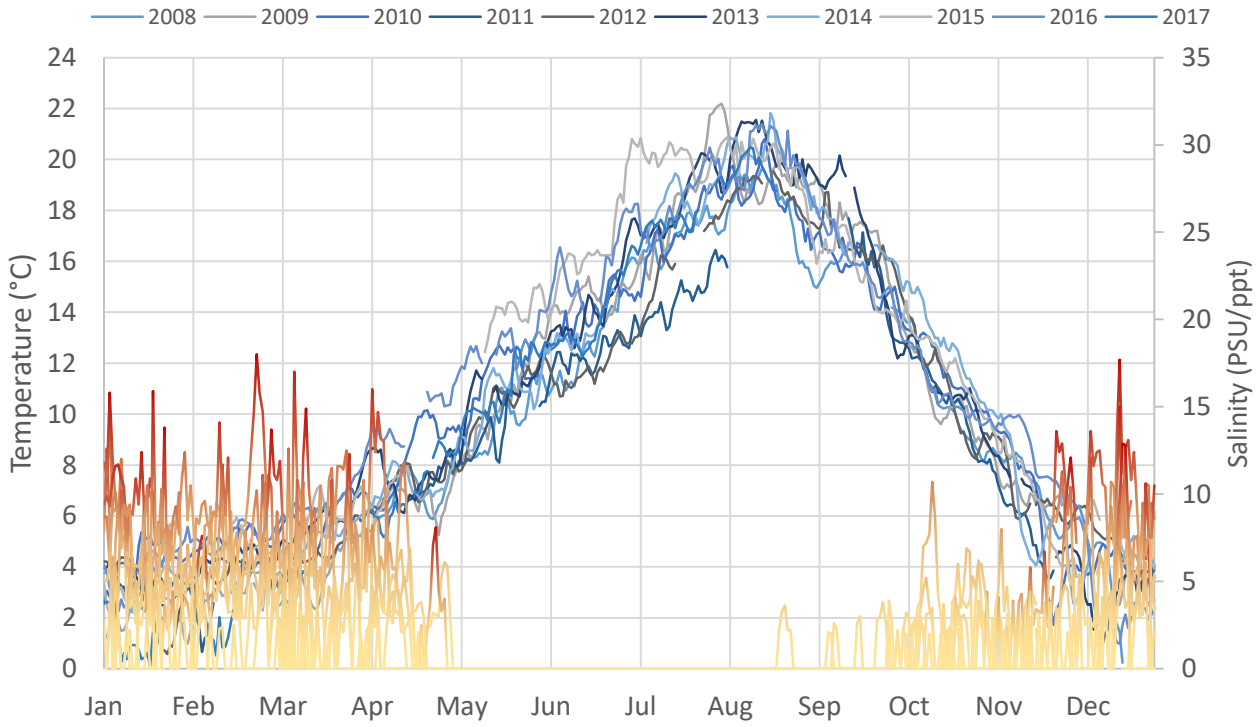


FIGURE 2-6: WATER TEMPERATURE AND SALINITY DATA FROM FRASER RIVER WQ BUOY (ENVIRODAT, 2017)

Figure 2-7 shows an example of the intertidal variation of salinity levels. The dark blue curve indicates the tide stage recorded at the buoy in meters relative to the scale on the left-hand side. The green curve shows the corresponding flow velocities in meters per second, measured on the same scale. Flood tides are denoted by positive values and ebb tides by negative values. It can be seen that the tidal currents oscillate around a mean of around -0.4 m/s, which represents the steady outflow from the river.

The variation of the salinity level is indicated by the orange/red curve, with units in PSU/ppt per the scale on the right-hand side of the figure. It can be seen that the variation of the salinity follows each tidal cycle, increasing on flood tides as saltwater propagates inland, and decreasing on ebb tides where more freshwater flows out.

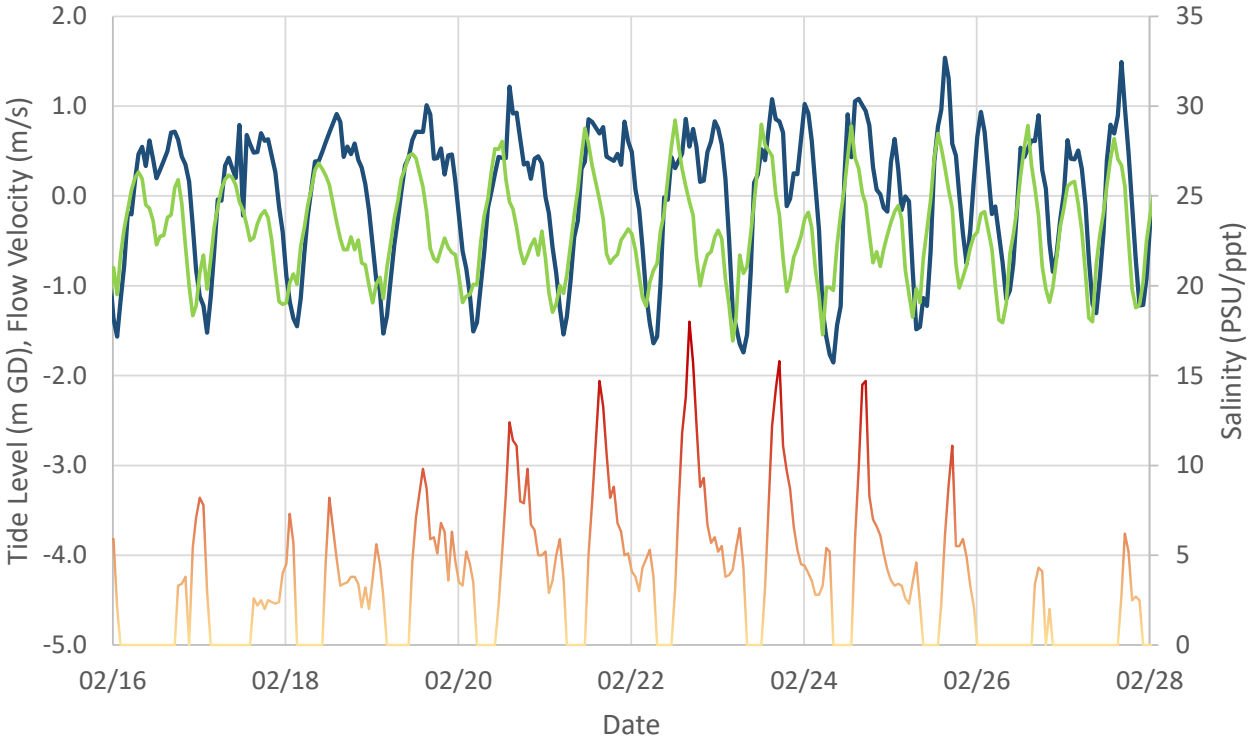


FIGURE 2-7: VARIATION OF SALINITY WITH FLOOD AND EBB TIDE (ENVIRODAT, 2017)

2.3. Environmental Conditions

2.3.1. Water Levels

Tidal information for the South Arm Jetty site was developed from information on Sand Heads Canadian Hydrographic Services (CHS) Chart 3490. Sand Heads is located approximately 5.5 kilometers downstream (West) from the project site. The conversion from Chart Datum (CD) to Geodetic Datum (GD) is based on published information provided by Canadian Coast Guard waterways management (km 6 to km 7 Fraser River South/Main Arm).

TABLE 2-2: SOUTH ARM JETTY TIDAL ELEVATIONS (M)

Tidal water surface	Chart Datum	Geodetic Datum
Higher High Water Large Tide (HHWLT)	+4.9	+2.5
Higher High Water Mean Tide (HHWMT)	+4.3	+1.9
Mean Water Level (MWL)	+3.1	+0.7
Lower Low Water Mean Tide (LLWMT)	+1.3	-1.1
Lower Low Water Large Tide (LLWLT)	+0.2	-2.2
Chart Datum (CD)	0.0	-2.4

In navigable waters, Chart Datum is the common vertical datum reference. In inland waters, Geodetic Datum is more commonly utilized. Figure 2-8 shows how tidal datums at Point Atkinson and at Sand Heads relate to water level datums of the Fraser River at Steveston. Tidal datums at Point Atkinson and at Sand Heads (left side of the figure) are purely astronomical. Tidal datums on the Fraser River, however, are affected by the amount of outflow from the river *(CHS, 2014)*. The figure shows how the tidal datums vary with reference to Geodetic Datum depending on discharge as measured at Hope. Geodetic Datum (GD) at Steveston is located at +2.2 m CD per *CHS (2005)*. It can be seen that the elevations of higher high water mean and large tides remain fairly constant. Elevations of lower low tides (mean and large) increase with increasing discharge.

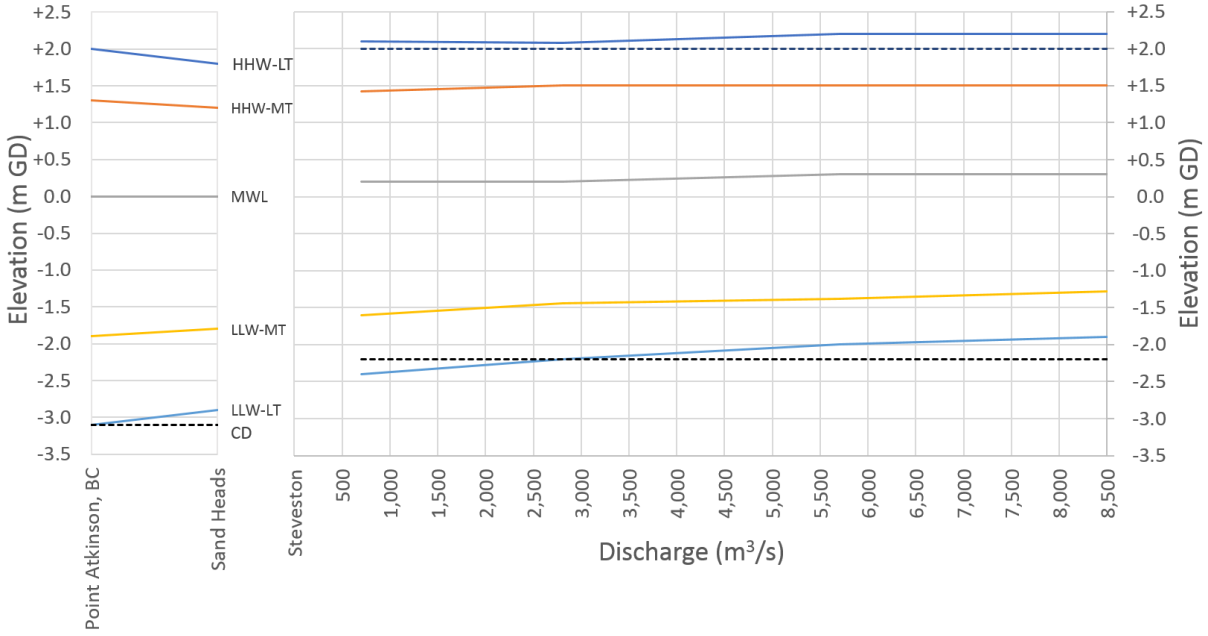


FIGURE 2-8: VARIATION OF TIDAL DATUMS AT STEVESTON WITH FRASER RIVER DISCHARGE

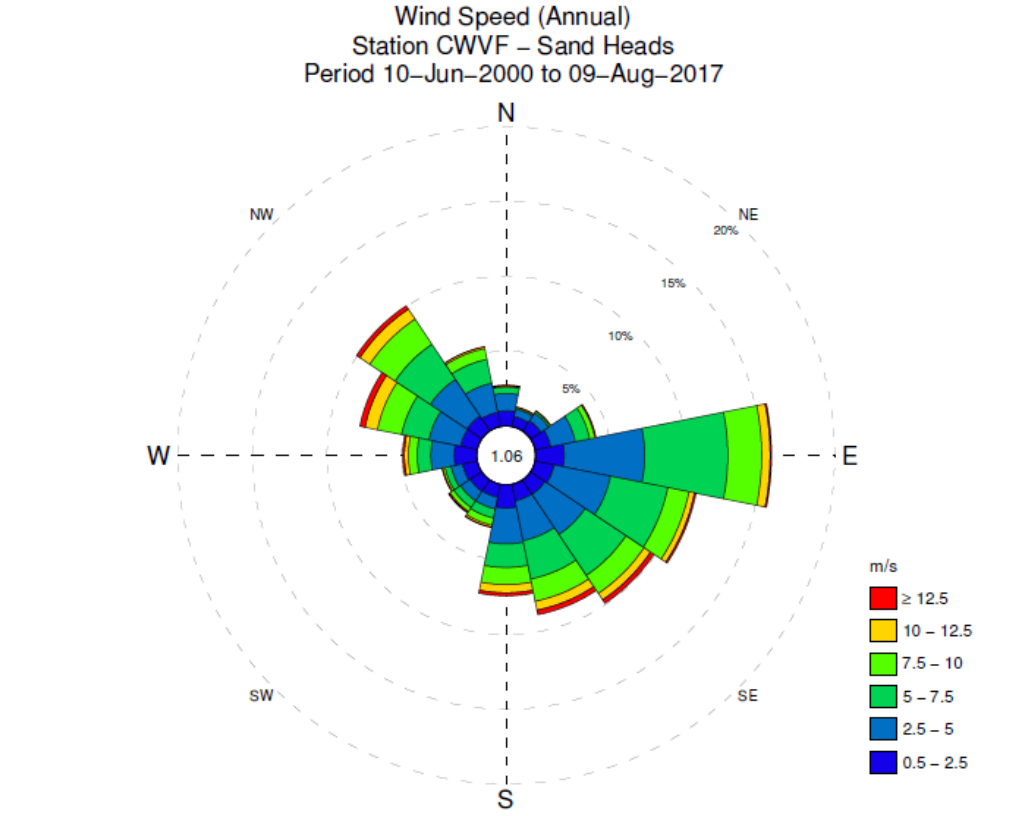
2.3.2. Winds

A metocean gauge located at Sand Heads has collected data on wind speed and direction since 2000. Wind statistics for the station are summarized in Figure 2-9Figure 2-9: . The distribution of winds by direction shows that predominant wind directions are from north-westerly directions, and the sector from south to easterly directions.

These directions reflect open-water conditions in the Salish Sea, having a great expanse to the northwest. The pronounced winds from easterly directions are representative of overland conditions. The topography of the inland area and mountain ranges to the north have the effect of generally funneling winds from east over the Vancouver area. The effect is consistent and the Vancouver Airport runways are therefore aligned approximately east-west.

The table in Figure 2-9 summarizes the occurrence of wind speeds by direction. It can be seen that extreme wind speeds can exceed 12 m/s, but are more commonly below 10 m/s. The distribution of

the highest wind speeds shows that storm systems entering the Salish Sea can produce high winds from virtually any direction at Sand Heads, but less frequently from north-easterly direction.



Percentage of Occurrence

Wind Speed, m/s	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	2.71	1.30	1.58	4.12	15.77	10.97	9.91	8.87	7.40	2.92	2.63	2.36	4.93	7.99	10.05	5.42	98.94
12.5						0.11	0.27	0.31	0.20				0.11	0.35	0.26		1.81
10					0.57	0.37	0.52	0.61	0.55	0.14			0.27	0.84	0.80	0.12	5.01
7.5				0.35	2.27	1.44	1.45	1.52	1.15	0.49	0.32	0.15	0.59	1.65	2.03	0.73	14.27
5	0.43	0.10	0.14	0.99	5.57	3.91	3.29	2.62	1.58	0.62	0.54	0.41	0.90	1.87	2.82	1.63	27.43
2.5	1.16	0.50	0.62	1.68	5.38	3.85	3.24	2.71	2.40	0.79	0.77	0.78	1.56	2.16	2.96	1.98	32.55
0.5	0.99	0.65	0.80	1.04	1.89	1.27	1.13	1.10	1.53	0.87	0.90	0.98	1.49	1.12	1.16	0.95	17.88
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total

FIGURE 2-9: ANNUAL AVERAGE WIND STATISTICS BY SPEED AND DIRECTION

2.3.3. Wave Statistics

Wave data for Station C46146, Halibut Bank is summarized in Figure 2-10. The data shows the annual average percentage of occurrence. The majority (87%) of the waves recorded at the buoy have wave periods in the range from 2 to 10 seconds, which is representative of wind-waves generated within the Salish Sea. The remainder of the data is representative of longer-period waves in the form of remnant swell wave components entering the Salish Sea from the Pacific Basin.

During storm events, wind-generated wave heights can reach up to 2.1 meters in magnitude. This is expressed as the significant wave height, which is the average of the 1/3 of the largest waves. From a more practical perspective, the magnitude of waves will vary substantially over the course of a storm. As a rule-of-thumb, the highest waves can be estimated at around 1.8 times the significant wave height, and the highest waves on record at the buoy are therefore on the order of: 1.8 × 2.1 m = 3.8 m. For reference, the height of an individual wave is measured from the trough to the crest.

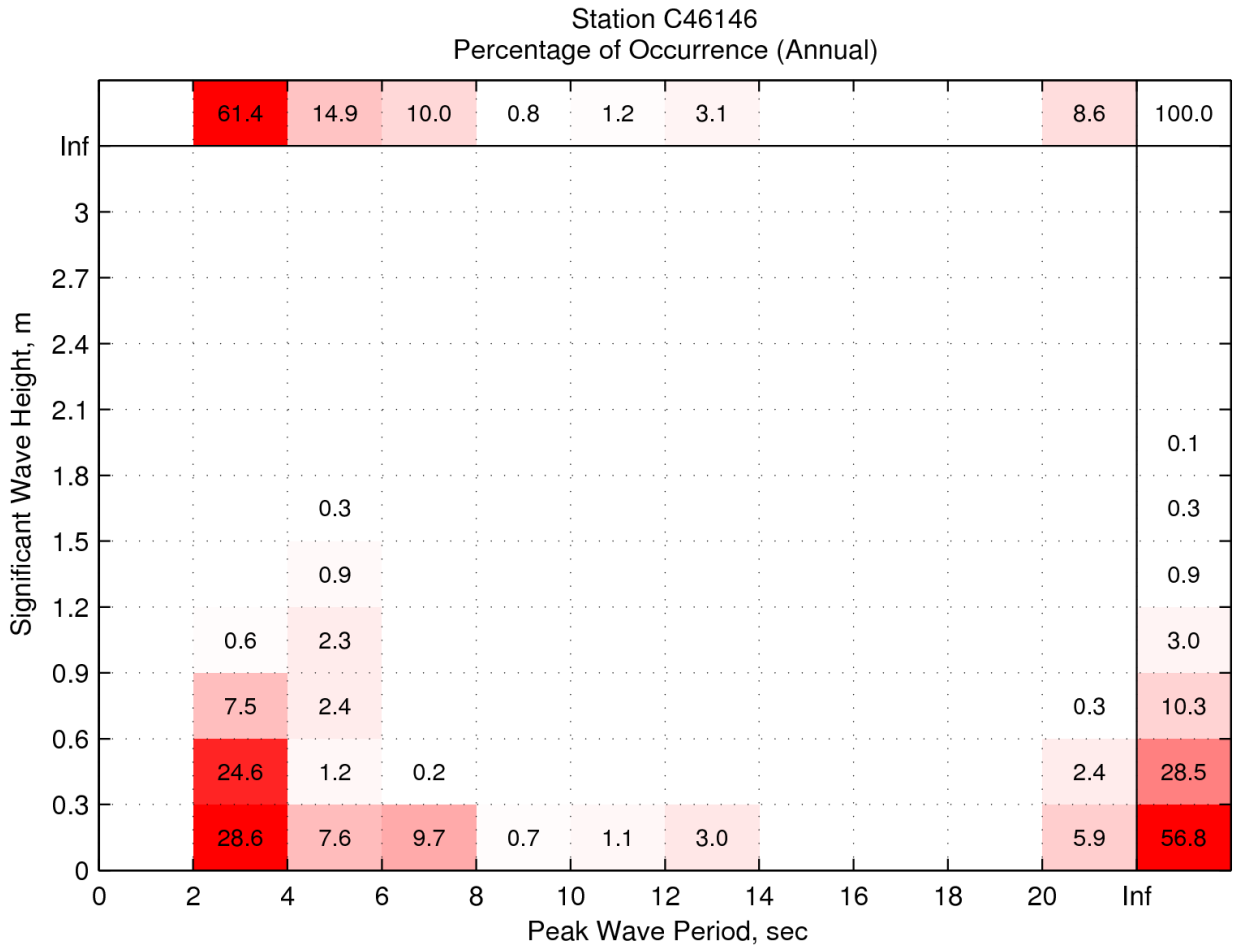


FIGURE 2-10: WAVE STATISTICS FOR HALIBUT BANK BUOY

A detailed discussion of wind wave analysis is presented in Appendix E. In summary, at the South Arm Jetty Tidal Marsh wave breaking processes associated with water levels govern the potential wave heights at the project site. Table 2-3 summarizes the design wave combinations associated with varying water levels for each structure.

TABLE 2-3: WATER LEVEL AND MAXIMUM SIGNIFICANT WAVE HEIGHT COMBINATIONS

Water Level (m, GD)	Cobble Beach Berm (West End)		Containment Structure (East End)	
	Wave Height, Hs (m)	Wave Period, Tp (sec)	Wave Height, Hs (m)	Wave Period, Tp (sec)
0.4	0.71	7.4	0.18	7.4
1.2	1.06	7.4	0.47	7.4
2.4	1.60	7.4	0.89	7.4

2.3.4. Currents

Currents at the South Arm Jetty Tidal Marsh are generated by a combination of discharge from the South Arm of the Fraser River and tidal flows over Sturgeon Bank. Design peak current speeds at the east end of the cobble beach berm and the east side of the containment structure are 0.7 m/s with velocities within the project site below this value. A detailed discussion of site hydrodynamics is presented in Appendix E.

2.4. Project Site Physical Characteristics

The South Arm Jetty Tidal Marsh is located along the north side of the Steveston Jetty within the Steveston Bend Reach of the Fraser River South Arm. This area is adjacent to the maintained South Arm navigation channel. A portion of hydrographic chart #3463 is shown in Figure 2-11 along with the location of the project site.

A large strip of marsh currently exists along the north side of the jetty. Based on observations from a site visit by PMV and others[2], it was determined that the lower, leading edge of the existing marsh (bulrush or *Schoenoplectus pungens*) is approximately at elevation El.0.0 m, Geodetic Datum (GD), which is slightly below mean water level.

[2] The site visit on May 7th, 2013 was attended by M&N, PMV, Hemmera, GLW, and DFO.

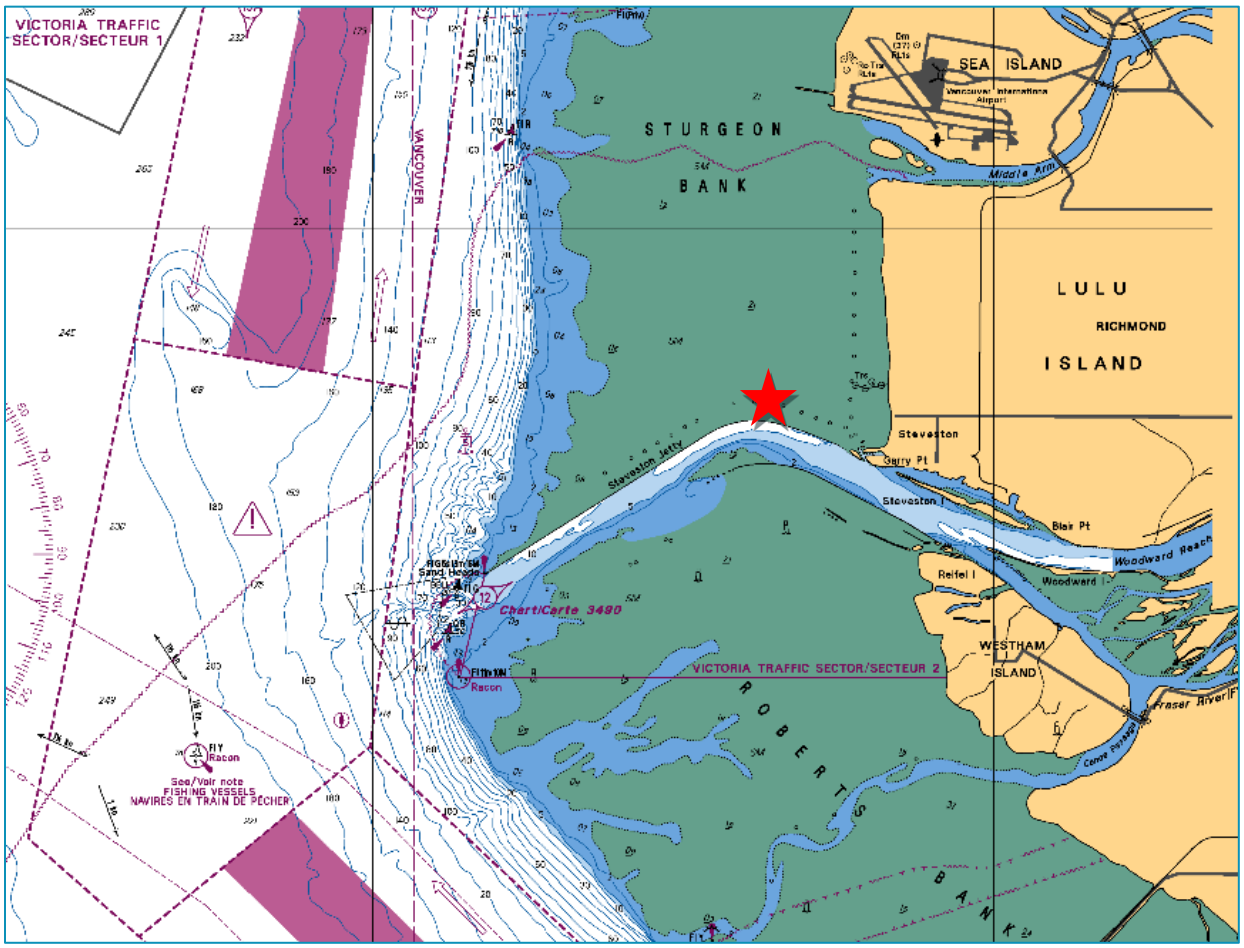


FIGURE 2-11: SOUTH ARM JETTY SITE

The South Arm Jetty Tidal Marsh site is on a shallow portion of Sturgeon Bank with elevations ranging from -0.75 m to 0.75 m GD, with low spots at the west end of the site as low as -1.5m GD. There is a higher elevation area which is referred to as the “sand island.” This area is remnant of dredge material disposal activities in the early 1980s. The adjacent Steveston Jetty is permeable and constructed of piled rock and concrete debris. A profile of the jetty crest is provided in Figure 2-12. There are two openings in the jetty near the project site which allow concentrated flow to pass through the jetty and onto Sturgeon bank. Additionally, the crest of Steveston Jetty varies and can contribute to concentrated flow over the site. A photo (2013) of the overtopping west of the proposed marsh is shown in Figure 2-13.

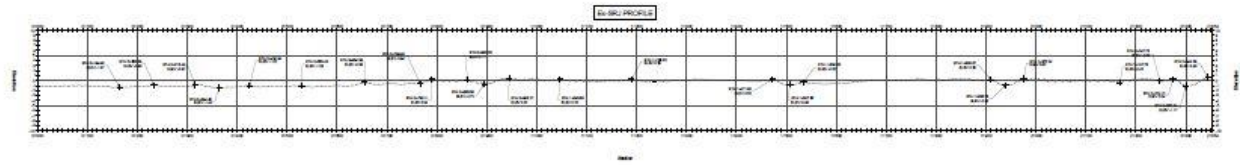


FIGURE 2-12: SOUTH ARM JETTY PROFILE



FIGURE 2-13: STEVESTON JETTY OVERTOPPING

Figure 2-14 through Figure 2-17 show photographs captured during a site visit on July 8, 2013. The photographs show typical existing conditions at the project site.



FIGURE 2-14: EXISTING MARSH AND SOUTH ARM JETTY LOOKING EAST (STA.1+200[3])



FIGURE 2-15: EXISTING SAND FLAT AND SOUTH ARM JETTY LOOKING EAST (STA.0+300)

[3] For Stationing (STA.) reference along the Jetty refer to Project Drawings Appendix B



FIGURE 2-16: EXISTING SAND FLAT AND SOUTH ARM JETTY LOOKING SOUTH (STA.0+100)



FIGURE 2-17: EXISTING MARSH AND SAND FLAT LOOKING WEST (STA.0+800)

2.5. Project Site Development

The South Arm Jetty site has been the subject of recent efforts by Fisheries and Oceans Canada (DFO) and RCF to introduce enhancements for salmon passage by introducing breaches into several locations along Steveston Jetty at the eastern fringe of the proposed habitat development. The design and modeling of these breaches was covered in the Tetra Tech 2019 modelling report. The report concluded that:

- The breaches would cause initial scour in Sturgeon Bank soon after opening,
- Current velocities would be higher initially and decrease over time as the channels stabilized,
- There would be an increase in sediment supply through the breaches
- Cross currents caused by backflow would not significantly affect navigation maneuverability
- Sedimentation from backflow through the breaches would not affect deposition within the navigation corridor footprint.

The breach construction is relatively recent, and the channels extending from these breaches have not completely formed as of the preparation of this report but are expected to continue to form and will ultimately reach to the eastern limit of the proposed mitigation habitat. A general plan indicating breach locations and configuration are included in Figure 2-18.

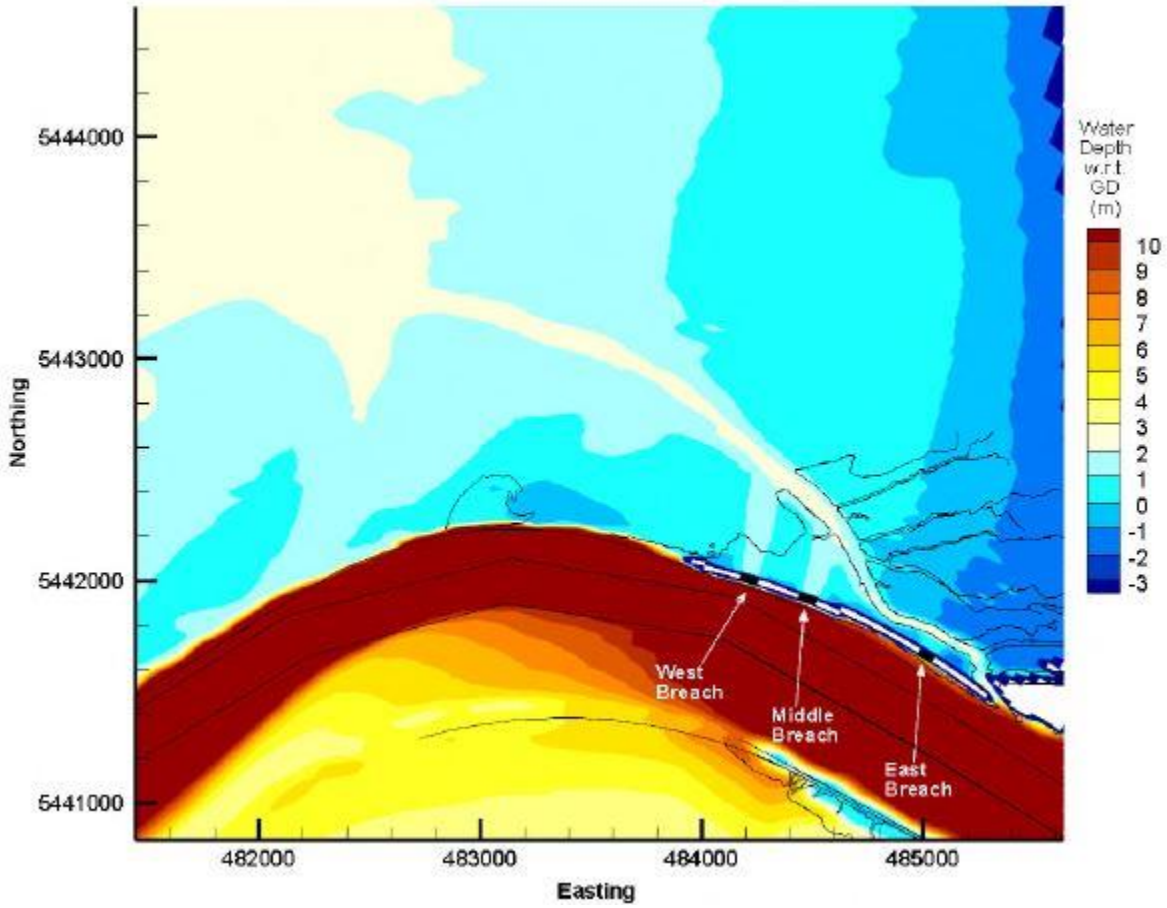


FIGURE 2-18: RCF BREACH LOCATIONS (TETRA TECH 2019)

3. Design Criteria

This section describes the criteria that guided the design of the proposed Project. This section includes a description of the functional, physical and biological design criteria (provided by others) as well as the applied engineering standards.

3.1. General Design Criteria

3.1.1. Project Datum and Units

Horizontal coordinate system is NAD83 UTM Zone 10. The vertical datum is Geodetic Datum (GD). All drawings are presented in SI (metric) units.

3.1.2. Service Life and Return Period

Standard industry practice is to design containment structures without any factors of safety implicit in the design methods applied. Durable design is achieved by selecting a design condition that is unlikely to be exceeded over the service life of the structure. For permanent structures that are designed to withstand no damage, such as a marine terminal, a 50 year or more return period event is often used. However, for this project the containment structures for the habitat features are less critical since the sites do not constitute flood protection infrastructure (BC MOE 2007). As such, a return period of 25 years for the extreme event will be used in the design. The containment structures under consideration is a rubble mound construction which typically does not fail catastrophically, but rather, tends to fail incrementally, which can be repaired to extend the lifespan.

3.1.3. Codes, Standards and Design Guidelines

The following guidelines, codes, and standards shall be used for this project:

- British Columbia Building Code 2018 (BCBC'18);
- Coastal Engineering Manual (CEM, US Army Corps of Engineers, 2002).

3.1.4. Functional Requirements

Figure 3-1 shows a schematic of processes and controls that define a habitat. Engineering and other interventions must take note of the delicate balance among relevant factors to avoid destruction or significant modification of a habitat.

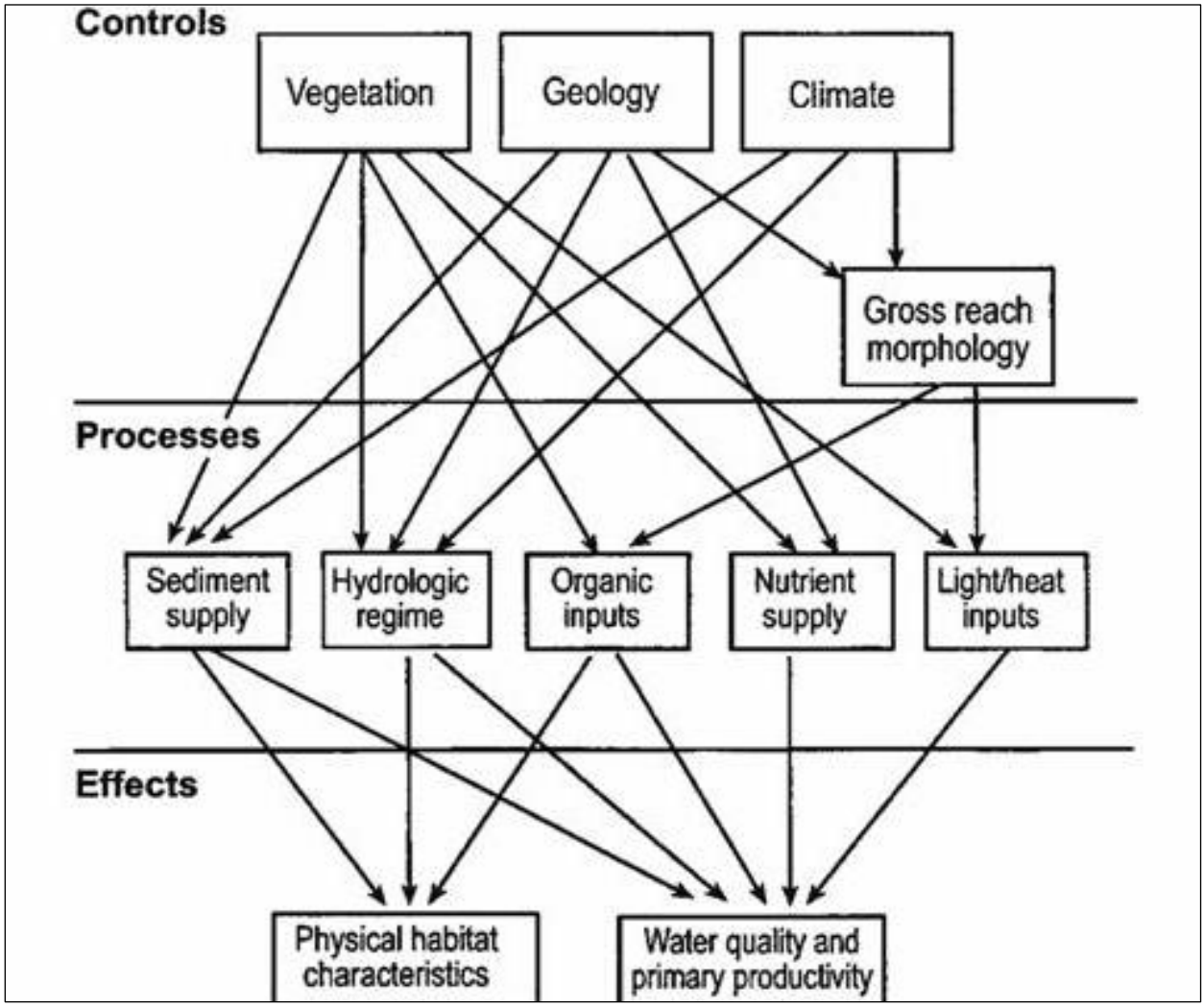


FIGURE 3-1: SCHEMATIC OF INTERRELATIONSHIPS AND HABITAT CHARACTERISTICS (*AFTER RONI ET AL, 2002)*

It is important that identified habitats are preserved and maintained. In their habitat management strategy policy statement, BIEAP-FREMP (CBA, 2010) has identified four basic guidelines for marine works. Relevant highlights of these guidelines are summarized in Table 3-1.

TABLE 3-1: BIEAP-FREMP HABITAT MANAGEMENT GUIDELINE (CBA 2010)

Guideline	Description
1	Preserve habitat features to maintain fish and wildlife functions: • fish feeding (marshes), • waterfowl and shorebird nesting, • roosting and feeding (trees and shrubs), • leaf and insect input, and • wildlife feeding and refuge cover.
2	Design facilities to minimize structure or surface footprints, even for elevated structures such as docks.
3	Preserve intertidal areas, including sand flats, mudflats and marsh to the degree possible.
4	For mitigation consider complexing marsh habitat, e.g. tidal channels, planting, large woody debris to improve fish access and utilization.

3.2. Description of Proposed Design

The overall goal for the site is to create marsh habitat with interconnected channels to enhance salmon passage and bird habitat. Elevations of the channels and surface are configured to maximize circulation, while minimizing erosion that would require maintenance or detrimental impacts to adjacent habitat and navigation channels. The design will also be configured to take advantage of existing site resources to lessen the need for imported material to the extent practical.

The main features of the site include a cobble beach berm to provide wave protection from northwest waves, slope protection rock in channel areas subjected to higher current velocities, sand fills to support planted vegetation, and drainage channels/ditch to connect the site to adjacent habitat and proposed marsh. A plan of the proposed alternative is shown in Figure 3-2.

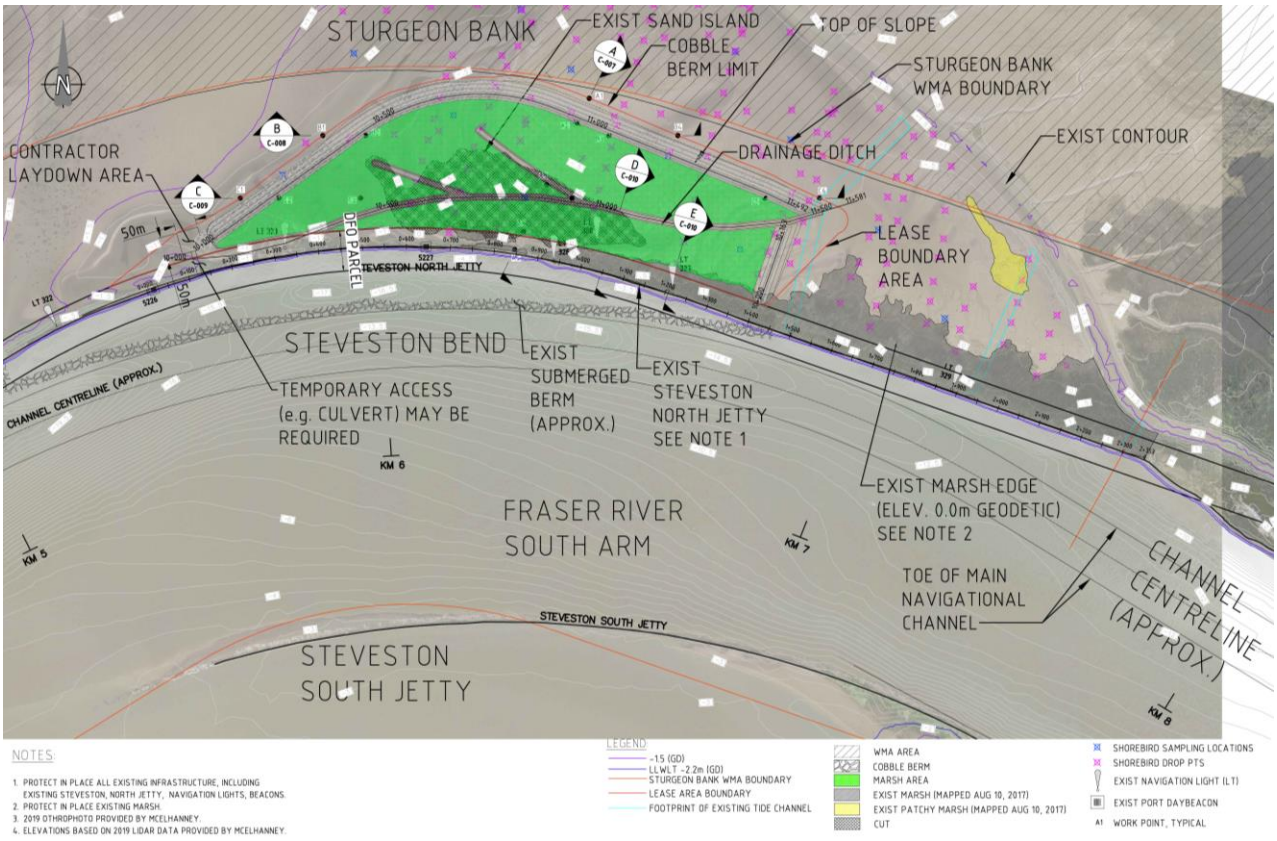


FIGURE 3-2: CONCEPT LAYOUT

3.3. Site Specific Design Criteria

3.3.1. Coastal Design Parameters

The description of coastal considerations, including tide, water levels, waves, and general salinity were previously covered in section 2.

3.3.2. Geotechnical Conditions

A preliminary geotechnical assessment was carried out based on a desktop geotechnical study and limited site reconnaissance (Appendix A). Based on existing data from the Fraser River channel immediately adjacent to the site the subsurface conditions may be comprised of a layer of sand up to 4m thick overlaying soft to firm clayey silt. Settlement during placement of the fill layer is expected to be on the order of approximately 50 to 150 mm during the construction period with an additional 25 mm over the following 18-month period.

Slope stability analyses were conducted for the cobble beach berm embankment along the northern boundary to the Site under static loading conditions and did not consider seismic (earthquake) loading effects. The calculated Factor of Safety (FOS) against failure of the proposed embankment was calculated to be greater than 1.5, and therefore slope stability is not considered an issue.

For the cobble berm construction in a critical location staged loading could be considered in lifts approximately 0.5 m thick. However, this staged loading is not practical for the marsh fill where most of the fill placement is relatively shallow and extends over a large area. This significantly lessens the possibility of deeper seated foundation failures.

3.3.3. Planting Elevations

Marsh construction at the South Arm Jetty habitat enhancement site will consist of extending the marsh platform over the tidal flats, contained within a cobble beach berm. The finished marsh design elevation will be 0.0 m GD for the silty sand marsh growing medium. However, to promote drainage over the large area of placed fill, it may be necessary to slightly "mound" the fill. The containment berm will consist of gravel and cobble placed at a 20 horizontal:1 vertical slope to address potentially erosive storm conditions. Suitable low marsh brackish plant species will be transplanted into the constructed marsh platform.

3.4. Modeling of the Proposed Project

3.4.1. Model Description

In 2017 Moffatt & Nichol performed spectral wave and hydrodynamic modeling of the South Arm Jetty tidal marsh project. This work was conducted prior to the establishment of breaches in the South Arm Jetty proposed by DFO and RCF that have since been implemented. A supplement has been prepared to this 2017 study to examine the impacts of current and proposed jetty breaching by building on the model created for the 2017 efforts. The main analyses were conducted to assess wave stress over the marsh substrate and to examine the salinity conditions to support the marsh habitat. Ostensibly, the outcome is being used to establish the amount of sheltering required to lessen wave action sufficiently to support vegetation as well as the salinity levels to allow plant survival. Details of the study are provided in Appendix E but are summarized in this report.

Coastal conditions for wind, wave, tides, and river flows have been covered in section 2 and were used as input parameters for the model. Topography was obtained from two LIDAR surveys conducted in 2013 and 2017 respectively. This was supplemented with additional data collected in 2019.

The modeling system, Mike 21 (DHI), was selected for its numerical efficiency provided by a flexible (unstructured) mesh configuration. This allows coarser grids in areas requiring less detail, and finer grids in the area of greatest concern. The computational time is therefore significantly improved without sacrificing informational needs. An example of the varying grid configuration is shown in Figure 3-3. Mike 21 has the capacity to use plug-in modules for different types of modeling features. In this case the Spectral Wave module was conducted as well as the Hydrodynamic & Salinity modules. This study employed both two and three dimensional approach for the tidal circulation and salinity.

The models were calibrated using historical events to compare model outputs versus actual measurements and were found to be within acceptable levels of comparison. Details are provided in Appendix E.

3.4.2. Wave Sheltering and Bed Shear Stress Analysis

Wave-induced bed shear stress with or without the proposed berm is shown in Figure 3-4. The figure indicates that bed shear stress is significantly reduced from the existing conditions to support the habitat features.

A sensitivity analysis was also conducted to review alternate marsh fill height configurations which resulted in findings that there was a low improvement with this scenario.

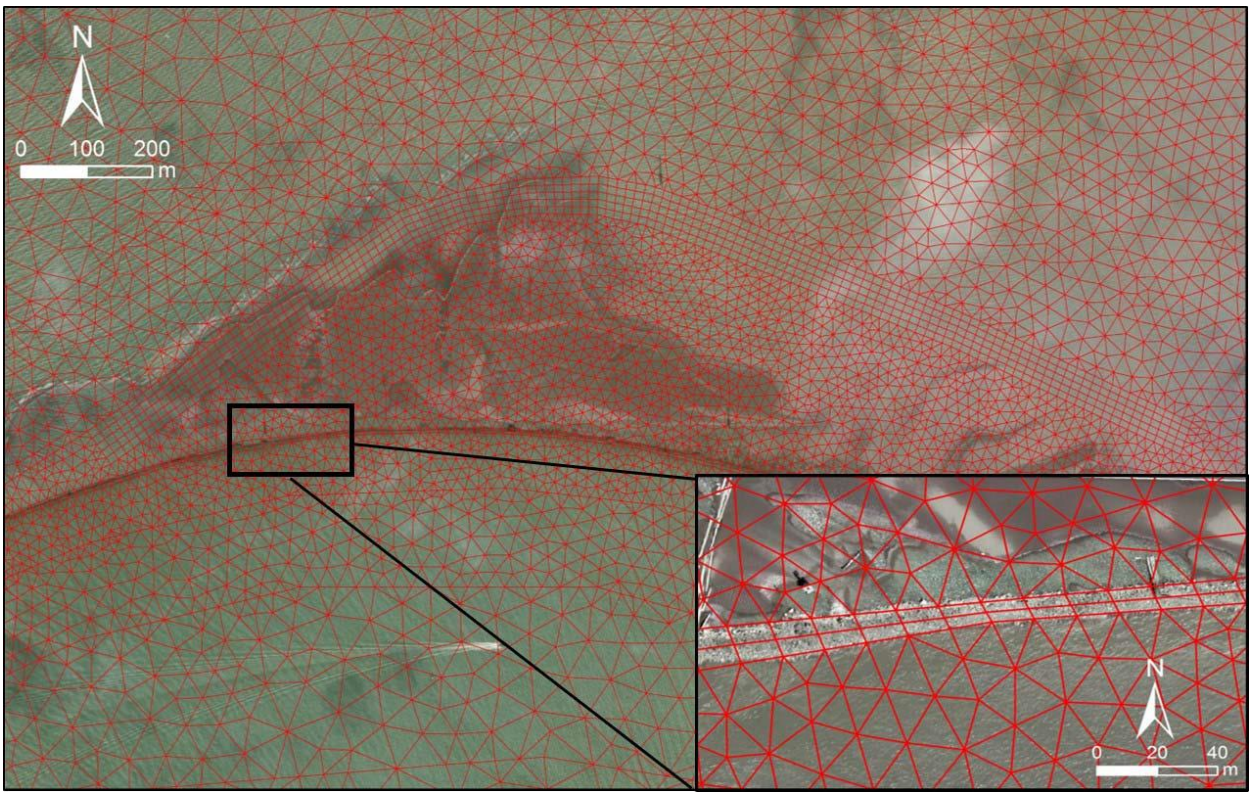


FIGURE 3-3: COMPUTATIONAL GRID AT THE PROJECT SITE.

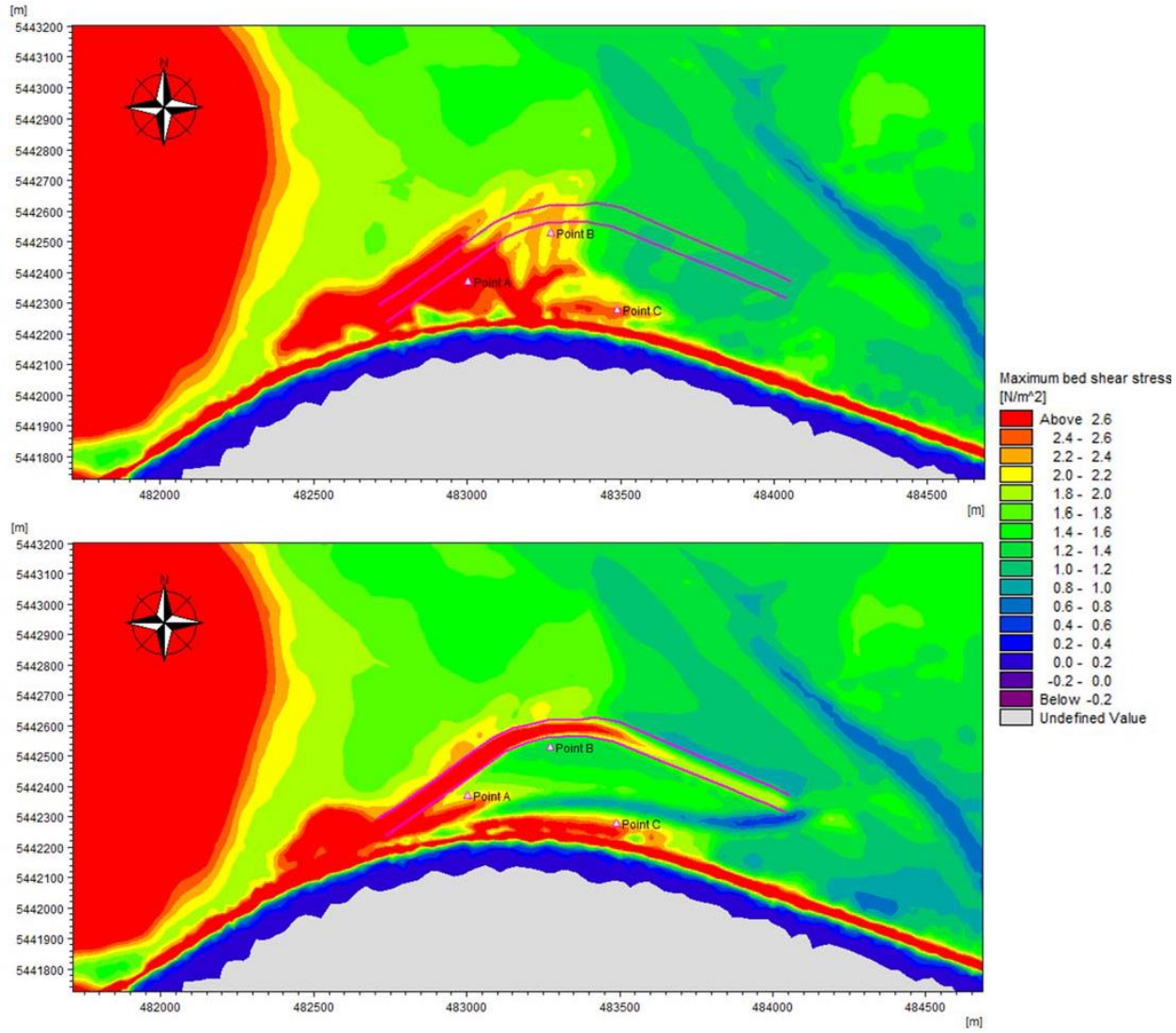


FIGURE 3-4: BED SHEAR STRESS FOR EXISTING (TOP) AND WITH-PROJECT CONDITIONS (BOTTOM)

3.4.3. Salinity Modeling

Salinity distribution in the Fraser River Estuary is controlled primarily by the amount of outflow from the Fraser River, varying significantly on a seasonal scale, and secondarily by the tidal phase, varying on an hourly to daily scale.

To evaluate the range of salinities at Sturgeon Bank and the proposed marsh area, three sets of salinity simulations were performed to represent low, medium and high discharge conditions from the Fraser River. For each discharge scenario, simulations of the existing and with-project bathymetric conditions in the marsh area (Figure 3-5) were conducted to evaluate potential changes in circulation and salinity distribution.

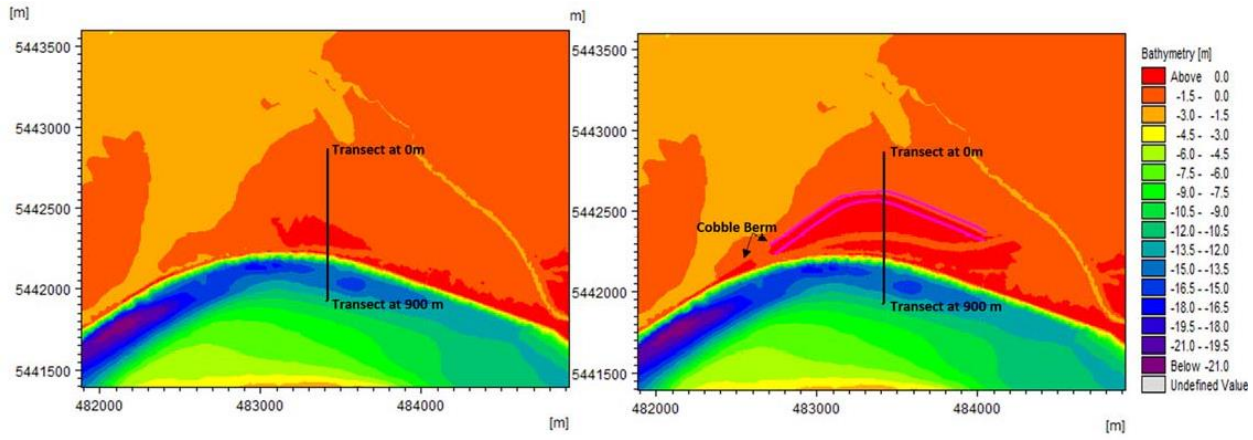


FIGURE 3-5: EXISTING AND PROPOSED MODEL ELEVATION AS WELL AS TRANSECT LOCATION

The main effects of the cobble berm on salinity of the proposed marsh area are as follows:

Under low discharge conditions, the cobble berm promotes somewhat lower salinity levels in the proposed marsh area. This suggests that the freshwater content in the marsh can be improved approximately 50% of the time during the year.

Under medium discharge conditions, representative of the transition between the non-freshet and freshet conditions, the cobble berm aids in significantly reducing the salinity range in the proposed marsh area.

Under high discharge conditions, fresh water is prevalent in the proposed marsh area almost entirely through the tidal cycle, and the cobble berm does not affect salinity levels.

Overall modelled salinity ranges from 0 to around 22 PSU, for both existing and with project conditions. Model results suggest that the cobble berm will bring salinities in the proposed marsh area closer to the existing marsh area (e.g. along the fringe of the Steveston North Jetty).

Figure 3-6 provides an example comparison of modelled depth averaged salinity in the proposed marsh area under existing (blue curve) and with project conditions (yellow curve) for the low flow conditions. The upper and lower limits for both curves (representing highest and lowest salinity, which may occur at different times) are comparable, indicating that the salinity range in the area will not be altered by the project. However, with-project salinity will tend to be lower throughout the tidal cycle. For reference, salinity levels for the existing marsh area are depicted by the green dashed curve. When compared to the yellow curve (proposed marsh) it can be concluded that the cobble berm will promote a salinity range in the proposed marsh area which is comparable to that of the existing marsh.

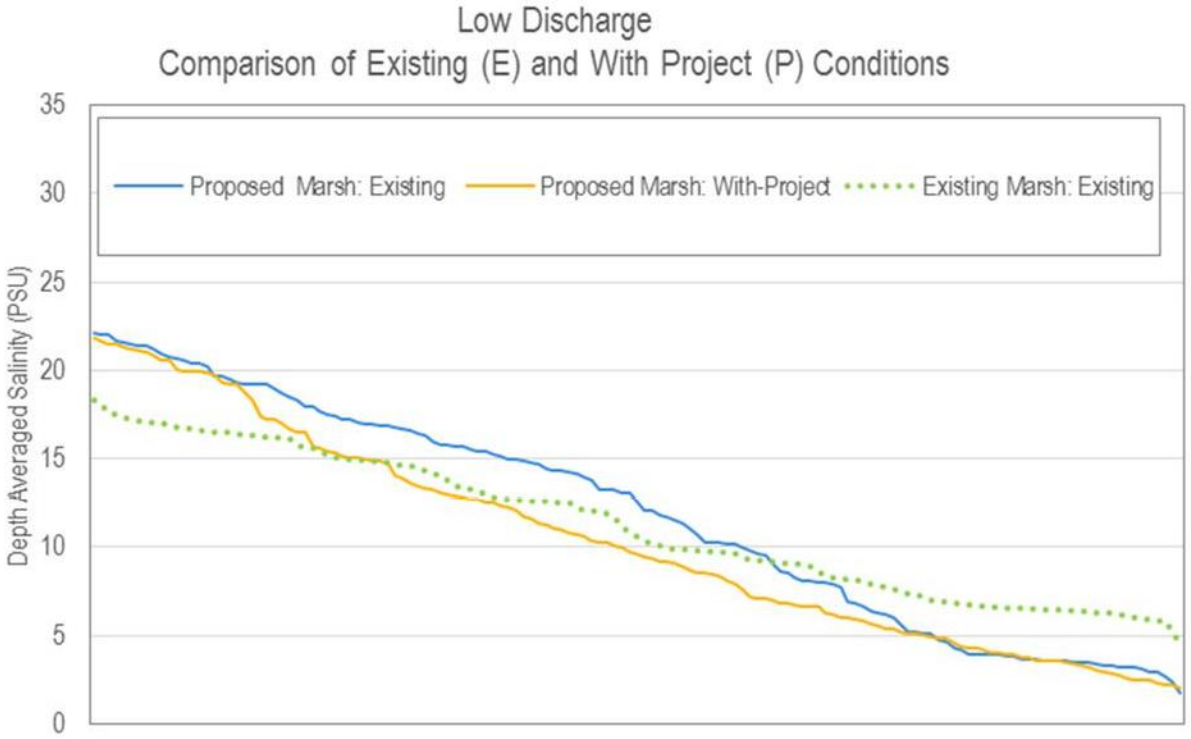


FIGURE 3-6: MODELLED SALINITY IN THE PROPOSED AND EXISTING MARSH AREA UNDER LOW DISCHARGE CONDITION

Supplemental modeling with the RCF breaches and the proposed SAJ breaches was also conducted to observe impacts to the salinity and potential scour impacts on either the existing breaches, or the proposed marsh. Details are provided in the supplemental report included in Appendix E. The modeling scenarios are shown in Figure 3-7.

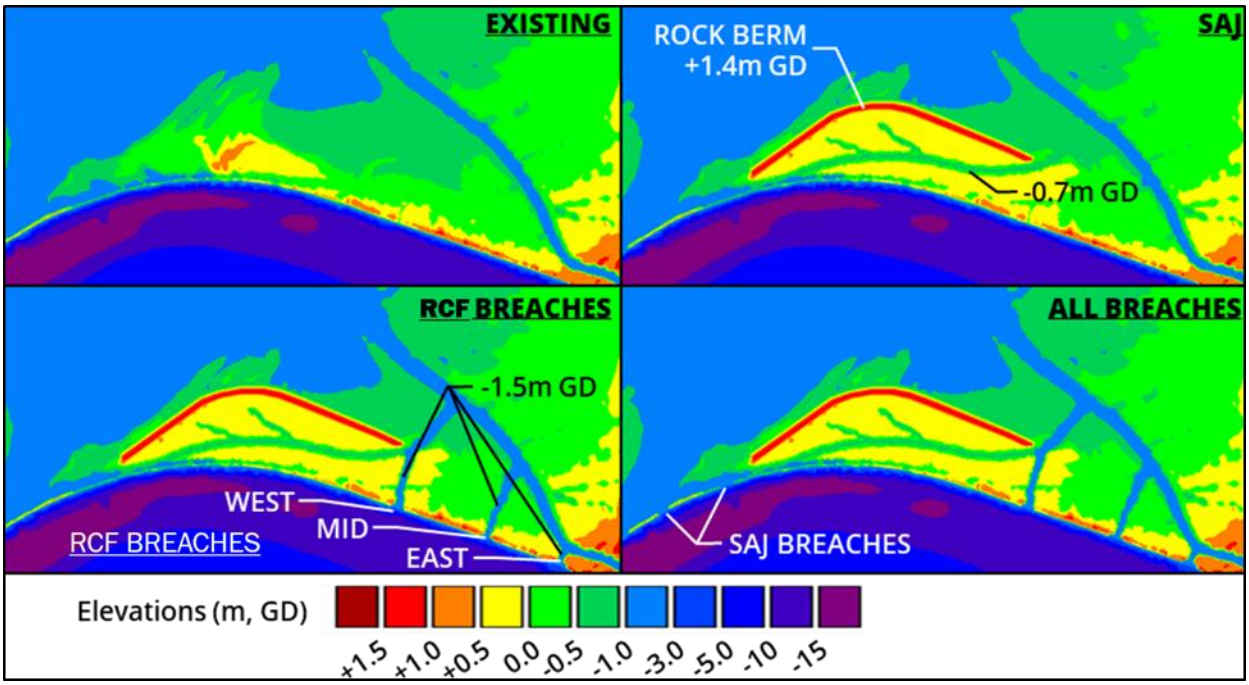


FIGURE 3-7: BATHYMETRY FOR MODEL SCENARIOS

The Main conclusions from this supplemental analysis are:

- The current speeds within the SAJ project area are not substantially affected by the RCF breaches or SAJ breaches, but the current speeds could be substantially higher without the SAJ project elements (e.g. cobble berm and raising site grades).
- Salinity in the project area does not change significantly with the breaches. The overall salinity range is similar, but a fresher environment was found when the SAJ project elements are implemented.
- The benefits of the proposed SAJ breaches are limited from the hydrodynamics and salinity perspective and are therefore not recommended for incorporation into the SAJ Project.

4. Construction Details

4.1. Site Descriptions

The limits of the South Arm Jetty Tidal Marsh are defined to the east by a drainage channel at approximately kilometer 7.5 of the navigation channel, to the south by the Steveston North Jetty and to the west at approximately kilometer 5.5 of the navigational channel. The site extends approximately 400 metres to the north at its furthest distance from the jetty. The objective of the proposed work is to raise the elevation of the existing sand flat to closely match existing marsh adjacent to the jetty along the southeastern extent of the site. By raising the elevation of the bench using infill sand and protecting it with the cobble beach berm, marsh vegetation can be planted and grow increasing the area of productive marsh. Detailed drawings of the South Arm Jetty site are included in Appendix B.

The project is defined by a containment structure, a cobble beach berm, and a marsh. The containment structure is located along the eastern extents of the project site and is approximately 190 metres in length. The purpose of the containment structure is to minimize the risk of the tidal marsh fill material impacting the existing drainage channel to the east. The northern and western fill boundaries of the site will be defined by a cobble beach berm (beach berm) approximately 2.4 kilometers in length. The beach berm is designed to contain and stabilize the placed material and enhance the habitat.

The beach berm will be constructed with a 4-metre wide construction access road at the HHWMT elevation. This road will be used to facilitate the construction of both the beach berm and the placement of the marsh fill material. Prior to demobilization from the site, the contractor will level the access road by 0.5m by pushing the excess material to the seaward (northern) side of the beach berm.

The area enclosed by the existing jetty, the cobble beach berm and the containment structure will be filled with sand to raise the marsh substrate up to the required elevation (El. 0.0m GD). The total gross area of habitat created by the marsh fill material is approximately 27.5 hectares. The total proposed habitat area are detailed in Table 4-1 below. The marsh area presented includes drainage channel, and the cobble berm area includes slope protection on the eastern edge of the habitat.

TABLE 4-1: TOTAL HABITAT AREA

MARSH AREA	COBBLE BERM AREA	TOTAL AREA
27.5 ha	6.7 ha	34.2 ha

4.2. Construction Features

4.2.1. Excavation

The containment structure will be comprised of a sand inner/core layer and a 0.5 m thick outer riprap layer of 5 kg rock (cobble). The crest of the structure will be set at El. 1.4m GD.

The cobble beach berm will be comprised of 5 kg rock overlain the fill material with a seaward slope of 20 (horizontal) to 1 (vertical). The landward slope will be 5 (horizontal) to 1 (vertical). The typical width of the beach berm will be 60 metres.

The sand fill material will be either dredgeate sourced from the Fraser River annual maintenance dredging or from local commercial quarries if the maintenance dredge material is not available. VFPA reports that approximately 80% of the annual maintenance dredging volume is removed from the lower reaches of the Fraser River near the site.

4.2.2. Site Access

Access to the South Arm Jetty Tidal Marsh site will be via marine based equipment from the Fraser River.

4.3. Construction Methodology

The proposed concept for the South Arm Jetty Tidal Marsh site is to expand the existing marsh along the north side of the Steveston Jetty to the north and west. A cobble beach berm will be constructed encompassing the proposed fill area. During construction the berm will include an access road. It is expected that the rock material for the berm will come from a commercial quarry operation by barge.

The significant technical issue associated with the berm construction, beyond those of any other offshore marine conditions (e.g., wind and wave conditions, vessel traffic, etc.), is marine access to the site. Water depths over the Sturgeon Bank are not sufficient for typical marine equipment to access the site. The current elevations surrounding the proposed site vary from -1.5 to +0.5m GD. Water depths approaching the site would be approximately 2m to 3m at the higher high water mean tide (HHWMT). Typical drafts for marine construction equipment (derrick barges, rock barges) are 2.2m to 3.7m. Tug boats required to move the barges can draft 3-4m, depending on the amount of fuel onboard.

At the current water depth, the site would be accessible only at high tide, which is an inefficient use of resources. The loaded rock barges and derrick barge would have to access the site at the high tide and sit on the bottom as the tide goes out. This may be feasible as long as there is no debris present at the site. Once the derrick barge is grounded, it will be limited to the reach of the crane with a loaded bucket of rock. Shallower draft barges could be used to deliver the rock but would require additional trips, increasing the cost of the materials. A crane could also be mounted on sectional barges which have shallower drafts, but generally do not have enough freeboard to handle the weather and wave environment that occur at the site. There are sectional barges that are jack-up units to allow the barge to elevate above the waves or above the existing ground rather than sitting on the bottom at low tide. These units are typically rented as they tend to be specialty equipment that most contractors do not own.

The containment structure will be constructed from rock offloaded to the site from a floating derrick situated in the navigation channel, alongside the jetty. The rock would then be placed and shaped using conventional land-based or if required amphibious equipment such as excavators and loaders. This would allow rock to be placed over the jetty at all tide levels and allow for placement by land

based equipment throughout most of the tidal cycle. Due to the location of the navigation channel at the Steveston Bend, the derrick barge would be required to move out of the channel to accommodate passing vessel traffic.

The proposed marsh area would encompass approximately 27.5 ha, requiring a significant volume of fill material that would be dredged from the Fraser River and pumped over the jetty to raise the elevation in the area between the containment berm and the existing jetty. For the estimates the required fill volume for the marsh has been increased by a factor to allow for settlement, consolation, and material losses during fill placement. Any fill material dredged from the main channel of the Fraser River will need to be performed by Fraser River Pile & Dredge (FRPD) as they hold the current maintenance dredging contract with PMV. FRPD currently owns a hopper dredge, *FRPD 309*, which is capable of performing the dredging and fill work. Figure 4-1 shows the hopper dredge *FRPD 309*.



FIGURE 4-1: HOPPER DREDGE *FRPD 309*

The dredged material could be placed over the jetty by either direct pumping from the hopper dredge through a pipeline or by rainbowing the material. Direct pumping of the dredged material over the jetty can be accomplished through installation of a floating and/or submerged discharge pipeline that is left in place between loads. One end of the discharge pipeline is placed over the jetty on top of the fill and the seaward end is connected to a buoy to allow for recovery and connection to the bow coupling on the dredge. This method allows the dredge to use the ship's power to pump the dredged material from the hopper to the fill area.

Rainbowing is the method of choice on modern hopper dredges to discharge large quantities of sand in shallow water location. Rainbowing is essentially the high pressure spraying of the dredge slurry through a nozzle located at the bow of the dredge. The nozzle size and angle affect the distance that the material is able to be projected. In order to achieve longer distances, a smaller diameter nozzle is required which has the effect of reducing production. The *FRPD 309* has the capability of direct pump-off or rainbowing. Most hopper dredges are capable of achieving rainbowing distances of 100 metres but this would need to be confirmed with FRPD. Figure 4-2 shows a typical hopper dredge rainbowing material ashore as beach fill between rock groins.



FIGURE 4-2: HOPPER DREDGE RAINBOWING MATERIAL (SOURCE: www.theartofdredging.com)

Regardless of whether the fill material is placed over the jetty through a pipeline or by rainbowing, final grading of the material will likely need to be performed by conventional land-based equipment such as low ground pressure dozers or amphibious excavators. Similar to the issue with the containment berm construction, equipment access to the site is limited. The equipment would need to access the fill area from across the jetty. Access over the jetty would require a portion of the marsh fill platform or containment berm to be raised above high water elevation to allow the equipment to remain out of the water at the higher tide levels while working at the fill site. The higher fill platform would be spread to lower elevations of the marsh prior to the equipment demobilizing from the site.

Construction of the containment berm and placement of marsh fill would need to occur during the summer/early-fall months, subject to environmental work windows, so rock and fill material can be placed prior to the late-fall/winter storms. Any marine equipment on Sturgeon Bank or land equipment working on the fill is at risk to damage from wind and storm waves if left exposed. If construction work continues into the winter months, careful planning around weather events will need to be observed and will likely slow the progress of construction.

Fill material should not be placed in the marsh area until the containment berm is constructed to help contain the fill. The rainbowing of material may cause localized turbidity in the vicinity of the project. Pending any regulatory constraints by DFO regarding turbidity, this method of placement may need to be revisited prior to final design.

4.4. Construction Schedule

The proposed Project would involve consideration of any constraints, typical production rates, and material delivery. Specifically, the schedule includes:

Fisheries Closures:

- Juvenile Salmon-applies to water column above elevation -5m (March 1 through August 15)
- Crab-applies to seabed below -5.0m (October 15 through March 30) (Not applicable to this project)

Marine Mammals:

- Temporary works stoppage if specific marine mammals are observed in the area.

Source/Equipment

- Fraser River Maintenance dredging operates from June 15 through February 28. Actual dates depend on freshet conditions and degree of shoaling in critical areas.
- The rates of offloading will consider the FRPD dredge 309 if the material is supplied through the Fraser River maintenance.
- Rock and some fill materials are assumed to be delivered by barge and spread on-site using land based equipment mobilized via barge/crane.

Production Rates

- Working hours M-F, 6am-5pm
- Dredge pumpout 2500 m^3/day. (Light loaded to allow closer approach to shore).
- Rock demolition/removal 500 m^3/day
- Rock placement 400 m^3/day
- On-site excavation/grading 1000 m^3/day.
- Planting (Not covered in this document).

Based on these assumptions the schedule indicates a construction period of approximately five (5) months, excluding planting. See Appendix D for schedule layout.

5. Construction Direct Cost

5.1. Cost Considerations

The cost estimate includes removal of concrete piling; supply and installation of the containment berm; marsh bench (sand); cobble beach berm; environmental protection measures; mobilization/demobilization; and Site Modifications. An allowance is included for possible environmental protections measures that may be required by the approving agencies, such as, preparing an environmental protection plan, installing and maintaining turbidity booms. Potential site modifications are limited and may include repairs to the existing jetty. Direct costs are based on anticipated equipment, labor and materials. The cost estimate excludes marsh planting; indirect costs for the owner's project management, construction administration and third-party consulting fees; and all applicable taxes.

- The costs are limited to the civil construction elements such as rock, mobilization, buoys, etc.
- Planting costs are excluded from these estimates.
- The overall 2020 RBT2 CDC opinion of probable cost unit rates were used where applicable.
- Contingency varies by status of design. The projects carries a 20% contingency.

For further background on the 2020 CDC RBT2 cost estimate methods, limitations and uncertainties refer to Moffatt & Nichol Memorandum RBT2 CDC Summary and Cost Drivers Memo, Rev.A – DRAFT. dated February 28, 2020.

TABLE 5-1: CONSTRUCTION DIRECT COST

Note – this section is removed.

5.2. Limitations

In providing opinions of estimate, it is recognized that the OE has no control over the costs of labour, equipment or materials, over the Contractor's methods of determining prices, or of the bidding climate. Opinions of estimate prepared by the OE are based on reasonable professional judgement and experience and do not constitute a warranty, expressed or implied, that the Contractor's bids or the negotiated price of the Work, or the actual cost of the Work, will not vary from the Client's budget or from any opinion of estimate prepared by the OE.

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Appendix A:
Geotechnical Recommendations

DRAFT REPORT

February 28, 2014

GEOTECHNICAL ASSESSMENT

Phase 2 Habitat Enhancement: South Arm Jetty Tidal Marsh, Richmond, BC

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Golder Associates

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Figure 1: Key Plan

Figure 2: Approximate Test Hole Locations

1.0 INTRODUCTION

As requested, Golder Associates Ltd. (Golder) has carried out a geotechnical assessment for the Phase 2 proposed habitat compensation sites located at the South Arm Jetty, Richmond, BC. The assessment was requested by Moffatt and Nichol (MN) on behalf of Port of Metro Vancouver (PMV). The development of the habitat compensation sites involves site grading and fill placement as required to achieve a ground surface elevation suitable for the support of habitat.

The geotechnical assessment was carried out on the basis of a desktop geotechnical study and limited site reconnaissance. This report presents the anticipated geotechnical conditions and preliminary comments on geotechnical considerations for design and construction of the habitat compensation sites. All elevations discussed within this report are referenced to Geodetic Datum.

The assessment of the South Arm Jetty is being carried out as a part of a larger habitat compensation project which includes additional Phase 1 and Phase 2 sites at various locations. The reports for other sites have been issued under separate cover, grouped by Phase and geographic location.

The work on this report has been carried out in accordance with Golder proposal for Phase 2 sites dated March 15, 2013. The work has been completed in accordance with the terms and conditions outlined in the Reciprocal Master Service Agreement for consulting services between MN and Golder dated March 11, 2011 and associated work order dated March 20, 2013.

The scope of this report is limited to geotechnical aspects of the proposed site development, and does not include any provision for environmental services such as the investigation, testing or assessment of the potential presence or impact of soil or groundwater contamination at the site, archeological or biological considerations or other hydrogeological services including but not limited to sediment transportation, erosion and/or scouring potential of the proposed developments.

This report should be read in conjunction with the ***"Important Information and Limitations of This Report"*** that follows this text. The reader's attention is specifically drawn to this information as it is essential for the proper use and interpretation of this report.

2.0 SITE AND PROPOSED DEVELOPMENT DESCRIPTION

2.1 South Arm Jetty Tidal Marsh

The proposed Sturgeon Bank site is located at South Arm Jetty Tidal Marsh at the mouth of the South Arm of the Fraser River as shown on the Key Plan, Figure 1. The site comprises of a sandflat zone; it is unvegetated, intertidal with shallow subtidal areas comprising medium to fine sand substrates that occur along the outer delta below mean water level. The sand flats are generally exposed to waves and high energy oceanographic conditions so the sands can be quite mobile are constantly being reworked (GL Williams & Associates 2006).

Drawings are included in Appendix B of M&N's Design Report. The sketch indicates the habitat compensation will involve construction of a marsh bench at Elevation 0.0 m, requiring up to 1.0 m of fill thickness to be placed over a width up to 320 m and an area of approximately 43.6 ha. In addition, an embankment will be constructed at the northern edge of the habitat enhancement area including up to 3 m of fill placement. It is understood that the grade fill will be sourced from Fraser River maintenance dredging operations and that about 238,000 m^3 of fill volume will be required.

3.0 SITE RECONNAISSANCE

A Golder representative attended a site viewing by boat of the Sturgeon Bank, on March 11, 2013, with representatives from MN and PMV. Site photographs were taken during the viewing.

4.0 REVIEW OF AVAILABLE INFORMATION

4.1 Regional Surficial Geology

Surficial geology information published by the Geological Survey of Canada (ref: Map 1486A dated 1979) indicates that the area is underlain by the following sequence of deposits:

- **Fraser River Sediments** comprising of:
  - Overbank silty to silt clay loam normally less than 2 m thick; overlying
  - Deltaic and distributary channel fill of interbedded fine to medium sand about 15 m thick; overlying
  - Estuarine interbedded fine sand to clayey silt, between 10 m to 185 m thick; overlying
- Up to approximately 400 m thickness of competent glacial and pre-glacial soils; overlying
- Bedrock.

4.2 Aerial Photographs

A review of historical aerial photographs, dating from 1938 through to 2004, was carried out. A summary of key review findings are presented in Table 1.

Table 1: Summary of Historical Aerial Photograph Review

Year	Sturgeon Bank – Key Findings
1938	Albion Dike No. 2 has yet to be constructed. No sandbar has formed
1946	No Change
1963	Albion Dike No. 2 has been constructed. The sandbar is beginning to form against the Dike.
1969	The sandbar is similar to the present day albeit with a slightly shallower configuration.
1976	The sandbar is similar to the present day configuration.
1982	The sandbar is similar to the present day configuration; however, it appears sediment is beginning to accrete to the west of the sandbar.
1989	A second sandbar has formed against Albion Dike No. 2. The second sandbar is a mirror image of the existing sandbar and together the two sandbars form a ribbon shape.
1994	The second sand bar is not present. The sandbar is similar to the present day configuration.
2004	The sandbar is similar to the present day configuration.

4.3 Previous Geotechnical Investigations

A review of available geotechnical reports in the vicinity of the Sites was carried out as summarized below.

Golder 1991

Golder carried out a geotechnical investigation at the South Arm Jetty Site in 1991. The investigation was for a proposed river channel training structure (ref: Golder Report No. 902-1222 titled "Report to Public Works Canada on Geotechnical Investigation Proposed River Channel Training Structure" dated March 1991). A total of eight boreholes (BH) and two dynamic cone penetration tests (PT) were put down to depths of up to 30 m below the river bed at the locations shown on Figure 2.

Golder 1992

Golder carried out a subsequent geotechnical investigation at the South Arm Jetty Site later in 1991 to test fill that had been placed for the above-mentioned river training structure (ref: Golder Report No. 902-1222 titled "Geotechnical Testing River Training Structure" dated January 1992). A total of eight Becker Penetration Tests (BPT) and 2 sampled open Becker boreholes (BO) were put down.

Golder 2009-2011

Golder previously carried out a geotechnical investigation approximately 8 km southwest of the Site. The investigation included a total of four test pits, four auger holes, one seismic cone penetration test and one cone penetration test. Standpipe piezometers were installed in selected augerholes. In addition, a test fill embankment was constructed and monitored over six months at site. The test fill included the installation and monitoring of 20 settlement gauges and comprised two zones as follows:

- A lower fill embankment constructed to approximately 1.5 m to 2 m above original site grade, measuring approximately 200 m by 100 m in plan; and
- A higher (upper) fill embankment constructed to approximately 4.5 m to 5 m above original site grade, measuring 50 m by 50 m.

This test embankment is considerable distance from the Site, however, it has been included herein since it is within the same geological sequence and represents a trail response of the deposits to fill placement.

5.0 INFERRED SITE CONDITIONS

The Golder 1991 investigation was carried out in close proximity to the South Arm Jetty Site and indicated minor surficial sand deposits over an extensive sequence of soft to firm normally consolidated to lightly overconsolidated, weak and compressible silt to depths of greater than 30 m below the existing river bed.

Very Loose to Loose Sand and Silty Sand

A surficial deposit of micaceous sand to silty sand was commonly encountered within 1 to 4 m of the existing river bed and is inferred to represent transient alluvial channel deposits. *In-situ* and laboratory testing indicated the following:

- Sieve analysis indicated the material consisted predominantly of medium sand, with some fine and coarse sand, and up to 20 per cent silt sizes.
- Dynamic Cone Penetration Test (DCPT) blow counts indicate the upper 3 to 5 m were particularly loose.

Soft to Firm Silt

An extensive deposit of soft to firm silt was encountered at all borehole locations either underlying the surficial sand stratum or at river bed level. The silt was thinly laminated and contained interbeds of sand and silty sand. The deposit was considered very weak and sensitive. *In-situ* and laboratory testing indicated the following:

- Standard Penetration Tests (SPT) blow counts ranged from less than 1 to a maximum of 5 blows per 300 mm penetration.
- Undrained shear strengths ranged from 15 to 24 kPa. Remoulded shear strengths in the ranged from 7 to 11 kPa. These values are indicative of high sensitivities.
- Moisture contents of samples typically ranged from 30 to 40 percent and were generally at, or above, the Liquid Limit. Plasticity Indices ranged from 9 to 13.
- A consolidated undrained triaxial test carried out on a sample of silt obtained at a depth of 6.5 m below river bed level showed an effective friction angle of 37 degrees with almost zero effective cohesion. Coefficients of consolidation in the range of 0.002 to 0.004 cm^2/s were recorded.
- A consolidation test carried out on a sample of silt obtained at a depth of approximately 3 m below river bed level indicated it was moderately compressible with a compression index of about 0.3 and a coefficient of consolidation of approximately 0.004 cm^2/s.

Firm Silt, Some Clay

At depths ranging from 19 to 25 m below existing river bed level the silt deposit was observed to become firmer, with less sandy interlayers and is inferred to be a marine silt deposit. *In-situ* and laboratory testing indicated the following:

- Moisture contents were slightly less than in the overlying deposit and were sometimes less than the Liquid Limit. Plasticity Indices ranged from 9 to 13.
- SPT blow counts ranged from 2 to a maximum of 8 blows per 300 mm penetration.
- Undrained shear strengths were approximately 30 kPa.

- One consolidation test carried out on a sample of silt obtained at a depth of approximately 19.5 m below river bed level indicated it was moderately compressible with a compression index of about 0.3 and a coefficient of consolidation of approximately 0.004 cm^2/s.

6.0 GEOTECHNICAL CONSIDERATIONS

The following briefly summarizes significant geotechnical design and construction considerations for the proposed habitat compensation embankments common to both sites:

- The subgrade soils comprise an extensive sequence of deltaic and estuarine deposits that are inferred to extend to depths in the order of 100 m below ground surface. These soils include weak and moderately compressible, near-surface silt to clayey silt deposits, extensive loose to compact sand deposits and an interlayered sequence of silt, sand and clayey silt soils.
- Development at the South Arm Jetty will require the placement of permanent grade fills of thickness up to 1.0 m over a wide area and up to 3 m over the proposed embankment area.
- The placement of these fills will cause consolidation of the underlying fine-grained subgrade soils.
- Sequencing should consider specifying limitations on the thickness of fill placed in any single lift; each lift placement should be separated from the next by a waiting period to allow strength gain and dissipation of pore water pressures in the underlying deposits.
- There may be difficulties in controlling and monitoring the nature of the fill placement due constraints associated with dredging and submerged fill placement.
- The low-plastic silt and extensive loose sand deposits are susceptible to soil liquefaction during strong seismic (earthquake) shaking, which will result in loss of soil strength.

6.1 Settlement of Compressible Deposits

As described in Section 4.3, a test fill embankment was constructed at a project 8 km from this Site. Settlement measured at gauges installed within a fill embankment indicated the following order of magnitude of settlement:

- 1.5- to 2-m-fill thickness: approximately 50 to 150 mm over the first 6 month period with an additional 25 mm over the following 18 month period.
- 4.5- to 5-m-fill thickness: approximately 60 to 250 mm over the same 6 month period with an additional 25 mm over the following 18 month period.

One-dimensional settlement calculations were carried out for the South Arm Jetty using the available information from the 1991 and 1989 Golder reports, respectively. The limitation of these calculations is that the thickness of the compressible deposits needed to be assumed, as it was not determined in any of the investigation holes. On the basis of regional geological information, the full depth of compressible deposits was assumed to extend to a depth of some 100 m below river bed level. These calculations indicate settlement in the order of 350 mm could be expected in the compressible deposits in response to 4 m of fill placement.

Based on the performance of the test fill embankment (with the assumption that similar behavior may be expected at the South Arm Jetty) and in conjunction with settlement calculations based on soil properties from the 1991 and 1989 investigations, settlement at the South Arm Jetty Site could be expected as follow:

- Areas with up to 1 m of fill placement: in the order of 50 mm could be expected to occur during the construction period with secondary consolidation of about 25 mm to 100 mm over the design life of the habitat embankment (assumed at 25 years); and
- Areas with up to 3 m of fill placement: in the order of 100 to 300 mm could be expected to occur during the construction period. Secondary consolidation of about 25 mm to 100 mm over the design life of the habitat embankment (assumed at 25 years) could be expected. However, based on the review of the aerial photographs, the area appears to be a dynamic environment. It is possible that at some time in history the land reclamation area may have been loaded with sand that has subsequently been scoured away. This may have imparted a preloading effect. If this is in fact the case, the settlements observed at the Site in response to site development, may be much smaller than those predicted above.

It should be noted that GL Williams & Associates have indicated that the entire delta area is subsiding in response to the ongoing inputs of sand as well as the process of dewatering and degassing of sediments and is likely most pronounced in the sandflats where the most recently deposited sediments occur.

6.2 Settlement of Dredged Sand Fill

In addition to settlement of the native compressible deposits described above, the dredged fill will also settle under its own self weight. This will occur concurrent with the construction process and therefore will not have an impact on design details, but will be an important consideration for volume calculations. The amount of settlement that could be expected within the dredged sand fill is a function of placement methods, as well as the type of material used. Assuming a relatively clean Fraser River Sand (say less than 15% fraction passing the 75 μm sieve) settlement in the order of 5 to 10 percent of the fill height could be expected.

6.3 Staged Fill Placement

The general purpose of staged fill placement is to allow sequential strength gain of the underlying compressible soils by administering a waiting period between lifts to allow dissipation of excess pore pressures induced by the fill, and to avoid overstressing the underlying fine-grained soils. The consequence of placement of fill in an uncontrolled manner (without staging) may result in failure of the underlying soils resulting in lateral movements at and beyond the toe of the fill affecting construction.

Construction using staged loading should be implemented. It is recommended to plan for staging of placement of fill in lifts no thicker than about 0.5 m.

6.4 Stability Assessment

Slope stability analyses were conducted for the embankment along the northern boundary to the Site using limit equilibrium methods with the commercially available computer software program SLOPE/W of the GeoStudio 2007 (Version 7.17) package by GEO-SLOPE International Ltd. Stability analyses were carried out under static loading conditions and did not consider seismic (earthquake) loading effects. The slope stability analyses were carried out using Modified Bishop's Method. The calculated FOS against failure of the proposed embankment was calculated to be greater than 1.5.

6.5 Suitability of Dredge Materials as Reclamation Fill

Generally, dredged and placed sand with less than 10% to 15% of fines is considered suitable as engineering fill. Sand meeting this criterion is a better reclamation material for the following reasons:

- It's easier to handle.
- Drainage is good and consolidation occurs quickly.
- The reclaimed land has a higher bearing capacity.
- The long-term settlements occurring within the reclaimed soils are small.

Dredged and placed sand with fines content greater than 15% could still be usable, but longer consolidation/settling times could be expected. It is anticipated that in-situ silty sands and sandy silts will lose some amount of fines during the dredging and reclamation processes followed for site development by the dredging contractor.

The amount of fines existing within the seabed deposits will be altered during the dredging and reclamation processes as the soil particles segregate during transportation and deposition into the reclamation cells. Determining the actual amount of fines that would remain in place within the reclamation area following dredging, pumping and placement of the dredgeate depends on how the reclamation work is staged and carried out and contractor's methodology, all of which are unknown at the time of preparation of this report.

6.6 Seismic Response

The soils at South Arm Jetty are expected to be potentially liquefiable under moderate to strong levels of seismic shaking. Liquefaction-induced ground movements (lateral spreading and settlement) are expected to occur during and following the cessation of shaking. Soils exhibiting clay-like behaviour are not expected to liquefy, however, they could experience cyclic softening under moderate to strong levels of shaking.

7.0 CLOSURE

We trust that the information presented in this report is sufficient for your immediate requirements. Should you have any questions or require further information, please feel free to contact us.

GOLDER ASSOCIATES LTD.

ORIGINAL SIGNED

Kieran McNally, EIT
Geotechnical Engineer

ORIGINAL SIGNED

Jo-Anne I. Perrett, P.Eng.
Associate, Senior Geotechnical Engineer

KM/JIP/sn

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o:\final\2013\1447\13-1447-0047\1314470047-002-r-rev0\1314470047-002-r-rev0 south arm jetty 28feb_14.docx

8.0 REFERENCES

Fraser River Estuary Management Program Roberts and Sturgeon Bank Reach Overview, Draft Final Report GL Williams & Associates/Northwest Hydraulics Consultants September 2009

U.S. Army Engineer Waterways Experiment Station. (1998) Considerations for Nearshore Placement of Mixed Dredged Sediments," Technical Note DOER-N3, Vicksburg, MS

Creed, G.C, Bodge K.R, and Sutler C. L. (2000) "Construction Slopes for Beach Nourishment Projects." Journal of Waterway, Port, Coastal, and Ocean Engineering

McLellan, N. (1990a). "Engineering design considerations for nearshore berms," Technical Note DRP-5-01, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

McLean, D.G.,M. A. Church, and B. Tassone (1999), Sediment transport along lower Fraser River 1 : Measurements and hydraulic computations, Water Resources Research, 35(8), 2533-2548

Environmental Management Strategy for Dredging in the Fraser River Estuary (2006) Fraser River Estuary Management Program

Welp, T.L, Clausner, J.E, Thompson D, Mujica J, and Boddie G, (2004) 'Demonstration Project on Dredging and Marsh Development Using a Flexible-Discharge Dustpan Dredge at Head of Passes/Southwest Pass Mississippi River.' U.S. Army Corps of Engineers Washington, DC

Port Metro Vancouver Website

IMPORTANT INFORMATION AND LIMITATIONS OF THIS REPORT

Standard of Care: Golder Associates Ltd. (Golder) has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practising under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this report. No other warranty, expressed or implied is made.

Basis and Use of the Report: This report has been prepared for the specific site, design objective, development and purpose described to Golder by the Client. The factual data, interpretations and recommendations pertain to a specific project as described in this report and are not applicable to any other project or site location. Any change of site conditions, purpose, development plans or if the project is not initiated within eighteen months of the date of the report may alter the validity of the report. Golder cannot be responsible for use of this report, or portions thereof, unless Golder is requested to review and, if necessary, revise the report.

The information, recommendations and opinions expressed in this report are for the sole benefit of the Client. No other party may use or rely on this report or any portion thereof without Golder's express written consent. If the report was prepared to be included for a specific permit application process, then upon the reasonable request of the client, Golder may authorize in writing the use of this report by the regulatory agency as an Approved User for the specific and identified purpose of the applicable permit review process. Any other use of this report by others is prohibited and is without responsibility to Golder. The report, all plans, data, drawings and other documents as well as all electronic media prepared by Golder are considered its professional work product and shall remain the copyright property of Golder, who authorizes only the Client and Approved Users to make copies of the report, but only in such quantities as are reasonably necessary for the use of the report by those parties. The Client and Approved Users may not give, lend, sell, or otherwise make available the report or any portion thereof to any other party without the express written permission of Golder. The Client acknowledges that electronic media is susceptible to unauthorized modification, deterioration and incompatibility and therefore the Client cannot rely upon the electronic media versions of Golder's report or other work products.

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Unless otherwise stated, the suggestions, recommendations and opinions given in this report are intended only for the guidance of the Client in the design of the specific project. The extent and detail of investigations, including the number of test holes, necessary to determine all of the relevant conditions which may affect construction costs would normally be greater than has been carried out for design purposes. Contractors bidding on, or undertaking the work, should rely on their own investigations, as well as their own interpretations of the factual data presented in the report, as to how subsurface conditions may affect their work, including but not limited to proposed construction techniques, schedule, safety and equipment capabilities.

Soil, Rock and Groundwater Conditions: Classification and identification of soils, rocks, and geologic units have been based on commonly accepted methods employed in the practice of geotechnical engineering and related disciplines. Classification and identification of the type and condition of these materials or units involves judgment, and boundaries between different soil, rock or geologic types or units may be transitional rather than abrupt. Accordingly, Golder does not warrant or guarantee the exactness of the descriptions.

Special risks occur whenever engineering or related disciplines are applied to identify subsurface conditions and even a comprehensive investigation, sampling and testing program may fail to detect all or certain subsurface conditions. The environmental, geologic, geotechnical, geochemical and hydrogeologic conditions that Golder interprets to exist between and beyond sampling points may differ from those that actually exist. In addition to soil variability, fill of variable physical and chemical composition can be present over portions of the site or on adjacent properties. **The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report.** The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.

Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities (traffic, excavation, groundwater level lowering, pile driving, blasting, *etc.*) on the site or on adjacent sites. Excavation may expose the soils to changes due to wetting, drying or frost. Unless otherwise indicated the soil must be protected from these changes during construction.

Sample Disposal: Golder will dispose of all uncontaminated soil and/or rock samples 90 days following issue of this report or, upon written request of the Client, will store uncontaminated samples and materials at the Client's expense. In the event that actual contaminated soils, fills or groundwater are encountered or are inferred to be present, all contaminated samples shall remain the property and responsibility of the Client for proper disposal.

Follow-Up and Construction Services: All details of the design were not known at the time of submission of Golder's report. Golder should be retained to review the final design, project plans and documents prior to construction, to confirm that they are consistent with the intent of Golder's report.

During construction, Golder should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not materially differ from those interpreted conditions considered in the preparation of Golder's report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in Golder's report. Adequate field review, observation and testing during construction are necessary for Golder to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, Golder's responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

Changed Conditions and Drainage: Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that Golder be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that Golder be employed to visit the site with sufficient frequency to detect if conditions have changed significantly.

Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. Golder takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the system.



LEGEND

- PREVIOUS BOREHOLE LOCATION
- PROPOSED SITE (APPROXIMATE LOCATION)
- MAJOR ROAD
- LOCAL ROAD
- RAILROAD

1 0 1

SCALE 1:50,000 KILOMETRES

REFERENCE

TRANSPORTATION FEATURES OBTAINED FROM THE PROVINCE OF BRITISH COLUMBIA.
IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS PUBLISHED BY MICROSOFT CORPORATION, REDMOND, WA, APRIL 2013.
INSET DATA OBTAINED FROM E.S.R.I.
DATUM: NAD83 PROJECTION: UTM ZONE 10

PROJECT

MOFFATT & NICHOL
HABITAT ENHANCEMENT
SOUTH ARM JETTY TIDAL MARSH

TITLE

KEY PLAN

Golder Associates

PROJECT	13-1447-0047		FILE No.	
DESIGN	JP	26 Feb. 2014	SCALE AS SHOWN	REV. 0
GIS	MH	26 Feb. 2014		
CHECK				
REVIEW				

FIGURE: 1

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LEGEND

- PREVIOUS TEST HOLE (APPROXIMATE LOCATION)
- PROPOSED SITE (APPROXIMATE LOCATION)
- MAJOR ROAD
- LOCAL ROAD
- RAILROAD

1 0 1

SCALE 1:50,000 KILOMETRES

REFERENCE

TRANSPORTATION FEATURES OBTAINED FROM THE PROVINCE OF BRITISH COLUMBIA.
IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS PUBLISHED BY MICROSOFT CORPORATION, REDMOND, WA, APRIL 2013.
INSET DATA OBTAINED FROM E.S.R.I.
DATUM: NAD83 PROJECTION: UTM ZONE 10

PROJECT

MOFFATT & NICHOL
HABITAT ENHANCEMENT
SOUTH ARM JETTY TIDAL MARSH

TITLE

APPROXIMATE TEST HOLE LOCATIONS

Golder Associates

PROJECT	13-1447-0047		FILE No.	
DESIGN	JP	26 Feb. 2014	SCALE AS SHOWN	REV. 0
GIS	MH	26 Feb. 2014		
CHECK				
REVIEW				

FIGURE: 2

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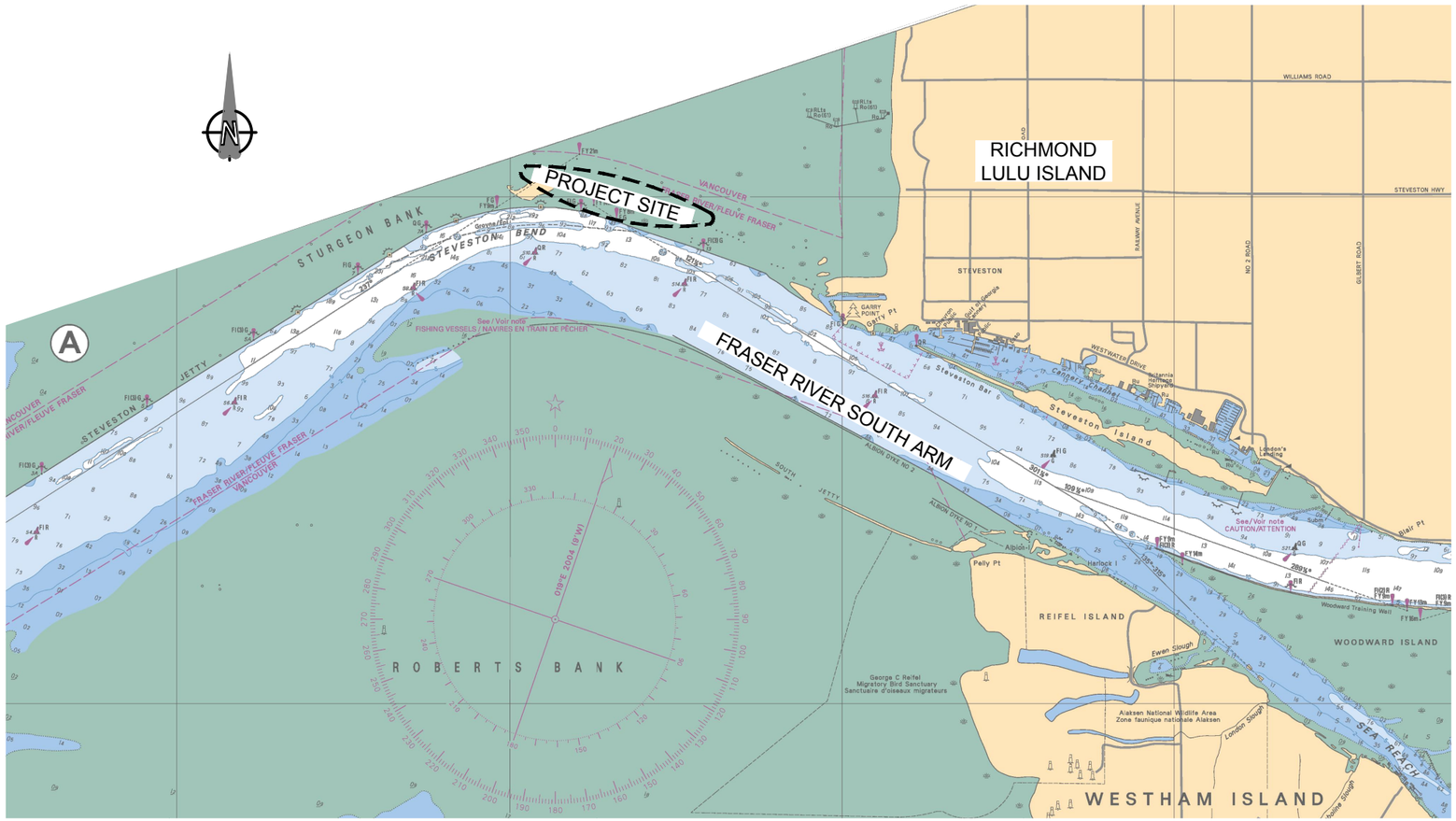
Golder Associates

Appendix B:
Project Drawings

VANCOUVER FRASER PORT AUTHORITY

HABITAT ENHANCEMENT PROGRAM

SOUTH ARM JETTY TIDAL MARSH



VICINITY MAP
NTS
(SEE REF. 1)

DRAWING LIST:

G-001 COVER SHEET & DRAWING INDEX
G-002 GENERAL NOTES
G-003 SURVEY CONTROL
C-001 EXISTING SITE PLAN
C-002 PHOTOS - EXISTING CONDITIONS
C-003 PROPOSED GRADING PLAN
C-004 PROPOSED REVETMENT PLAN
C-005 PROPOSED SITE PLAN
C-006 EXISTING JETTY PROFILE
C-007 SECTIONS (1 0F 4)
C-008 SECTIONS (2 0F 4)
C-009 SECTIONS (3 0F 4)
C-010 SECTIONS (4 0F 4)

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1	CHS CHART 3490
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IN ASSOCIATION WITH:

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Shoreline Management Consulting

No.	Date	REVISION	Dr'n	Ch'd
		REVISION IN PROGRESS		

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VANCOUVER FRASER PORT AUTHORITY
ENGINEERING DEPARTMENT

DESIGN BY	AC
DRAWN BY	AC
APPROVED	AA
DATE	July 24, 2020
SCALE	NO SCALE
PMV SITE	

RBT2 OFFSETTING
SOUTH ARM JETTY TIDAL MARSH
COVER SHEET & DRAWING INDEX

SIZE	DWG.	SHEET	REV.
D	G-001	1 of 13	

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1.0 GENERAL NOTES

1.1 ALL DIMENSIONS ARE GIVEN IN METERS UNLESS NOTED OTHERWISE. ELEVATIONS AND CONTOURS ARE GIVEN IN METRES AND DECIMALS THEREOF. SCALE INDICATED ON DRAWING IS APPROPRIATE TO SCALE AT FULL SIZE (D) 22" X 34"

1.2 SUPPLY AND INSTALLATION OF PLANTS BY OTHERS.

1.3 AERIAL PHOTOS SOURCE: 2019 MCELHANNEY

2.0 SURVEY, WATER LEVEL AND DATUM

2.1 ALL ELEVATIONS ARE TO GEODETIC DATUM.
CHART DATUM = (GEODETIC DATUM) + (2.4 METERS)
REF. CANADIAN COAST GUARD WATERWAYS MANAGEMENT (KM6 TO KM7 FRASER RIVER SOUTH/MAIN ARM)

UPLAND TOPOGRAPHIC SURVEY & HYDROGRAPHIC SURVEY DATA SOURCE: 2019 MCELHANNEY

2.2 COORDINATES ARE UTM (NAD 83) ZONE 10 MAPPING PLANE COORDINATES.

2.3 SURVEY REFERENCE MONUMENT MON 6901

X = 490336.877 Y = 5436561.963 Z = 1.753 (GEODETIC)

2.3 TIDAL DATUMS FOR THE SITE ARE AS FOLLOWS:

TIDAL PARAMETER	ELEVATION (GEODETIC)	ELEVATION (CHART DATUM)
HIGHER HIGH WATER LARGE TIDE (HHWLT)	2.5m	4.9m
HIGHER HIGH WATER MEAN TIDE (HHWMT)	1.9m	4.3m
MEAN WATER LEVEL (MWL)	0.7m	3.1m
LOWER LOW WATER MEAN TIDE (LLWMT)	-1.1m	1.3m
LOWER LOW WATER LARGE TIDE (LLWLT)	-2.2m	0.2m

3.0 AGGREGATE MATERIAL (RIPRAP, SAND)

3.1 RIPRAP SHALL BE IMPORTED CLEAN, ROUGH ANGULAR QUARRIED STONE OF A DENSE, HARD, DURABLE CHARACTER, FREE OF ORGANIC MATERIAL, IN-FILLED JOINTS, SEAMS, OR OTHER DEFECTS, RESISTANT TO BREAKDOWN BY HANDLING OR WEATHERING OR EXPOSED TO SEA WATER THAT MEETS THE TEST REQUIREMENTS PROVIDED IN THE SPECIFICATIONS, UNLESS NOTED OTHERWISE.

3.2 SAND SHALL BE DREDGED MATERIAL - REFER TO SPECIFICATION FOR DETAILS.

3.3 RIPRAP (CLASS 50 kg ROCK) FOR THE CONTAINMENT STRUCTURE SHALL MEET THE FOLLOWING GRADATION:

	% SMALLER (BY WEIGHT) THAN			
MASS (Kg)	TARGET	LOWER LIMIT	UPPER LIMIT	APPROX. AVE. DIMENSION ± (mm)
220	100	95	100	520
150	85	75	95	460
50	50	40	65	320
17	15	5	30	220
6	5	0	5	160

3.4 RIPRAP (CLASS 5 kg ROCK) FOR THE CONTAINMENT STRUCTURE AND COBBLE BEACH BERM SHALL MEET THE FOLLOWING GRADATION:

	% SMALLER (BY WEIGHT) THAN			
MASS (Kg)	TARGET	LOWER LIMIT	UPPER LIMIT	APPROX. AVE. DIMENSION ± (mm)
24	100	95	100	250
15	85	70	95	212
5	50	40	65	150
1.7	15	5	25	100
0.6	5	0	5	74

3.5 THE CONTRACTOR SHALL PROVIDE AGGREGATE SUPPLIER'S TEST RESULTS THAT THE AGGREGATE MATERIALS SUPPLIED CONFORMS TO THE REFERENCED SPECIFICATIONS / GRADATIONS.

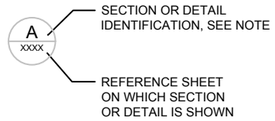
CROSS-REFERENCE LEGEND

1. ALL ELEVATIONS ARE TO GEODETIC DATUM.
CHART DATUM = (GEODETIC DATUM) + (2.4 METERS)
REF. CANADIAN COAST GUARD WATERWAYS MANAGEMENT (KM6 TO KM7 FRASER RIVER SOUTH/MAIN ARM).

UPLAND TOPOGRAPHIC SURVEY DATA (2009) PROVIDED BY MCELHANNEY, AND UNDERWATER HYDROGRAPHIC SURVEY DATA (2012) WAS PROVIDED BY ATEK HYDROGRAPHIC SURVEYS LTD.

2. COORDINATES ARE UTM (NAD 83) ZONE 10 MAPPING PLANE COORDINATES.

CROSS-REFERENCE LEGEND



NOTE: LETTER INDICATES SECTION; NUMBER INDICATES DETAIL. WHERE THERE IS NO REFERENCE SHEET INDICATED, IT MEANS THE DETAIL OR SECTION IS TAKEN AND SHOWN ON THE SAME SHEET.

ABBREVIATIONS:

ELEV	ELEVATION
EXIST	EXISTING
HHWLT	HIGHER HIGH WATER LARGE TIDE
HHWMT	HIGHER HIGH WATER MEAN TIDE
MWL	MEAN WATER LEVEL
LLWMT	LOWER LOW WATER MEAN TIDE
LLWLT	LOWER LOW WATER LARGE TIDE
HOR	HORIZONTAL
VERT	VERTICAL
APPROX	APPROXIMATE
WP	WORK POINT

PRELIMINARY
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IN ASSOCIATION WITH:

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Shoreline Management Consulting

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		REVISION IN PROGRESS		

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ENGINEERING DEPARTMENT

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DRAWN BY	AC
APPROVED	MA
DATE	July 24, 2020
SCALE	
PMV SITE	

RBT2 OFFSETTING
SOUTH ARM JETTY TIDAL MARSH
GENERAL NOTES

SIZE	DWG.	SHEET	REV.
D	G-002	2 of 13	



AERIAL IMAGE

1. PROVIDED BY GOOGLE EARTH.

LEGEND:

- BENCH MARK
- EXIST PATCHY MARSH (MAPPED AUG 10, 2017)
- EXIST MARSH (MAPPED AUG 10, 2017)

400 0m 400 800

SCALE: 1 : 20000

PRELIMINARY
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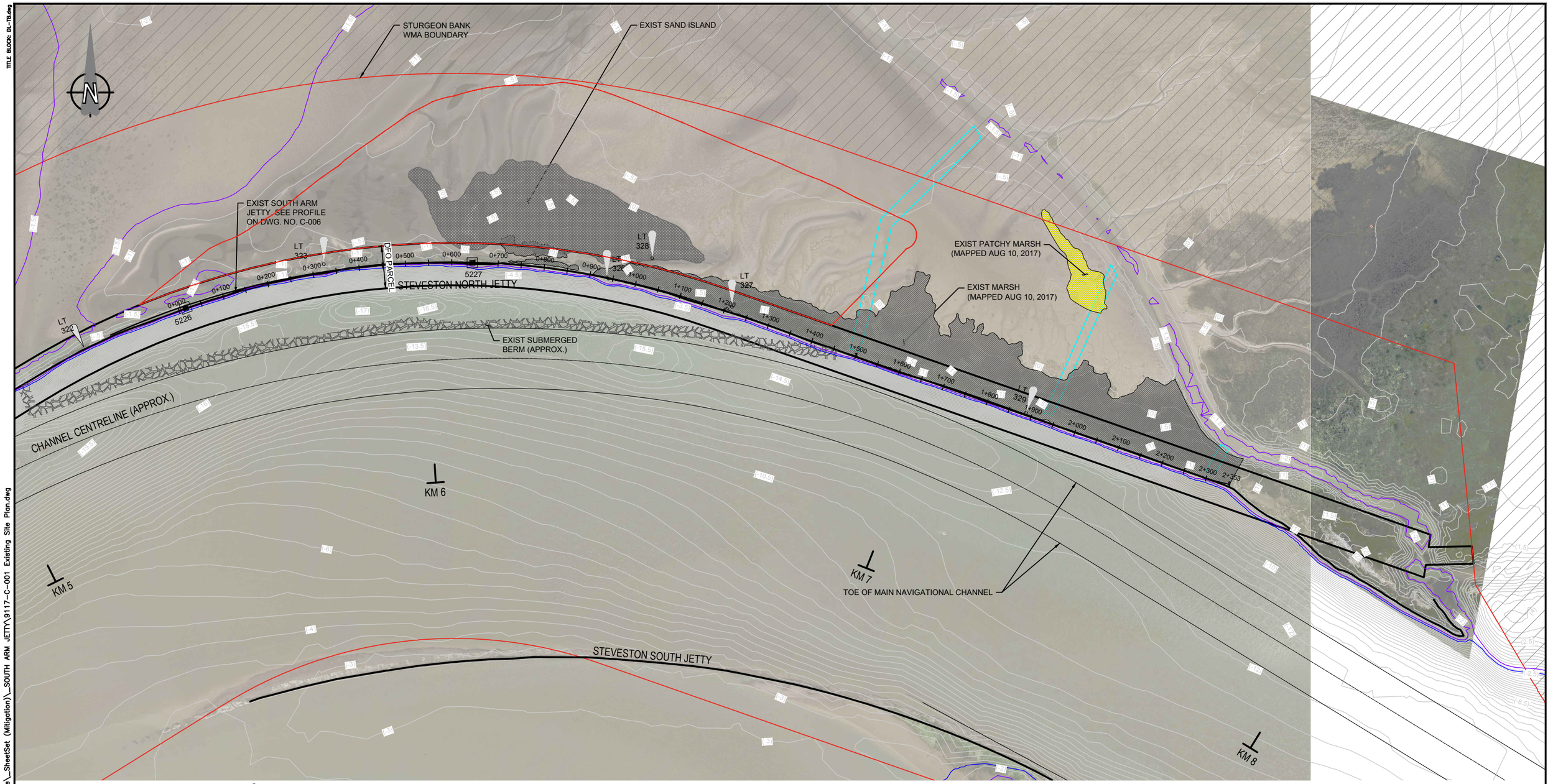
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APPROVED	AA
DATE	July 24, 2020
SCALE	AS SHOWN
PMV SITE	

RBT2 OFFSETTING
SOUTH ARM JETTY TIDAL MARSH
SURVEY CONTROL

SIZE D | DWG. G-003 | SHEET 3 of 13 | REV.

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DATE: 2020/07/24 - 2:52pm
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LEGEND:

- -1.5 (GD)
- LLWLT -2.2m (GD)
- STURGEON BANK WMA BOUNDARY
- LEASE AREA BOUNDARY
- FOOTPRINT OF EXISTING TIDE CHANNEL
- WMA AREA
- EXIST NAVIGATION LIGHT (LT)
- EXIST PORT DAYBEACON
- EXIST PATCHY MARSH (MAPPED AUG 10, 2017)
- EXISTING ISLAND CUT
- EXIST MARSH (MAPPED AUG 10, 2017)
- EXIST SUBMERGED BERM

NOTES:

1. 2019 OTHROPHOTO PROVIDED BY MCELHANNEY.
2. ELEVATIONS BASED ON 2019 LIDAR DATA PROVIDED BY MCELHANNEY.

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80m 0 80m 160m
SCALE: 1 : 4000

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APPROVED	AA
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SCALE	AS SHOWN
PMV SITE	

RBT2 OFFSETTING
SOUTH ARM JETTY TIDAL MARSH
EXISTING SITE PLAN

SIZE	DWG.	SHEET	REV.
D	C-001	4 of 13	

TITLE BLOCK: DL-TB.dwg
DATE: 2020/07/24 - 2:53pm
PATH: Q:\VAN\9117 RBT2 Working Folder\CADD_Active_SheetSet (Mitigation)_SOUTH ARM JETTY\9117-C-001 Existing Site Plan.dwg

TITLE BLOCK DL-TB.dwg

DATE: 2020/07/24 - 2:53pm
PATH: Q:\VAN\9117 RBT2 Working Folder\CADD_Active_SheetSet (Mitigation)_SOUTH ARM JETTY\9117-C-002 Photos - Existing Conditions.dwg

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

Ref.No.	REFERENCE

moffatt & nichol

IN ASSOCIATION WITH:

GL Williams & Associates Ltd.
Shoreline Management Consulting

No.	Date	REVISION	Dr'n	Ch'd
		REVISION IN PROGRESS		

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ENGINEERING DEPARTMENT

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DRAWN BY	AC
APPROVED	AA
DATE	July 24, 2020
SCALE	NO SCALE
PMV SITE	

RBT2 OFFSETTING
SOUTH ARM JETTY TIDAL MARSH
PHOTOS – EXISTING CONDITIONS

SIZE	DWG.	SHEET	REV.
D	C-002	5 of 13	

TITLE BLOCK DL-TB.dwg

STURGEON BANK

COBBLE BERM LIMIT

STURGEON BANK WMA BOUNDARY

SOUTH ARM JETTY MAIN BERM
FILL ELEV=0.0

SOUTH ARM JETTY FEEDER CHANNEL 2

EXIST SAND ISLAND

SOUTH ARM JETTY FEEDER CHANNEL 1

FILL ELEV=0.0

BOTTOM OF DRAINAGE CHANNEL
ELEV -0.7
WIDTH=10M
5:1 SLOPES

TOE OF SLOPE
20:1

TOP OF BERM
ELEV +0.9
WIDTH=8.9M

TOE OF 8:1 SLOPE

DRAINAGE CHANNEL

SOUTH ARM JETTY MAIN CHANNEL

STEVESTON NORTH JETTY

DFO PARCEL

5227

LT 328

LT 326

LT 327

EXIST STEVESTON NORTH JETTY
SEE NOTE 1

SOUTH ARM JETTY BERM GROIN

LEASE BOUNDARY AREA

CONTRACTOR LAYDOWN AREA

TEMPORARY ACCESS (e.g. CULVERT) MAY BE REQUIRED

STEVESTON BEND

CHANNEL CENTERLINE (APPROX.)

EXIST SUBMERGED BERM (APPROX.)

SUBMERGED BERM (APPROX.)

NOTES:

1. PROTECT IN PLACE ALL EXISTING INFRASTRUCTURE, INCLUDING EXISTING STEVESTON, NORTH JETTY, NAVIGATION LIGHTS, BEACONS.
2. PROTECT IN PLACE EXISTING MARSH.
3. 2019 OTHROPHOTO PROVIDED BY MCELHANNEY.
4. ELEVATIONS BASED ON 2019 LIDAR DATA PROVIDED BY MCELHANNEY.

QUANTITIES:

NOTE: QUANTITIES INCLUDE 15% ALLOWANCES FOR MATERIAL LOSSES.

SAND (MARSH)	
CUT	38,100 m^3
FILL	127,200 m^3
NET (FILL)	89,100 m^3

COBBLE BERM AREA:	6.7 ha
MARSH AREA (INCLUDES CHANNELS:	27.5 ha
DRAINAGE CHANNEL AREA:	2.7 ha

LEGEND:

- -1.5 (GD)
- LLWLT -2.2m (GD)
- STURGEON BANK WMA BOUNDARY
- LEASE AREA BOUNDARY
- FOOTPRINT OF EXISTING TIDE CHANNEL
- COBBLE BERM
- EXIST NAVIGATION LIGHT (LT)
- EXIST PORT DAYBEACON
- A1 WORK POINT, TYPICAL

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

40 0m 40 80
SCALE: 1 : 2000

Ref.No.	REFERENCE

moffatt & nichol

IN ASSOCIATION WITH:

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APPROVED	AA
DATE	July 24, 2020
SCALE	AS SHOWN
PMV SITE	

RBT2 OFFSETTING
SOUTH ARM JETTY TIDAL MARSH
PROPOSED GRADING PLAN

SIZE	DWG.	SHEET	REV.
D	C-003	6 of 13	

DATE: 2020/07/24 - 2:54pm
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TITLE BLOCK DL-TB.dwg

STURGEON BANK

A C-007

TOE OF SLOPE

COBBLE BERM LIMIT

TOE OF 5:1 SLOPE
TOP OF 20:1 SLOPE

SOUTH ARM JETTY MAIN BERM

5:1

20:1

TOE OF SLOPE

TOP OF BERM
ELEV +1.9
WIDTH=4M

STURGEON BANK
WMA BOUNDARY

B C-008

SOUTH ARM JETTY
FEEDER CHANNEL 2

SOUTH ARM JETTY
FEEDER CHANNEL 1

D C-010

C C-009

TOE OF 5:1 SLOPE
TOP OF 20:1 SLOPE

TOE OF SLOPE

TOP OF BERM
ELEV +1.9
WIDTH=4M

TOE OF SLOPE

DRAINAGE DITCH

E C-010

SOUTH ARM JETTY MAIN CHANNEL

50m

LT 323

LT 328

LT 326

LT 327

STEVESTON NORTH JETTY

DFO PARCEL

5227

EXIST STEVESTON NORTH JETTY
SEE NOTE 1

TOP OF BERM
ELEV +1.9
WIDTH=4M

SOUTH ARM JETTY BERM GROIN

TOE OF SLOPE

TOE OF SLOPE

LEASE
BOUNDARY AREA

CONTRACTOR
LAYDOWN AREA

TEMPORARY ACCESS
(e.g. CULVERT) MAY BE REQUIRED

STEVESTON BEND

CHANNEL CENTERLINE (APPROX.)

EXIST SUBMERGED
BERM (APPROX.)

SUBMERGED
BERM (APPROX.)

NOTES:

1. PROTECT IN PLACE ALL EXISTING INFRASTRUCTURE, INCLUDING EXISTING STEVESTON, NORTH JETTY, NAVIGATION LIGHTS, BEACONS.
2. PROTECT IN PLACE EXISTING MARSH.
3. 2019 OTHROPHOTO PROVIDED BY MCELHANNEY.
4. ELEVATIONS BASED ON 2019 LIDAR DATA PROVIDED BY MCELHANNEY.

QUANTITIES:

NOTE: QUANTITIES INCLUDE 25% ALLOWANCES FOR OVERBUILD AND SINKAGE.

5KG ROCK	55,500 m^3

COBBLE BERM AREA:	6.7 ha
MARSH AREA (INCLUDES CHANNELS:	27.5 ha
DRAINAGE CHANNEL AREA:	2.7 ha

LEGEND:

- -1.5 (GD)
- LLWLT -2.2m (GD)
- STURGEON BANK WMA BOUNDARY
- LEASE AREA BOUNDARY
- FOOTPRINT OF EXISTING TIDE CHANNEL
- COBBLE BERM
- EXIST NAVIGATION LIGHT (LT)
- EXIST PORT DAYBEACON
- A1 WORK POINT, TYPICAL

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

40 0m 40 80
SCALE: 1 : 2000

Ref.No.	REFERENCE

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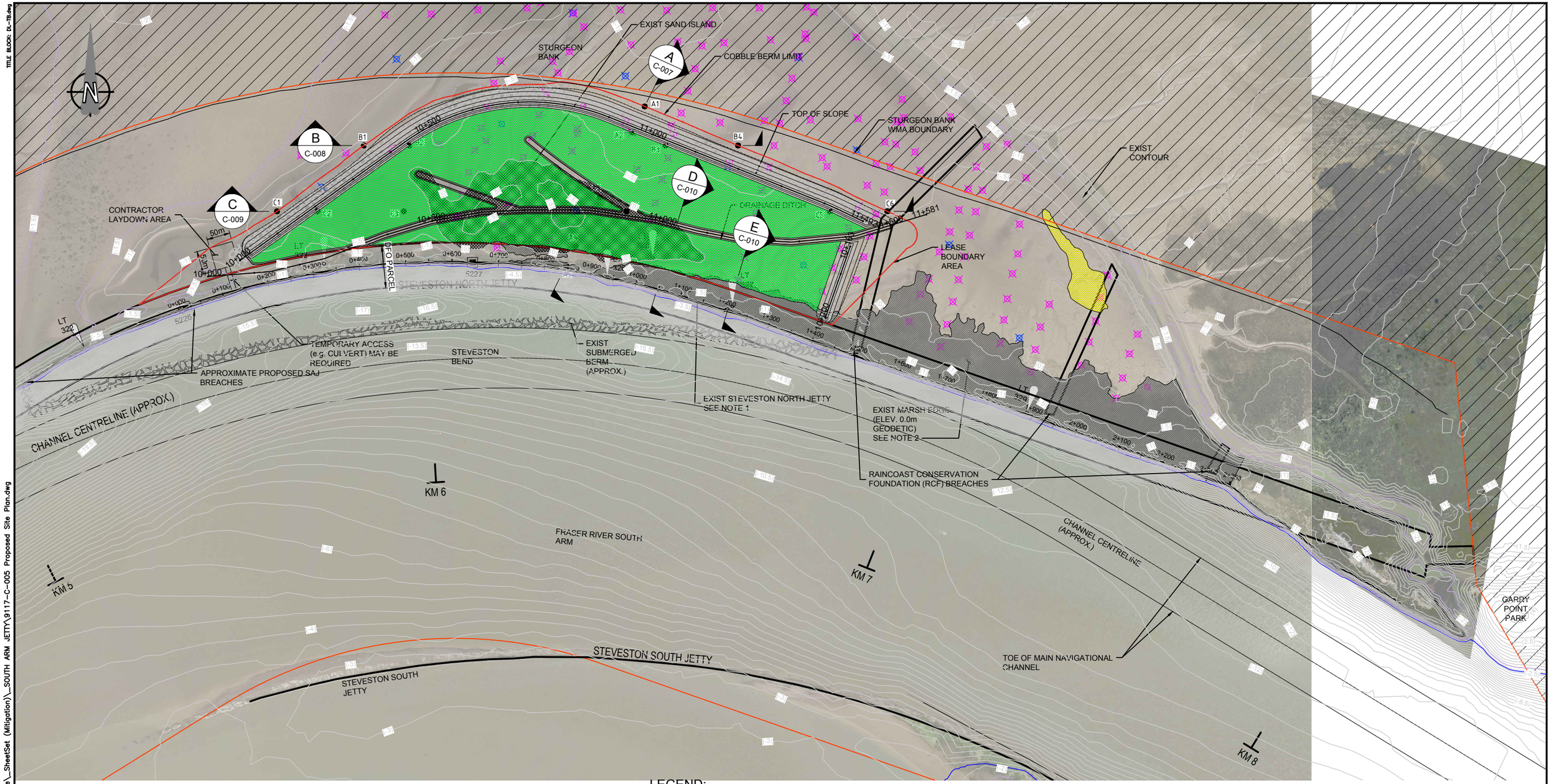
VANCOUVER FRASER PORT AUTHORITY
ENGINEERING DEPARTMENT

DESIGN BY	AC
DRAWN BY	AC
APPROVED	AA
DATE	July 24, 2020
SCALE	AS SHOWN
PMV SITE	

RBT2 OFFSETTING
SOUTH ARM JETTY TIDAL MARSH
PROPOSED REVETMENT PLANS

SIZE	DWG.	SHEET	REV.
D	C-004	7 of 13	

DATE: 2020/07/24 - 2:55pm
PATH: Q:\VAN\9117 RBT2 Working Folder\CADD_Active_SheetSet (Mitigation)_SOUTH ARM JETTY\9117-C-004 Proposed Revetment Plan.dwg



NOTES:

1. PROTECT IN PLACE ALL EXISTING INFRASTRUCTURE, INCLUDING EXISTING STEVESTON, NORTH JETTY, NAVIGATION LIGHTS, BEACONS.
2. PROTECT IN PLACE EXISTING MARSH.
3. 2019 OTHROPHOTO PROVIDED BY MCELHANNEY.
4. ELEVATIONS BASED ON 2019 LIDAR DATA PROVIDED BY MCELHANNEY.

COBBLE BERM AREA:	6.7 ha
MARSH AREA (INCLUDES CHANNELS):	27.5 ha
DRAINAGE CHANNEL AREA:	2.7 ha

LEGEND:

- -1.5 (GD)
- LLWLT -2.2m (GD)
- STURGEON BANK WMA BOUNDARY
- LEASE AREA BOUNDARY
- EXPECTED CHANNEL FOOTPRINT FROM RCF BREACHES
- WMA AREA
- COBBLE BERM
- MARSH AREA
- EXIST MARSH (MAPPED AUG 10, 2017)
- EXIST PATCHY MARSH (MAPPED AUG 10, 2017)
- CUT
- SHOREBIRD DROPPINGS SAMPLING LOCATIONS, 2014
- SHOREBIRD DROP PTS
- EXIST NAVIGATION LIGHT (LT)
- EXIST PORT DAYBEACON
- A1 WORK POINT, TYPICAL

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

80m 0 80m 160m
SCALE: 1 : 4000

Ref.No.	REFERENCE

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ENGINEERING DEPARTMENT

DESIGN BY	AC
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APPROVED	AA
DATE	July 24, 2020
SCALE	AS SHOWN
PMV SITE	

RBT2 OFFSETTING
SOUTH ARM JETTY TIDAL MARSH
PROPOSED SITE PLAN

SIZE	DWG.	SHEET	REV.
D	C-005	8 of 13	

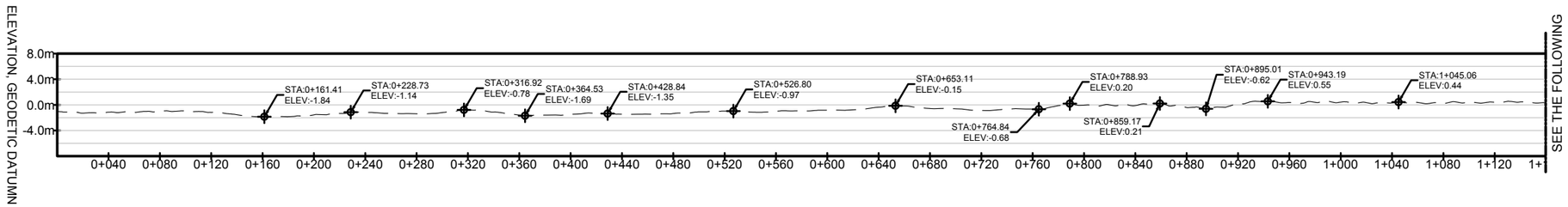
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TITLE BLOCK DL-TB.dwg

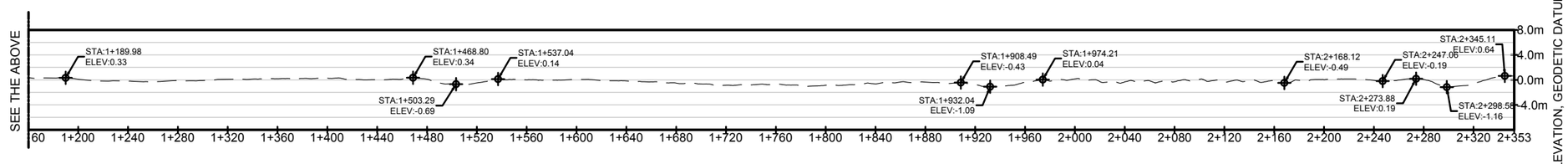
NOTES:

1. REFERENCE SHEET C-001 FOR PLAN VIEW



EXISTING SOUTH ARM JETTY - STA 0+000 TO STA 1+160

HOR: 1:2000
VERT: 1:400



EXISTING SOUTH ARM JETTY - STA 1+160 TO STA 2+353

HOR: 1:2000
VERT: 1:400

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

40 0m 40 80
HORIZONTAL SCALE: 1 : 2000

8 0m 8 16
VERTICAL SCALE: 1 : 400

DATE: 2020/07/24 - 2:56pm
PATH: Q:\VAN\9117 RBT2 Working Folder\CADD_Active_SheetSet (Mitigation)_SOUTH ARM JETTY\9117-C-006 Existing Jetty Profile.dwg

Ref.No.	REFERENCE

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		REVISION IN PROGRESS		

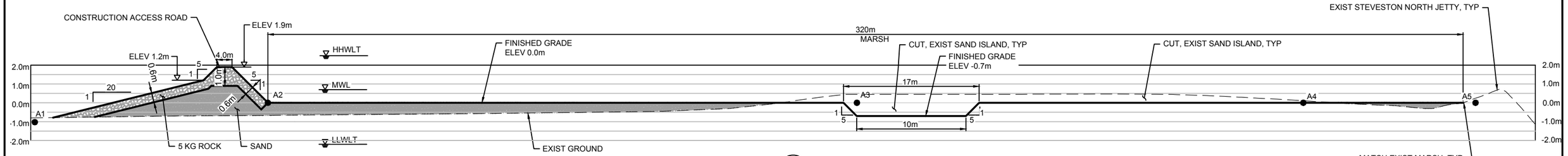
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ENGINEERING DEPARTMENT

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DRAWN BY	AC
APPROVED	AA
DATE	July 24, 2020
SCALE	AS SHOWN
PMV SITE	

RBT2 OFFSETTING
SOUTH ARM JETTY TIDAL MARSH
EXISTING JETTY PROFILE

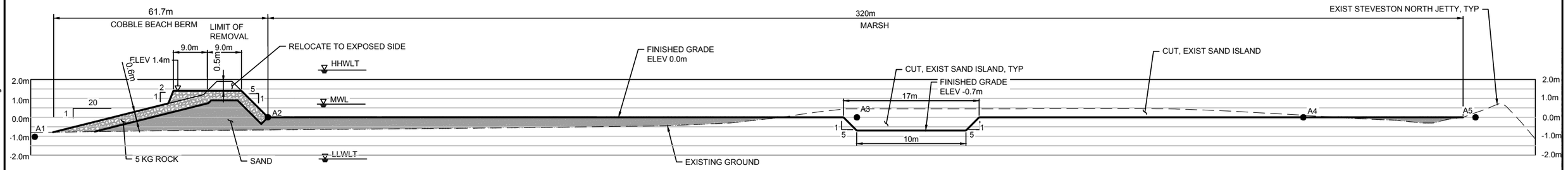
SIZE	DWG.	SHEET	REV.
D	C-006	9 of 13	

TITLE BLOCK DL-TB.dwg



SECTION A
HOR: 1:500 C-003 TO C-005
VERT: 1:100

CONSTRUCTION



SECTION A
HOR: 1:500 C-003 TO C-005
VERT: 1:100

POST CONSTRUCTION

WORK POINTS			
	NORTHING	EASTING	ELEVATION (m) GEODETIC DATUM
A1	5442568.81	483573.31	-1.03
A2	5442513.45	483545.91	0.0
A3	5442373.32	483476.54	0.0
A4	5442267.50	483424.17	0.0
A5	5442226.74	483404.00	0.0

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

LEGEND:

5KG ROCK

SAND

2m 0m 2m 4m
VERTICAL SCALE: 1 : 100

10m 0m 10m 20m
HORIZONTAL SCALE: 1 : 500

DATE: 2020/07/24 - 2:57pm
PATH: Q:\VAN\9117 RBT2 Working Folder\CADD_Active_SheetSet (Mitigation)_SOUTH ARM JETTY\9117-C-007 Sections - 1.dwg

Ref.No. | REFERENCE

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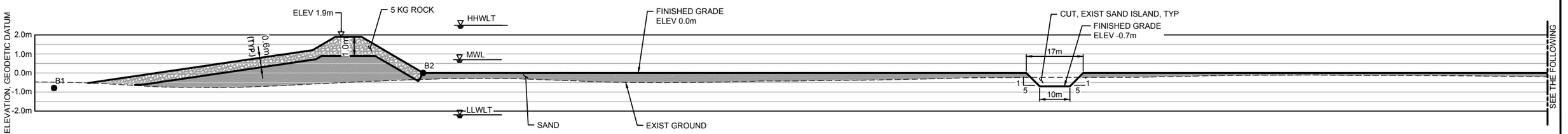
No.	Date	REVISION	Dr'n	Ch'd
		REVISION IN PROGRESS		

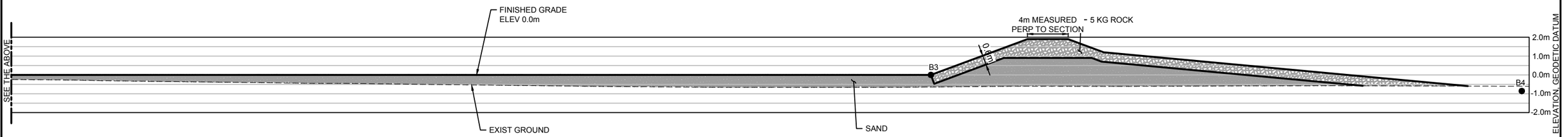
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DRAWN BY	AC
APPROVED	AA
DATE	July 24, 2020
SCALE	AS SHOWN
PMV SITE	

RBT2 OFFSETTING
SOUTH ARM JETTY TIDAL MARSH
SECTIONS (1 OF 4)

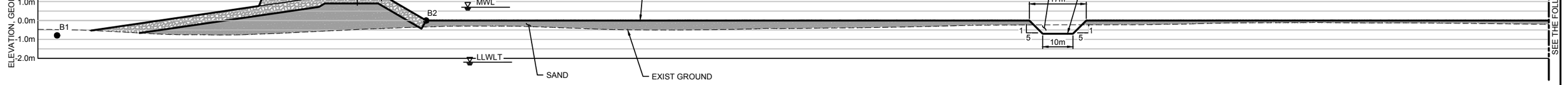
SIZE	DWG.	SHEET	REV.
D	C-007	10 of 13	

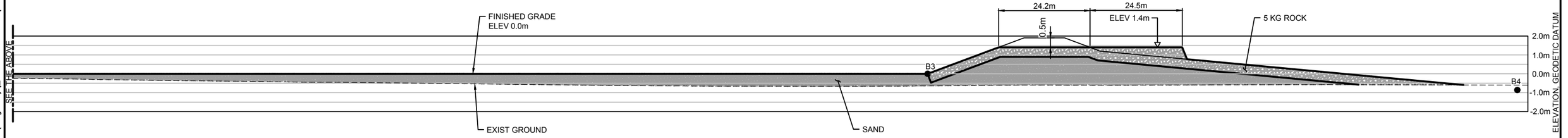




SECTION B
HOR: 1:500
VERT: 1:100
C-003 TO C-005

CONSTRUCTION





SECTION B
HOR: 1:500
VERT: 1:100
C-003 TO C-005

POST CONSTRUCTION

WORK POINTS			
	NORTHING	EASTING	ELEVATION (m) GEODETIC DATUM
B1	5442484.73	482968.46	-0.79
B2	5442484.73	483065.77	0.0
B3	5442484.73	483618.18	0.0
B4	5442484.73	483774.59	-0.86

LEGEND:

5KG ROCK

SAND

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

2m 0m 2m 4m
VERTICAL SCALE: 1 : 100

10m 0m 10m 20m
HORIZONTAL SCALE: 1 : 500

Ref.No.	REFERENCE

moffatt & nichol

IN ASSOCIATION WITH:

GL Williams & Associates Ltd.
Shoreline Management Consulting

No.	Date	REVISION IN PROGRESS REVISION	Dr'n	Ch'd

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DATE	July 24, 2020
SCALE	AS SHOWN
PMV SITE	

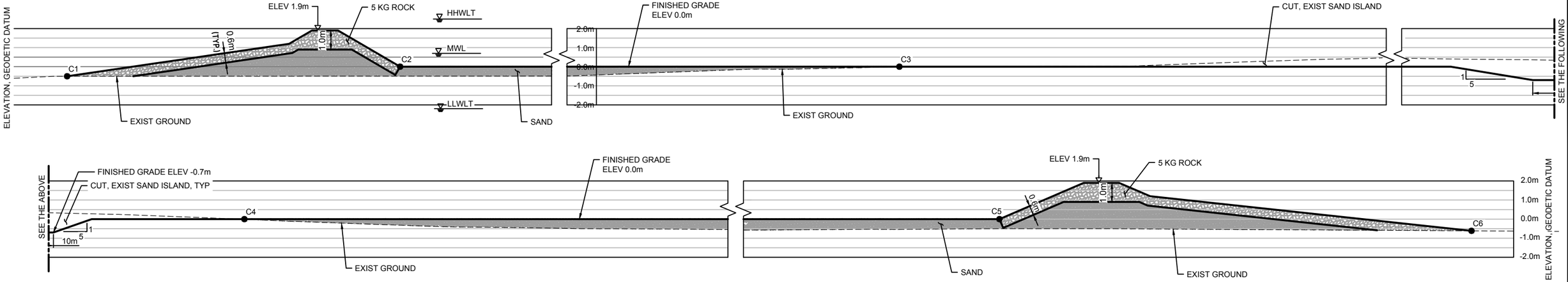
RBT2 OFFSETTING
SOUTH ARM JETTY TIDAL MARSH
SECTIONS (2 OF 4)

SIZE	DWG.	SHEET	REV.
D	C-008	11 of 13	

TITLE BLOCK DL-TB.dwg

DATE: 2020/07/24 - 2:57pm
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TITLE BLOCK: DL-TB.dwg



SECTION C

HOR: 1:500
VERT: 1:100

C-003 TO C-005

CONSTRUCTION

WORK POINTS			
	NORTHING	EASTING	ELEVATION (m) GEODETIC DATUM
C1	5442342.84	482781.05	-0.5
C2	5442342.84	482868.41	0.0
C3	5442342.84	483054.18	0.0

WORK POINTS			
	NORTHING	EASTING	ELEVATION (m) GEODETIC DATUM
C4	5442342.84	483534.20	0.0
C5	5442342.84	483972.30	0.0
C6	5442342.84	484096.15	-0.61

SECTION C

HOR: 1:500
VERT: 1:100

C-003 TO C-005

POST CONSTRUCTION

LEGEND:

5KG ROCK

SAND

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

2m 0m 2m 4m
VERTICAL SCALE: 1 : 100

10m 0m 10m 20m
HORIZONTAL SCALE: 1 : 500

DATE: 2020/07/24 - 6:15pm
PATH: Q:\VAN\9117 RBT2 Working Folder\CADD_Active_SheetSet (Mitigation)_SOUTH ARM JETTY\9117-C-009 Sections - 3.dwg

Ref.No.	REFERENCE

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DRAWN BY	AC
APPROVED	AA
DATE	July 24, 2020
SCALE	AS SHOWN
PMV SITE	

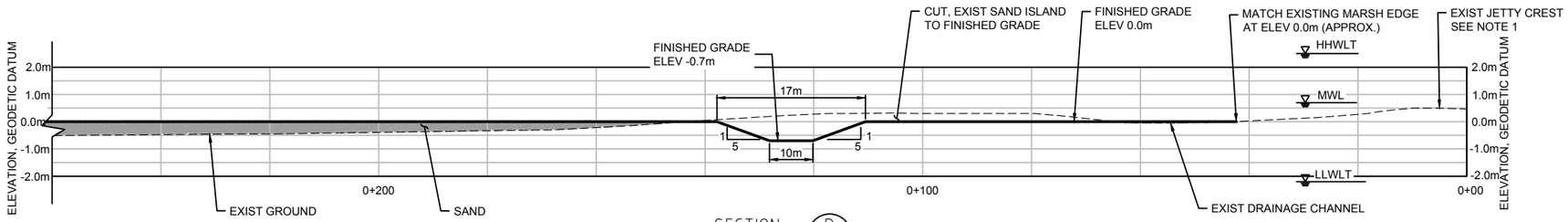
RBT2 OFFSETTING
SOUTH ARM JETTY TIDAL MARSH
SECTIONS (3 OF 4)

SIZE	DWG.	SHEET	REV.
D	C-009	12 of 13	

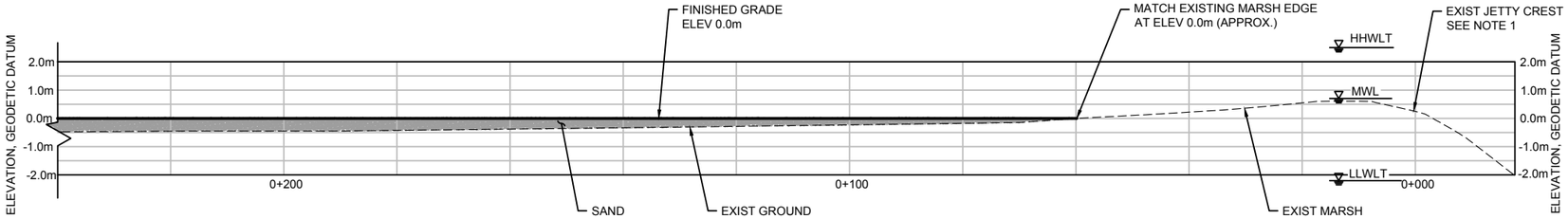
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NOTES:

1. THE PRECISE LOCATIONS OF THE EXISTING ELEMENTS AS SHOWN ON THE DRAWINGS ARE APPROXIMATE VALUES ONLY. IT IS NOTED THE ELEVATION OF THE STEVESTON NORTH JETTY VARIES. THE CONTRACTOR SHALL VISIT THE SITE OF THE WORK. TAKE HIS OR HER OWN MEASUREMENTS OF THE EXISTING STRUCTURES, GROUND AND OTHER WORK. ALL DIMENSIONS AND DETAILS SHALL BE VERIFIED BY THE CONTRACTOR PRIOR TO CONSTRUCTION. ANY DISCREPANCIES SHALL BE BROUGHT TO THE ATTENTION OF THE ENGINEER.



SECTION D
HOR: 1:500 C-003 TO C-005
VERT: 1:100



SECTION E
HOR: 1:500 C-005 TO C-003
VERT: 1:100

LEGEND:
SAND

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

2m 0m 2m 4m
VERTICAL SCALE: 1 : 100
10m 0m 10m 20m
HORIZONTAL SCALE: 1 : 500

DATE: 2020/07/24 - 6:15pm
PATH: Q:\VAN\9117 RBT2 Working Folder\CADD_Active_SheetSet (Mitigation)_SOUTH ARM JETTY\9117-C-010 Sections - 4.dwg

Ref.No.	REFERENCE

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		REVISION IN PROGRESS		

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ENGINEERING DEPARTMENT

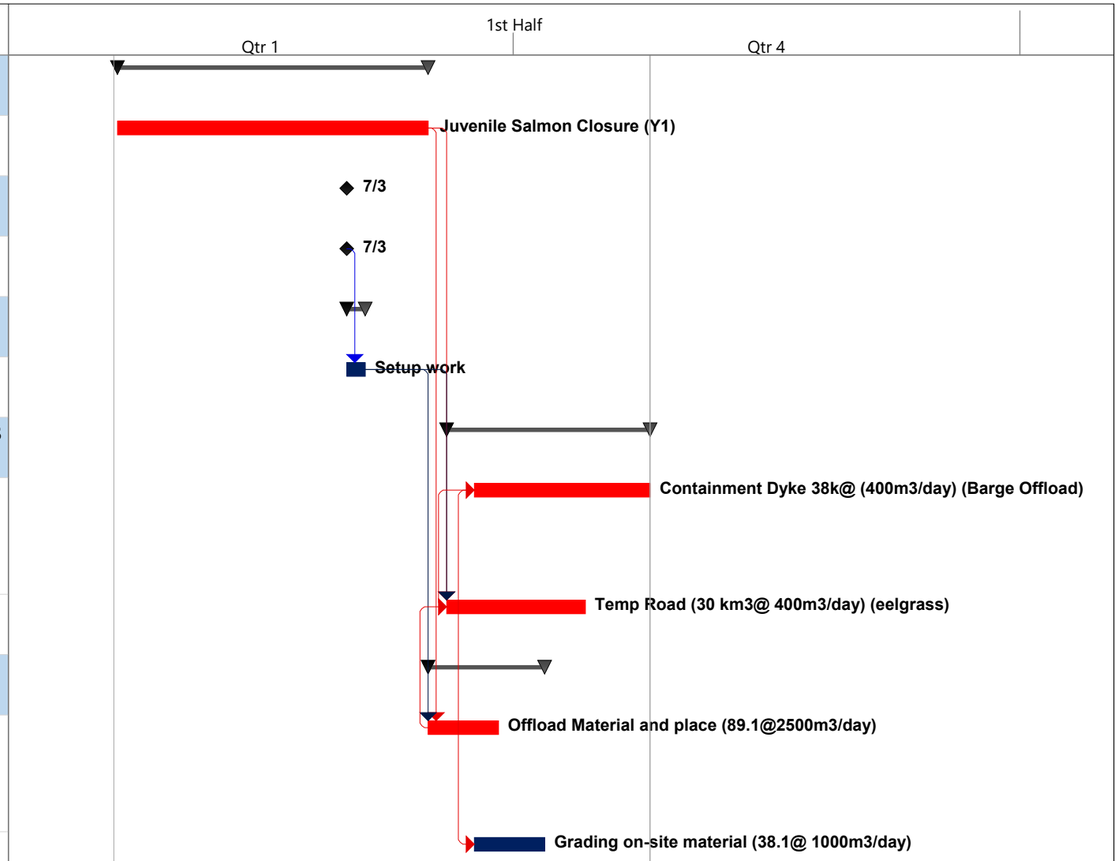
DESIGN BY	AC
DRAWN BY	AC
APPROVED	AA
DATE	July 24, 2020
SCALE	AS SHOWN
PMV SITE	

RBT2 OFFSETTING
SOUTH ARM JETTY TIDAL MARSH
SECTIONS (4 OF 4)

SIZE	DWG.	SHEET	REV.
D	C-010	13 of 13	

Appendix C:
Construction Schedule

ID	Task Name	Duration	Predecessors	Start	Finish
1	**Environmental Closures**	**168 days**		**Wed 3/1/23**	**Tue 8/15/23**
2	Juvenile Salmon Closure (Y1)	168 days		Wed 3/1/23	Tue 8/15/23
3	**Milestones and Target Dates**	**0 days**		**Mon 7/3/23**	**Mon 7/3/23**
4	Start of Construction	0 days		Mon 7/3/23	Mon 7/3/23
5	**Demolition, Setup**	**10 days**		**Mon 7/3/23**	**Wed 7/12/23**
6	Setup work	10 days	4	Mon 7/3/23	Wed 7/12/23
7	**Marsh Dyking (Inc Cobble) (38kM3)**	**110 days**		**Sat 8/26/23**	**Wed 12/13/23**
8	Containment Dyke 38k@ (400m3/day) (Barge Offload)	95 days	9SS+15 days	Sun 9/10/23	Wed 12/13/23
9	Temp Road (30 km3@ 400m3/day) (eelgrass)	75 days	2,6,11SS+10 days	Sat 8/26/23	Wed 11/8/23
10	**Fill Marsh Areas (127 kM3)**	**63 days**		**Wed 8/16/23**	**Tue 10/17/23**
11	Offload Material and place (89.1@2500m3/day)	38 days	2,6	Wed 8/16/23	Fri 9/22/23
12	Grading on-site material (38.1@ 1000m3/day)	38 days	8SS	Sun 9/10/23	Tue 10/17/23



Project: 2020.06.18 South Arm Jetty C
Date: Thu 6/18/20

Task	Inactive Task	Manual Summary Rollup	External Milestone	Manual Progress
Split	Inactive Milestone	Manual Summary	Deadline	
Milestone	Inactive Summary	Start-only	Critical	
Summary	Manual Task	Finish-only	Critical Split	
Project Summary	Duration-only	External Tasks	Progress	

Appendix D:
Coastal Analysis Report

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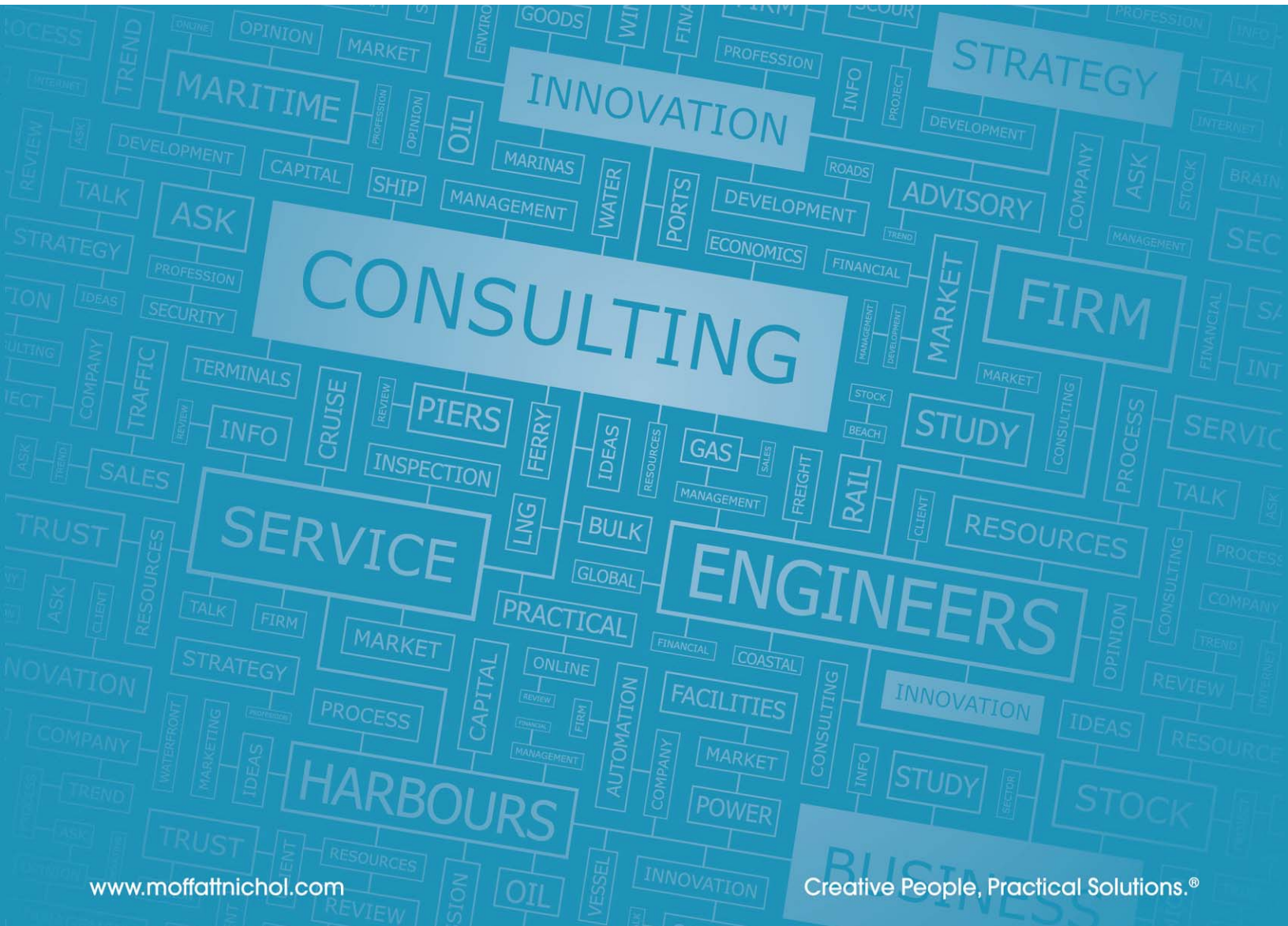
HABITAT ENHANCEMENT PROGRAM

South Arm Jetty Tidal Marsh
Coastal Processes & Salinity Modeling

PRODUCED FOR

PORT of vancouver

MAY 28, 2020



Document Verification

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Glossary

Ah	Ampere-hour
AIS	Automatic Identification System
CD	Chart Datum
CHS	Canadian Hydrographic Service
CTD	Conductivity, Temperature and Depth
CGVD2013	Canadian Geodetic Vertical Datum of 2013
d_{50}	Average Particle Size (50% Finer by Weight)
d_{75}	Quartile Particle Size (75% Finer by Weight)
DC	Direct Current
DO	Dissolved Oxygen
DHI	Danish Hydraulic Institute
FHWA	Federal Highway Administration
GD	Geodetic Datum
GLW	GL Williams & Associates Ltd
HD	Hydrodynamic
HEP	Habitat Enhancement Program
HHW	Higher High Water
HHWLT	Higher High Water Large Tide
HHWMT	Higher High Water Mean Tide
kt	Knot
LiDAR	Light Detection and Ranging
LL	Liquid Limit
LLW	Lower Low Water
LLWLT	Lower Low Water Large Tide
LLWMT	Lower Low Water Mean Tide
m	metres
M&N	Moffatt & Nichol
MWL	Mean Water Level
NRCS	National Resources Conservation Service
PI	Plasticity Index

PCB	Polychlorinated Biphenyl
PBDE	Polybrominated Diphenyl Ether
PAH	Polycyclic Aromatic Hydrocarbon
ppt	Parts Per Thousand (‰)
PSU	Practical Salinity Unit
PWGSC	Public Works and Government Services Canada
RCF	Raincoast Conservation Foundation
SAJ	South Arm Jetty
SW	Spectral Wave
τ_{max}	Maximum Bed Shear Stress (N/m^2)
US	United States
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
VFPA	Vancouver Fraser Port Authority
WQ	Water Quality

Executive Summary

Moffatt & Nichol (M&N) has been retained by the Vancouver Fraser Port Authority (VFPA) to conduct numerical modelling in support of their Habitat Enhancement Program (HEP), and the design and construction of the South Arm Jetty (SAJ) tidal marsh. The SAJ project includes construction of a cobble beach berm, raising the site grades with dredged sandy materials, and marsh planting. M&N developed spectral wave and hydrodynamic models for the Lower Fraser River and the Strait of Georgia.

Two main analyses were performed with the objectives of: *1)* Quantifying the distribution of wave-induced shear stresses at the surface of the proposed marsh substrate for existing and proposed project conditions (spectral wave simulations); and *2)* Determining the distribution of salinity between the Fraser River and Sturgeon Bank for existing and proposed project conditions (hydrodynamic simulations). A summary of the findings from both analyses is presented below.

Wave Induced Bed Shear Stress Evaluation

Introduction of the cobble berm at Sturgeon Bank can achieve the objective of reducing wave-induced bed shear stresses in the proposed marsh area and promote favorable conditions for marsh growth.

Overall, results clearly show that the cobble berm effectively reduces wave-induced bed shear stresses. Although it is noted that under extreme storm conditions, above-threshold values occur over the majority of the marsh area with or without the presence of the cobble berm, the berm does promote favorable conditions for development of the proposed marsh growth consistently throughout most of the year (e.g. 99th percentile).

Vulnerable areas, where the 99th percentile τ_{max} exceeding the threshold value, were identified in the south and southwest portions of the marsh. This is because the cobble berm provides only limited sheltering from waves in this area, and there is a more direct exposure to waves from southerly directions.

In addition, it was found that the cobble berm crest elevation is the most influential factor for reducing bed shear stresses. Shear stress values were reduced for the cases where the berm crest elevation is at +1.9 m GD. Preliminary results suggest that a short cobble berm could be implemented and still provide favorable conditions for the marsh growth. However, a more thorough investigation would be required to determine the feasibility of this option.

Salinity Distribution Analysis

Overall, model results suggest that the cobble berm will bring salinities in the proposed marsh area closer to those of the existing marsh.

During low discharge periods (e.g. winter months), the cobble berm promotes somewhat lower salinity levels in the proposed marsh area. This suggests that the fresh water retained in the marsh can be improved approximately 50% of the time during the year.

During medium discharge periods, the cobble berm also aids in a significant reduction of the salinity in the proposed marsh area.

During high discharge periods (e.g. freshet), fresh water is dominant in the proposed marsh area almost always throughout the tidal cycle, and hence the cobble berm does not affect salinity levels.

Incorporation of the Phase 2 Raincoast Project

A supplemental analysis of tidal hydrodynamics and salinity was conducted in spring 2020 to assess potential effects in the SAJ project area following the introduction of Raincoast Phase 2 breaches in the Steveston North Jetty. The hydrodynamic modelling results suggest that current speeds and salinity within the project area are similar or slightly lower in magnitude compared to the without-breaches condition. In addition, results show that the effects of the proposed SAJ breaches are limited in the project area. Therefore, the breaches of the Raincoast Project do not present any adverse effects in the SAJ project area and the proposed SAJ breaches do not provide significant benefits to the project area from a hydrodynamics and salinity perspective.

1. Introduction

1.1. Project Background

The Habitat Enhancement Program (HEP) from the Vancouver Fraser Port Authority (VFPA) has been developed to create and improve fish and wildlife habitat in advance of port development projects, to make certain that any impacts to existing habitat can be offset. Typical examples of habitat that could potentially be affected by port development include eelgrass beds, saltwater marshes and intertidal marshes. The HEP endeavors to improve or create these types of habitats, to offset any future loss.

The HEP includes the construction of the proposed South Arm Jetty (SAJ) Tidal Marsh, an intertidal marsh located on the South Arm of the Fraser River along the north side of Steveston Jetty. The site lies in Sturgeon Bank offshore of Steveston Village in Richmond, British Columbia (see Figure 1-1). In general, the project consists of a cobble beach berm, raising of site grades with sand fill, and marsh planting.

Moffatt & Nichol (M&N) was retained by VFPA to conduct wave exposure and hydrodynamic/salinity analyses in support of the design in 2017. The draft revision of the current report was submitted to VFPA on December 22, 2017.

In 2018, the Raincoast Conservation Foundation (RCF) proposed the Fraser River Estuary Connectivity Project that consists of breaching sections of the Steveston North Jetty. Tetra Tech Inc. was retained by RCF to investigate the impacts of the proposed project on navigation and on sedimentation processes in the vicinity. At present, the Phase 1 of breaches had been implemented and the Phase 2 of breaches is scheduled to proceed in spring 2020.

As a result of the RCF Project, supplemental analyses of tidal hydrodynamics and salinity were conducted to assess if the breaches implemented by the RCF could have potential impacts to the SAJ Project. The findings of these supplemental analyses are included in Appendix A of this updated report.

1.2. Project Site

The proposed South Arm Jetty Tidal Marsh is located along the north side of the Steveston Jetty within the Steveston Bend Reach of the Fraser River South Arm (Figure 1-2). This area is adjacent to the maintained deep-sea shipping channel. A large strip of marsh currently exists along the north side of the jetty.

The proposed tidal marsh site is on a shallow portion of Sturgeon Bank with elevations ranging from -0.75 m to +0.75 m Geodetic Datum (GD), with low spots at the west end of the site as low as -1.5 m GD. There is an area with higher elevation which is referred to as the “sand island.” This area is a remnant of dredge material disposal activities in the early 1980s. The adjacent Steveston North Jetty is permeable and constructed of piled rock and concrete debris. There are several low points along the jetty which allow flow to pass over the jetty and onto Sturgeon Bank (Figure 1-2).

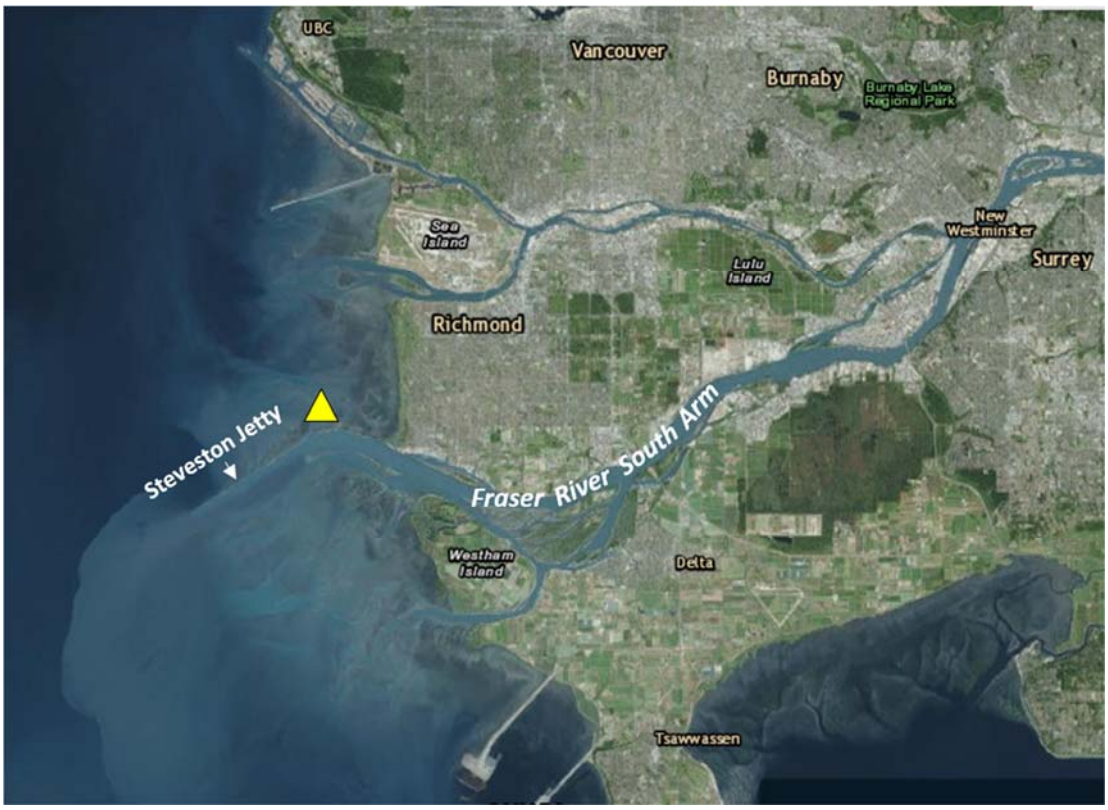


FIGURE 1-1: LOCATION OF PROJECT SITE AT FRASER RIVER SOUTH ARM



FIGURE 1-2: LOCATION OF PROPOSED SAJ TIDAL MARSH AREA

1.3. Scope of Work

The objectives of this study are to:

1. Quantify the changes of wave-induced shear stresses at the surface of the proposed marsh substrate for existing and with-project scenarios;
2. Quantify the changes of salinity for existing and with-project scenarios; and
3. Assess if the breaches implemented by the RCF Project have any potential impacts to the SAJ project area.

Two primary analyses were investigated, wave exposure and salinity analysis.

Wave exposure analysis included the following tasks:

- Simulate wave exposure for existing conditions, for a range of wind speeds, directions, and tides;
- Estimate wave-induced bed shear stress distribution over a storm cycle, as well as for dominant conditions;
- Compare to naturally colonizing areas and establish target shear stress criteria for proposed marsh; and
- Simulate wave exposure for with-project scenario, and estimate changes of wave-induced bed shear stress distribution.

Salinity analysis included the following tasks:

- Develop a coupled hydrodynamic and salinity model for tides & salinity, using the recent Light Detection and Ranging (LiDAR) bathymetry and observations of tides, river flow, and salinity;
- Simulate circulation and salinity processes for existing conditions, for a sufficient length of time (at a minimum a full spring-neap cycle);
- Compare to naturally colonizing areas and establish target criteria for proposed marsh; and
- Evaluate salinity changes for with-project scenario by using proposed marsh elevations, based on discussions with the project team and Fisheries and Oceans Canada.

2. Basis of Analysis

2.1. Topographic Data

Topographic data at the project site consists primarily of LiDAR data acquired by Stantec in 2013 and 2017. In addition, the RCF Project surveyed eastern half of the project site as well as the parcel to the east in 2019.

2.1.1. LiDAR Topography in 2013

Topographic data for the project site and vicinity was collected on October 24, 2013 using airborne LiDAR data collection. The survey was conducted at low tide and covers the area of Sturgeon Bank and Roberts Bank. Elevations were in the range from -2.6 m GD to +7.2 m GD.

Vertical datum is the Canadian Geodetic Vertical Datum of 2013 (CGVD2013, short as GD), which represents the coastal mean sea level in North America.

2.1.2. LiDAR Topography in 2017

Topographic data for the project site and vicinity was collected on August 9, 2017 using airborne LiDAR data collection. The survey was conducted at low tide and covers the areas of Sturgeon Bank, Roberts Bank, and Steveston. Elevations were in the range from -2.5 m GD to +5.7 m GD.

2.1.3. LiDAR Topography in 2019

Topographic data for the RCF Project was collected in summer 2019 by McElhanney Consulting Ltd. The survey was conducted at low tide and covers eastern half of the project site as well as the parcel to the east. Elevations were in the range from -2.3 m GD to +4.5 m GD. This latest topographic information was incorporated in the supplemental analyses (Appendix A).

2.1.4. Bed Level Changes at Project Site

Figure 2-1 shows bed level changes at the project site between the 2013 and 2017 LiDAR data. The proposed cobble beach berm is shown for reference.

Shades of red indicate lowering of the grade (erosion), shades of blue indicate an increase in elevation (accretion), and white color represents neutral, unchanged conditions. In general, Sturgeon Bank was subject to both accretion and erosion between 2013 and 2017. West of the proposed marsh area, alternating blue and red patterns indicate migration of bed forms (i.e. sand waves and dunes). The marsh area exhibits mild erosion (indicated by faint shades of red), although somewhat higher erosion occurred around the Sand Island (depicted in darker red); closer to the Richmond shoreline, blue color is more typical, indicating an increase in elevations.

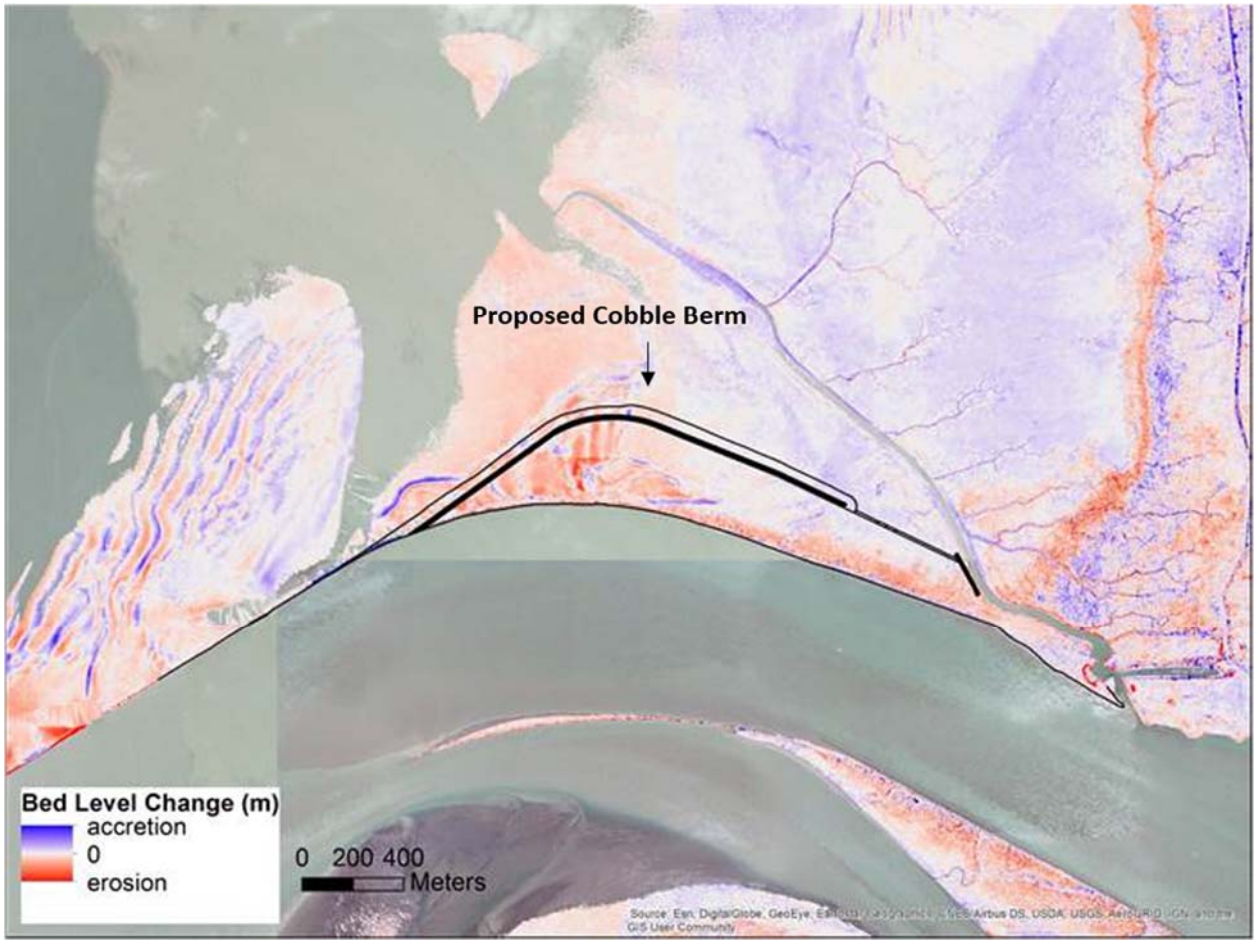


FIGURE 2-1: BED LEVEL CHANGES BETWEEN 2013 AND 2017 (*STANTEC, 2017*)

2.2. Bottom Conditions

A characterization of materials over the mudflat in the vicinity of the project site is provided in *Hemmera (2017)*. Figure 2-2 provides the location and logging of samples taken. Sample material characterization was subsequently used to develop the shaded areas in the figure depicting surficial sediments in the form of marsh (blue), mud (pink), sand (yellow), and sand/mud mix (orange).

Golder (2014) conducted a site reconnaissance, and characterizes the bottom material as overbank Fraser River sediments comprising of silty to silt clay loam, normally less than 2 m thick; overlying deltaic and distributary channel fill of interbedded fine to medium sand.

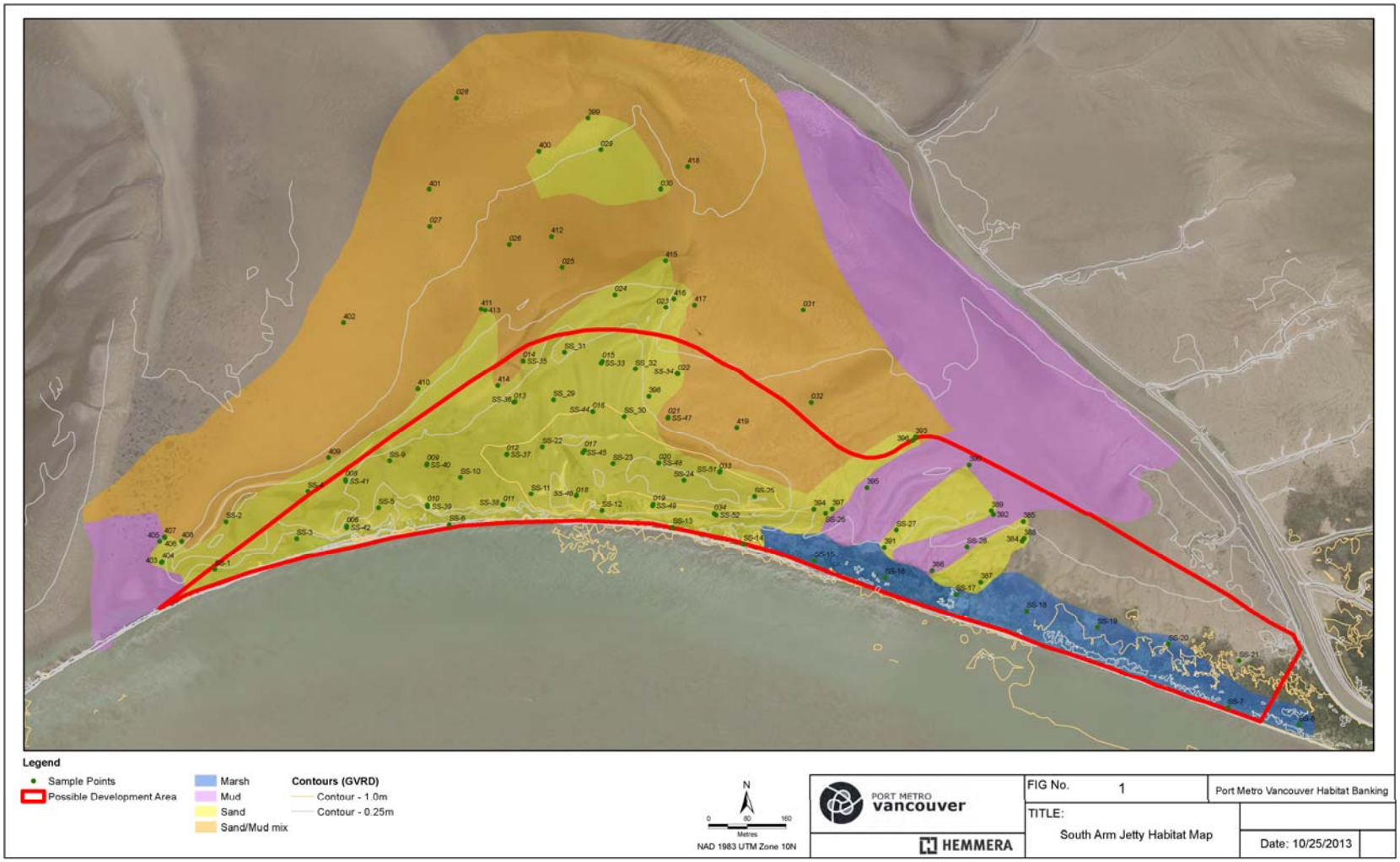


FIGURE 2-2: CHARACTERIZATION OF BOTTOM MATERIALS *(HEMMERA, 2017)*

2.3. Tidal Datums

Tidal datums for Sand Heads from published Nautical Chart *(CHS, 2005)* are provided in Table 2-1.

TABLE 2-1: TIDAL DATUMS AT SAND HEADS

Datum	m CD	Description
HHW-LT	4.9	Higher High Water – Large Tide
HHW-MT	4.3	Higher High Water – Mean Tide
MWL	3.1	Mean Water Level
LLW-MT	1.3	Lower Low Water – Mean Tide
LLW-LT	0.2	Lower Low Water – Large Tide
CD	0.0	Chart Datum

In navigable waters, Chart Datum is the common vertical datum reference. In inland waters, Geodetic Datum is more commonly used. Figure 2-3 shows how tidal datums at Point Atkinson and Sand Heads relate to water level datums for the Fraser River at Steveston. Tidal datums at Point Atkinson and at Sand Heads (left side of the figure) are purely astronomical. Tidal datums for the Fraser River, however, are affected by the amount of outflow from the river *(CHS, 2014)*. The figure shows how the tidal datums vary with reference to Geodetic Datum depending on discharge as measured at Hope. Geodetic Datum (GD) at Steveston is located at +2.2 m CD per *CHS (2005)*. It can be seen that the elevations of higher high water mean and large tides remain fairly constant. Elevations of lower low tides (mean and large) increase with increasing discharge.

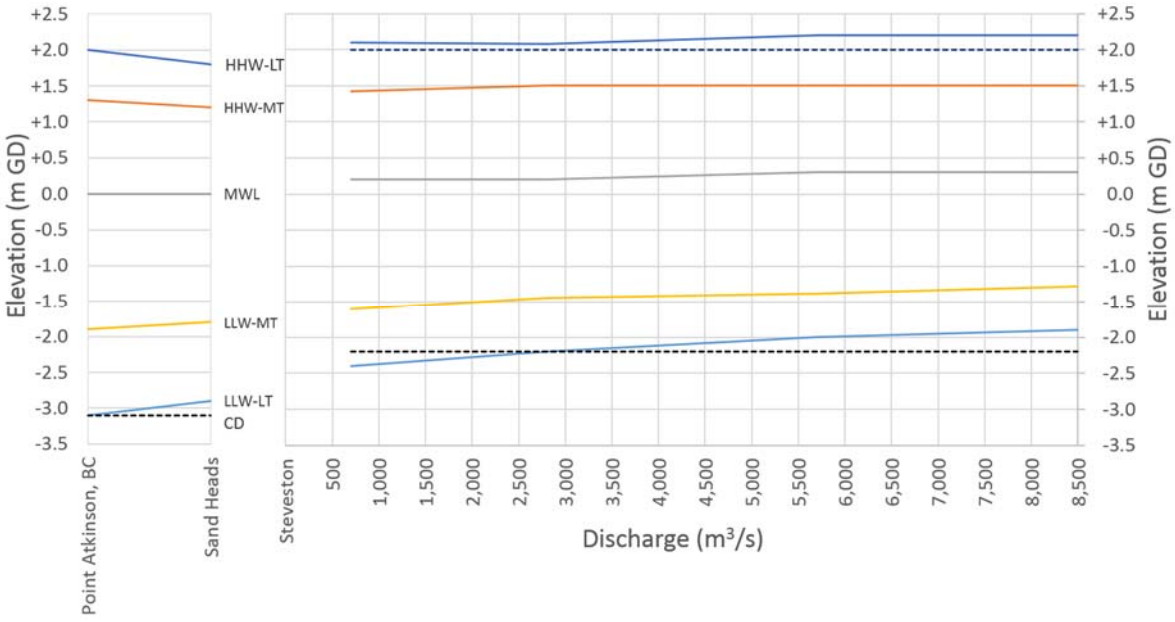


FIGURE 2-3: VARIATIONS OF TIDAL DATUMS AT STEVESTON VS. FRASER RIVER DISCHARGE

2.4. Fraser River Discharge

The gross drainage area of the Fraser River is approximately 217,000 km^2. Hydrometric data, including water levels and discharge data has been measured at Hope (Figure 4-1) since 1912, capturing a period of record of 106 years.

Figure 2-4 summarizes the maximum, minimum, and mean discharge data recorded at Hope. Additionally, the year 1991 is shown, taken as representative of average conditions.

It can be seen that outflow from the river remains fairly constant over the months from January to mid-April, and increases rapidly through mid-June. Over the months of July to October, the outflow decreases pronouncedly, followed by a more gradual decrease in October and November, until a somewhat constant discharge is reached around December.

The rapid increase of outflow over the spring and summer months (freshet) is due to melting of snow accumulated in the mountains over the winter months.

The annual peak discharge around mid-June can range from approximately 4,000 m^3/s (blue curve) to 15,000 m^3/s (green curve). The average peak discharge is around 7,000 m^3/s (brown curve). In dry years, the base outflow can be lower than 1,000 m^3/s, increasing to 2,000-4,000 m^3/s in wet years.

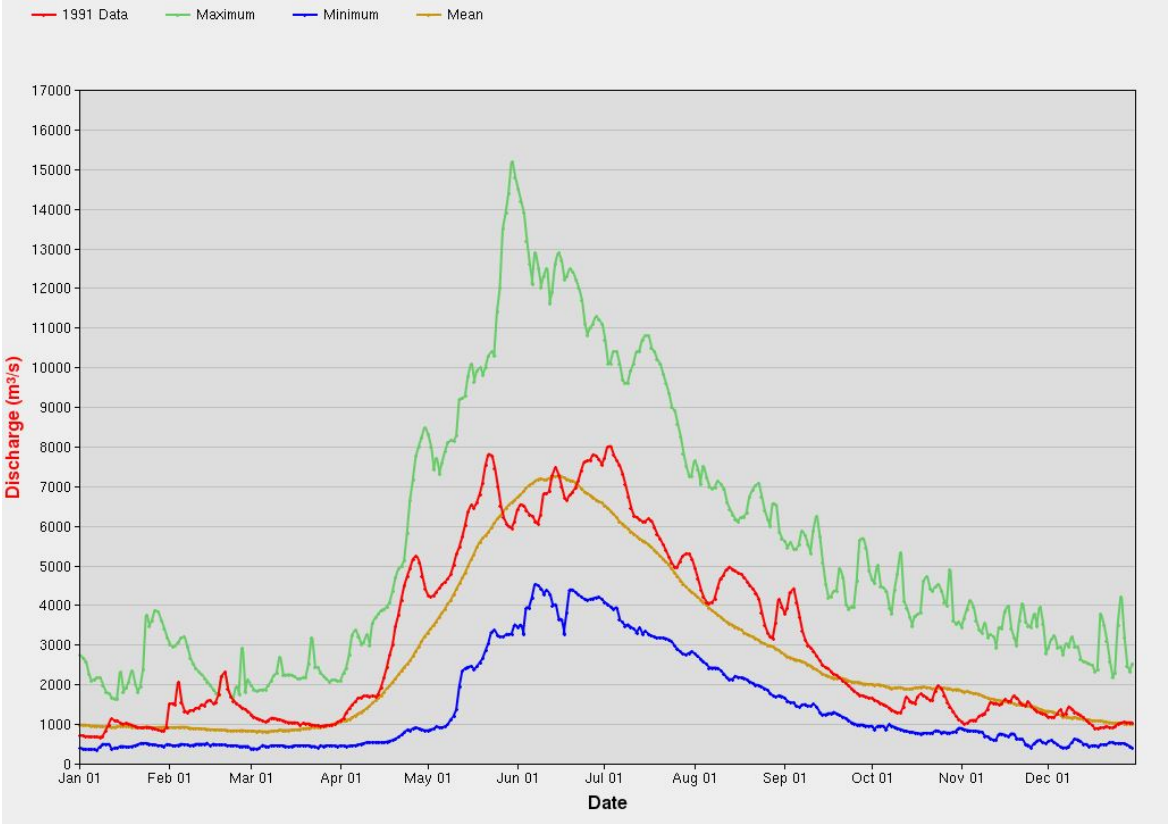


FIGURE 2-4: FRASER RIVER DISCHARGE (*EC, 2017*)

2.5. Fraser River Salinity Data

Water is drawn from the Fraser River for consumption, industrial, and agricultural uses. The salinity of the water depends on how far upstream the water is sourced. The extent of salinity intrusion up the Fraser River is strongly dependent on the river outflow (discharge), which varies annually. The salinity intrusion is greater in years with low river discharge.

Salinity data was acquired from *ENVIRODAT (2017)* for the Fraser River Water Quality Buoy. The buoy provides continuous real-time sampling of surface water quality parameters utilized to assess the quality of Fraser River. The location of the buoy is shown in Figure 2-5, which is near Tilbury at Gravesend Reach, at Latitude/Longitude 49.1484°N, 123.0392°W.

The buoy provides continuous real-time tracking of dissolved oxygen (DO) content, water pH value, conductivity, turbidity, water velocity, and water temperature. Levels of trace metals, nutrients, major ions, and coliforms are logged bi-weekly. The buoy also has the ability to track levels of a range of organic contaminants, including pesticides, nonylphenols, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and polybrominated diphenyl ether (PBDEs).

Additional instrumentation on the buoy captures wind speed, wind direction, air pressure, relative humidity, water depth, and buoy position and heading.

The buoy is also outfitted with an Automatic Identification System (AIS) transmitter and amber flashing navigational light, which enables vessels on the river to track and identify the buoy location.

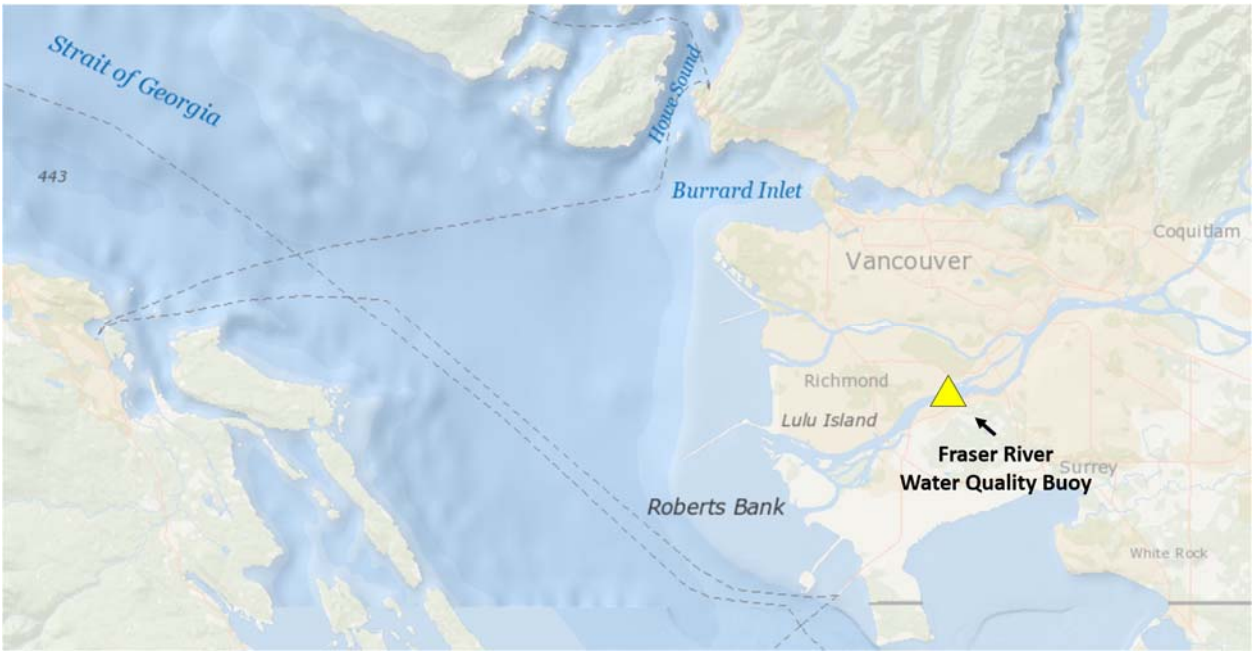


FIGURE 2-5: LOCATION OF FRASER RIVER WATER QUALITY BUOY

Figure 2-6 provides a summary of water temperature and salinity over the range of years from 2008 through 2017. Water temperature is indicated by the blue and grey curves according to the scale on

the left side of the figure. Salinity levels are indicated by the yellow to red curves per the scale on the right side of the figure.

It can be seen that the water temperature variation falls within a fairly narrow range, progressively increasing from 2-4°C in January to 18-22°C peaking in August, followed by a steady decrease through December.

Salinity levels through the year are inversely related to outflow from the Fraser River. Salinities of up to 15-18 ppt are recorded in the months from September to December through April (low discharge months). Over the summer months from May through August, i.e. the peak discharge months, the water is fresh.

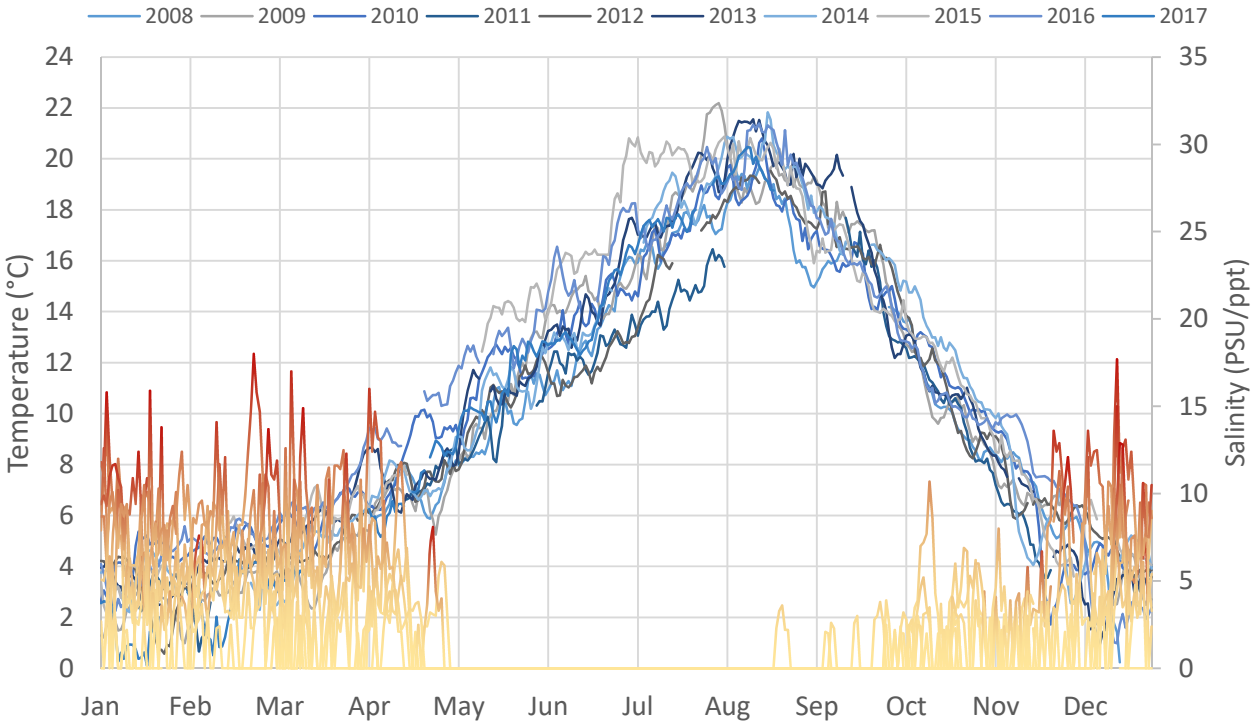


FIGURE 2-6: WATER TEMPERATURE AND SALINITY DATA FROM FRASER RIVER WQ BUOY *(ENVIRODAT, 2017)*

Figure 2-7 shows an example of the intertidal variation of salinity levels. The dark blue curve indicates the tide stage recorded at the buoy in meters relative to the scale on the left side. The green curve shows the corresponding flow velocities in meters per second, measured on the same scale. Flood tides are denoted by positive values and ebb tides by negative values. It can be seen that the tidal currents oscillate around a mean of around -0.4 m/s, which represents the steady outflow from the river.

The variation of the salinity level is indicated by the orange/red curve, with units in PSU/ppt per the scale on the right side of the figure. It can be seen that the variation of the salinity follows each tidal cycle, increasing on flood tides as saltwater propagates inland, and decreasing on ebb tides where more freshwater flows out.

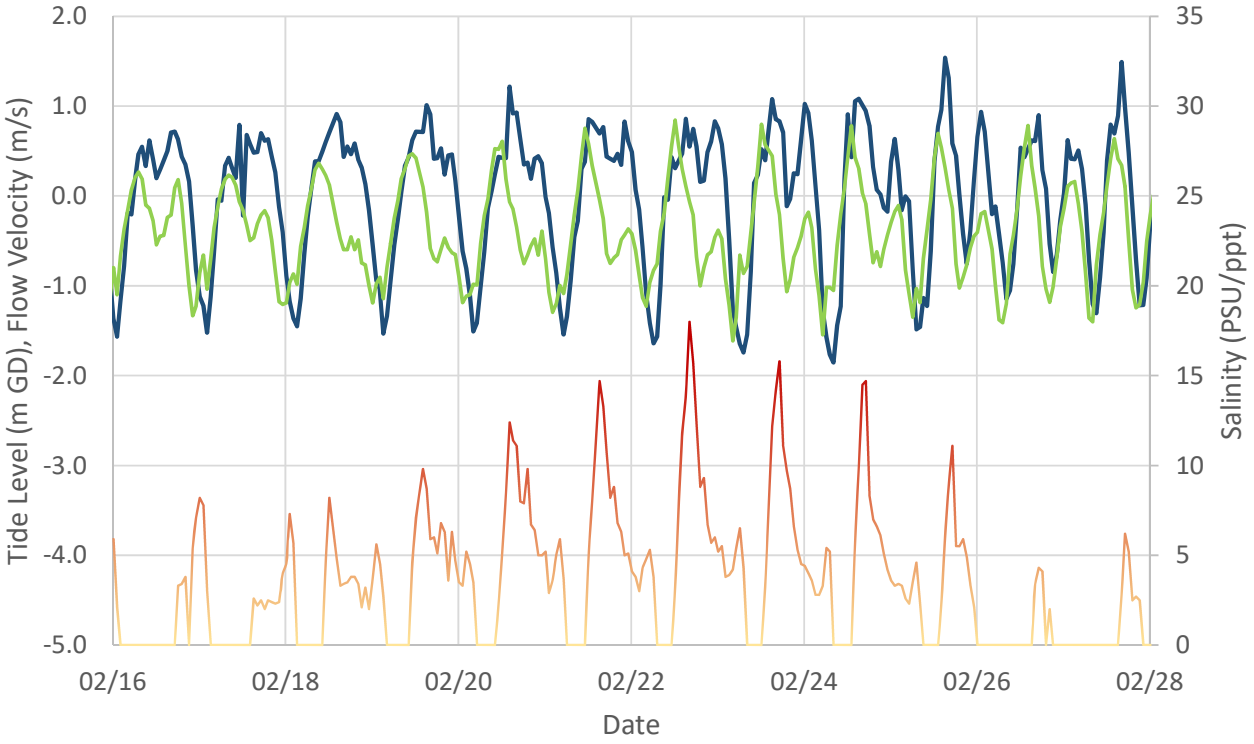


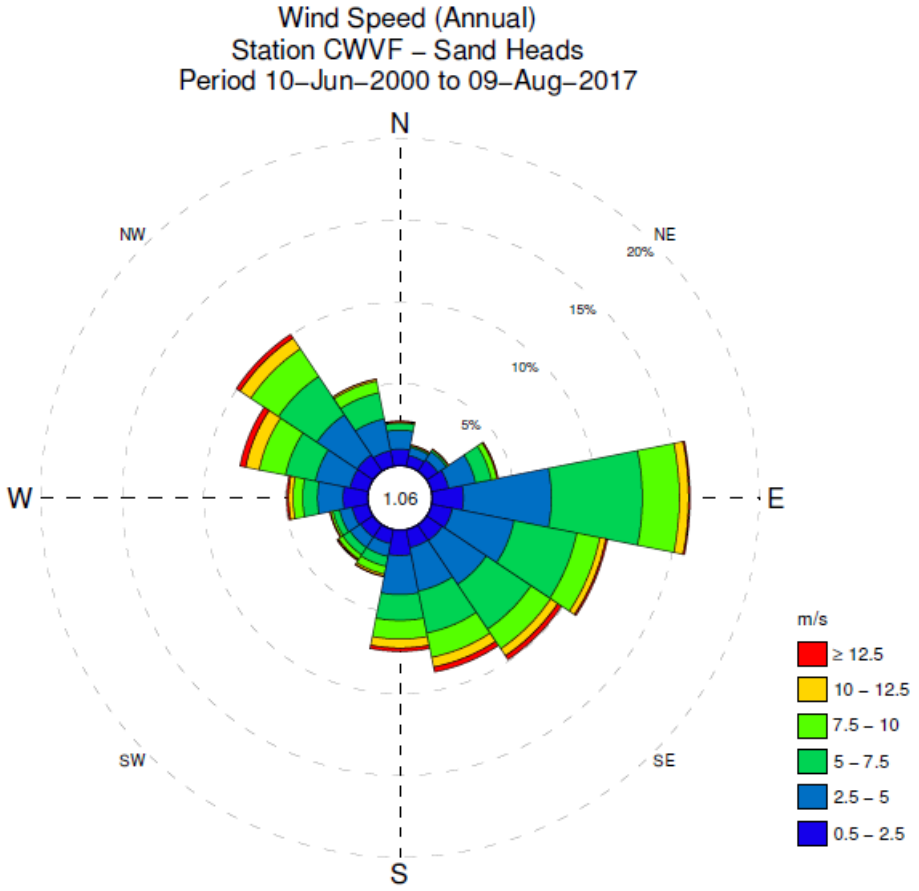
FIGURE 2-7: VARIATIONS OF SALINITY DURING FLOOD AND EBB TIDE *(ENVIRODAT, 2017)*

2.6. Wind Statistics

A metocean gauge located at Sand Heads has collected wind data since 2000. The location of the gauge (labeled as CWVF) is shown in Figure 4-1. Wind statistics for the station are summarized in Figure 2-8. The distribution of wind direction shows that predominant wind directions are from west-to-northwest sector, and from south-to-east sector.

These directions reflect the open-water configuration in the Strait of Georgia, having a great expanse to the northwest. The winds from easterly directions are representative of overland conditions. The topography of the inland area and mountain ranges to the north have the effect of generally funneling winds from east over the Vancouver area. The effect is consistent and the Vancouver Airport runways are therefore aligned approximately east-west orientation.

The table in Figure 2-8 summarizes the occurrence of wind speeds by direction. It can be seen that extreme wind speeds can exceed 12 m/s, but winds are more commonly below 10 m/s. The distribution of the highest winds shows that storm systems entering the Strait of Georgia can generate high winds from virtually any direction at Sand Heads, but less frequently from north-easterly direction.



Percentage of Occurrence

Wind Speed, m/s	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	2.71	1.30	1.58	4.12	15.77	10.97	9.91	8.87	7.40	2.92	2.63	2.36	4.93	7.99	10.05	5.42	98.94
12.5						0.11	0.27	0.31	0.20				0.11	0.35	0.26		1.81
10					0.57	0.37	0.52	0.61	0.55	0.14			0.27	0.84	0.80	0.12	5.01
7.5				0.35	2.27	1.44	1.45	1.52	1.15	0.49	0.32	0.15	0.59	1.65	2.03	0.73	14.27
5	0.43	0.10	0.14	0.99	5.57	3.91	3.29	2.62	1.58	0.62	0.54	0.41	0.90	1.87	2.82	1.63	27.43
2.5	1.16	0.50	0.62	1.68	5.38	3.85	3.24	2.71	2.40	0.79	0.77	0.78	1.56	2.16	2.96	1.98	32.55
0.5	0.99	0.65	0.80	1.04	1.89	1.27	1.13	1.10	1.53	0.87	0.90	0.98	1.49	1.12	1.16	0.95	17.88
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total

FIGURE 2-8: ANNUAL WIND ROSE AT SAND HEADS

2.7. Wave Statistics

Wave data for Station C46146 Halibut Bank (see Figure 4-1) is summarized in Figure 2-9. The data shows the annual percentage of occurrence. The majority (87%) of the waves recorded at the buoy have wave periods in the range from 2 to 10 seconds, which is representative of wind-waves dominated in the Strait of Georgia. The remaining longer-period waves in the form of remnant swell wave components may enter Strait of Georgia from the Pacific Basin.

During storm events, wind-generated wave heights can reach up to 2.1 meters in magnitude. This is expressed as the significant wave height, which is the average of the 1/3 of the largest waves. As a rule-of-thumb, the highest waves can be estimated around 1.8 times the significant wave height, and therefore on the order of 4 m (1.8×2.1). For reference, the height of an individual wave is measured from the trough to the crest.

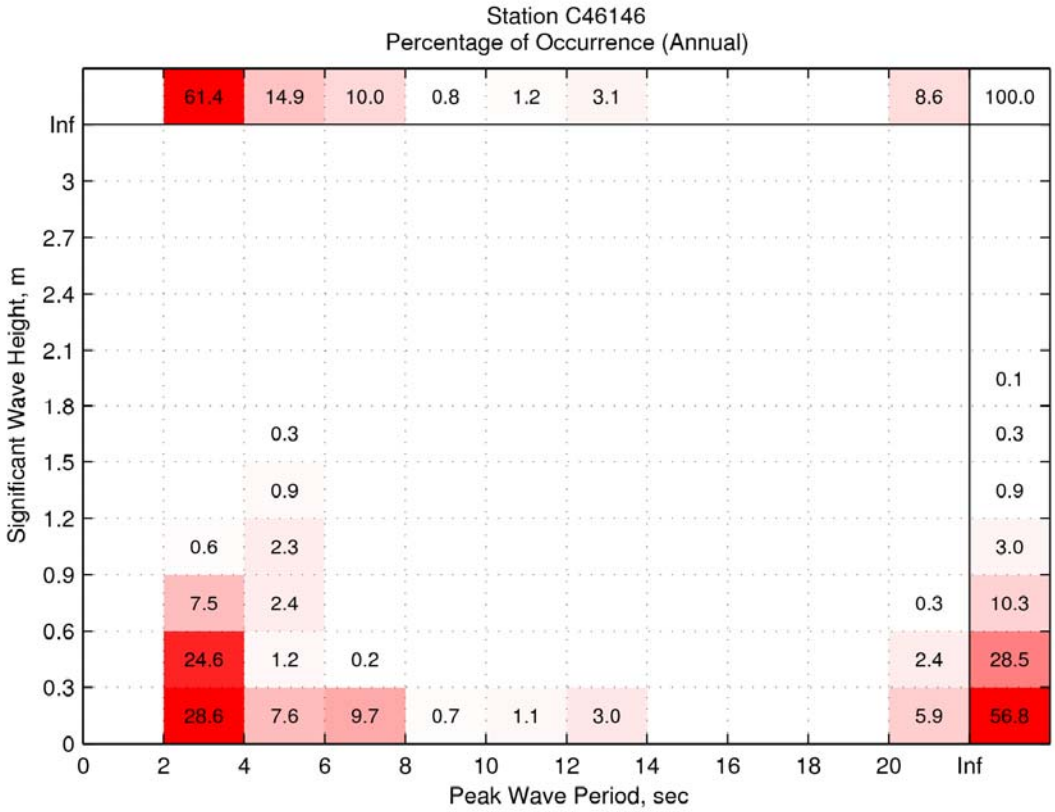


FIGURE 2-9: WAVE STATISTICS FOR HALIBUT BANK BUOY

3. Tidal Marsh Ecological Criteria

3.1. Soils

A characterization of surficial soils at the site is summarized in Figure 2-2. In addition to materials existing at the site, new fill material will be introduced in order to develop the grade at the site to the level appropriate for marsh vegetation.

In the following, information is provided on the permissible shear stress for material types such as those existing and planned for the site.

Table 3-1 summarizes typical permissible shear stresses for channels in bare soil to rock with linings across the range from non-cohesive to cohesive materials. Shear stress is defined as the force per unit area (expressed in N/m^2) applied parallel to the surface of a material.

TABLE 3-1: TYPICAL PERMISSIBLE SHEAR STRESS, REPRODUCED FROM *FHWA (2005)*

Material Category	Material Type	Permissible Shear Stress (N/m^2)
Bare Soil (PI = 10)	Clayey sands	1.8 to 4.5
	Inorganic silts	1.1 to 4.0
	Silty sands	1.1 to 3.4
Bare Soil Cohesive (PI ≥ 20)	Clayey sands	4.5
	Inorganic silts	4.0
	Silty sands	3.5
	Inorganic sands	6.6
Bare Soil Non-cohesive (PI < 10)	Finer than coarse sand d_{75} < 1.3 mm	1.0
	Fine gravel d_{75} = 7.5 mm	5.6
	Gravel d_{75} = 15 mm	11.0
Gravel Mulch	Coarse gravel d_{50} = 25 mm	19.0
	Very coarse gravel d_{50} = 50 mm	38.0
Rock riprap	d_{50} = 0.15 m	113.0
	d_{50} = 0.30 m	227.0

Permissible shear stress for non-cohesive material depends on the submerged weight of the material relative to the tractive force. The submerged weight is commonly described by a characteristic material grain size. The angularity of the material also affects its stability, but to a lesser degree when the material is placed horizontally or near-horizontally.

The grain sizes of cohesive materials are typically so small that the diameter does not affect the stability of the materials. The permissible shear stress for cohesive materials is therefore more complex and depends primarily on the plasticity index (PI) of the material, the void ratio, and to a lesser extent the angularity of the grains.

Details on permissible shear stress for non-cohesive and cohesive soils are provided in the following.

3.1.1. Non-Cohesive Soils

Figure 3-1 shows the allowable effective stress for non-cohesive materials for the range from fine sand to coarse gravel (solid black line). The theoretical threshold of mobility is indicated by the yellow line. This relation arises from the following relations:

$$\theta_c = \frac{U_{fc}^2}{(s-1)gd}$$

Where θ_c is the dimensionless critical Shield's Parameter, g is the gravitational acceleration, d is the sediment grain diameter, and s is the relative density of the sediment defined as:

$$s = \frac{\rho_s}{\rho_w}$$

Where ρ_s is the density of the sediment, and ρ_w is the density of the water.

The critical bed friction velocity, U_{fc}, is defined as:

$$U_{fc} = \sqrt{\frac{\tau_b}{\rho_w}}$$

Where τ_b is the critical bed shear stress.

The theoretical threshold of sediment mobility indicated by the yellow line in Figure 3-1 arises following introduction of the Shields-Rouse equation for the threshold of incipient motion (critical Shields Parameter), given by:

$$\theta_c = \frac{0.23}{d_*} + 0.054 \cdot \left(1 - exp\left(-\frac{d_*^{0.85}}{23}\right)\right)$$

Where d_* is the dimensionless sediment grain diameter, defined as:

$$d_* = \left(\frac{(s-1)g}{\nu^2}\right)^{\frac{1}{3}} d$$

Where ν is the kinematic viscosity of water.

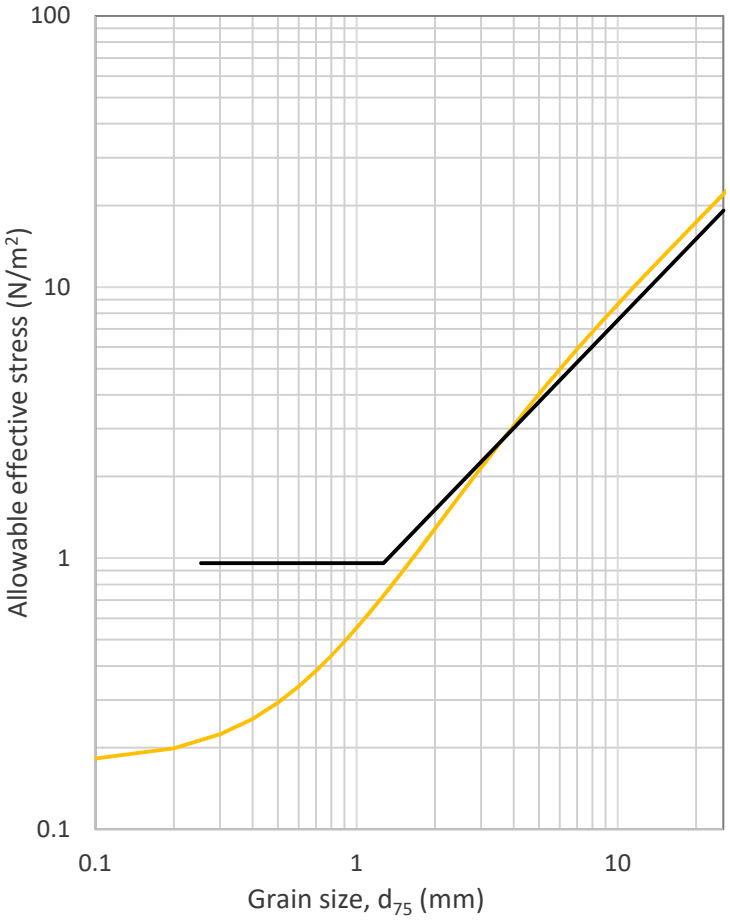


FIGURE 3-1: ALLOWABLE STRESS FOR NON-COHESIVE SOILS (*USDA, 2007*)

3.1.2. Cohesive Soils

Allowable stress for cohesive soils is summarized in Figure 3-2. The data covers selected material types as categorized per the Unified Soil Classification System (USCS) summarized in Table 3-2. The materials include clayey gravel (GC), fat clay (CH), silty gravel (GM), lean clay (CL), clayey sand (SC), elastic silt (MH), organic clay and organic silt (OH) with LL≥50, silt (ML), organic clay and organic silt (OL) with LL<50, and silty sand (SM).

TABLE 3-2: UNIFIED SOIL CLASSIFICATION SYSTEM (ABBREVIATED)

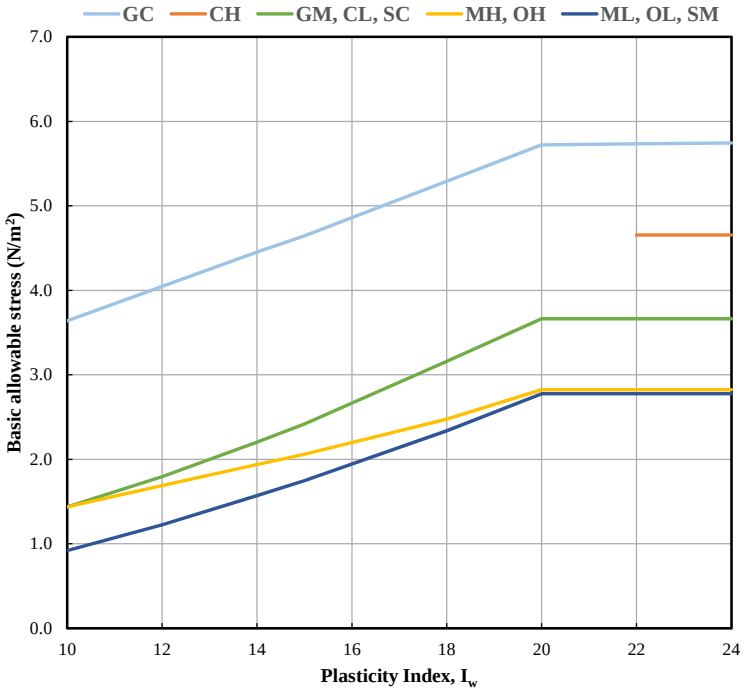
Classification		ID	Description
Gravels	Clean	GW	Well graded gravels
		GP	Poorly graded gravels
	With Fines	GM	Silty gravels
		GC	Clayey gravels
Sands	Clean	SW	Well graded sands
		SP	Poorly graded sands
	With Fines	SM	Silty sands
		SC	Clayey sands
Silts and Clays LL 50% or less		ML	Inorganic silts
		CL	inorganic clays
		OL	Organic silts or clays
Silts and Clays LL greater than 50%		MH	Inorganic silts
		CH	inorganic clays
		OH	Organic silts or clays
Highly Organic Soils		Pt	Peat

The graph on the left side of Figure 3-2 provides the basic allowable shear stress as a function of the plasticity index. The figure on the lower right provides an adjustment factor, which can range from 0.8 to 1.2 dependent on the void ratio of the material,

The void ratio of the material is the ratio of the volume of voids to the volume of the solids. The void ratio, e, also relates to porosity, n, as follows:

$$e = \frac{n}{1-n}$$

And is thus a measure of the compactness of the material, e.g. in non-cohesive materials the level of compaction from loose (n = 0.4) to dense (n = 0.3). In broadly graded materials such as glacial till, where smaller particles can be enclosed in the pores between larger grains, the void ratio can be as low as 0.3 (n = 0.2). Conversely, organic soils can have a very loose structure, e.g. loess having a void ratio of 0.9 ($n \approx 0.5$). Void ratios for cohesive soils are usually on the higher side with e = 0.9 to 3.2 (n = 0.47 to 0.76).



Soil Type	Void ratio, e
Loose angular-grained silty sand	0.65
Dense angular-grained silty sand	0.4
Stiff clay	0.6
Soft clay	0.9–1.4
Loess	0.9
Soft organic clay	2.5–3.2
Glacial till	0.3

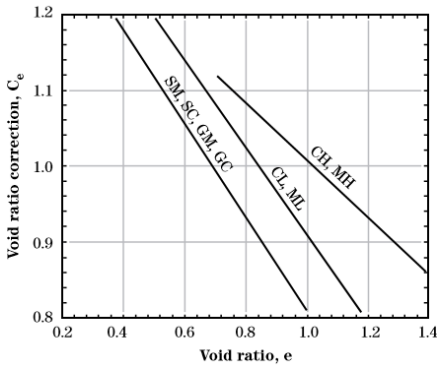


FIGURE 3-2: ALLOWABLE STRESS FOR COHESIVE SOILS *(USDA, 2007)*

3.1.3. Characteristics of Soils at Project Site

Hemmera (2014) and *GLW (2014)* summarized soils data for the habitat site and a wide range of dredge material source locations along the Fraser River and offshore.

Figure 3-3 characterizes soil types at the project location determined from samples taken at the South Arm Marsh site, *Hemmera (2014)*. The data is indicated by the crosses (×) in the figure, and shaded so that material with high sand content (left side of figure) is yellow, and transitions across orange to red with increasing amount of fines and organic content. The figure also shows soils data for source (dredge) material from Sand Heads Reach, which was determined by *GLW (2014)* to be the most suitable fill material for the site restoration. The data for this material is indicated by the circles (○) in the figure.

It can be seen that soils of the area characterize as: *sand, loamy sand, sandy loam, loam, and silt loam*.

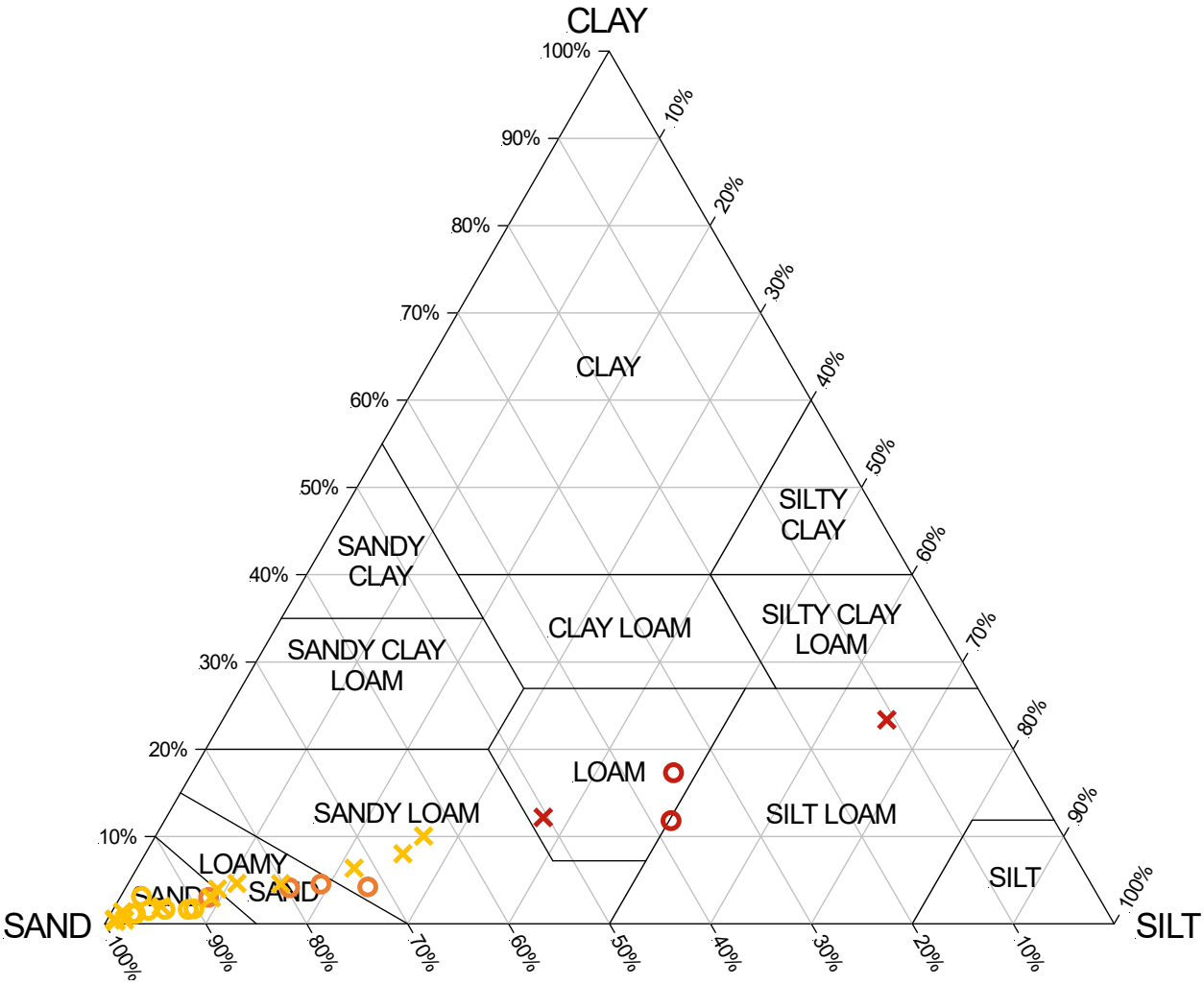


FIGURE 3-3: SOIL TYPES CHARACTERISTIC OF SOUTH ARM MARSH SITE AND SAND HEADS REACH

In order to assess the level of erodibility of materials, Figure 3-4 shows the corresponding mapping of soils characteristics per the USCS classification, which enables a characterization of the threshold of erodibility of materials via Figure 3-1 for non-cohesive sediments, and Figure 3-2 for cohesive materials.

Per the USCS classification, the South Arm Marsh and Sand Heads Reach materials generally characterize as: Well-graded sand (SW), silty sand (SM), sandy silt (MS), lean silt (ML), and clay of low plasticity, lean clay (CL).

Based on the information provided above regarding permissible shear stress and soil characteristics at Sturgeon Bank, it can be concluded that 1 N/m^2 is a reasonable and conservative target for bed shear stress in the proposed marsh area.

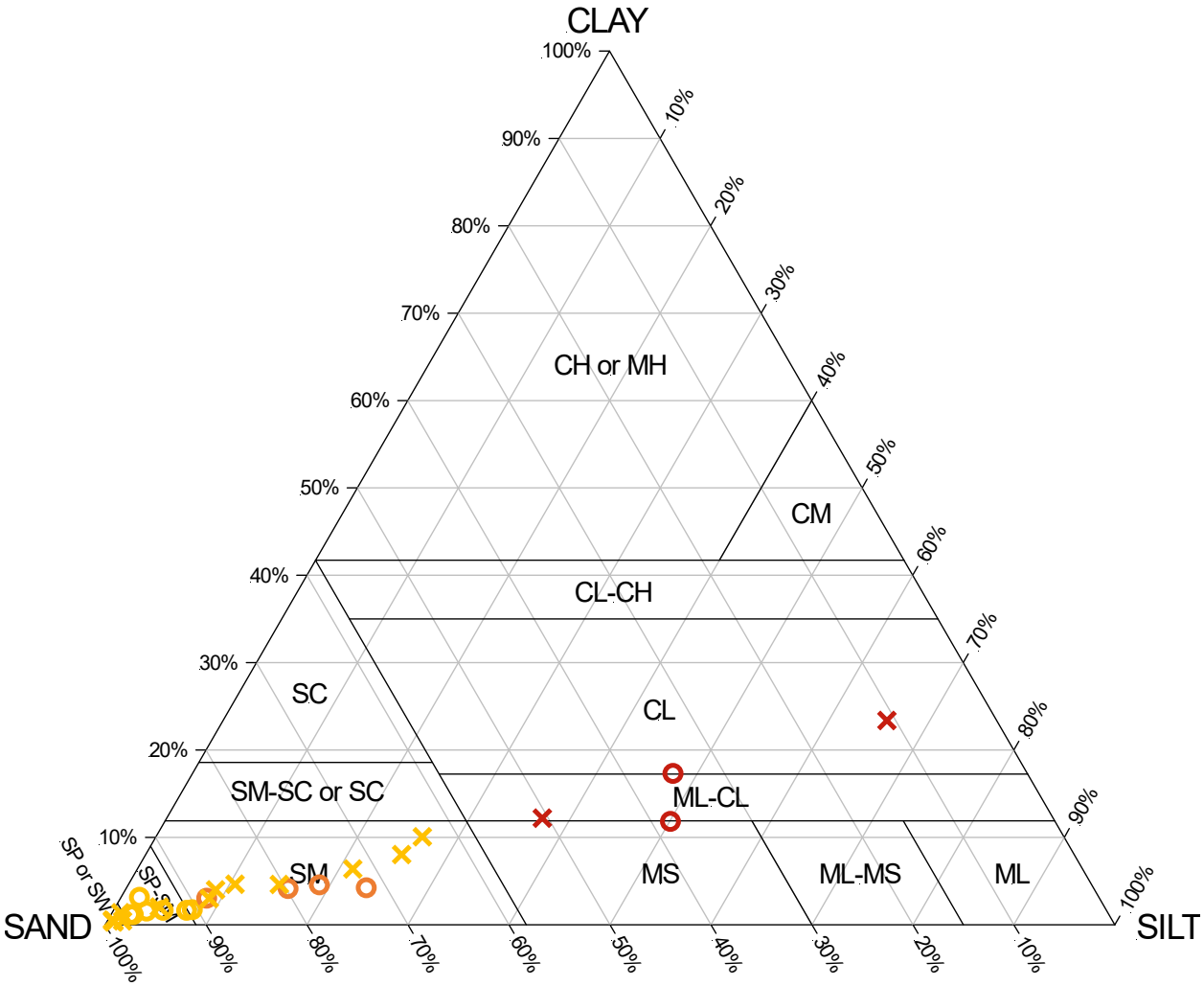


FIGURE 3-4: USCS SOIL CLASSIFICATION OF SOUTH ARM JETTY RESTORATION MATERIALS

3.2. Marsh Vegetation

3.2.1. Existing Marsh

An area of existing marsh vegetation has developed along a portion of the South Arm North Jetty, consisting of a 40-120 m wide band of marsh vegetation consisting of baltic rush, lyngbye's sedge, three-square bulrush and seacoast bulrush, *GLW (2017a)* and *M&N (2017)*. The vegetation is characterized by healthy stands of bulrush and adjoining rills 0.3 to 0.5 m deep (1 to 1½ feet). Other areas feature isolated patches of emerging stands of bulrush.

Observations from site visits indicate that the establishing marsh vegetation is likely affected by factors such as: elevation, bottom shear stress, soil organic content, salinity changes, and drainage patterns.

Sediment surface water salinities measured at the marsh platform during field visits were on the order of 4-5 PSU. Surface water salinities measured further north on the outer mudflat were 8-15 PSU.

Table 3-3 summarizes elevation ranges of plant species identified in field surveys at the South Arm Jetty and adjoining Roberts Bank.

TABLE 3-3: PROJECT AND REGIONAL PLANT ELEVATION RANGES

Plant Species	Elevation Range (m CD)		
	South Arm Jetty [1]	Roberts Bank [2]	DeltaPort Causeway [2]
Seacoast Bulrush	3.0 – 3.2	3.0 – 3.8	3.4 – 4.0
Lyngbye's Sedge	3.1 – 3.9	*3.1 – 4.2*	
Saltgrass		*3.8 – 5.0*	3.8 – 5.0
Baltic Rush	3.2 – 4.0	*3.0 – 3.4*	
Pacific Silverweed		*3.0 – 4.2*	
Pickleweed		*3.6 – 4.5*	3.6 – 4.7
Three-Square Bulrush	2.8 – 3.3	2.6 – 3.8	3.2 – 3.9
Softstem Bulrush		*3.1 – 4.3*	
Arrowgrass		*3.6 – 4.0*	3.6 – 4.0

References:

1) *GLW (2017a)*
2) *GLW (2009)*

3.2.2. Candidate Marsh Vegetation

Classification and characterization of proposed marsh vegetation is provided in the following. Candidate plants are based on existing vegetation identified during field visits *(GLW, 2017a)*, and the planting scheme proposed by GL Williams *(GLW, 2017b)*.

The taxonomy of the marsh vegetation considered is provided in Table 3-4 along with a guide to identification.

TABLE 3-4: TAXONOMY

Common Name *Scientific Name*	Clade	Family	Identification
Seacoast Bulrush *Bolboschoenus maritimus*	Monocot	Cyperaceae	
Lyngbye's Sedge *Carex lyngbyei*	Monocot	Cyperaceae	

Common Name *Scientific Name*	Clade	Family	Identification
Saltgrass *Distichlis spicata*	Monocot	Poaceae	
Baltic Rush *Juncus arcticus*	Monocot	Juncaceae	
Pacific Silverweed *Potentilla anserina*	Dicot	Rosaceae	
Pickleweed *Sarcocornia pacifica*	Dicot	Chenopodiaceae	
Three-Square Bulrush *Schoenoplectus pungens*	Monocot	Cyperaceae	
Softstem Bulrush *Schoenoplectus tabernaemontani*	Monocot	Cyperaceae	
Arrowgrass *Triglochin maritima*	Monocot	Juncaginaceae	

Table 3-5 summarizes the phytomorphology of the marsh vegetation considered. Data summarized based on information from *USDA (2017)* and *Baye (2007)*.

TABLE 3-5: PHYTOMORPHOLOGY

Common Name	Description	Foliage Color	Height (m)	Growth Form	Root Depth (m)
Seacoast Bulrush	Graminoid	Green	1.50	Rhizomatous	0.75
Lyngbye's Sedge	Graminoid	Green	1.00	Bunch	0.36
Saltgrass	Graminoid	Green	0.34	Rhizomatous	0.05
Baltic Rush	Graminoid	Green	0.70	Rhizomatous	0.40

Common Name	Description	Foliage Color	Height (m)	Growth Form	Root Depth (m)
Pacific Silverweed	Forb/herb/subshrub	Gray-Green	0.50	Multiple Stem	0.10
Pickleweed	Forb/herb/subshrub	Green	0.30	Multiple Stem	0.15
Three-Square Bulrush	Graminoid	Green	1.00	Rhizomatous	0.15
Softstem Bulrush	Graminoid	Green	2.00	Rhizomatous	0.41
Arrowgrass	Graminoid	Green	0.80	Tufted	0.20

Plant life cycle data, growth periods, growth rates, and lifespan is summarized in Table 3-6. A short lifespan is considered 1-3 years, a moderate life span 3-10 years and a long lifespan 10-20 years.

TABLE 3-6: GROWTH AND DEVELOPMENT

Common Name	Life Cycle	Active Growth Period	Lifespan
Seacoast Bulrush	Perennial	Spring, Summer	Long
Lyngbye's Sedge	Perennial	Spring, Summer	Long
Saltgrass	Perennial	Spring, Summer, Fall	Long
Baltic Rush	Perennial	Spring, Summer	Moderate
Pacific Silverweed	Perennial	Spring, Summer	Moderate
Pickleweed	Perennial	Spring, Summer	Short
Three-Square Bulrush	Perennial	Summer, Fall	Moderate
Softstem Bulrush	Perennial	Spring, Summer, Fall	Long
Arrowgrass	Perennial	Spring, Summer	Long

The salinity tolerance of marsh vegetation can be categorized as shown in Table 3-7 *(GLW, 2017b)*.

TABLE 3-7: MARSH TYPES

Marsh Type	Salinity Range (PSU)
Freshwater marsh	< 0.5
Brackish marsh	0.5 to 18
Saltmarsh	18 to 30

The pH scale shown in Table 3-8 ranges from 0-14, with neutral in the middle. Values below 7 indicate increasing acidity, while values above 7 indicate increasing alkalinity. The tabled pH values indicate that the candidate plants generally tolerate somewhat acidic to somewhat alkaline conditions. This is in line with the range expected for a saltwater marsh environment. The normal range of stream water has pH around 6 to 8, and seawater approximately pH 8.

TABLE 3-8: SALINITY AND PH TOLERANCE

Common Name	Salinity (PSU)	pH	Substrate
Seacoast Bulrush	2 - 20	4.3 - 9.0	Fines to sand
Lyngbye's Sedge	0 - 15	4.0 - 7.5	Fines to sand
Saltgrass	4 - 35	6.4 - 10.5	Fines to sand
Baltic Rush	2 - 15	7.8 - 9.1	Fines to sand
Pacific Silverweed	0 - 15	4.0 - 7.5	Fines
Pickleweed	18 - 35	6.0 - 10.0	Fines to sand
Three-Square Bulrush	0 - 20	6.0 - 7.0	Fines to sand
Softstem Bulrush	0 - 11	5.4 - 7.5	Fines
Arrowgrass	0 - 30	6.7 - 8.7	Fines



Figure 3-5 summarizes preferred water depths and salinity tolerance for the candidate marsh vegetation species. Each species is identified by its common name and its scientific name. The vertical scale on the left side of each figure provides a measure of the height of mature plants relative to ground level. Similarly, the approximate root depth is indicated below grade. The aquamarine horizontal lines indicate the preferred water level range for propagation of plant seedlings. The range indicated is typically quite narrow, but for most species fluctuating water levels will promote propagation of new shoots. The darker blue horizontal lines indicate the range of water depths preferred by the distinct types of vegetation. The lower line reflects the limit of desiccation, which is however approximate as it depends on the depth of the root system. The extent of the root system is in turn dependent on the characteristics of the substrate. The upper line can be taken as the maximum level of periodic inundation. It should be noted that some species, e.g. bulrushes prefer an environment with their root mass permanently submerged, whereas other species tolerate only periodical immersion. The maximum level of inundation is indicated by the dark blue dotted line, which is mostly shown as a wavy line, indicating that the respective species is tolerant to tidal inundation.

The vertical bar in yellow on the right-hand side of the figures indicates the salinity levels in PSU tolerated by each species. Light blue shading at the lower portion of the scale indicates species that tolerate brackish and fresh water.

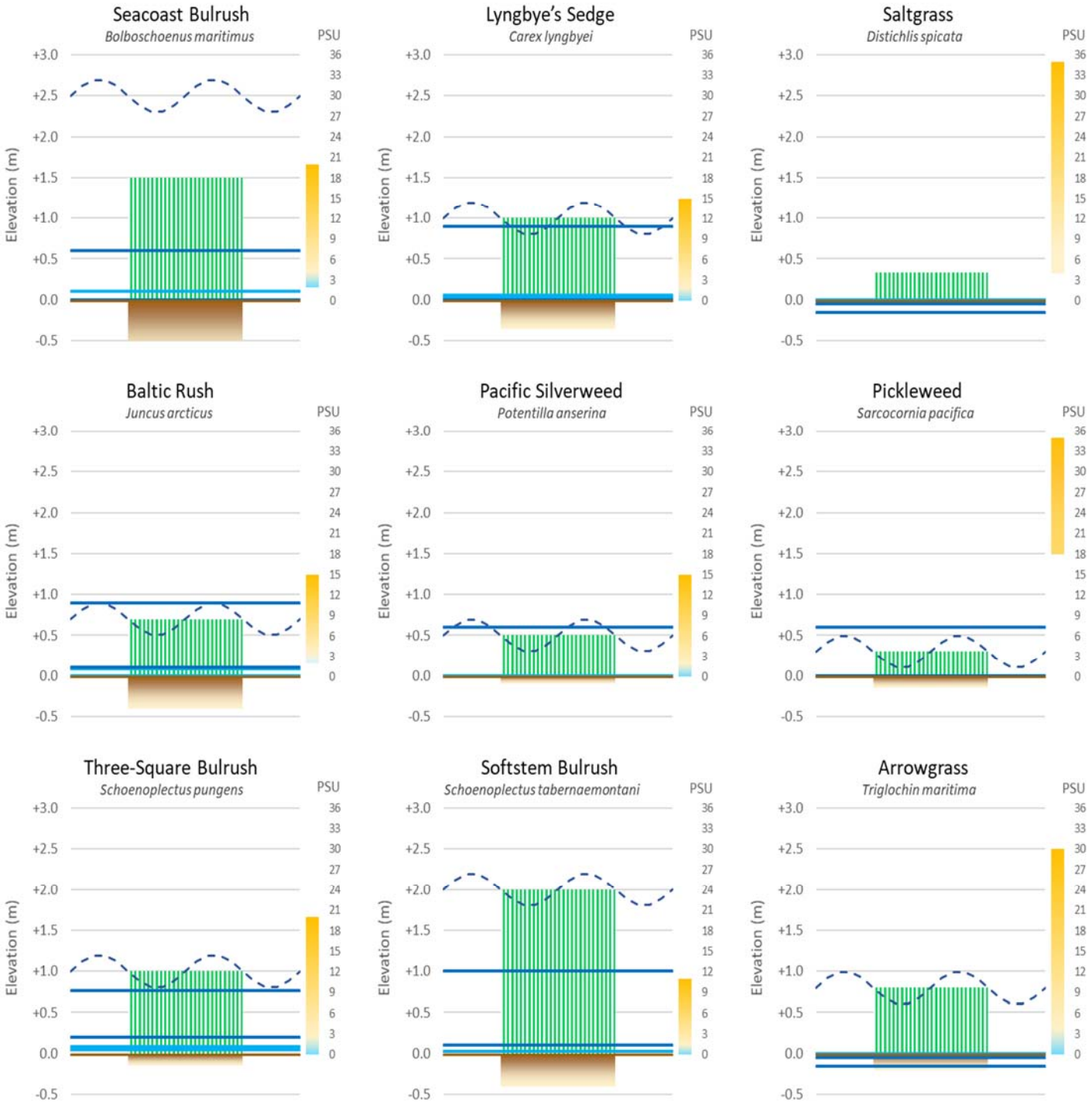


FIGURE 3-5: MARSH VEGETATION ELEVATION RANGE AND SALINITY TOLERANCE

4. Numerical Model Development

The Danish Hydraulic Institute MIKE-21 Spectral Wave (SW) and MIKE-21/3 Hydrodynamic (HD) models were developed for the Lower Fraser River and Strait of Georgia to carry out the relevant analyses and to determine engineering requirements for the proposed marsh. Both models were calibrated to ensure that wave, hydrodynamic, and salinity mixing processes were adequately reproduced. Figure 4-1 depicts the locations of the metocean data stations used in the model development.

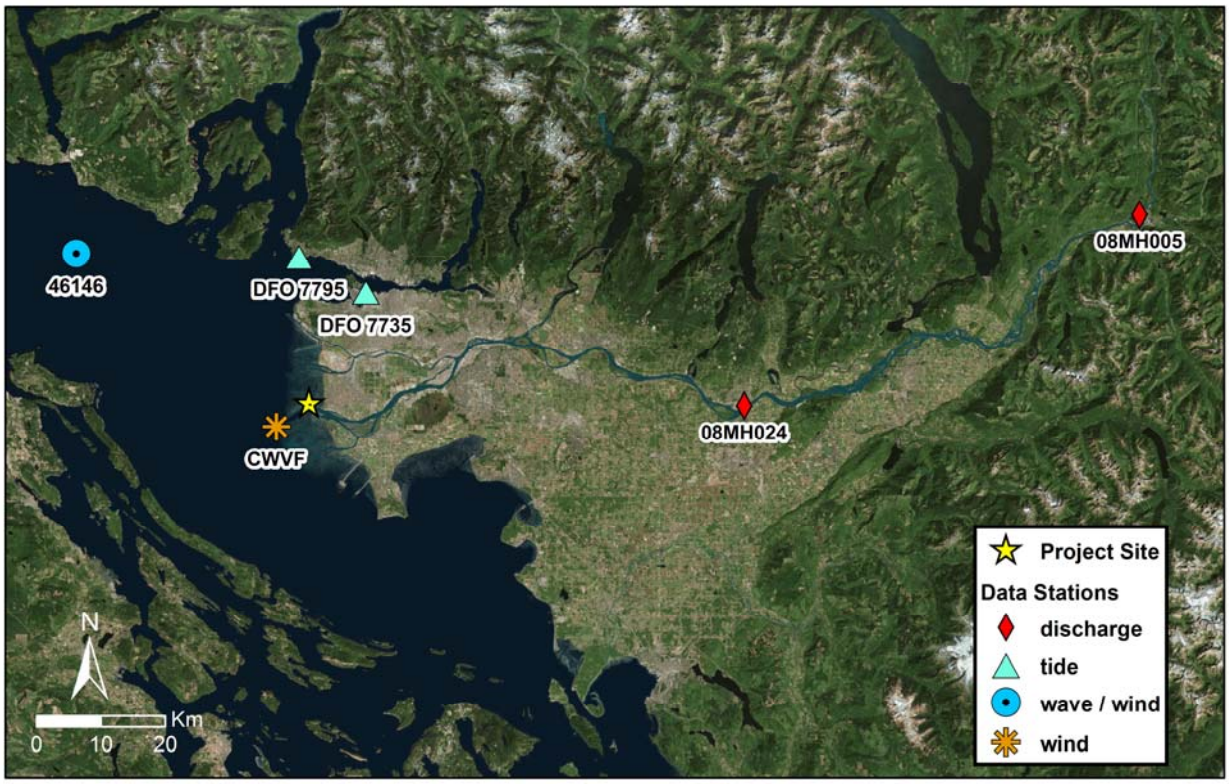


FIGURE 4-1: METEOCEAN DATA SOURCES

4.1. Model Description

MIKE is a modelling system developed by the Danish Hydraulic Institute (DHI) Water and Environment. It was selected for the project because of the flexibility and computational efficiency with its unstructured grid configuration. The unstructured grid makes it possible to resolve both large and small-scale flow and wave processes effectively. Finer resolution grid elements are used in the vicinity of the project area while coarser grid elements are used away from the areas of interest.

The two-dimensional SW model solves the wave action conservation equations and simulates the growth, decay, and transformation of wind-generated seas and long-period swells in offshore and coastal areas. The SW considers important physical processes, including wave growth by action of winds, shoaling and refraction due to depth variations, diffraction and reflection near structures, wave

breaking in the surf zone, wave dissipation (including bottom friction, white capping, and wave-wave interaction), and some non-linear wave-current interactions.

The HD model solves flow continuity, momentum, temperature, salinity and density equations and simulates water level variations and flows in response to a variety of forcing functions. Because of the complex variations in salinity mixing within the water column, the computational-demanding three-dimensional HD model was used in the study.

4.2. Model Grid and Bathymetry

For computational efficiency and accuracy purposes, different model grids were developed for the SW and HD model. To accurately reproduce wave processes such as growth and propagation to the SAJ project site, the computational domain for the SW model covers the Strait of Georgia Basin, extended around Texada Island to the northwest and Birch Bay to the south (orange polygon in Figure 4-2); while a smaller domain for the HD model (pink polygon in Figure 4-2) to resolve the complex circulation processes in the Fraser River Delta. The HD domain extends inland to Mission as the freshwater discharge source.

Figure 4-3 shows the unstructured grid elements near the project site. The finest element resolution along the SAJ North Jetty is approximately 10 m.

Bathymetry (or seabed elevations) for the majority of model domain was extracted from the C-Map Software of DHI, incorporating Jeppesen Norway's electronic database of global nautical charts (*DHI, 2008*). Figure 4-4 shows the average water depth in the Strait of Georgia is approximately 150 meters. The maximum depth can reach 400 meters, just south of Texada Island. Water depths in the Fraser River are largest on its South Arm (up to approximately 15 m) due to the presence of the navigation channel. Vertical datum reference is Geodetic Datum (GD).

A zoom-in view of the model bathymetry at Sturgeon Bank and the project site is provided in Figure 4-5. Noticeable bathymetric features in the view are the "Sand Island" shoal, with bed elevations of up to + 1.2 m GD, and the Scotch Pond and Scotch Pond Channel, dredged to elevations of around - 1.8 m GD.

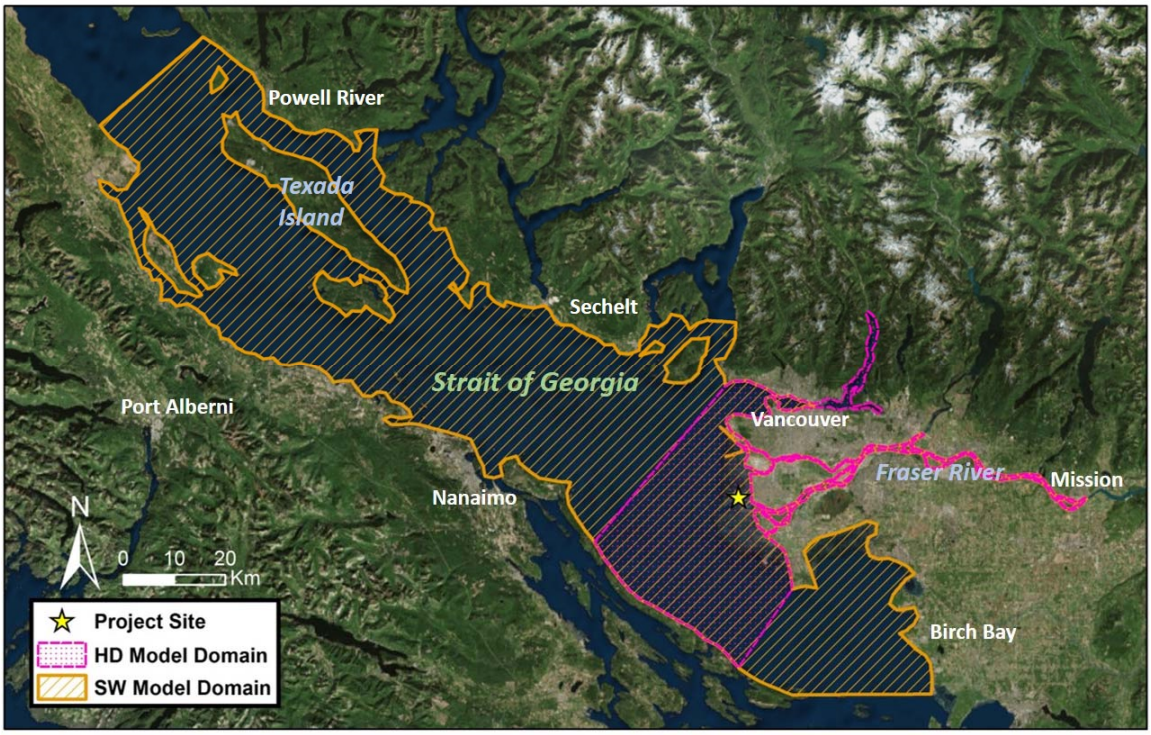


FIGURE 4-2: MODEL DOMAIN FOR SPECTRAL WAVE AND HYDRODYNAMIC MODELS

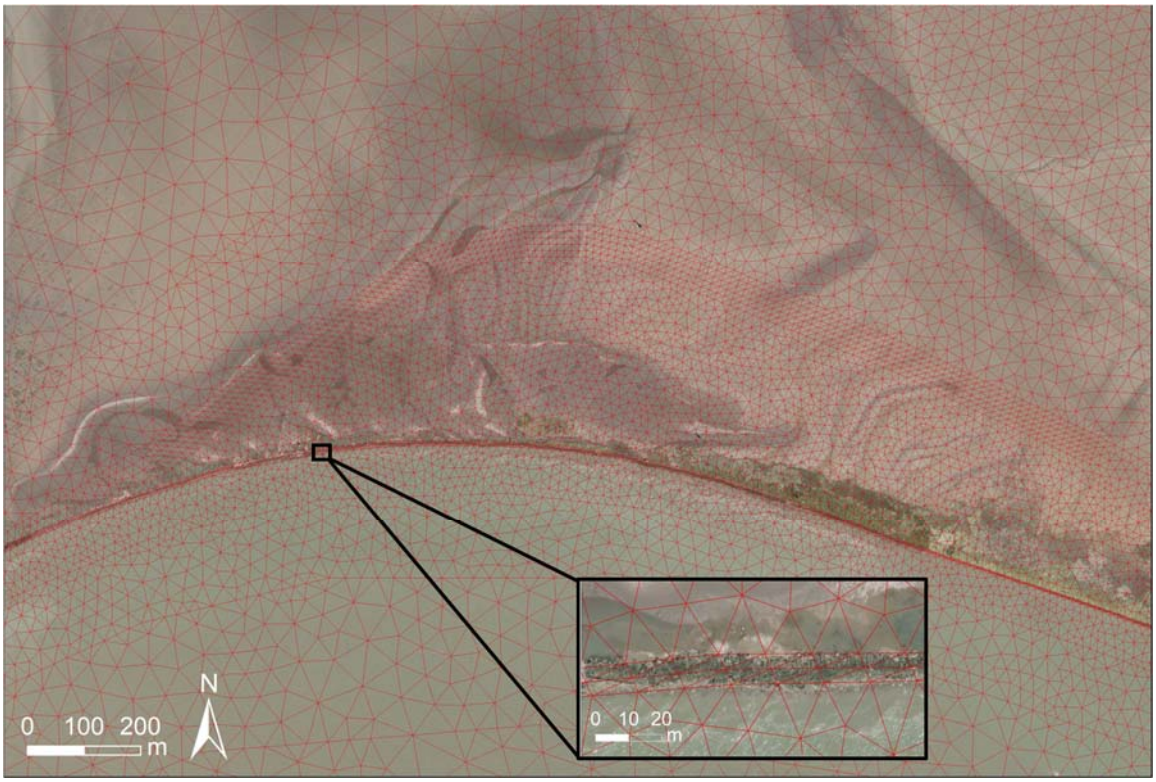


FIGURE 4-3: UNSTRUCTURED GRID ELEMENTS AT PROJECT SITE

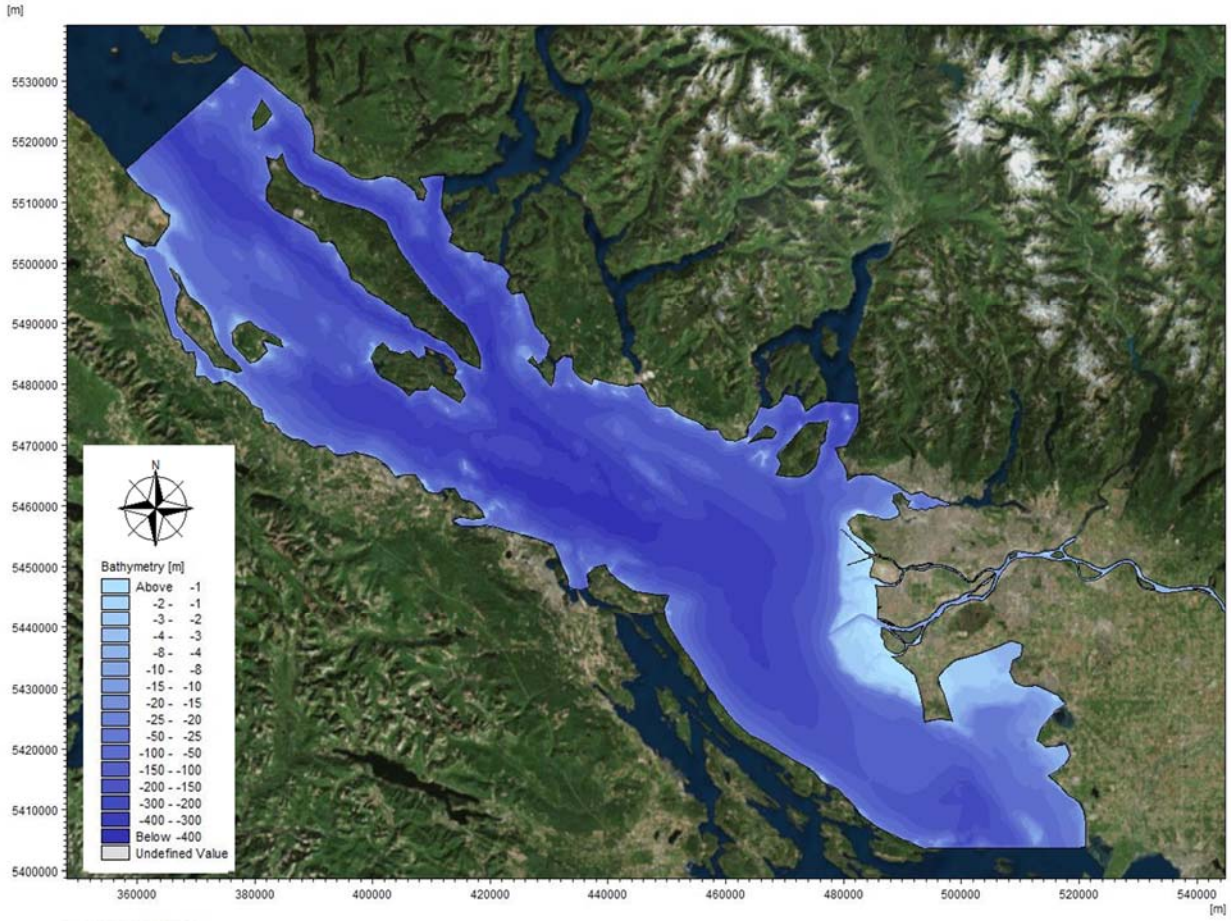


FIGURE 4-4: MODEL BATHYEMTRY (INCLUDING STRAIT OF GEORGIA)

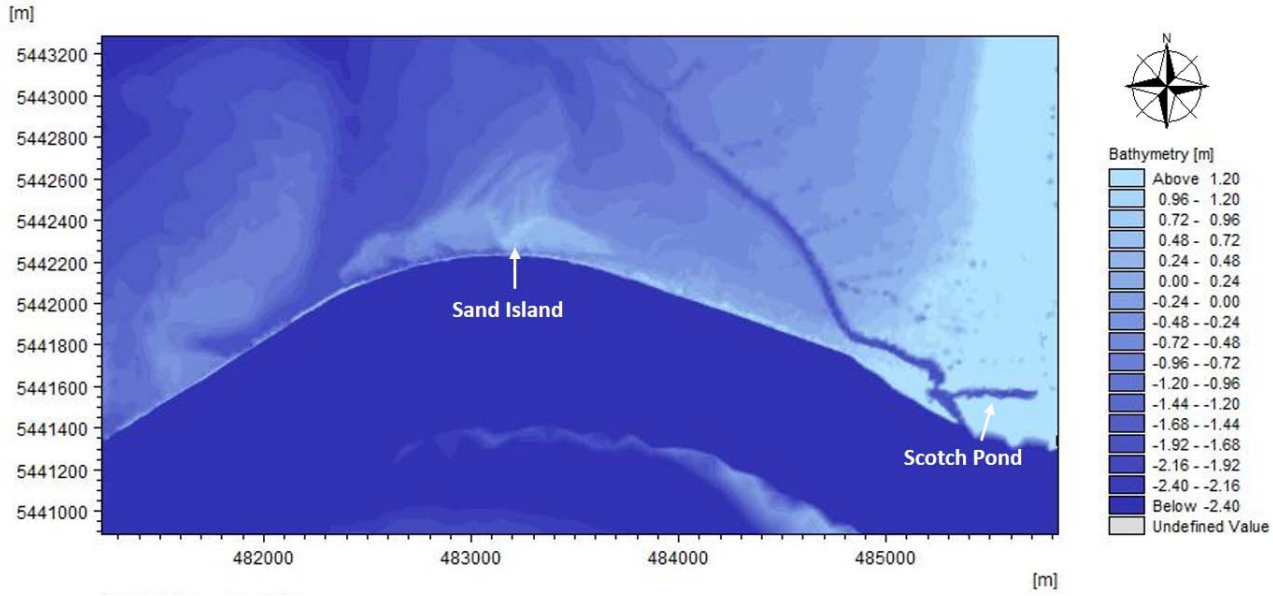


FIGURE 4-5: MODEL BATHYMETRY AT PROJECT SITE

4.3. SW Model Calibration

Typically, outputs from any numerical model need to be verified with field measurements, in order to show the model can reasonably reproduce the processes or environment of interest. This procedure is called model calibration.

The SW model was calibrated against hourly wave records at DFO Halibut Bank station (C46146, Figure 4-1), which include observations of significant wave height (H_s) and peak wave period (T_p) from 1996 to 2017.

A winter storm which occurred in Strait of Georgia in December 2001 was selected for SW model calibration because the storm had lasted more than 12 hours. Figure 4-6 shows the selected storm had retained a speed up to 40 knots (or 20 m/s) at Halibut Bank with predominant northwest-southeast directions.

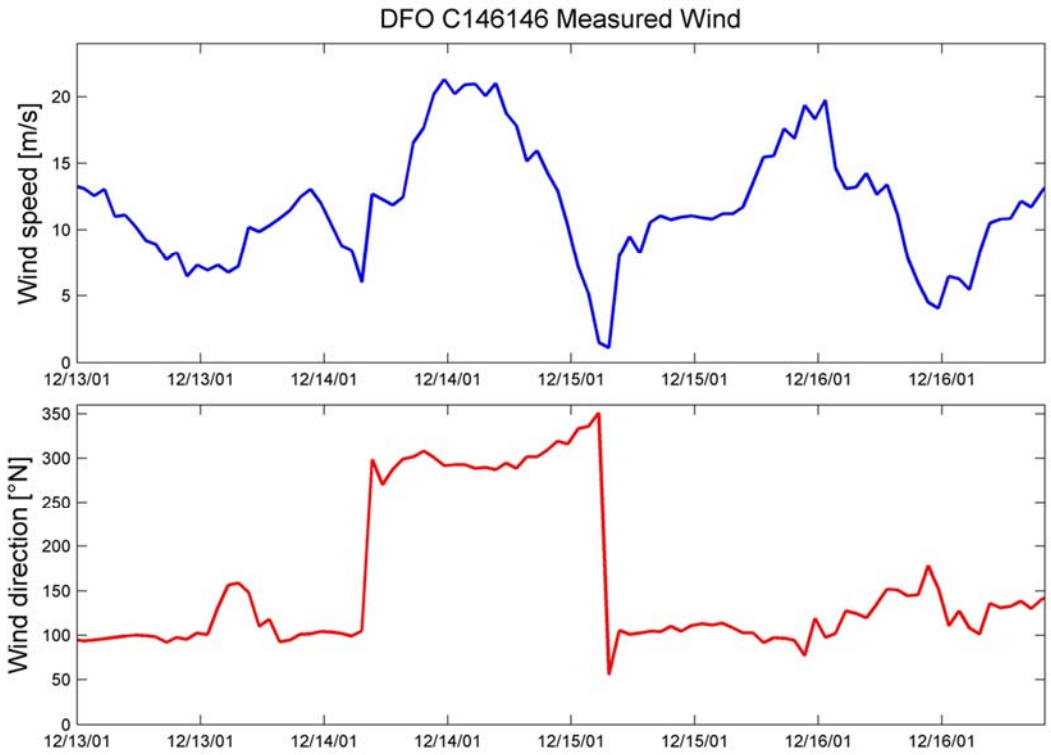


FIGURE 4-6: SELECTED WINTER STORM EVENT FOR WAVE CALIBRATION

Wave calibration was achieved by adjusting wave dissipation coefficients as well as spectral properties. In order to quantify the agreement between measured and model data, the following statistical parameters were determined.

- Root Mean Square Error (RMSE): $\varepsilon_{RMS} = \sqrt{\overline{(x-y)^2}}$
- Mean Absolute Error (MAE, m): $MAE = \overline{|x-y|}$

- Index of Agreement (d): $d = 1 - \frac{\sum (x-y)^2}{\sum \left(|x-\bar{x}| + |y-\bar{x}| \right)^2}$, $0 \le d \le 1$

Where, *x* and *y* represent the measured and modelled data, respectively. A comparison between measured and modelled wave statistical parameters is presented in Figure 4-7 and Figure 4-8, and shows that the model is in reasonable agreement with the measurements.

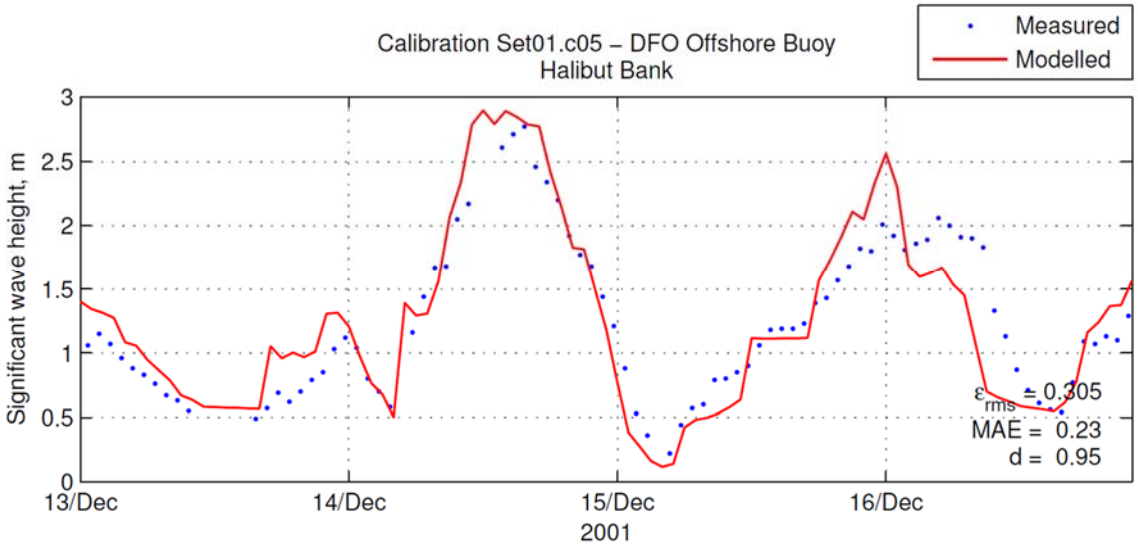


FIGURE 4-7: MEASURED VS. MODELLED H_S AT HALIBUT BANK

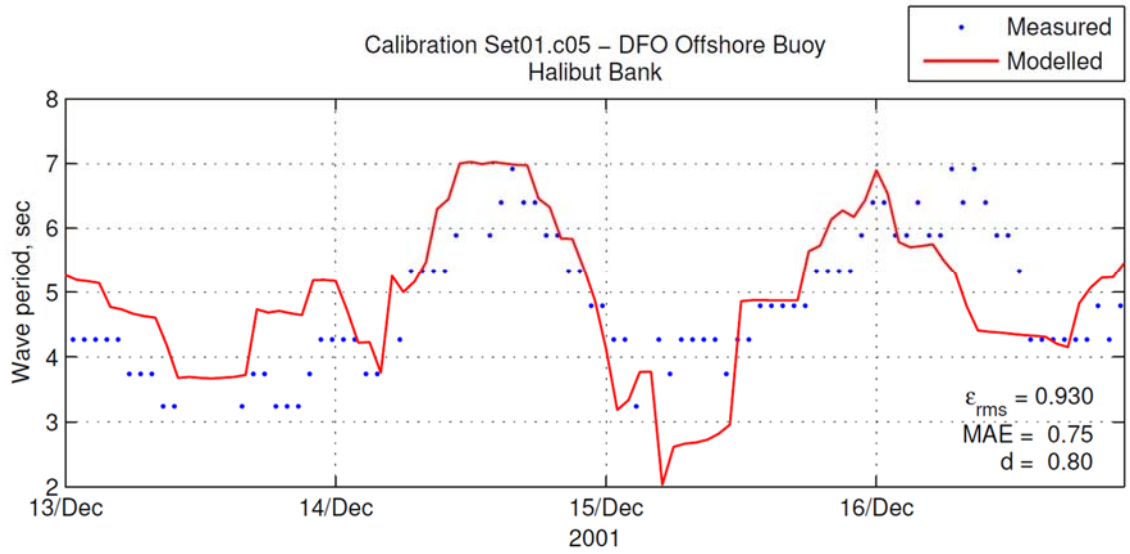


FIGURE 4-8: MEASURED VS. MODELLED T_P AT HALIBUT BANK

4.4. HD Model Calibration

The HD model was calibrated against water levels and flow split. Modelled water levels were compared with tides measured at two DFO tide gauges, namely Point Atkinson and Vancouver, labelled as DFO7795 and DFO7735 in Figure 4-1. Modelled flow split was compared to measurements as reported by North Hydraulic Consultants (NHC, 2006).

The HD model was forced with astronomical tides and tidal currents, derived from the tidal constituent global database developed from TOPEX/Poseidon altimetry data (Egbert & Erofeeva, 2010), along its offshore tidal boundaries. In addition, Fraser River discharge measured at Mission (station 08MH024 in Figure 4-1) was used as the inland freshwater boundary.

A two-month simulation period was conducted between June 1 and July 31, 2012, in order to capture the higher-than-average discharges observed during the 2012 freshet season. A graphical comparison between measured and modelled water levels is provided in Figure 4-9 and shows that the HD model closely reproduces observed water level variations. Model prediction capability indices (d) of 0.99 corroborate the accuracy of the modelled water levels at both tide gauges.

In addition, a comparison between the measured and modelled tidal constituents (i.e. the astronomical components of the tides) at both tide gauges was made. Figure 4-10 shows that the model adequately captures the amplitude of these constituents, with the M2 component amplitude being overpredicted by less than 7% and 3%, and the K1 component being overpredicted by 16% and 15%, respectively.

To confirm that the model correctly distributes flow into the North, Middle and South Arm of the Fraser river, modelled flow splits were also calculated. Flow split data collected by Public Works and Government Services Canada (PWGSC) from May 2005 to January 2006, was processed and reported by NHC in 2006. The blue and red boxes in Figure 4-11 indicate the measured and modelled flow splits, respectively. Overall, the model reproduces closely the flow distribution in the North, Middle and South Arm, with differences less than 1%. A slightly larger difference of 3% is found near Steveston.

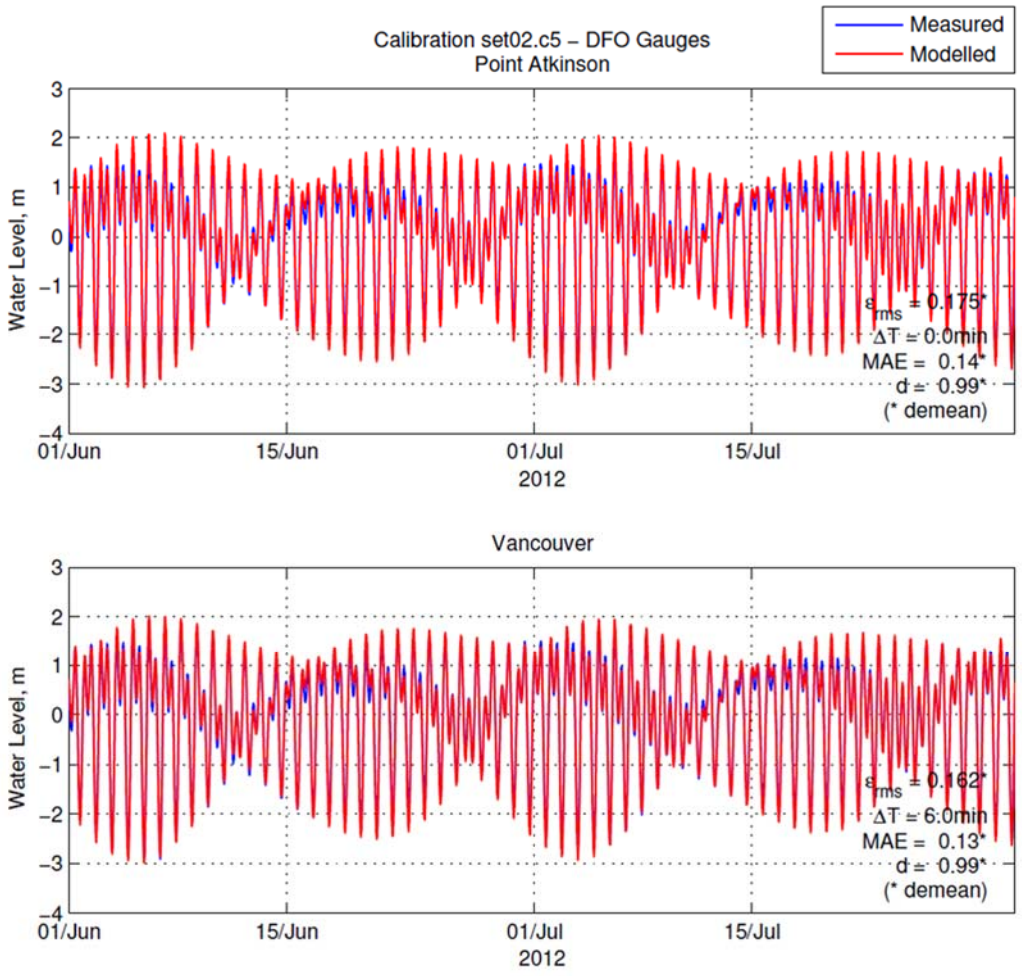


FIGURE 4-9: MEASURED VS. MODELLED WATER LEVELS AT DFO TIDE GAUGES

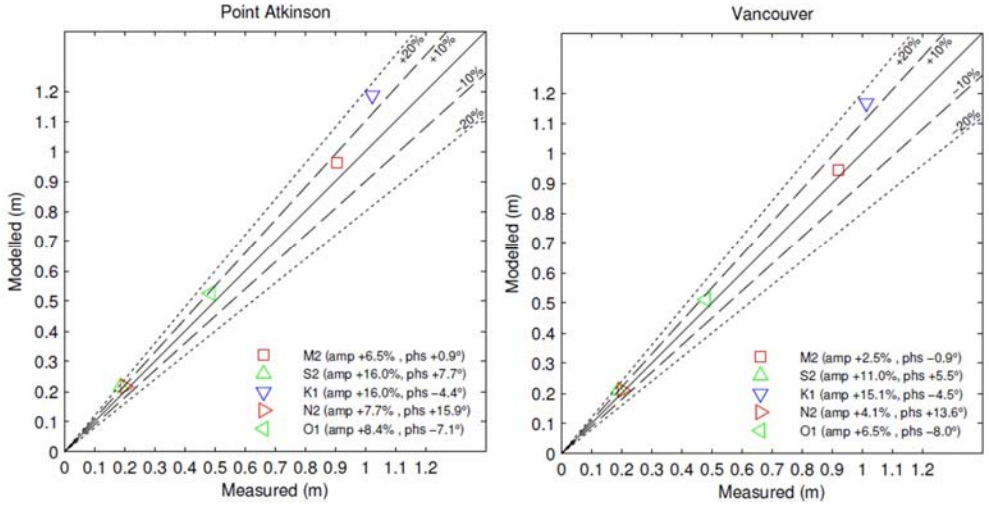


FIGURE 4-10: MEASURED VS. MODELLED TIDAL CONSTITUENTS AT DFO TIDE GAUGES

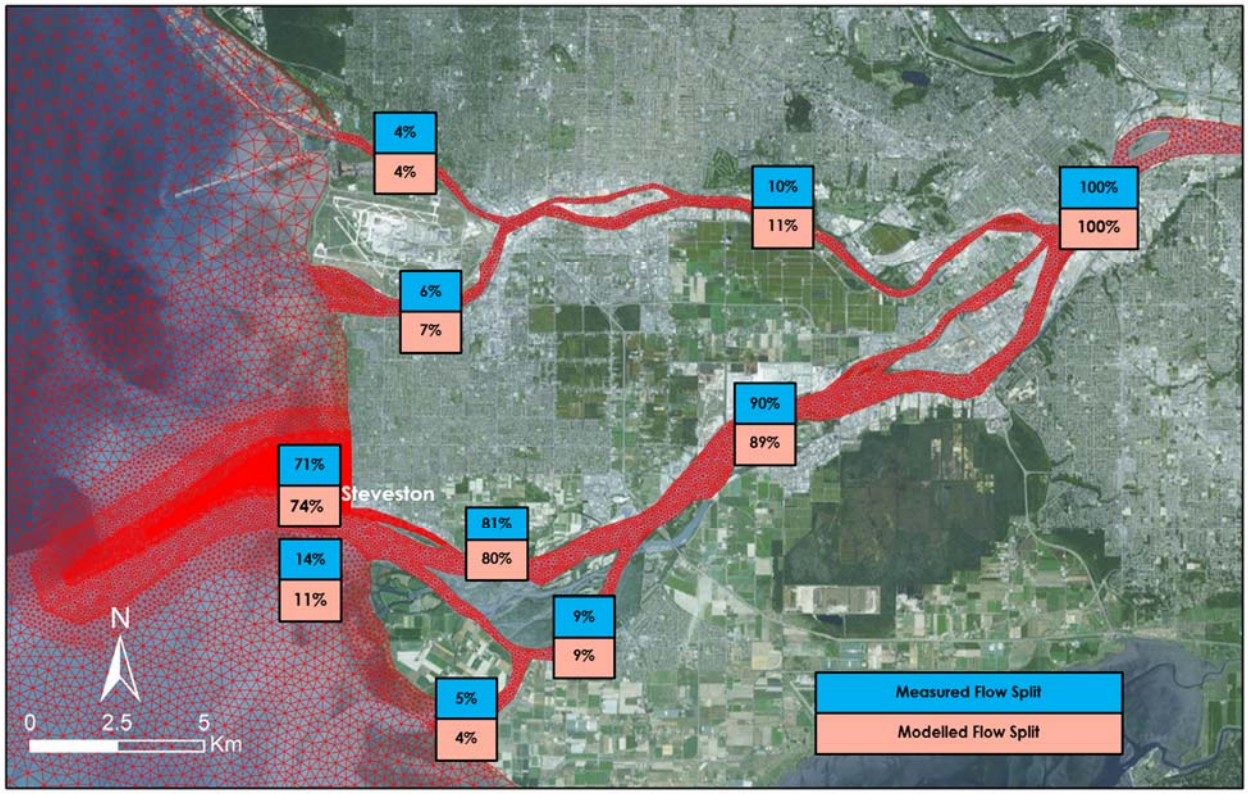


FIGURE 4-11: MEASURED VS. MODELLED FLOW SPLIT

4.5. Validation of Salinity Mixing

Once the comparison of water levels and flow split was deemed adequate, the salinity module within the HD model was activated to assess salinity mixing. The validation process compared the modelled salt wedge to findings reported in literature at locations in the South Arm.

Ages (1979), studied the salinity intrusion in the main South Arm of the Fraser River by conducting measurements under a range of discharges observed during 1976. Findings from the study indicate that the location of the salinity front varies within a single day in response to tidal fluctuations as well as seasonally in response to variations of river discharge.

The validation test was set up by imposing discharge recorded at Mission during the dates in which the measurements took place. A high and a low outflow condition were selected for the test. The focus of this validation was not to capture the exact location and shape of the salt wedge, but instead to ensure that the three-dimensional flows are adequately resolved in the model leading to a good representation of the salinity mixing in the Fraser River as well as in the intertidal zone of Sturgeon Bank, where the proposed marsh area is located.

Figure 4-13 to Figure 4-15 compare findings from the literature with model results. The literature, presented in the upper plot of each figure, depicts the distribution of salinity (with contour lines) along the main channel of the South Arm, under a specific discharge condition and tide stage. The lower plot of each figure represents the modelled salt wedge under the same tide and discharge conditions.

Four reference locations, including Sand Heads, Steveston, Deas Island, and Annacis Island, are used in comparison. Figure 4-12 shows the locations.



FIGURE 4-12: REFERENCE POINTS FOR VALIDATION OF MODELLED SALINITY

Under high discharge flow in Fraser River, the South Arm is primarily influenced by fresh outflows pushing saline water away. At a low tide stage, the salt wedge is typically kept out of the South Arm. Both measured and modelled data indicate that salinity is transitioning from saline to fresh in a narrow stretch close to Sand Heads (Figure 4-13). For the same high discharge flow but a higher tide stage, the salt wedge penetrates slightly into the South Arm. Intrusion of saline water (above 25 PSU, depicted in red in Figure 4-14) is shown halfway between Sand Heads and Steveston, while brackish waters (transitioning from saline to fresh) occur up to around Steveston.

Under low discharge flow in Fraser River, saline water intrudes further into the South Arm and can be observed halfway between Steveston and Deas Island, while the transition to fresh water occurs pass Deas Island (Figure 4-15).

Based on the similarity of measured and modelled salinity distributions, it is concluded that the salinity mixing processes in the HD model are captured satisfactorily and are capable of assessing potential changes in salinity distribution at the project site, where the proposed project elements are incorporated.

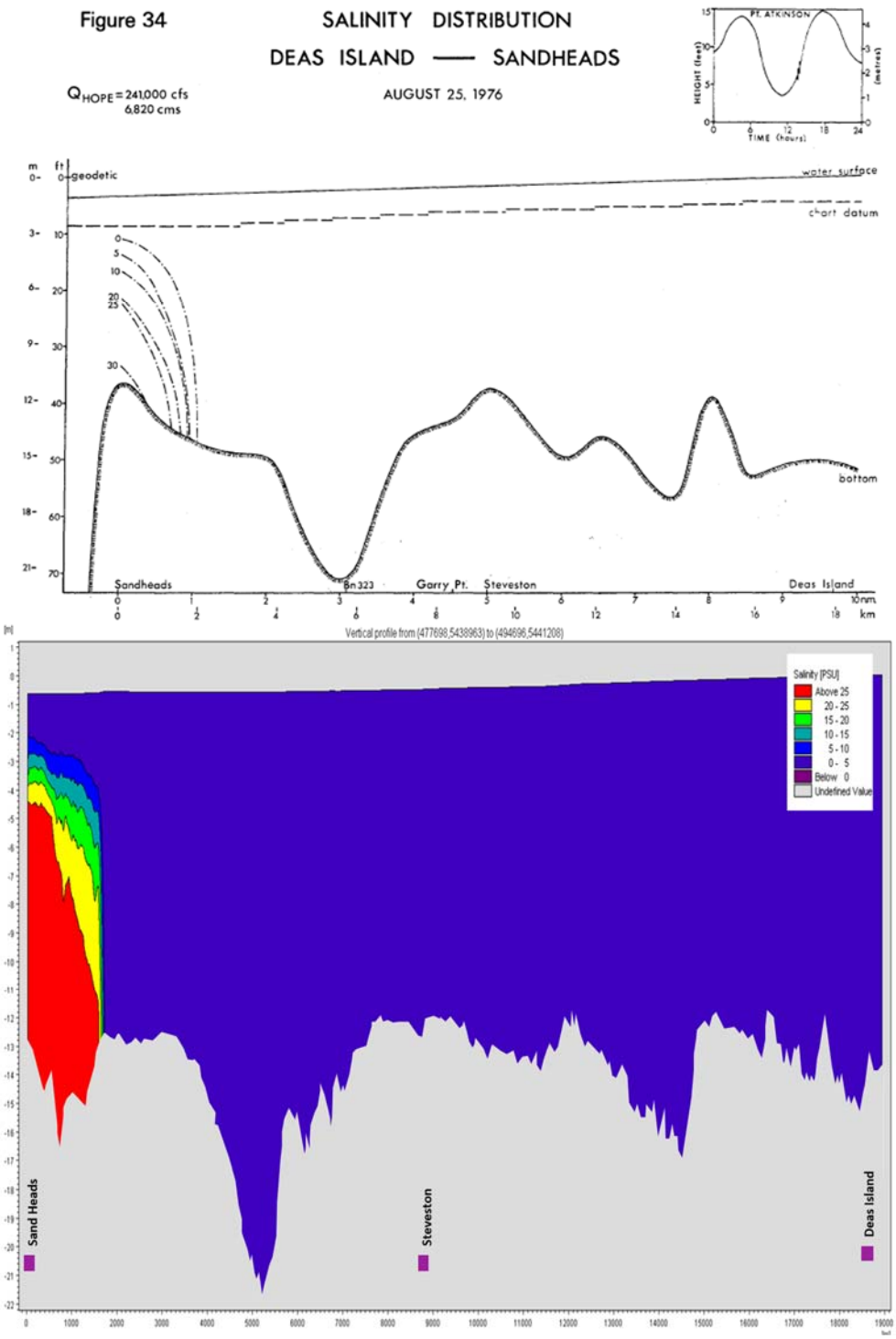


FIGURE 4-13: LOCATION OF SALT WEDGE UNDER HIGH DICHARGE FLOW AND LOW TIDE

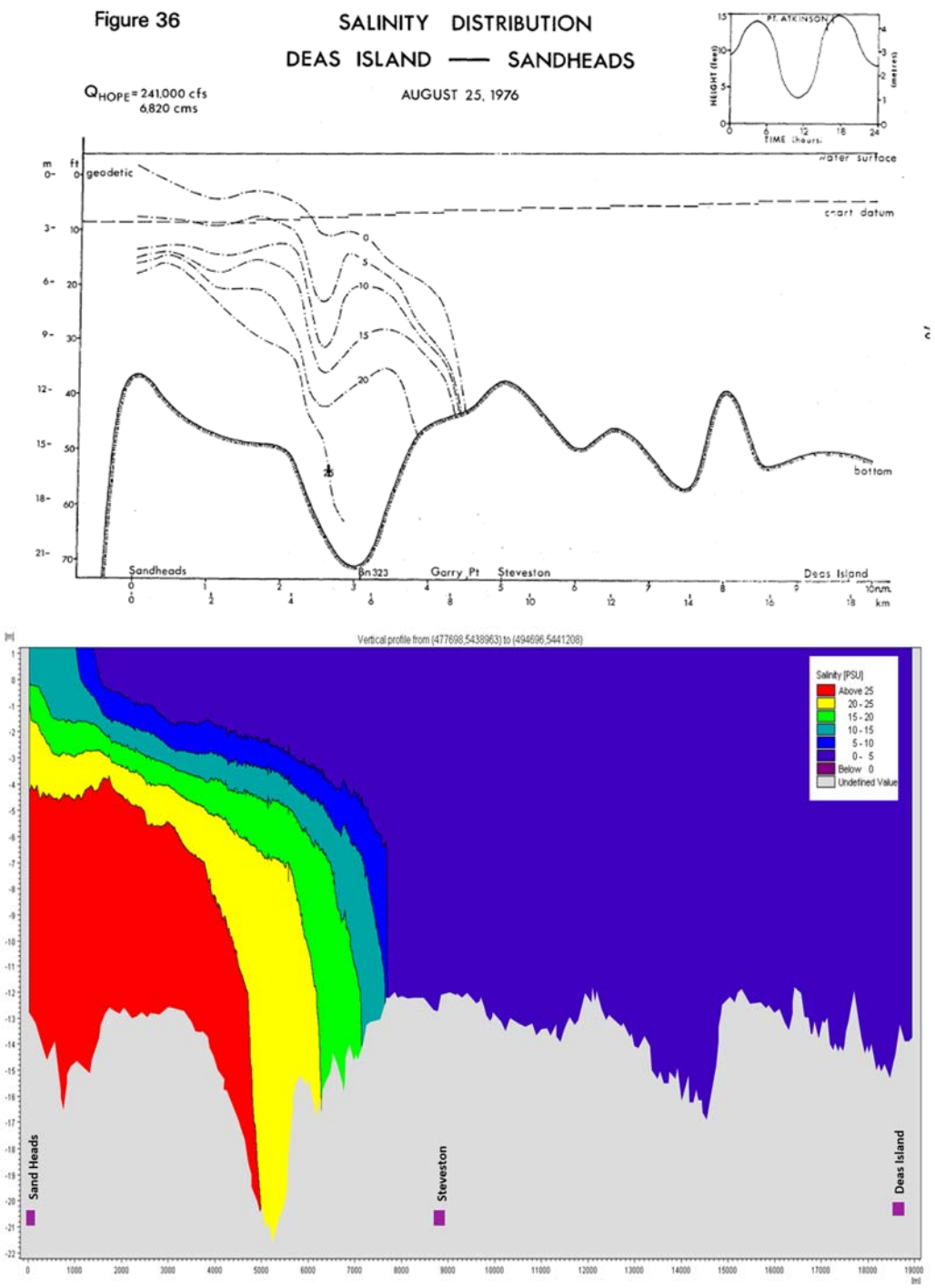


FIGURE 4-14: LOCATION OF SALT WEDGE UNDER HIGH DICHARGE FLOW AND HIGH TIDE

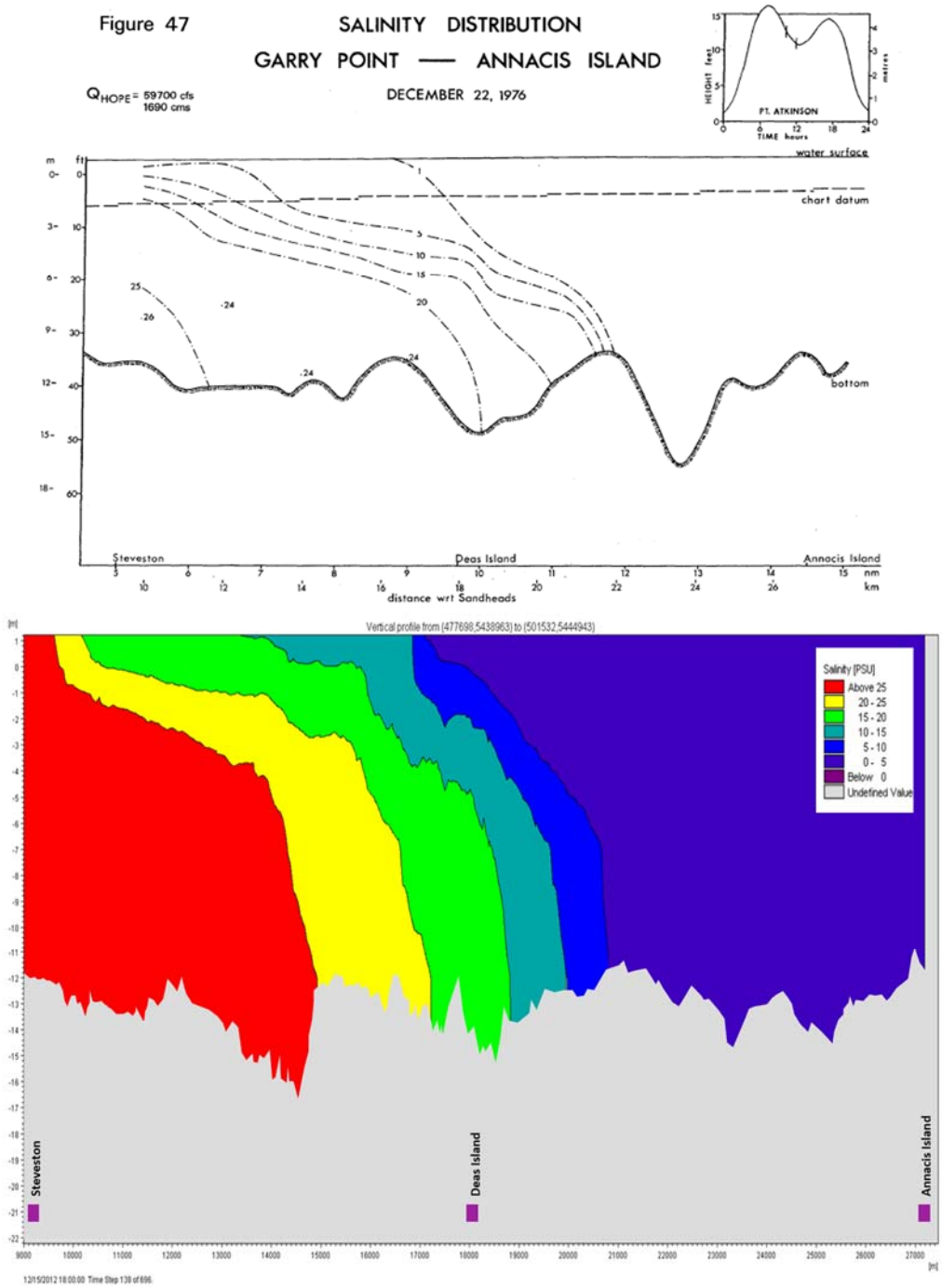


FIGURE 4-15: LOCATION OF SALT WEDGE UNDER LOW DICHARGE FLOW AND HIGH TIDE

5. Wave Exposure and Wave-Induced Bed Shear Stress Analysis

5.1. Introduction

Wave action represents a limiting factor for growth and development of the proposed marsh, as it affects the stability of the substrate. For a successful marsh establishment or restoration, evaluation of wave induced bed shear stresses at the site is necessary to determine the stability requirements for the new substrate. Values for allowable bed shear stresses for a range of substrate materials were provided in Section 3.1. As discussed, the existing substrate at Sturgeon Bank and the dredged material, proposed as new substrate, range from coarser well graded sands, to fine silts and clays. It was concluded that 1 N/m^2 (i.e. the permissible bed shear stress for finer sediments) is a reasonable and conservative target for allowable bed shear stress on the proposed marsh.

Evaluation of wave induced bed shear stresses was carried out for two scenarios, i.e. existing and with-project conditions, representing incident wave conditions at the project site in a typical year. Post-processing of the results was performed to compute the maximum bed shear stress τ_{max} according to *Fredsøe and Deigaard (1992)*, as well as its statistics during the entire simulation period.

For the with-project scenario, the bathymetry at the SAJ project area was adjusted to incorporate the proposed 1,500 m long cobble berm (crest elevation of +1.4 m GD) as well as raising of site grades in the lee of the cobble berm. Fill material slopes down from an elevation of +0.5 m GD at the toe to an elevation of approximately +0.3 m GD at the top of the proposed swale. This swale (invert at -0.7 m GD), running in the east-west direction approximately in the middle of the proposed marsh, is included to promote drainage and to enhance circulation in the project area. Figure 5-1 compares the bathymetry for the existing and with-project scenario. To emphasize the differences between them, the figure only depicts bed elevations of -1.4 m and higher. The proposed cobble berm footprint is depicted in orange to red shades in the lower plot of Figure 5-1. It is noted that the berm discontinues at its southwest corner (a gap of around 150 m), at the location of the swale.

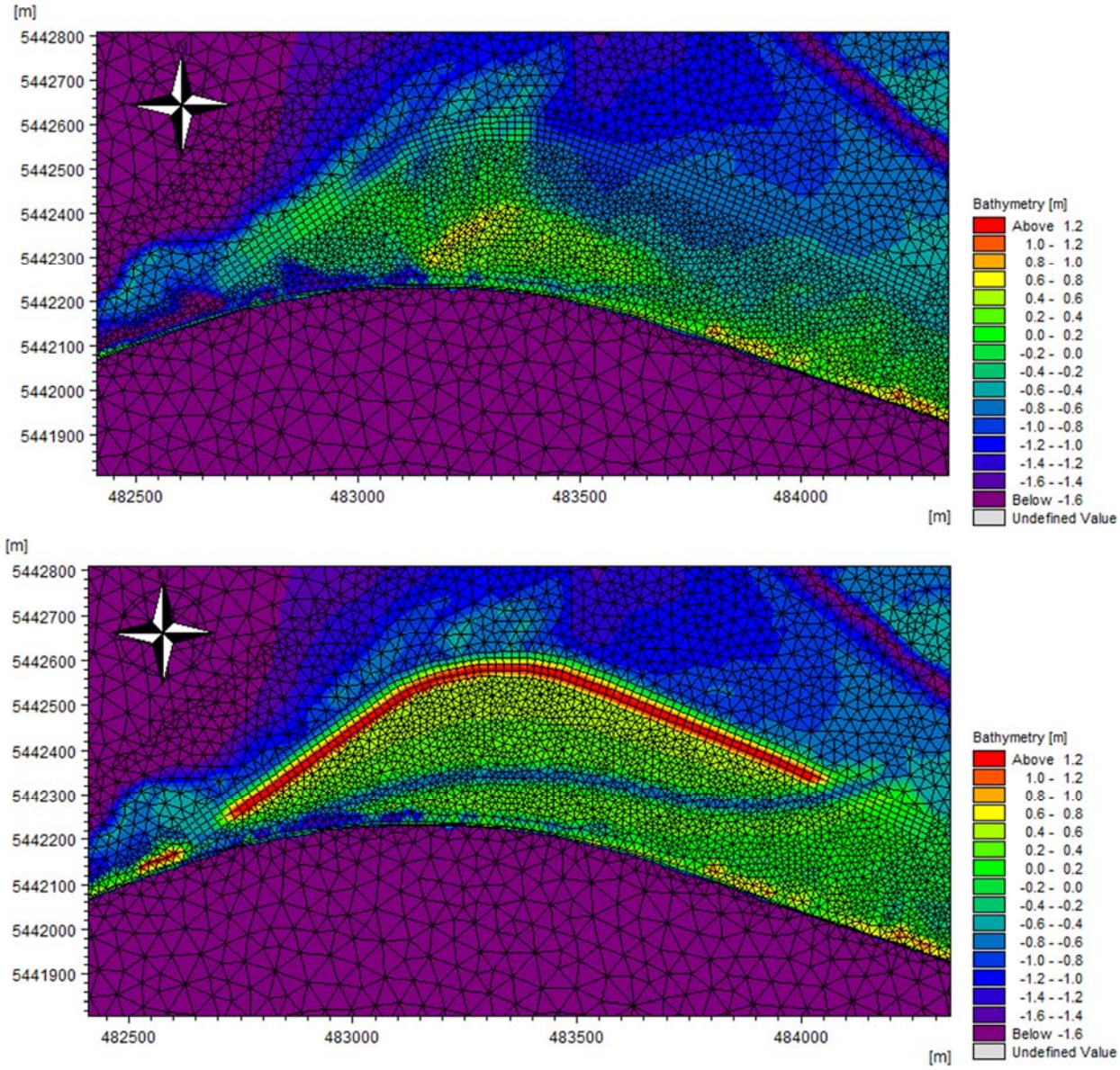
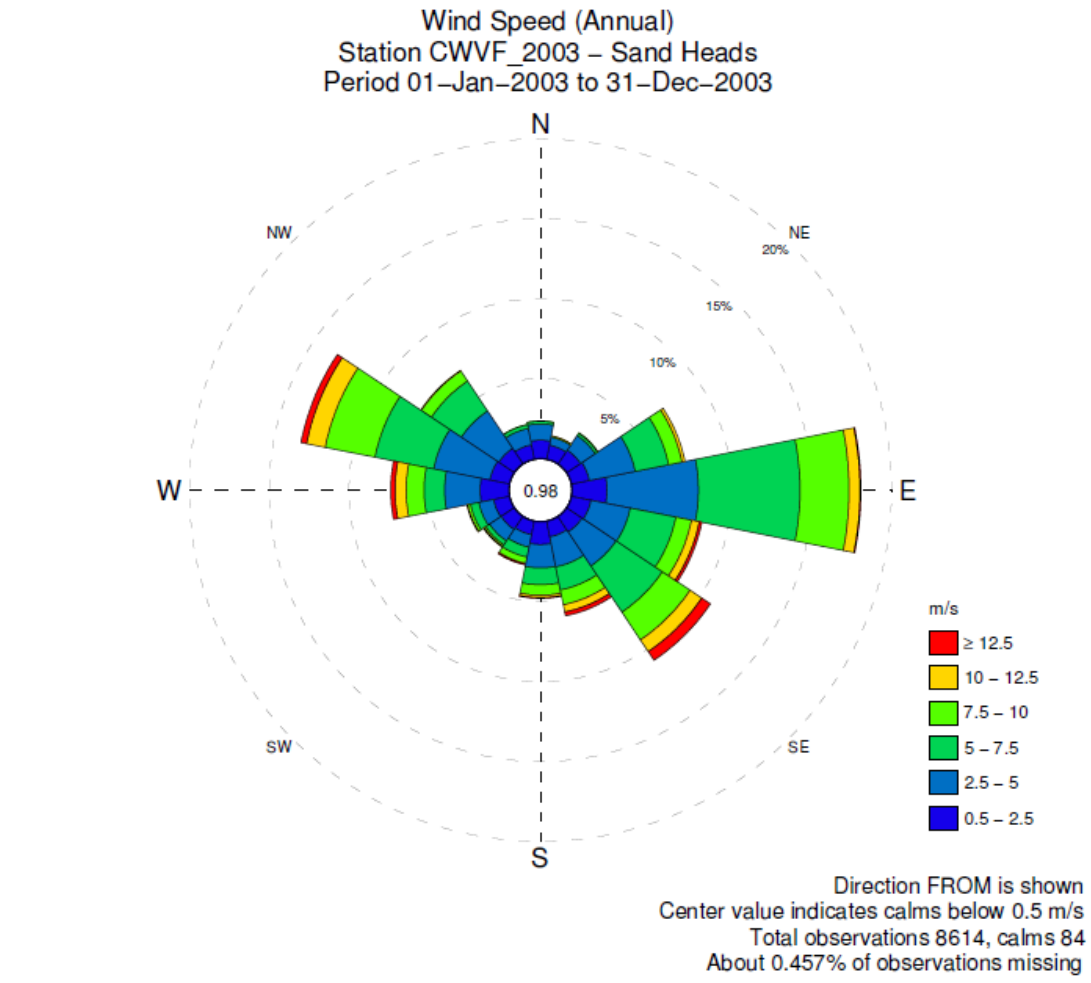


FIGURE 5-1: EXISTING VS. WITH-PROJECT BATHYMETRY

5.2. Imposed Wind Conditions

Wave exposure analysis in a typical year was conducted for year 2003 because it was found to be the most representative year in the full wind records at Sand Heads. Figure 5-2 presents the wind rose for year 2003. About 50% of the recorded wind speeds were at or below 5 m/s; while the predominant wind direction was East (approximately 18% of observations), higher wind speeds (i.e. above 12.5 m/s) were more frequently from the southeast and northwest sectors.

The hourly time series of wind speed and wind direction recorded at Sand Heads in 2003 was imposed in the SW model for the purpose of reproducing wave conditions that were observed during a typical year.



Percentage of Occurrence

Wind Speed, m/s	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
Total	2.33	1.47	2.33	7.23	18.08	8.31	10.81	6.03	4.77	2.76	2.30	2.69	7.38	13.30	7.02	2.19	99.02
12.5						0.16	0.65	0.24					0.27	0.36			1.78
10				0.19	0.68	0.50	0.88	0.46	0.15				0.70	1.18			4.97
7.5				0.86	3.08	1.00	2.09	0.94	0.66	0.41	0.12	0.17	1.13	3.18	0.77		14.48
5	0.17		0.17	2.14	6.36	2.91	3.48	1.47	1.06	0.64	0.29	0.53	1.28	3.75	2.25	0.24	26.81
2.5	1.01	0.51	1.10	2.93	5.73	2.51	2.57	1.92	1.46	0.79	0.87	0.94	2.23	3.59	2.82	1.03	32.01
0.5	1.14	0.88	1.02	1.13	2.17	1.23	1.14	0.99	1.40	0.85	0.96	1.00	1.79	1.24	1.15	0.91	18.99

FIGURE 5-2: WIND ROSE FOR YEAR 2003

5.3. Results

The maximum bed shear stress (τ_{max}), computed from a series of waves (or called a wave train), is a function of the wave period and the horizontal wave orbital velocity near bed. τ_{max} was computed at each grid element for every time step for the existing and with-project conditions. Results are summarized in the following by means of τ_{max} statistics. As a reference, the footprint of the proposed cobble berm is depicted in pink in both figures.

Figure 5-3 compares the 99th percentile τ_{max} at the proposed marsh area for the existing (upper plot) and the with-project (lower plot) conditions. The 99th percentile value indicates that only 1% of the maximum bed shear stress would exceed the value (or equivalent to 88 hours per year).

As seen in the figures, the τ_{max} distribution follows the bathymetric contours closely. For the existing condition, the highest value (e.g. 2 N/m^2 depicted in yellow), is observed at the Sand Island, where bed elevations are higher. Around the Sand Island, τ_{max} values are consistently greater than the established threshold for sediment motion (e.g. 1 N/m^2).

For the with-project condition, the area surrounding the Sand Island as well as most of the marsh area are now depicted in blue shades, indicating a reduction of bed shear stresses (τ_{max} values between 0.3 and 0.8 N/m^2). The lowest values are observed at the location of the swale, where bed elevations are low. Higher values (e.g. 1 N/m^2) are observed at the south portion of the marsh area, between the swale and the Steveston North Jetty, or at the southwest corner, close to the cobble berm gap. Areas depicted in red, indicate the highest shear stress values over the cobble berm due to wave breaking, and do not impact the proposed marsh area.

Similarly, Figure 5-4 compares the statistical maximum of τ_{max} for the existing and the with-project conditions. These values represent the bed shear stresses reached only once per year (e.g. the highest within all τ_{max}). It is noted that the statistical maximum of τ_{max} values are higher than the threshold in most of the existing and the with-project conditions. For the existing condition, τ_{max} at the Sand Island and the surrounding area is now above 2.6 N/m^2 (depicted in red). For the with-project condition, τ_{max} above 2.6 N/m^2 is observed again in the south and southwest portions of the proposed marsh.

The bar plots in Figure 5-5 provide τ_{max} statistics for three selected points within the proposed marsh area. 75th Percentile (gray), 90th (yellow), 99th (green) and the maximum τ_{max} (blue) are compared for the existing and the with-project conditions. Locations for points A, B and C are depicted in Figure 5-3 and Figure 5-4. Points A and B represent areas where a considerable reduction in bed shear stresses is observed (τ_{max} decreases around 30%), as a result of wave sheltering from the cobble berm. In contrast, point C does not exhibit an obvious decrease in bed shear stresses (τ_{max} only decreases about 10%), since its location is farther away from the cobble berm and the area of influence. This area is more exposed and therefore more influenced by waves that approach from the south to south-southeast directions propagating over the Steveston North Jetty.

Overall, results clearly show that introduction of the cobble berm effectively reduces wave-induced bed shear stresses. It is noted that under extreme storm conditions, above-threshold values occur over the majority of the marsh area with or without the presence of the cobble berm, as shown in Figure 5-4. However, the berm does promote favorable conditions for development of the proposed marsh growth consistently throughout most of the year (e.g. 99th percentile).

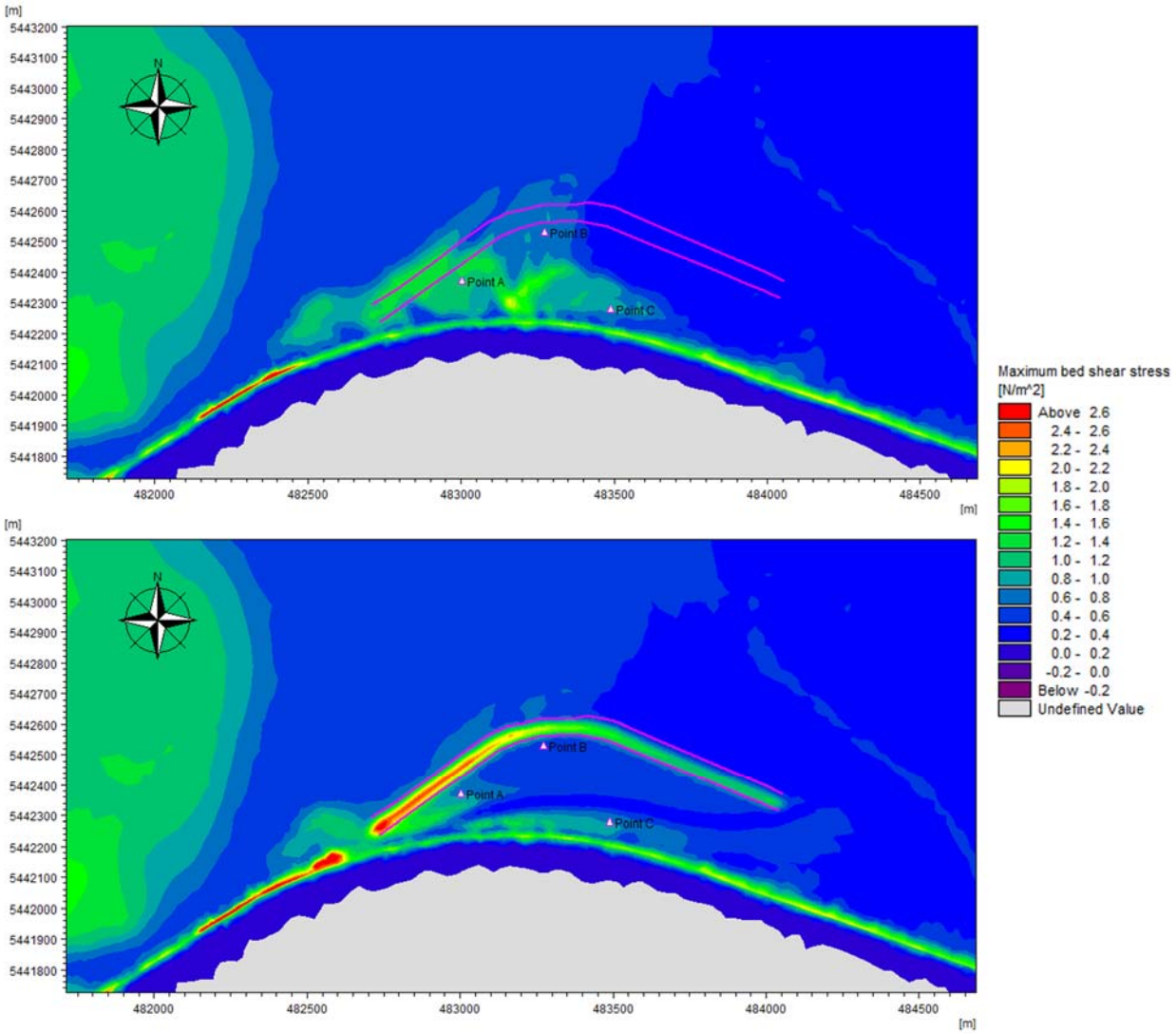


FIGURE 5-3: 99TH PERCENTILE BED SHEAR STRESS FOR EXISTING (TOP) AND WITH-PROJECT (BOTTOM) CONDITIONS

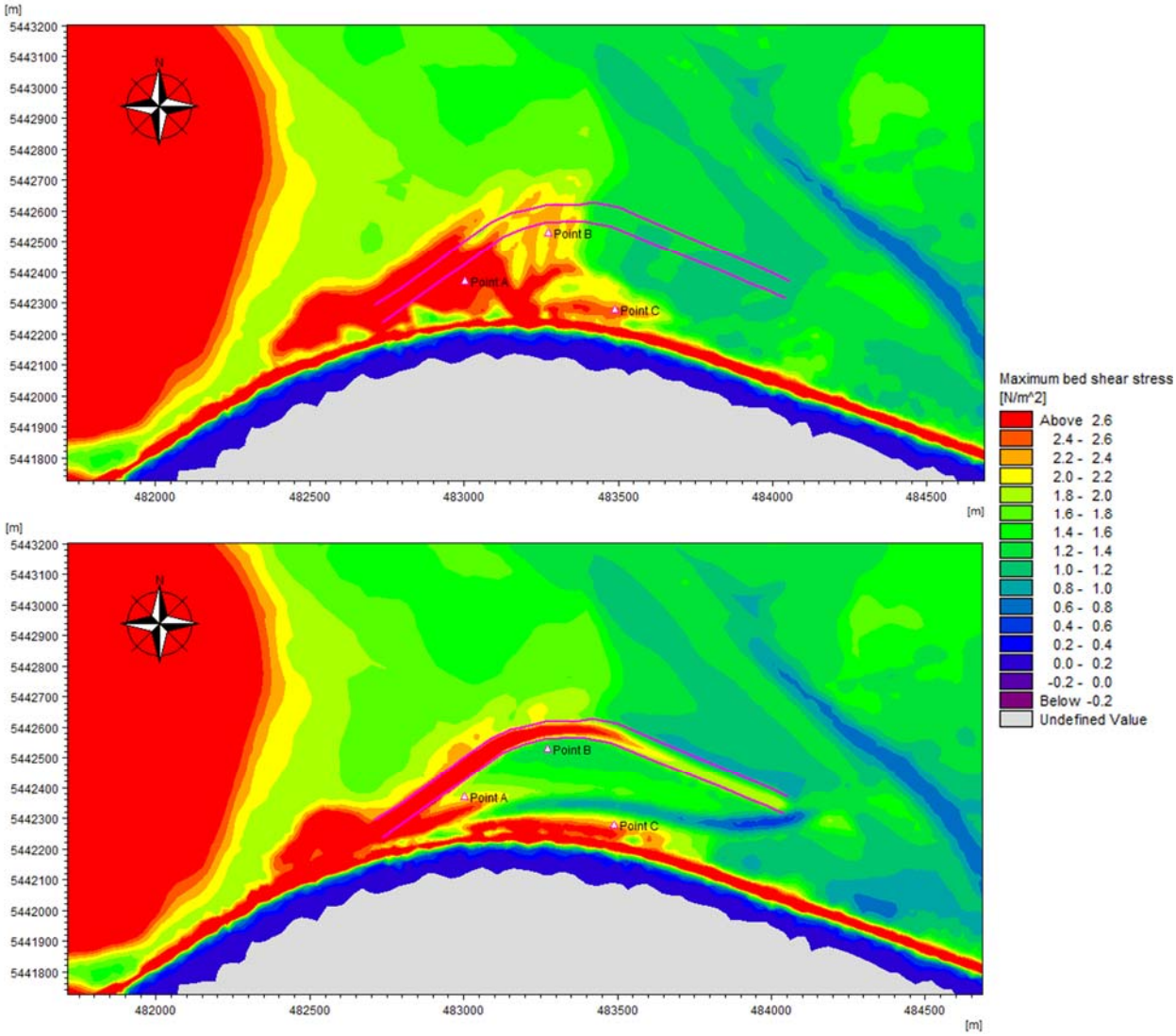


FIGURE 5-4: MAXIMUM BED SHEAR STRESS FOR EXISTING (TOP) AND WITH-PROJECT (BOTTOM) CONDITIONS

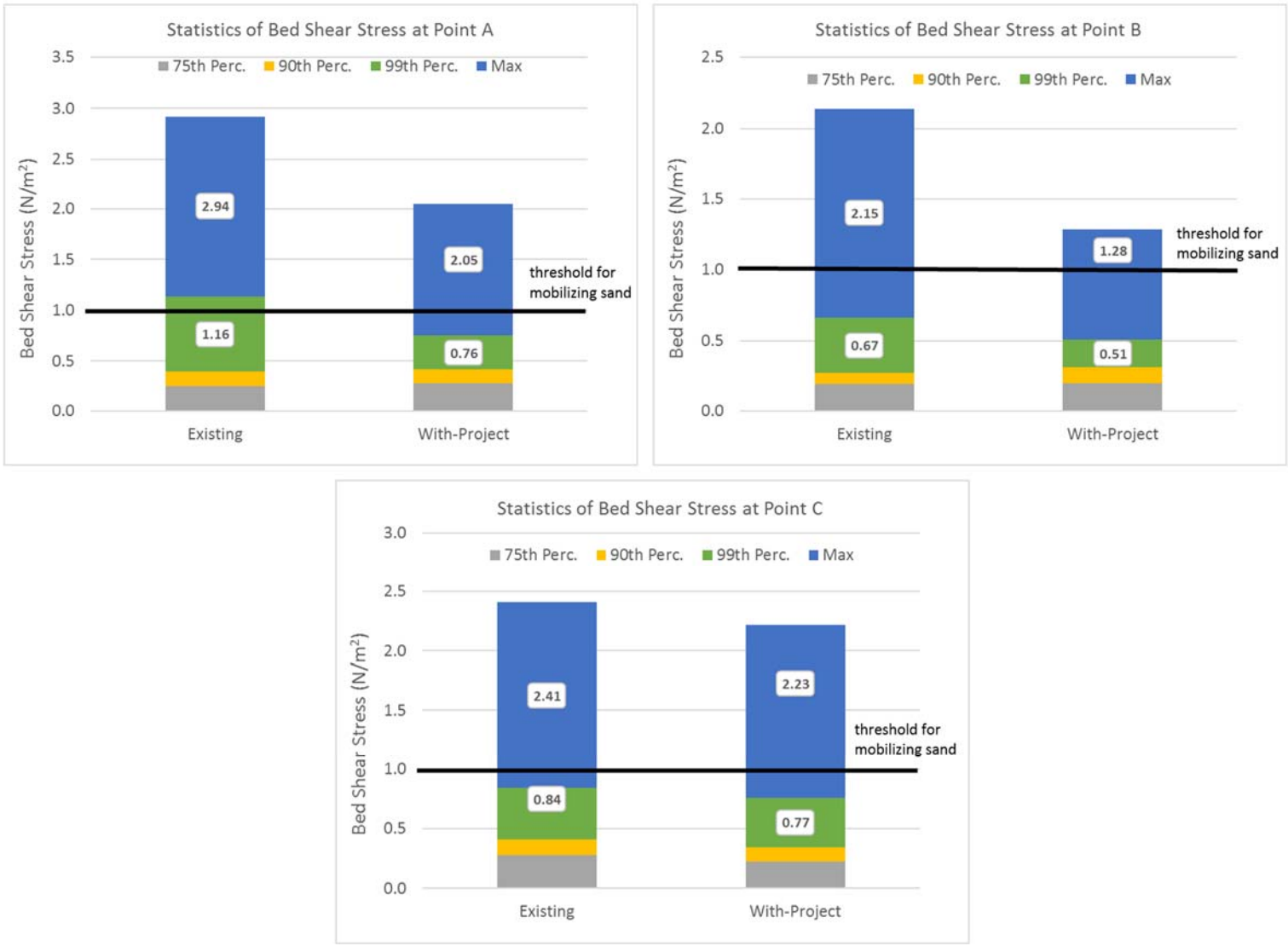


FIGURE 5-5: STATISTICS OF BED SHEAR STRESS AT POINTS A, B, AND C

5.4. Sensitivity to Project Modifications

In this section, sensitivity to the wave results were assessed for three project modifications.

- Case 1 (High Fill): This case changes the proposed grades to accommodate a steeper drainage slope. The grade slopes down from an elevation of +1.0 m GD (previously +0.5 m GD) at the interior toe of the cobble berm to an elevation of +0.3 m GD at the location of the swale.
- Case 2 (Berm Crest El. +1.9 m): For this case, the crest elevation of the cobble berm was raised from +1.4 m to +1.9 m GD. This corresponds to the crest elevation during construction (i.e. construction access road elevation).
- Case 3 (Short Cobble Berm): For this case, only the western reach of the cobble berm is incorporated in the model bathymetry. The shortened cobble berm length is approximately 900 m, and its crest elevation is +1.9 m GD. This layout corresponds to construction completed in Phase II.

Sensitivity cases were performed and the statistical maximum of τ_{max} was computed at the proposed marsh area, as described in Section 5.3. The simulation period (October 10 through November 3, 2003) was chosen to include the longest storm event recorded in 2003 (see Figure 5-6).

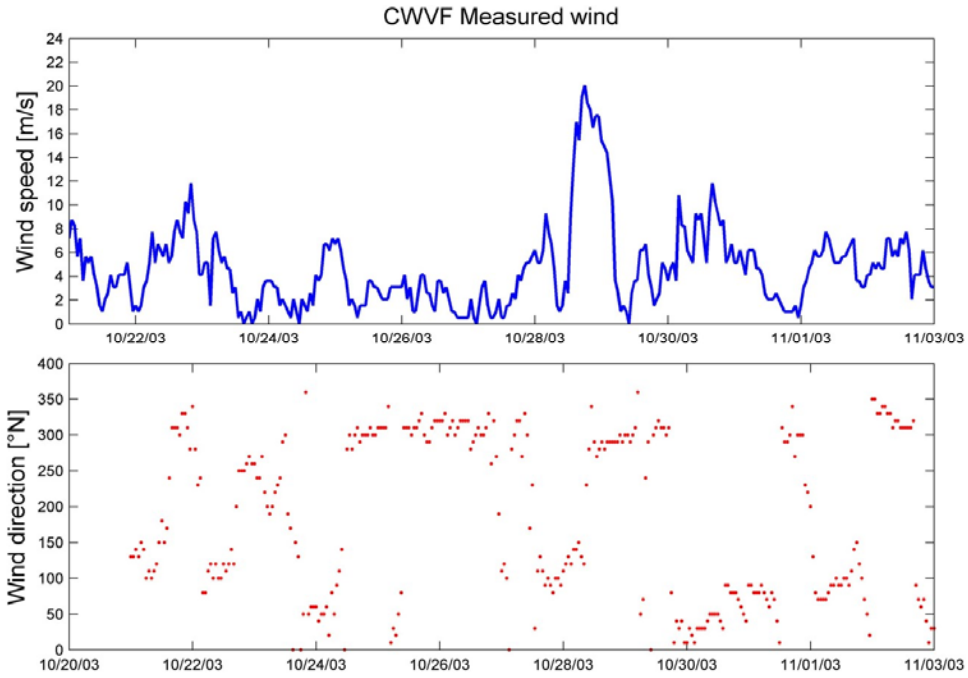


FIGURE 5-6: IMPOSED STORM EVENT FOR SENSITIVITY TESTS

To provide a direct comparison between the short sensitivity cases and the full year simulation, a normalized τ_{max} was computed as below.

$$Norm.\tau_{max} = \frac{\tau_{max}Case}{\tau_{max}base}$$

Where $\tau_{max}Case$ represents the statistical maximum for each sensitivity case, and $\tau_{max}base$ represents the base case without any project modifications. Figure 5-7 shows the normalized τ_{max} at Points A, B and C.

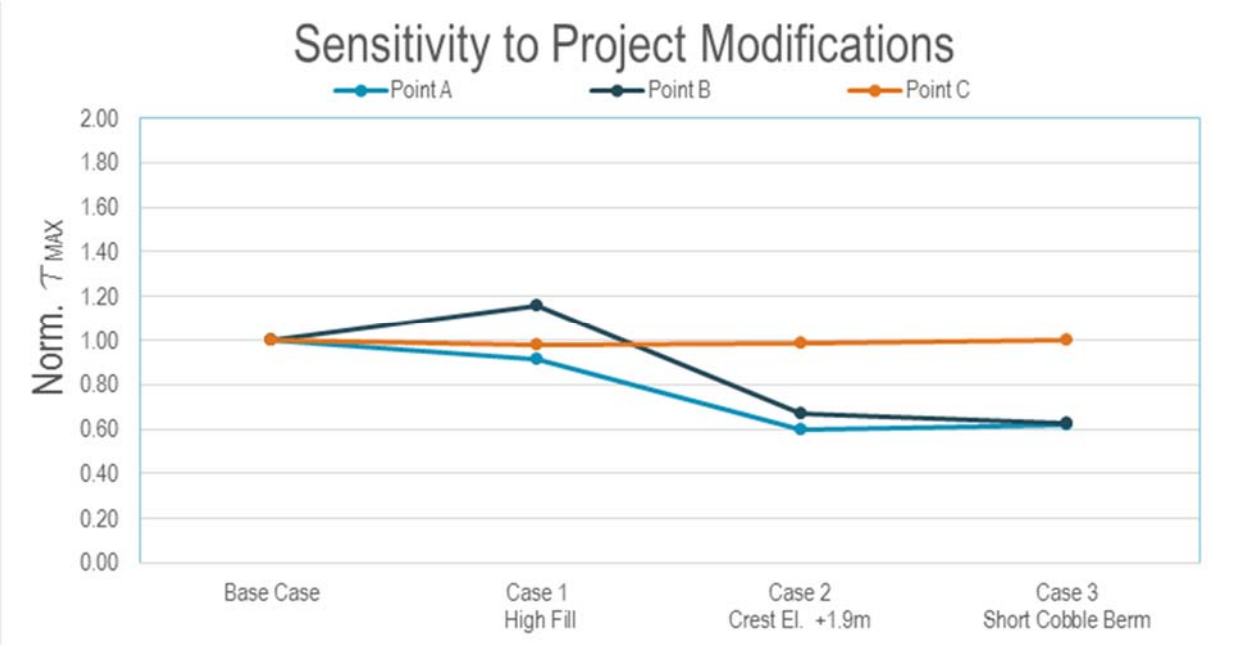


FIGURE 5-7: NORMALIZED T_{MAX} AT POINTS A, B AND C FOR SENSITIVITY CASES

τ_{max} sensitivity is somewhat similar at points A and B. For the high fill case (Case 1), bed shear stresses are comparable to the base case. Normalized τ_{max} values are 0.9 and 1.2 for Point A and B, respectively. These values do not represent a significant deviation in the resulting shear stresses, indicating low sensitivity to modification of the grades in the proposed marsh area.

Meanwhile, raising crest elevation of +1.9 m (Case 2) reduces to approximately 60% and 70% of the maximum shear stresses for points A and B, respectively. Result is similar for the short cobble berm case (Case 3). Normalized τ_{max} values of 0.6 for both A and B indicate that even for a shorter structure, with a crest elevation of +1.9 m provides sufficient sheltering from the predominant wave direction and hence can provide the area with favorable conditions for marsh development. However, a more thorough investigation would be required to determine the feasibility of this option.

For point C, normalized τ_{max} values are approximately one for all sensitivity cases. As mentioned before, point C is representative of an area in which the influence by the cobble berm is limited; therefore, no significant differences in wave-induced bed shear stresses are expected from project modifications.

5.5. Summary of Wave Exposure & Wave-Induced Bed Shear Stress Analysis

Introduction of the cobble berm at Sturgeon Bank can achieve the objective of reducing wave-induced bed shear stresses in the proposed marsh area and promote favorable conditions for marsh growth.

Overall, results clearly show that the cobble berm effectively reduces wave-induced bed shear stresses. Although it is noted that under extreme storm conditions, above-threshold values occur over the majority of the marsh area with or without the presence of the cobble berm, the berm does promote favorable conditions for development of the proposed marsh growth consistently throughout most of the year (e.g. 99th percentile).

Vulnerable areas, where the 99th percentile τ_{max} exceeding the threshold value, were identified in the south and southwest portions of the marsh. This is because the cobble berm provides only limited sheltering from waves in this area, and there is a more direct exposure to waves from southerly directions.

In addition, it was found that the cobble berm crest elevation is the most influential factor for reducing bed shear stresses. Shear stress values were reduced for the cases where the berm crest elevation is at +1.9 m GD. Preliminary results suggest that a short cobble berm could be implemented and still provide favorable conditions for the marsh growth. However, a more thorough investigation would be required to determine the feasibility of this option.

Changes in site grades in the marsh area were found to have limited to no impacts on bed shear stresses.

6. Salinity Distribution Analysis

6.1. Introduction

As discussed in Section 2.5, salinity distribution in the Fraser River is controlled primarily by the amount of outflow from the Fraser River, which varies significantly on a seasonal scale, and is controlled secondarily by the tidal phase, varying on an hourly to daily scale.

To evaluate the range of salinity at Sturgeon Bank and the proposed marsh area, three sets of simulations were performed to represent low, medium and high flow discharge in the Fraser River. For each flow discharge, simulations of the existing and with-project conditions were conducted to compare flow circulation and salinity distribution.

6.2. Imposed Boundary Conditions

The 27-year Fraser River discharge recorded at Mission (Station 08MH024, Figure 4-1) was analyzed to determine the river outflow that resemble the low, medium and high flow discharge occurring throughout the year. Figure 6-1 illustrates the daily and monthly averaged discharge for the full records at Mission.

A discharge of 2,000 m^3/s, representative of winter months, was selected for the low flow discharge. The high flow discharge was set to 8,000 m^3/s, an average peak discharge during the freshet. The medium flow discharge of 5,500 m^3/s represents a transition from the low to the high flow.

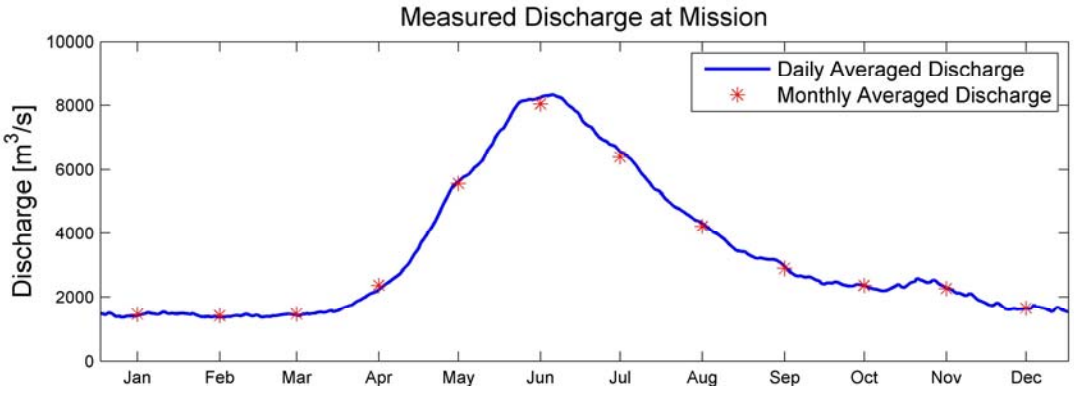


FIGURE 6-1: AVERAGE DAILY AND MONTHLY FRASER RIVER DISCHARGE AT MISSION

The three-dimensional hydrodynamic model with the salinity module was conducted for each discharge scenario for a spring-neap tidal cycle. Figure 6-2 depicts the tidal boundary conditions used to force the model, and illustrates the definition of terminologies used in the discussion. This figure shows how the tidal range varies with time; during neap tides (first and last days of the simulation), the offshore tidal range is around 2.5 m, and increases to approximately 4 m during spring tides (occurring halfway through the simulation period).

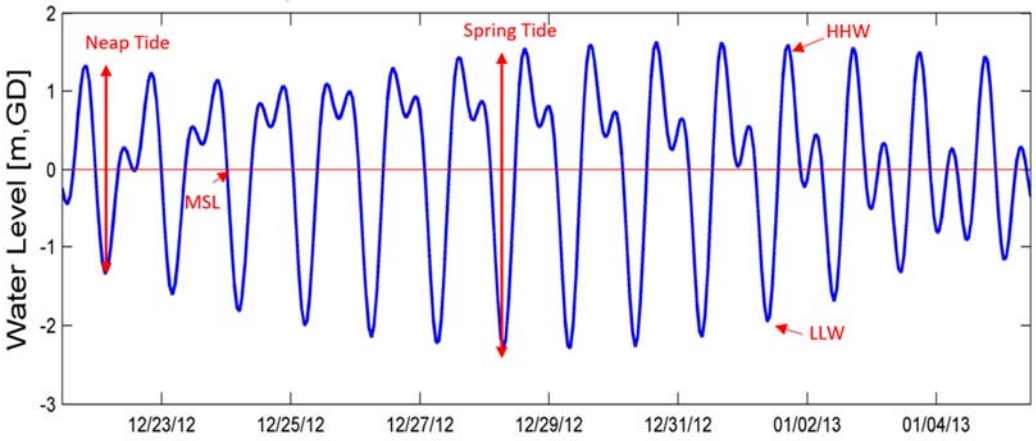


FIGURE 6-2: IMPOSED WATER LEVEL BOUNDARY CONDITIONS

6.3. Results

A comparison of salinity for the existing and the with-project conditions is provided in the form of snapshots at the surface (low discharge) or intermediate depth (medium and high discharge) at selected tide stages. Because the surface salinity becomes all fresh in the medium and high discharge scenario, salinity at the intermediate depth was analyzed instead. The footprint of the proposed cobble berm is depicted with a black solid line for the with-project condition, and with a dashed line for the existing condition (as a reference only). Vertical profiles along a transect are also provided in the figures and illustrate salinity stratification in the marsh area. Figure 6-3 indicates the transect location.

It is noted that some areas immediately adjacent to the Richmond shoreline are only active in the model computations when tidal elevations (i.e. high tides) are sufficient to inundate the areas. They should be disregarded from further interpretation. Better estimates of salinity values at the higher ground can be achieved with longer simulation run time.

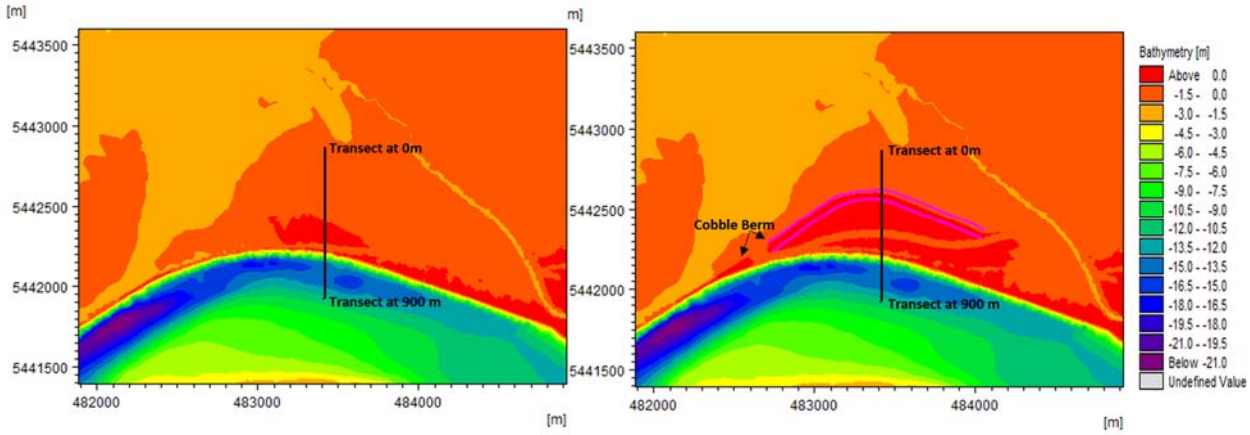


FIGURE 6-3: LOCATION OF SELECTED TRANSECT

6.3.1. Low Discharge Scenario

During low discharge periods, salinity in the Fraser River is primarily controlled by the tides. Brackish to salty sea water is predominant, and there is limited influence from the Fraser River in both fresh water input and circulation. Figure 6-4 depicts surface salinity distribution in the marsh area for the existing condition at low and high tide, respectively. Fresh water outflow reaches its maximum extent around Sand Heads (left plot), when the low tide is present. In the offshore areas, surface salinities are in the brackish range, depicted in green shades. At high tide (right plot), the intertidal areas of Sturgeon Bank exhibit higher salinity. In addition, higher salinity concentrations intrude into the South Arm, pushing freshwater upriver.

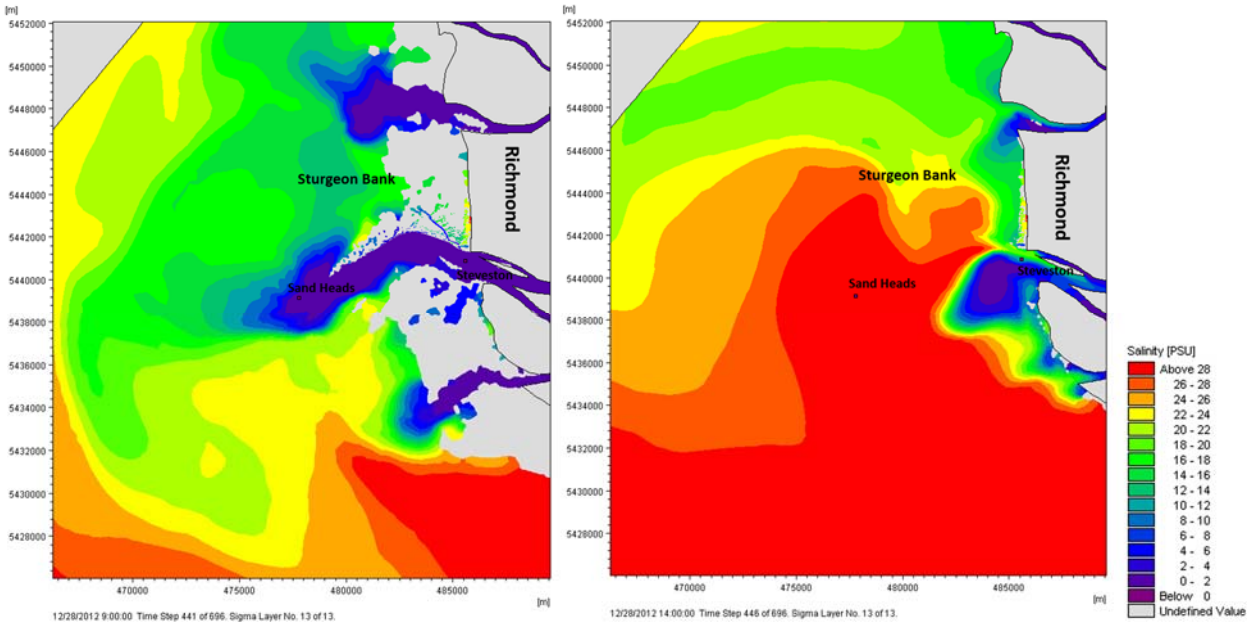


FIGURE 6-4: SURFACE SALINITY DISTRIBUTION UNDER LOW DISCHARGE AT LOW (LEFT) AND HIGH (RIGHT) TIDE, EXISTING CONDITION

The main effects of the cobble berm on the salinity are the following:

- Retention of fresh water overflowing the Steveston North Jetty or brought into the area from Scotch Pond.

  During low discharge, input of fresh water to the marsh area occurring by overflow of the Steveston North Jetty is limited to the time where salty sea water has not penetrated into the South Arm. Under the proposed project conditions, the flow pattern generated by the cobble berm, aids in retaining fresh water for a prolonged time.

- Obstruction of tidal flows that bring salty sea water to the proposed marsh area (Figure 6-7).

  This typically occurs as the tide rises between LLW and HHW. However, when HHW is reached, tidal elevations are high enough for salty sea water to overflow the cobble berm into

the marsh area (Figure 6-8). This effect could be mitigated by raising the crest elevation of the cobble berm.

- Retaining salty sea water (Figure 6-9).

  Mainly occurring after HHW, due to the overflow described above. As the tide retreats in Sturgeon Bank, the cobble berm retains salty sea water for a longer time when compared to existing conditions (where flow is not impeded).

Figure 6-5 provides a comparison of modelled depth-averaged salinity in the proposed marsh area for the existing (blue curve) and the with-project conditions (yellow curve). The upper and lower limits for both curves (representing highest and lowest salinity, which may occur at different times) are comparable, indicating that the salinity range in the area will not be altered by the project. However, with-project salinity will tend to be lower throughout the tidal cycle. For reference, salinity levels for the existing marsh area are depicted by the green dashed curve. When compared to the yellow curve (proposed marsh) it can be concluded that the cobble berm will promote a salinity range in the proposed marsh area which is comparable to that of the existing marsh.

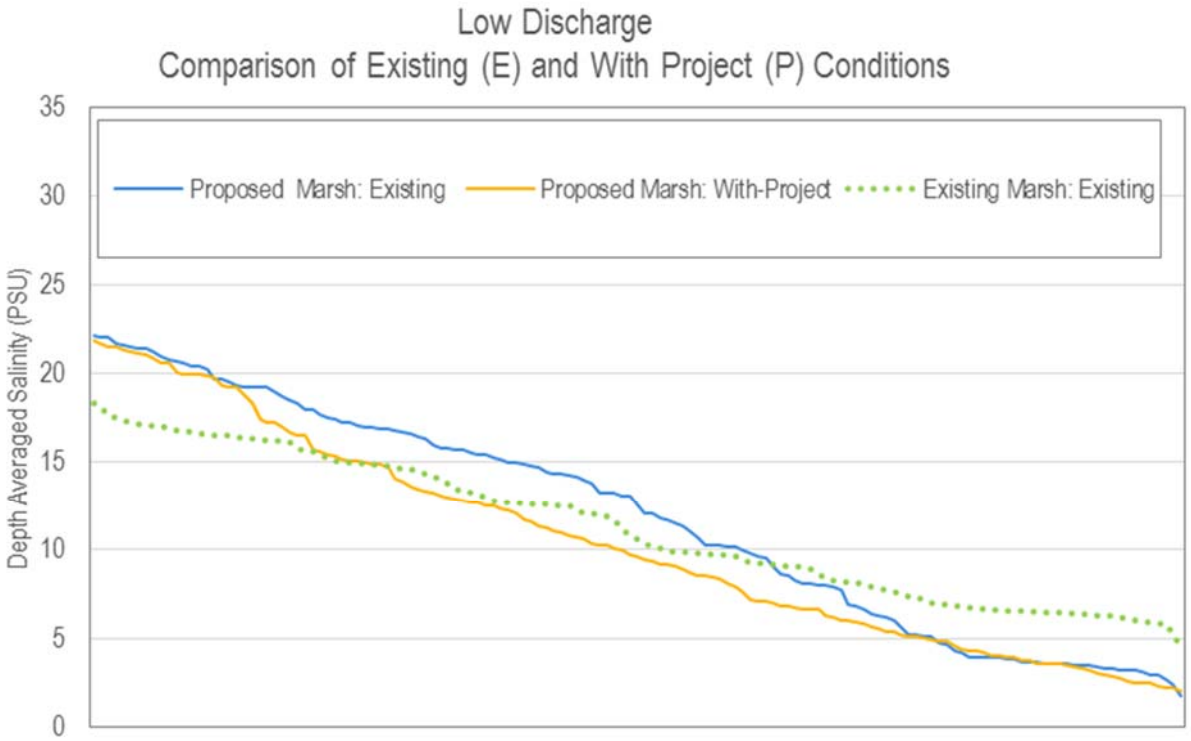


FIGURE 6-5: SALINITY VARIATIONS IN THE PROPOSED AND EXISTING MARSH AREA UNDER LOW DISCHARGE

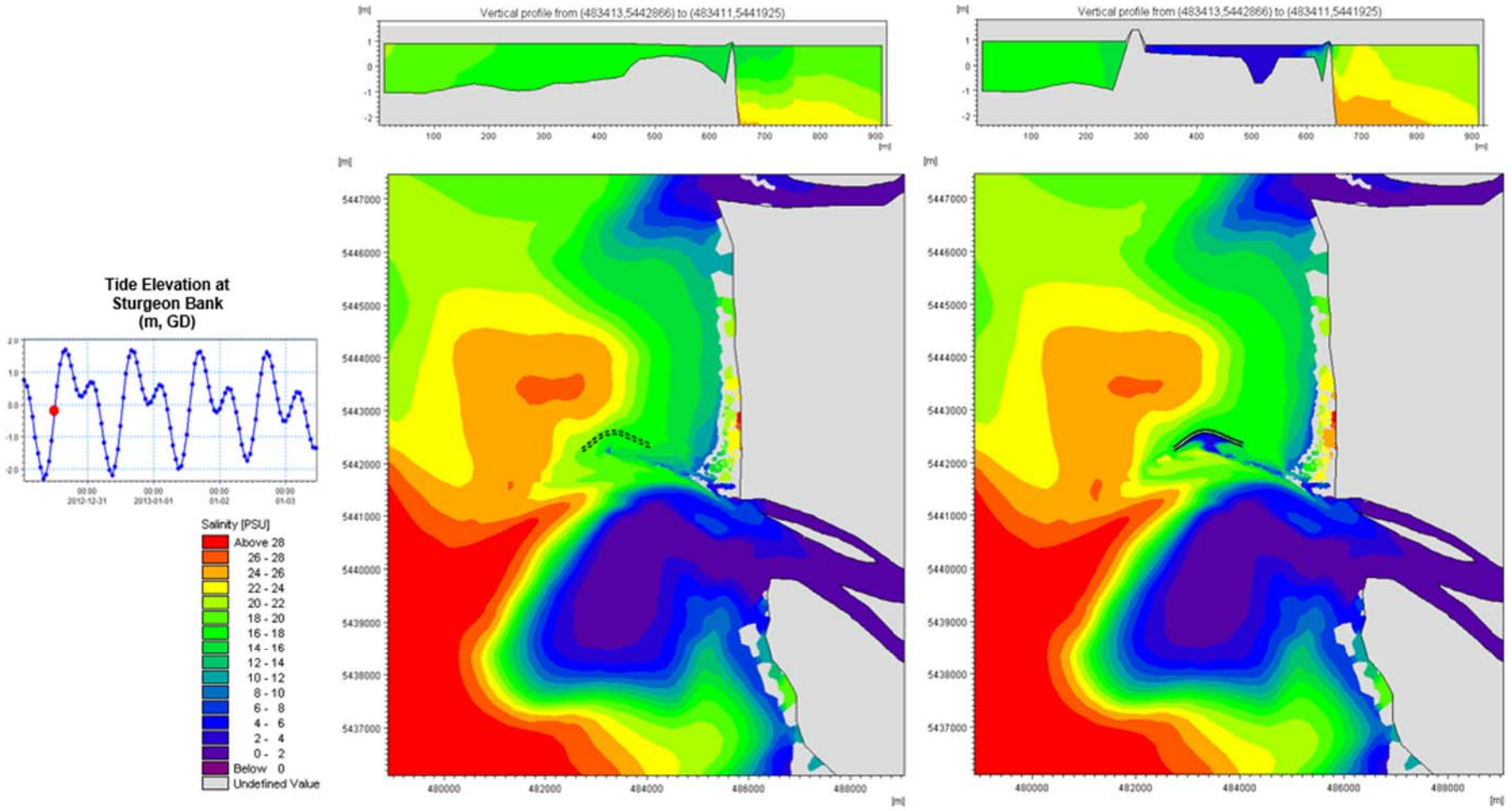


FIGURE 6-6: SALINITY PROFILE AND SURFACE SALINITY UNDER LOW DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS. TIDE EL. AROUND MSL

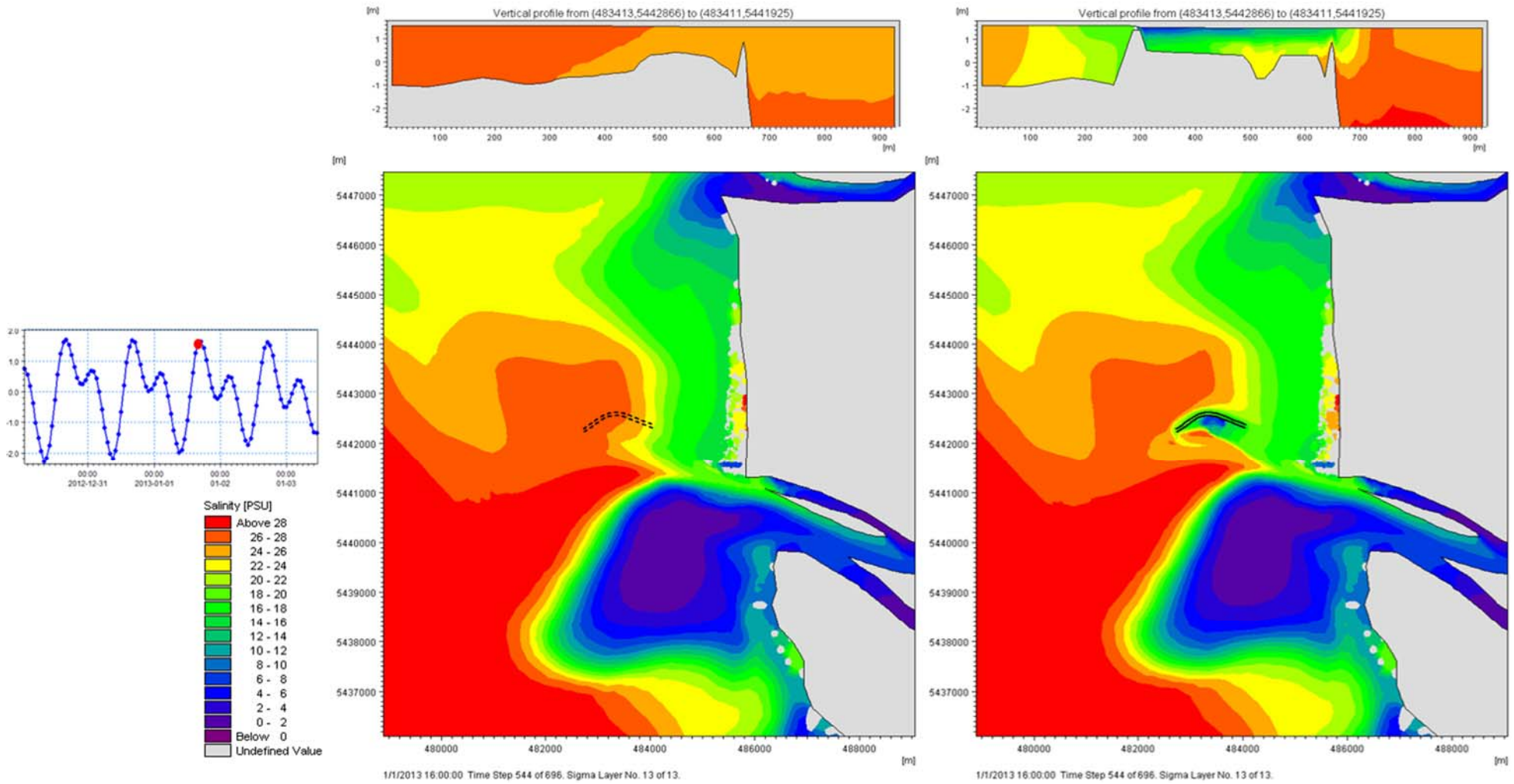


FIGURE 6-7: SALINITY PROFILE AND SURFACE SALINITY UNDER LOW DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS. TIDE EL. CLOSE TO HHW

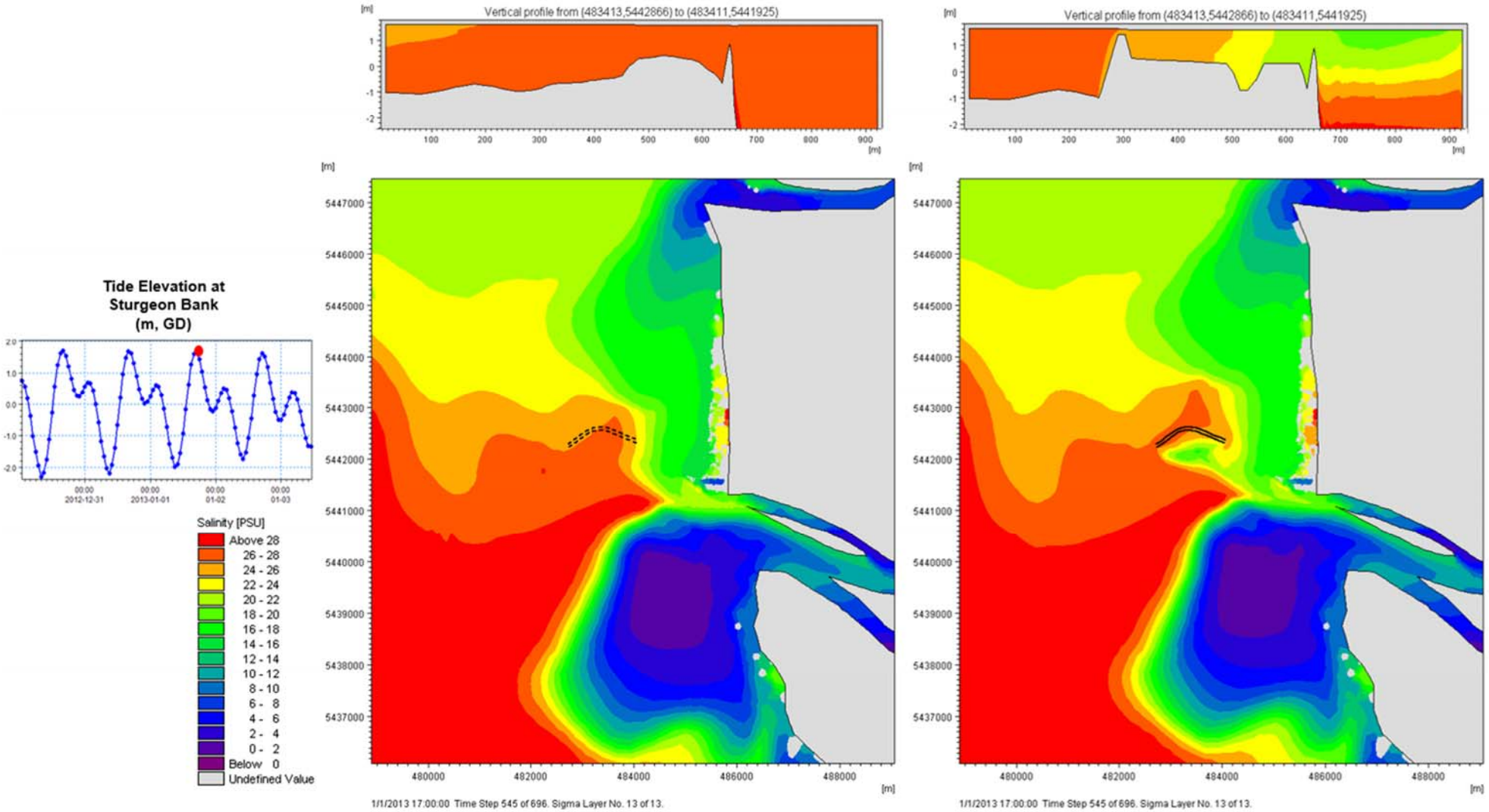


FIGURE 6-8: SALINITY PROFILE AND SURFACE SALINITY UNDER LOW DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS TIDE EL. AT HHW

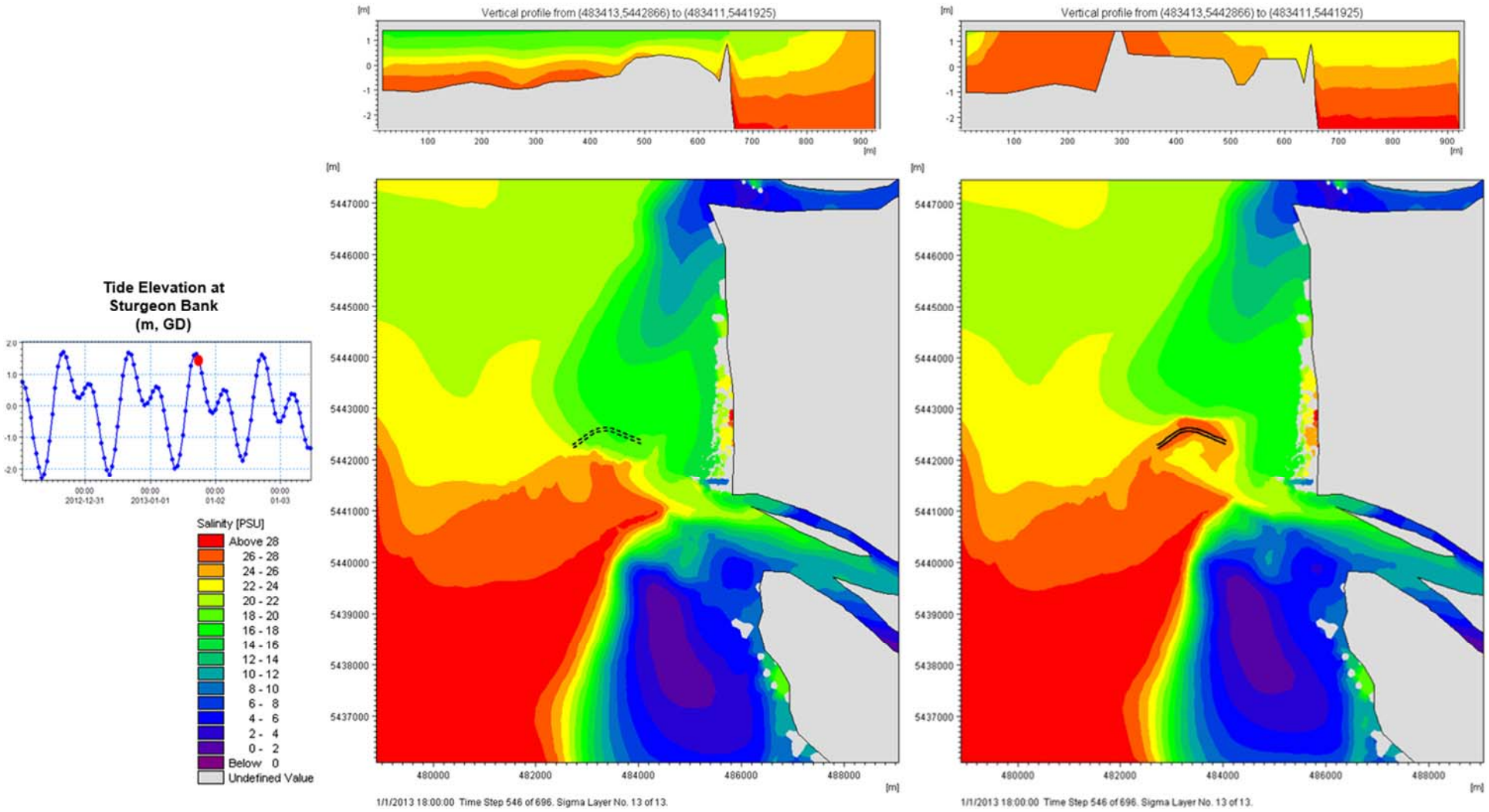


FIGURE 6-9: SALINITY PROFILE AND SURFACE SALINITY UNDER LOW DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS. TIDE EL. PASSED HHW

6.3.2. Medium Discharge Scenario

During medium discharge periods, the Fraser River has a larger influence on salinity and circulation in the area. As the tides retreat, fresh water pushes further into the ocean and spreads over a wider area, as depicted in the left plot of Figure 6-10, where blue shades are present in the offshore areas. Subsequently, Sturgeon Bank will be exposed to water of lower salinity during high tides, as depicted in the right plot of Figure 6-10 where brackish water (green shades) inundates the intertidal areas of Sturgeon Bank.

The stronger river flow in the South Arm starts to dominate over tidal flows, restricting salinity intrusion into the Fraser River.

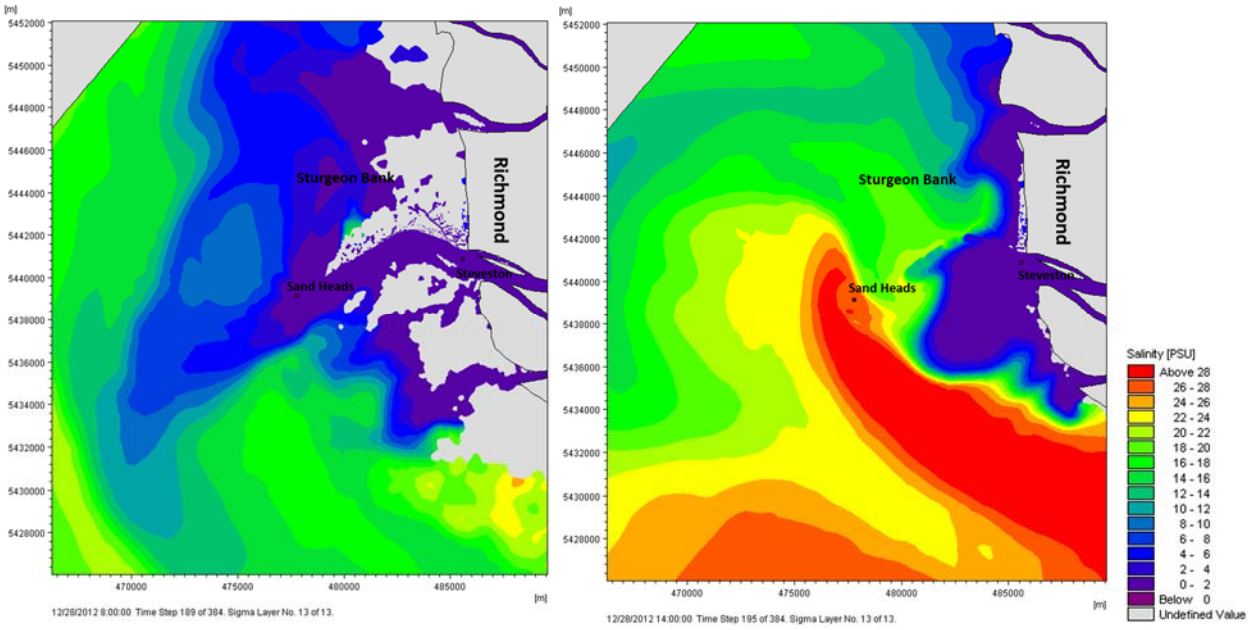


FIGURE 6-10: SURFACE SALINITY DISTRIBUTION UNDER MEDIUM DISCHARGE AT LOW (LEFT) AND HIGH (RIGHT) TIDE, EXISTING CONDITION

During times of medium discharge, there is a continuous supply of fresher water into the proposed marsh area flowing directly over the Steveston North Jetty or with the incoming tide for both the existing and the with-project conditions. For this reason, the main effect of the cobble berm on the salinity is:

- Obstruction of tidal flows that bring brackish water to the proposed marsh area.

Brackish waters are typically brought to Sturgeon Bank between LLW and HHW. The cobble berm effectively keeps brackish waters from coming into the marsh area (Figure 6-12). Even when the tide reaches HHW, flow from the river may overcome the tide (flowing in opposite directions), pushing brackish waters away from the marsh area (Figure 6-13). Exposure of the marsh area to brackish waters is therefore significantly reduced under the with-project condition.

The range of modelled depth-averaged salinities in the proposed marsh area for the existing and the with-project conditions is depicted with blue and yellow curves in Figure 6-11. Additionally, the range

of modelled salinities for the existing marsh area is depicted with the green dashed curve. This figure indicates that fresher waters are predominant through the tidal cycle in the area. However, the range of salinity in the proposed marsh area is considerably reduced for the with-project condition. The effect of the cobble berm is that salinities in the proposed marsh area are brought closer to the existing marsh.

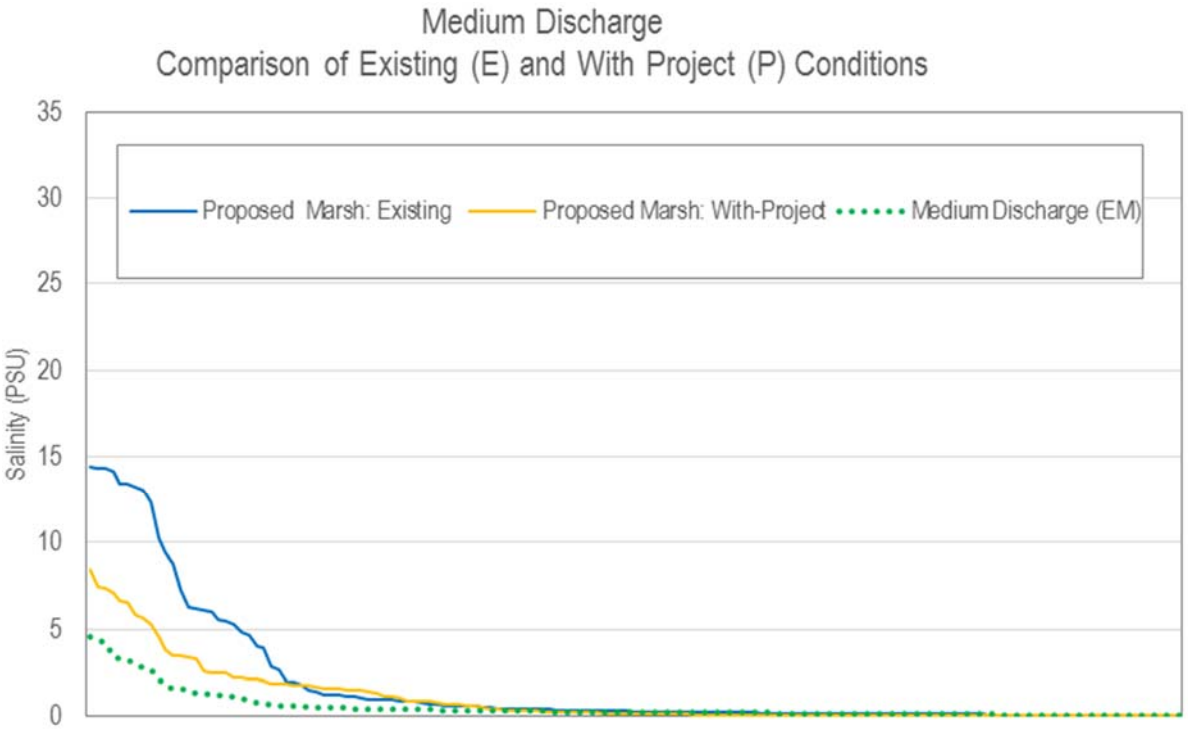


FIGURE 6-11: SALINITY VARIATIONS IN THE PROPOSED AND EXISTING MARSH AREA UNDER MEDIUM DISCHARGE

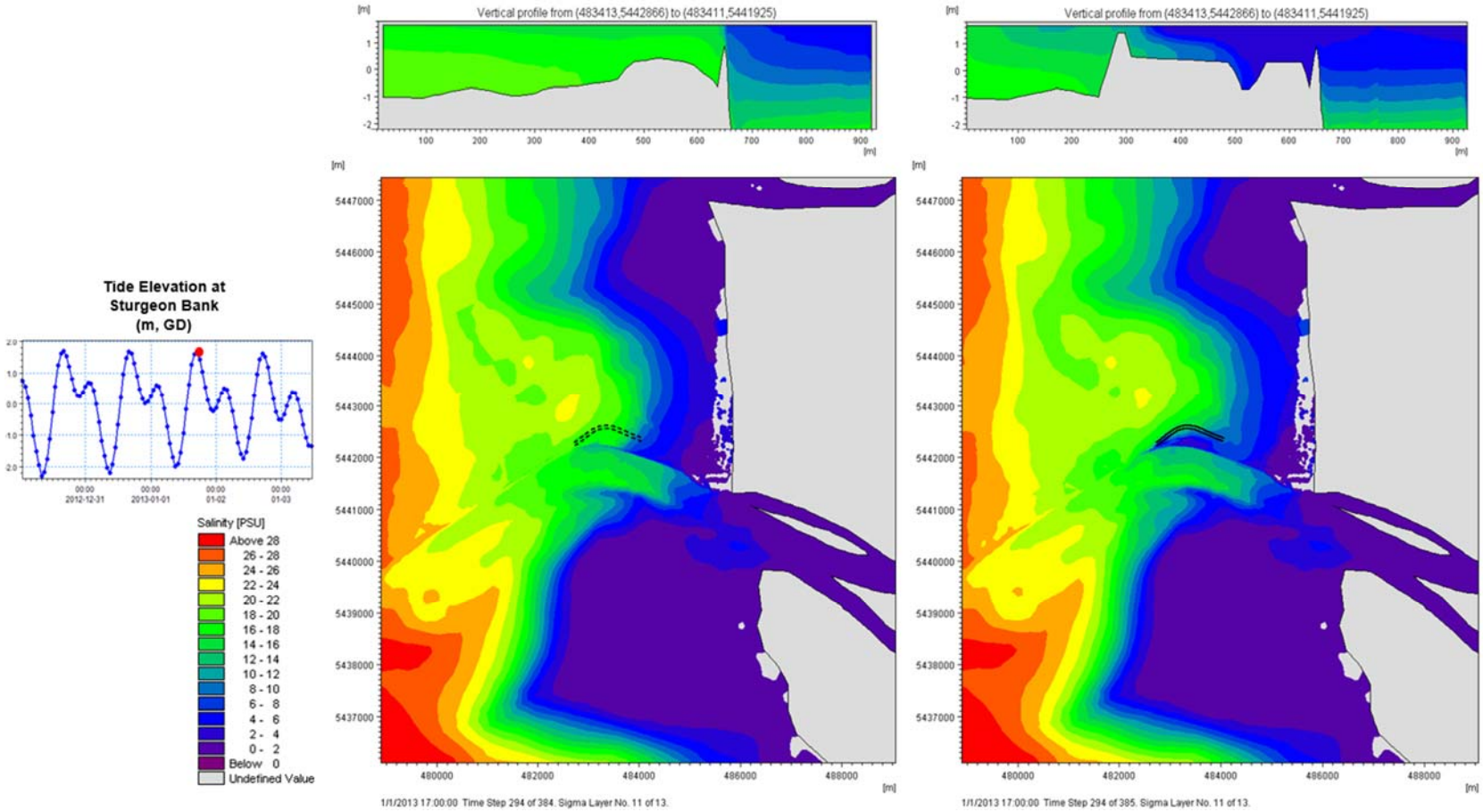


FIGURE 6-12: SALINITY PROFILE AND SALINITY AT INTERMEDIATE DEPTH UNDER MEDIUM DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS. TIDE EL. AT HHW

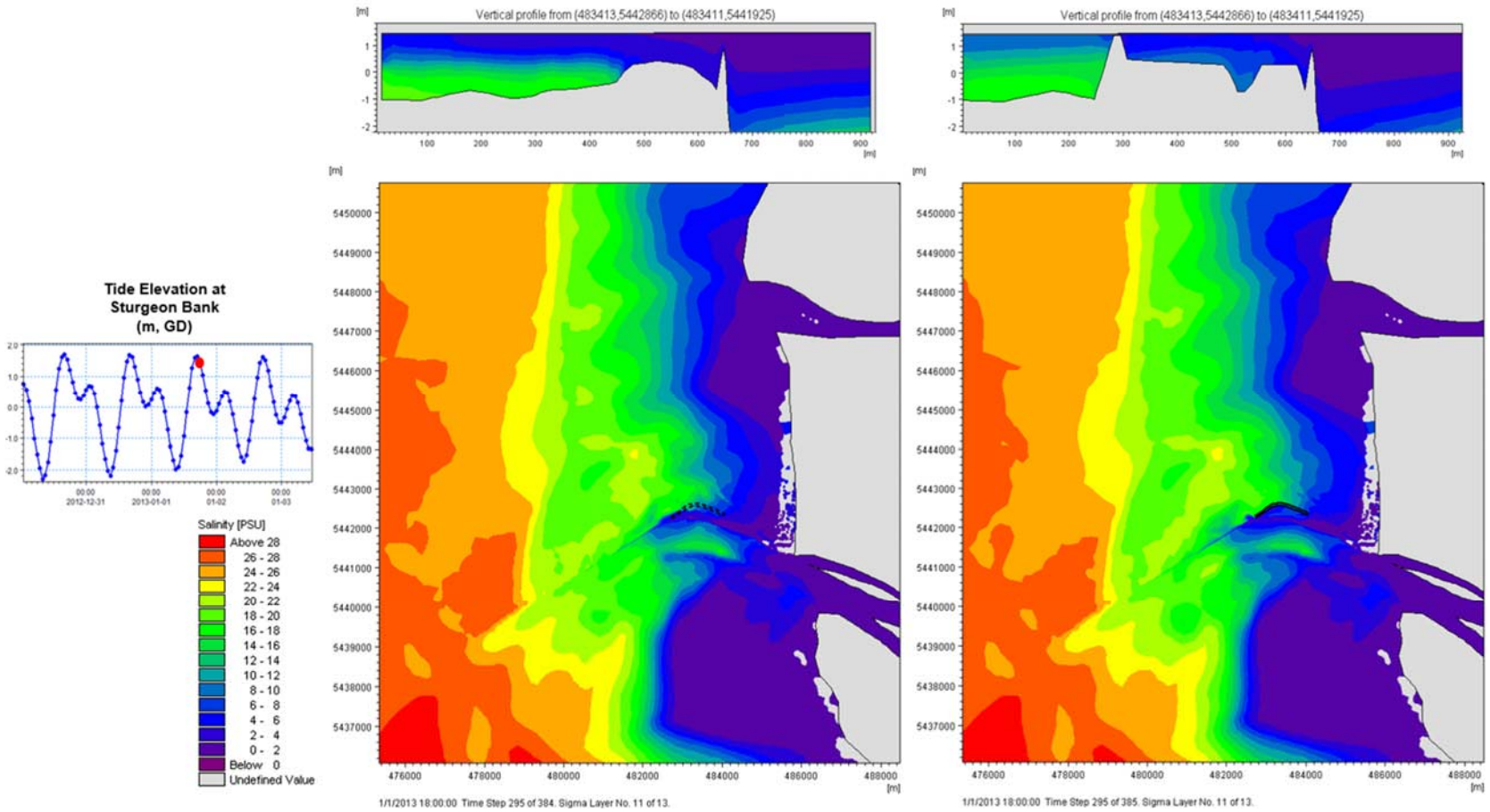


FIGURE 6-13: SALINITY PROFILE AND SALINITY AT INTERMEDIATE DEPTH UNDER MEDIUM DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS. TIDE EL. PASSED HHW

6.3.3. High Discharge Scenario

During freshet (high discharge) periods, salinities in the Fraser River are at the lowest levels. Fresh water is predominant, and intrusion of brackish water is limited at both Sturgeon Bank and the South Arm as illustrated in Figure 6-14, representing typical surface salinity distribution at low and high tide, respectively.

Maximum salinities within the marsh area are around 4-6 PSU and are limited to periods around Higher High Water (Figure 6-15). During the remaining time in the tidal cycle, salinities in the marsh area are close to 0 PSU.

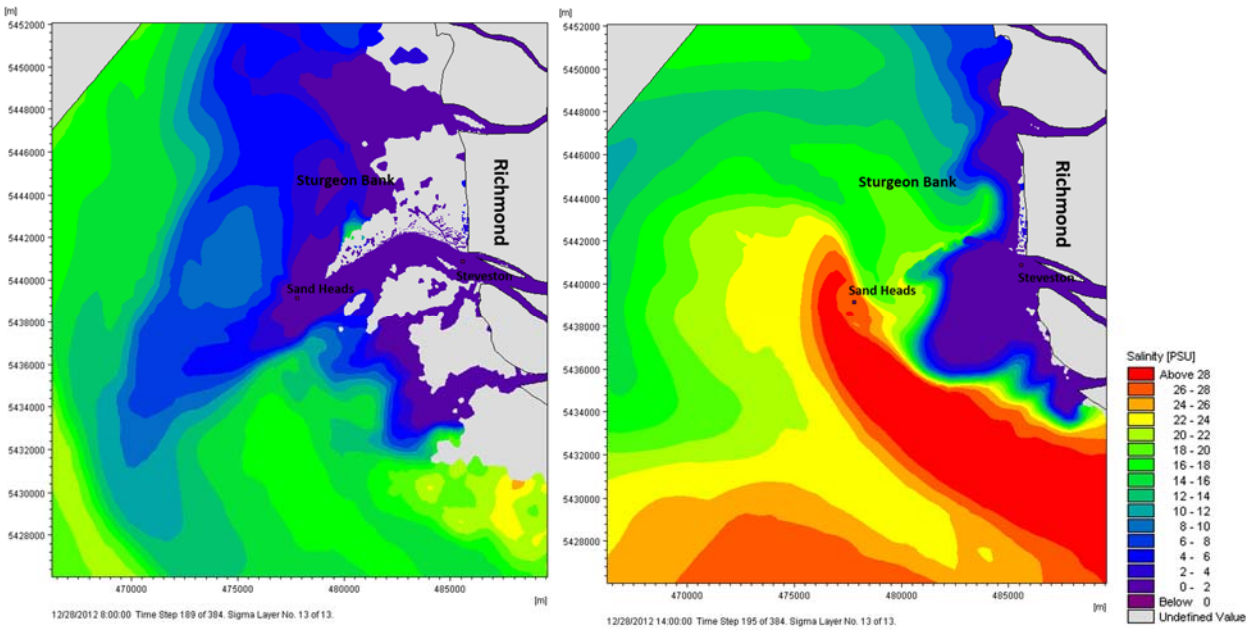


FIGURE 6-14: SURFACE SALINITY DISTRIBUTION UNDER HIGH DISCHARGE AT LOW (LEFT) AND HIGH (RIGHT) TIDE, EXISTING CONDITION

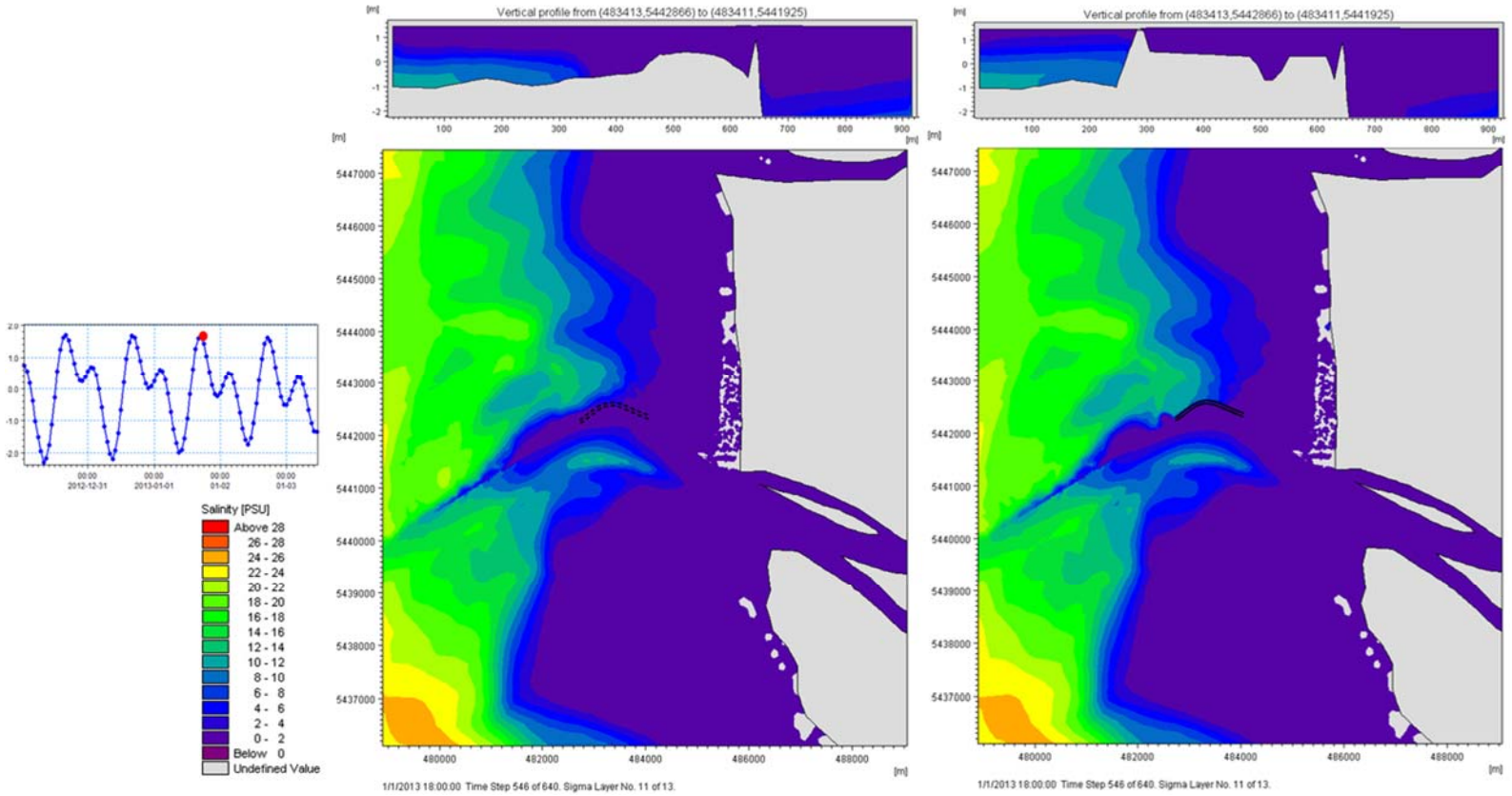


FIGURE 6-15: SALINITY PROFILE AND SALINITY AT INTERMEDIATE DEPTH UNDER HIGH DISCHARGE FOR EXISTING (LEFT) AND WITH-PROJECT (RIGHT) CONDITIONS. TIDE EL. AT HHW

6.4. Summary of Salinity Distribution Analysis

Overall the modelled salinity ranges from 0 to around 22 PSU, for both the existing and the with-project conditions. Model results suggest that the cobble berm will bring salinities in the proposed marsh area closer to the existing marsh.

The range of salinity at the proposed marsh area varies primarily as a function of discharge from the Fraser River, which in turn varies throughout the year.

During low discharge periods (e.g. winter months), the cobble berm promotes somewhat lower salinity levels in the proposed marsh area. This suggests that the fresh water retained in the marsh can be improved approximately 50% of the time during the year.

During medium discharge periods, the cobble berm also aids in a significant reduction of the salinity in the proposed marsh area.

During high discharge periods (e.g. freshet), fresh water is dominant in the proposed marsh area almost always throughout the tidal cycle, and hence the cobble berm does not affect salinity levels.

7. Climate Change Impacts

The response of the marsh vegetation to sea level rise and climate change impacts depends on several factors, including the rate of sea level rise, the resiliency of the marsh vegetation, input of sediment/fines to the marsh area, flow circulation, and potentially other elements of climate change such as temperature and insolation.

A detailed study of the response of the proposed marsh to sea level rise is beyond the scope of the present study, but a cursory overview based on current research findings is provided in the following.

7.1. Sea Level Rise

The indication is that the marsh could be fairly resilient to sea level rise, having the ability to grow in parallel with a rise of the mean sea level, provided that a sufficient influx of sediment will continue to deposit and raise the marsh plain. Based on the experience to date, the Fraser River provides a substantial throughput of sediment and fines to Sturgeon Bank and Roberts Bank. If the marsh vegetation remains vigorous it will have the ability to trap sediment, raising the marsh plain. However, if the rate of sea level rise accelerates to a degree that rising ocean levels outcompete the raising of the marsh plain, then the marsh will gradually submerge.

Considering the Steveston North Jetty, sea level rise would have the effect of enabling more water to overtop the jetty, and more frequently. This could have the net effect of providing more freshwater inflow to the marsh area.

In terms of the cobble berm, sea level rise would have the effect of allowing more wave overtopping, and also allow increased saltwater inflow. Raising the crest elevation of the cobble would improve on both of these two aspects.

In terms of the Sturgeon Bank mudflats, if sea level rise outcompetes mudflat buildup (i.e. sediment input to the mudflat is insufficient to raise the bed elevation at the rate of the sea level rise), this could lead to larger water depths in the area of the cobble berm. Deeper water would in turn enable larger waves to impinge on the marsh area. The stability of the cobble berm should in this case potentially be re-evaluated.

7.2. Increases in Temperature

The indication is that increases in peak temperature or its frequency could present an adverse impact to marsh vegetation, resulting in a decrease in plant cover. This in turn may affect species utilizing the marsh as habitat. Temperature-related impacts may be ameliorated somewhat at Sturgeon Bank due to the pronounced flow exchange over tidal cycles which can aid in reducing peak temperature levels.

7.3. Changes in Salinity

In terms of potential changes in salinity due to changes in river outflow and/or ocean circulation patterns, the indication is that the marsh may well be able to accommodate small, gradual changes.

This is due to the typical marsh vegetation being tolerant to a wide range of salinity levels. A long-term effect may transition in terms of the type and species of marsh vegetation.

7.4. Marsh Resiliency

The long-term marsh resiliency is difficult to ascertain due to many factors affecting the health of the marsh. However, at the onset of the marsh restoration, the key factors that aid in establishment of the marsh vegetation are: 1) to reduce wave exposure; 2) to provide a terrain elevation that balances wetting and drying over tidal cycles; and 3) to improve salinity levels, in particular reduce exposure to very high salt concentrations.

8. Conclusions and Recommendations

From the analyses conducted for this study, the following can be concluded:

- Introduction of the cobble berm at the proposed marsh area will be effective in providing shelter from waves, reducing the amount of bed shear stresses, and promote favorable conditions for growth and development of the future marsh.
- The cobble berm will aid in reducing salinities in the proposed marsh area, and shift salinity ranges closer to those occurring in the existing marsh area.

M&N recommends further investigations on the efficacy of a higher cobble berm and its effect on reducing saline water exposure for the proposed marsh area. Additionally, simulations of salinities over longer periods would enable a better understanding of project impacts on salinities at Sturgeon Bank.

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Appendix A:
Supplemental Hydrodynamic and Salinity Analysis with Incorporation of Phase 2 Raincoast Project

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MEMORANDUM

To: Michael Cho, P.Eng., M&N

From: Cheng-Feng Tsai, P.E., & Dilip Trivedi, P.E., M&N

Date: May 28, 2020

Subject: Supplemental Hydrodynamic and Salinity Analysis by Incorporating Phase 2 Breaching into the South Arm Jetty Tidal Marsh Project

EXECUTIVE SUMMARY

The purpose of this memo is to analyze potential changes in the South Army Jetty (SAJ) Tidal Marsh project area following the introduction of Raincoast Conservation Foundation (RCF) Phase 2 breaches in the Steveston North Jetty east of the SAJ project. The hydrodynamic modeling results suggest that current speeds and salinity within the project area are similar or slightly lower in magnitude compared to the without-breaches condition. Therefore, the breaches of the RCF Project do not present any adverse effects in the SAJ project area. In addition, results show that the effects of the proposed SAJ breaches located to the west of the SAJ site are limited and therefore not recommended to be included as part of the SAJ project.

BACKGROUND

The Vancouver Fraser Port Authority (VFPA) has developed the Habitat Enhancement Program (HEP). HEP has been developed to improve fish and wildlife habitat in advance of port development projects, to offset impacts to existing habitat. As part of the HEP, the South Arm Jetty Tidal Marsh (SAJ) project is a proposed intertidal marsh located along the north side of Steveston North Jetty (SNJ). Moffatt & Nichol (M&N) has been retained by VFPA for the design of the SAJ Project, which included a cobble beach berm, general raising of site grades with sand fill, drainage channels suitable for marsh planting (by others). M&N completed wave exposure and hydrodynamic/salinity analyses to support the design in Dec. 2017[1].

In 2018, RCF proposed the Fraser River Estuary Connectivity Project that consists of breaching sections of the SNJ surrounding the SAJ project. Tetra Tech Inc. was retained by the RCF to investigate the impacts of the proposed project on navigation and on sedimentation processes in the vicinity, and two reports were prepared (a Phase 1 report in Feb. 2018[2], and a Phase 2

[1] Moffatt & Nichol, 2017. Coastal Processes & Salinity Modeling, South Arm Jetty Tidal Marsh Project. Draft Report.

[2] Tetra Tech, 2018. Investigation of the Hydrodynamic and Sedimentation Impacts in the Fraser River from the Proposed Openings along the Steveston North Jetty. Technical Memorandum.

report in Jan. 2019[3]). The VFPA and M&N provided review comments on both reports. At present, Phase 1 of breaches east of the SAJ project (hereafter referred as RCF breaches) has been implemented and the formation of natural channels have been occurring. Phase 2 of breaches is scheduled to potentially proceed in 2020.

A supplemental analysis of tidal hydrodynamics and salinity was conducted to assess whether the RCF breaches have potential impacts to the SAJ Project. In addition, two proposed SAJ breaches west of the SAJ project (hereafter referred to as SAJ breaches) were evaluated to examine if there are any benefits by incorporating the SAJ breaches in the future project footprint. This addendum report is intended to supplement the 2017 M&N main report. **Figure 1** shows the SAJ Project footprint and the locations of three RCF breaches and two proposed SAJ breaches.

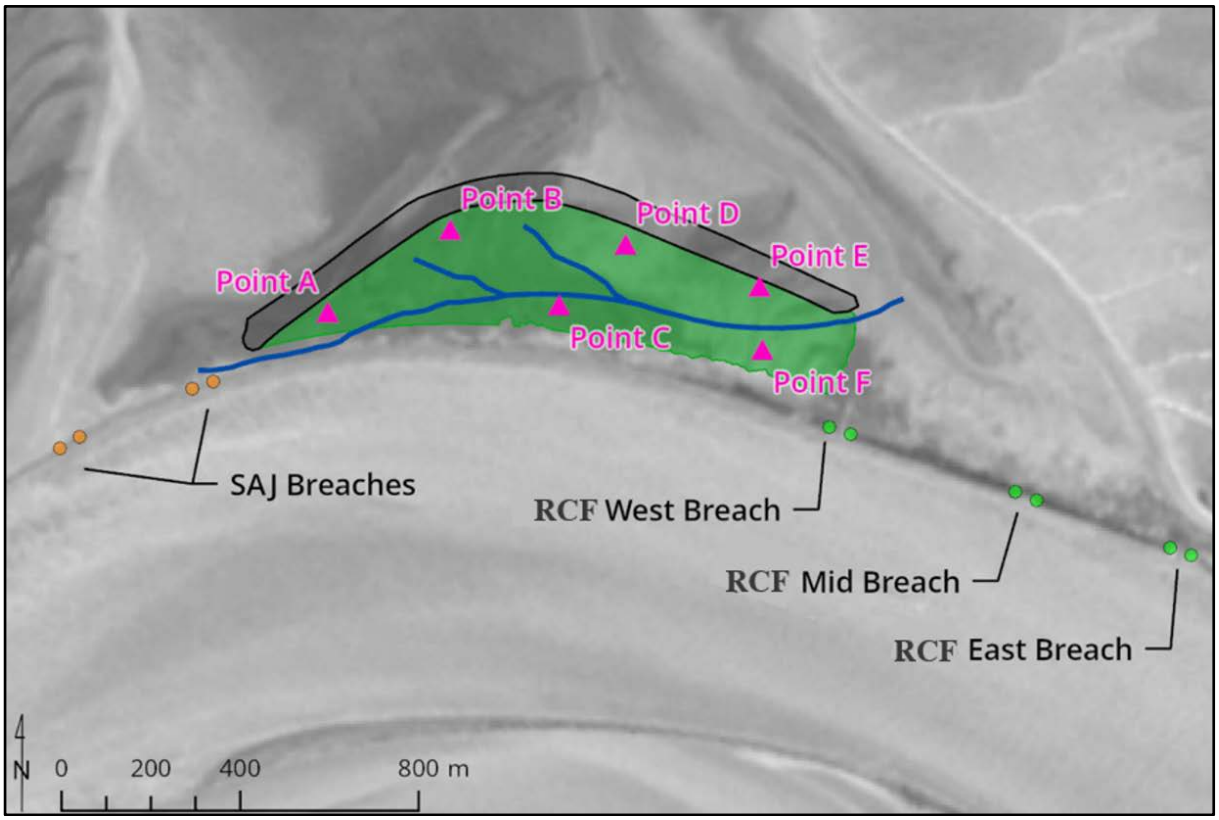


Figure 1: The SAJ Project Footprint, Locations of Three RCF Breaches and Two Proposed SAJ Breaches, and the Six Model Data Extraction Points (Point A-F Triangles).

MODELING APPROACH

[3] Tetra Tech, 2019. Phase 2 Report - Hydrodynamic and Sedimentation Study for the Proposed Breaches on Steveston North Jetty in the Fraser River. Presented to Raincoast Conservation Foundation.

The modeling approach and model performance characteristics (e.g. model development, calibration) are addressed in the main report of the 2017 M&N modeling work and are therefore not reiterated here. The only changes are to introduce the breaches and to incorporate the latest 2019 LiDAR data in the vicinity of the RCF breaches.

The latest LiDAR data was collected for the RCF Project in summer 2019 by McElhanney Consulting Ltd[4]. The survey was conducted at low tide and covers eastern half of the project area as well as the parcel to the east. Elevations were in the range from -2.3 m GD to +4.5 m GD.

Two additional scenarios were developed in the supplemental analysis to assess the effects of breaches on the SAJ Project. The first scenario incorporates the RCF breaches, while the second scenario incorporates both the RCF breaches and the proposed SAJ breaches. The existing condition (without any breaches and without the SAJ project) and the with-SAJ project scenarios developed in 2017 were also included for comparison purposes. Six model data extraction points were used to analyze the effects of the breaches in the SAJ project area. The extraction points are denoted by the triangles shown in **Figure 1**, Point A-F.

Three discharge flow conditions in the Fraser River were investigated in the supplemental analysis to allow direct comparison to the 2017 modeling results. The low flow of 2,000 m^3/s represents the base flow condition. The high flow was set to 8,000 m^3/s, an average peak discharge during the freshet. The medium flow of 5,500 m^3/s represents a transition from the low to the high flow.

MODEL SCENARIOS

The associated tidal channel will form and evolve naturally after a breach is created. A desktop analysis of tidal channel geometry was performed based on the literature to identify the extent of tidal channels connecting the RCF breaches.

Hydrodynamic model results found that the peak discharge through the RCF west breach (most impacting the SAJ project) is approximately 40 m^3/s. Friedrichs (1995[5]) and some other studies suggest the existence of a relationship between cross-sectional area and peak discharge for sheltered tidal channels. **Figure 2** presents the observed relationship. Using this relationship, an equilibrium cross-sectional area for the RCF tidal channel at peak discharge is estimated to around 60 m^2, which further indicates a RCF tidal channel width of around 20 to 25 m. Similarly, the peak discharge through the SAJ marsh channel is approximately 10 m^3/s, corresponding to a channel with an estimated cross-sectional area of 30 m^2 and a channel width of 10 to 15 m.

While there is great variability within tide-dominated systems, the channel width-to-depth ratio can be split into two discrete groups of tidal channels: vegetated channels and channels on bare

[4] McElhanney Consulting Services Ltd. (2019). LiDAR for Raincoast Conservation Foundation 2019.

[5] Friedrichs, C. T. , 1995. Stability Shear Stress and Equilibrium Cross-Sectional Geometry of Sheltered Tidal Channels. Journal of Coastal Research (11), p1062-1074.

flats (Hughes, 2011[6]). Aerial photographs and LiDAR data were used to estimate the width-to-depth ratios for vegetated channels around Sturgeon Bank and the results are shown in **Figure 3**. Also shown in the figure is the estimated RCF breach channel (a width of 20 m and a depth of 1.5 m at MWL) and the SAJ marsh channel geometry (a width of 10 m and a depth of 0.7 m). The estimated channel geometries are aligned well with the surrounding vegetated channels.

Two additional model scenarios were developed using these estimated channel geometries. They were then incorporated into the earlier with-SAJ Project scenario, which adds a rock berm, a marsh channel, and raising of site grades to support marsh habitat.

The first scenario, "RCF Breaches", adds the three RCF breaches and associated tidal channels to the with-SAJ Project scenario. The second scenario, "All Breaches", adds the two proposed SAJ breaches to the first scenario. The bathymetry of four model scenarios are shown in **Figure 4.**

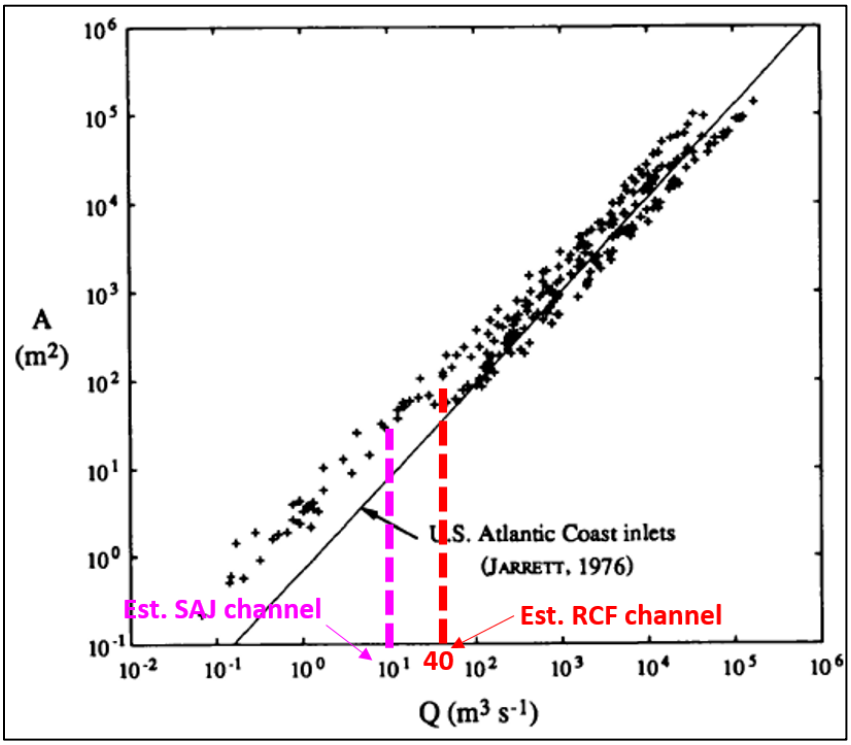


Figure 2: Cross-Sectional Area vs. Peak Discharge for Tidal Channels (Friedrichs, 1995)

[6] Hughes, Z. J. , 2011. Chapter 11: Tidal Channels on Tidal Flats and Marshes, Principles of Tidal Sedimentology. Editors: Davis Jr. , R. A. and Dalrymple, R. W. Publisher: Springer Netherlands.

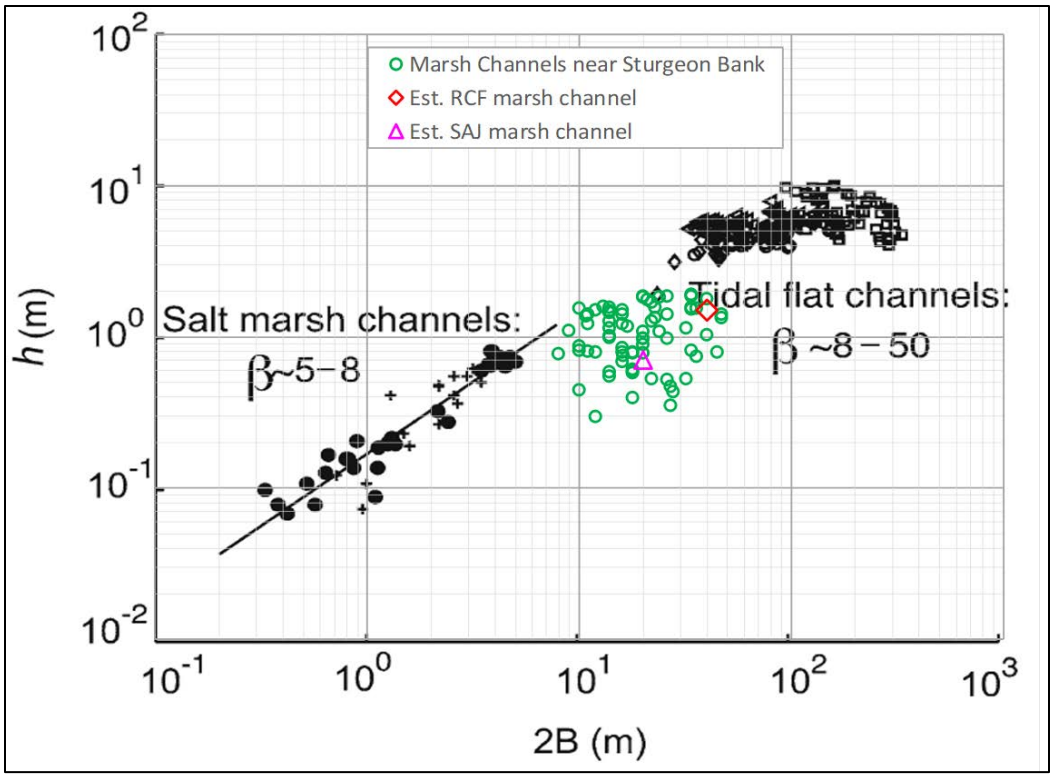


Figure 3: Width-to-Depth Ratio for Tidal Channels (Revised from Hughes 2011)

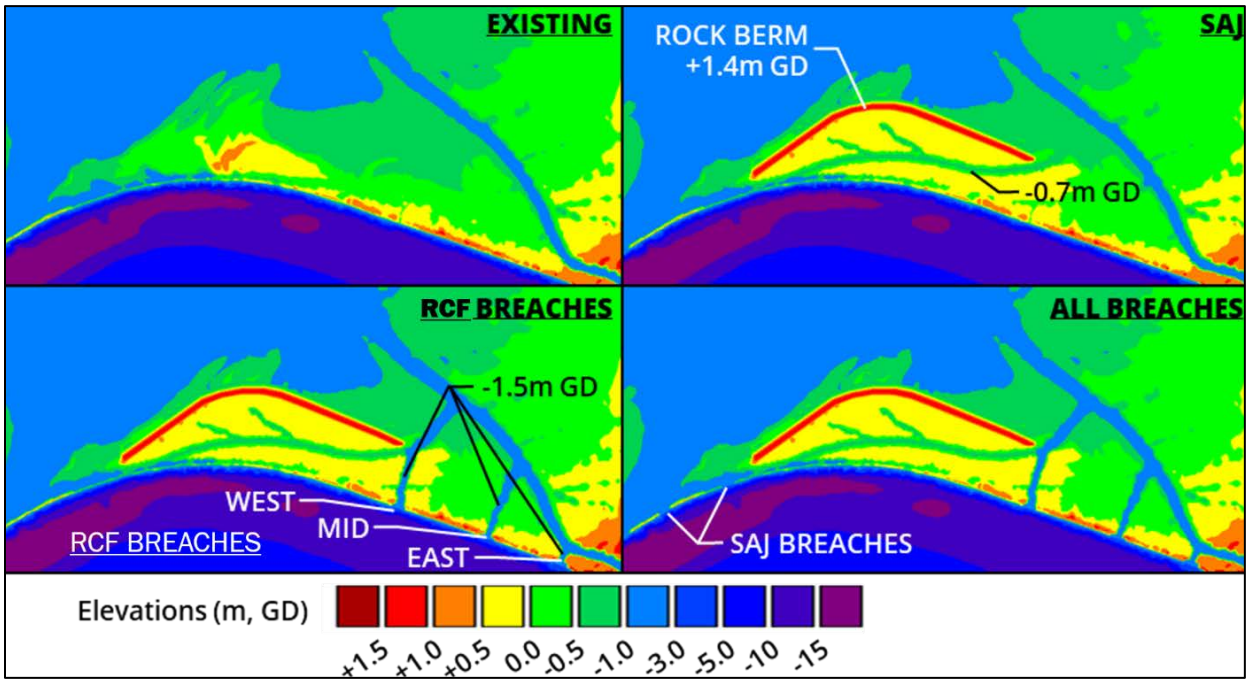


Figure 4: Bathymetry for Model Scenarios

MODEL RESULTS

Figure 5 and **Figure 6** show current speeds and surface salinities at Point "A" and Point "F", respectively. Points "A" and "F" were chosen because they are on the opposite ends of the project area and the results at the other four locations mostly fall between Points "A" and "F". All three conditions: high flow (8,000 m^3/s), medium flow (5,500 m^3/s), and low flow (2,000 m^3/s) were investigated in the supplemental analysis. Results show that there are no discernible differences with the addition of the RCF breaches or SAJ breaches under all flow conditions. Only the low flow condition is presented in the figures for illustrative purposes.

Results indicate that the current speeds within the SAJ project area are not substantially affected by the addition of the RCF breaches or the SAJ breaches. At all extraction points, the range of current speeds during the simulation period are similar as long as the SAJ project elements such as the cobble berm and raising the site grades, are implemented (e.g. "SAJ", "RCF Breaches", and "All Breaches") and are generally less than 0.3 m/s. However, a substantial reduction of current speeds can be seen between the scenarios with the SAJ project elements and the existing condition, in which the current speed could reach around 0.7 m/s at Point A. Therefore, it confirms the positive effects with the proposed SAJ project elements. At the eastern portion of the SAJ project area (Point "E" and Point "F"), a slight reduction of the current speed can be observed with the addition of the RCF breaches, though the reduction is minor.

The maximum current speed in the RCF west breach is about 1.2 m/s. Because the channel flow and waves present in the channel may potentially erode the eastern edge of the marsh area, slope protection is recommended along the sides of the channel.

Similarly, surface salinity in the project area does not change significantly with the breaches. Although the overall salinity range (e. g. 0 to 29 PSU) during the simulation period is indiscernible between the scenarios with the SAJ project elements and the existing condition, the former may show lower daily variations in salinity (e. g. 3 to 15 PSU at Point "A" on 12/26) than the existing condition (e.g. 3 to 26 PSU), indicating a modest fresher environment when the SAJ project elements are implemented. At Point "F", occasional reduction in salinity is observed during certain flooding tide stage with the addition of the SAJ breaches. This is because less saline water flows to the eastern end of the project area (Points "E" and "F") when the flow conveyance through the SAJ breaches is provided. However, the lower salinity state is fairly short (an hour per day). Therefore, the benefits of the SAJ breaches are considered limited.

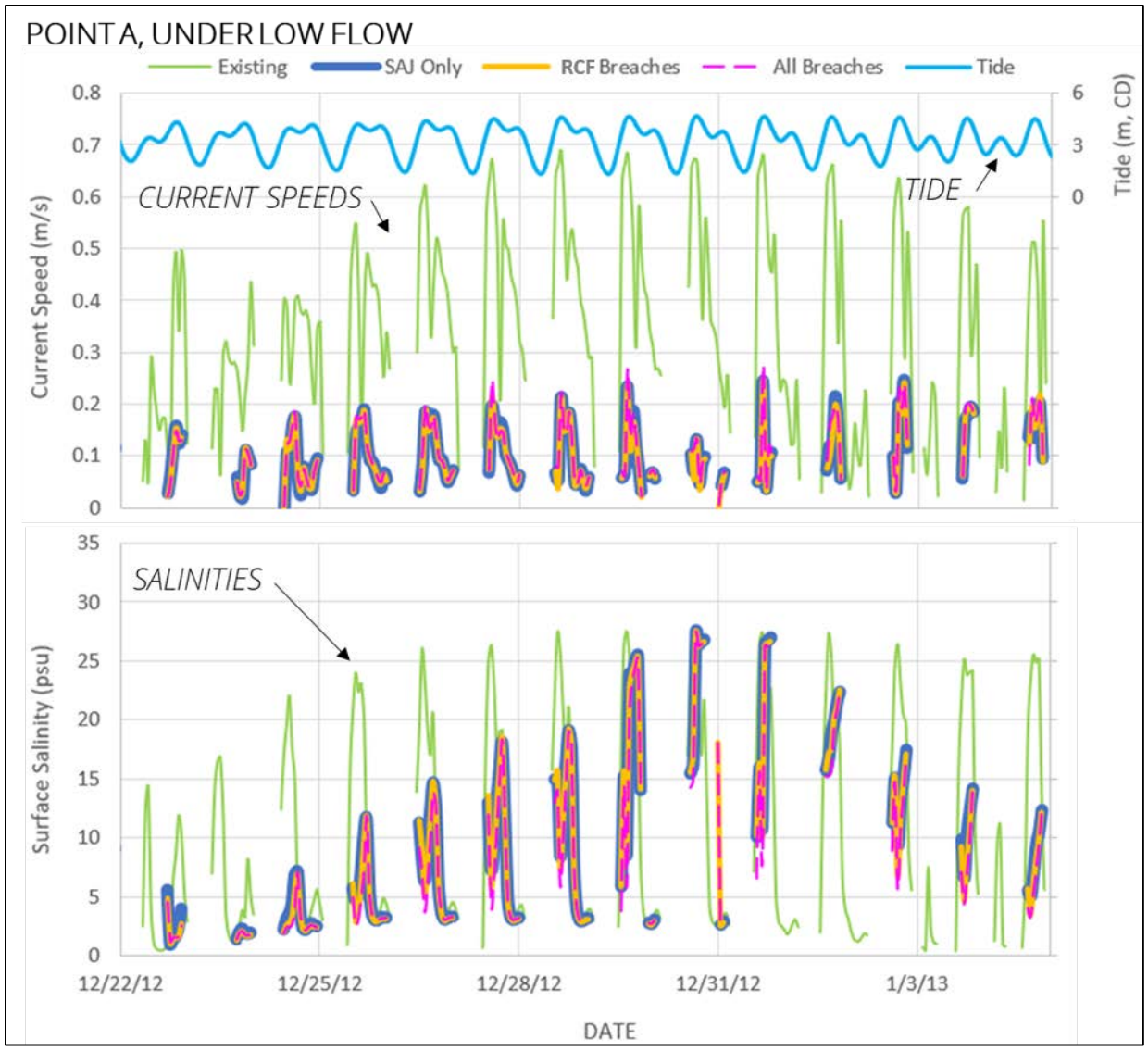


Figure 5: Current Speed and Surface Salinity at Point A, Under Low Flow.

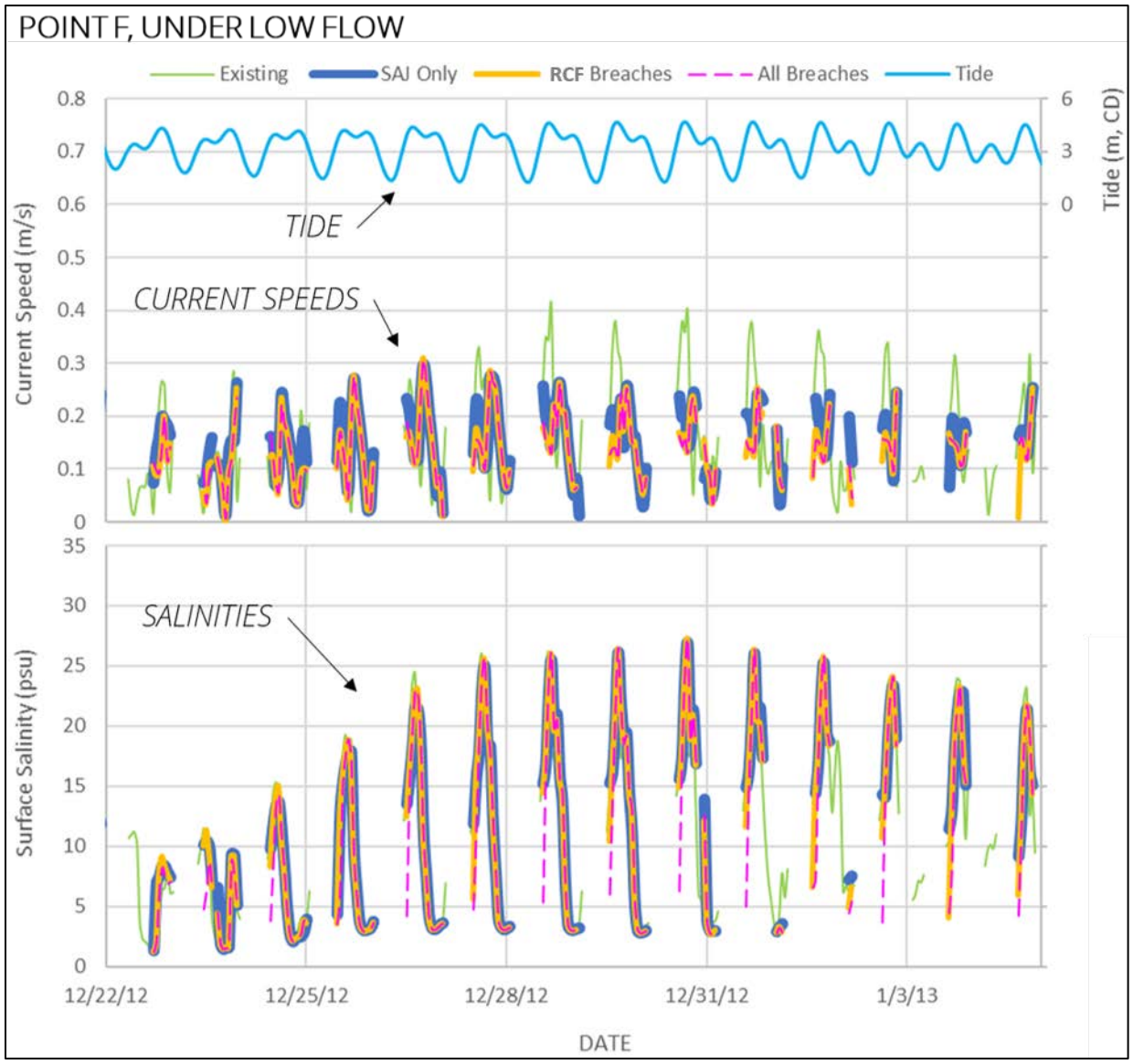


Figure 6: Current Speed and Surface Salinity at Point F, Under Low Flow.

CONCLUSIONS & RECOMMENDATIONS

The main conclusions from this supplemental analysis are:

- The current speeds within the SAJ project area are not substantially affected by the RCF breaches or SAJ breaches.
- The current speeds could be substantially higher in the project area without the SAJ project elements (e. g. cobble berm and raising site grades).
- The maximum current speed in the RCF west breach is about 1.2 m/s. Because the channel flow and waves present in the channel may erode the eastern edge of the SAJ marsh area, slope protection (0.3 m median rock size) is recommended along the sides of the channel.
- Salinity in the SAJ project area does not change significantly with the breaches and the overall salinity range is similar.
- The benefits of the proposed SAJ breaches are limited from a hydrodynamics and salinity perspective and therefore are not recommended for incorporation into the SAJ Project.



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Appendix IR2020-1.1-A9

Existing Ecological Conditions – Proposed South Arm Jetty Tidal Marsh Project

Existing Ecological Conditions
Proposed South Arm Jetty Tidal Marsh Project

Prepared for:
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Prepared by:
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File: 302-035.05
February 2018

Hemmera
An Ausenco Company

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1.0 INTRODUCTION

The proposed South Arm Jetty Tidal Marsh Project (the Project) near the City of Richmond, B.C., is being considered as a potential project under Vancouver Fraser Port Authority's (VFPA's) Habitat Enhancement Program. The Project is being developed in accordance with the "Working Agreement Concerning Procedures for Development and Operation of the Port Metro Vancouver Habitat Bank" (2012) between Fisheries and Oceans Canada (DFO) and VFPA.

The objective of this report is to document existing ecological features and potential species use of the proposed Project Site (the Site), situated at the mouth of the Fraser River. The general ecosystem conditions and occurrences of species of management concern will be used throughout Project planning to inform the design and construction mitigation at the Site.

1.1 RATIONALE

As part of the Habitat Enhancement Program, VFPA is applying a landscape approach to identifying potential sites where the productivity of fish habitat can be increased, existing habitat can be enhanced to increase its productivity, or degraded habitat can be restored to benefit fish and wildlife species that utilize the lower Fraser River estuary and Burrard Inlet.

The Project is located within the "Fraser Estuary, Boundary Bay, Burrard Inlet, Fraser and North Arms" Geographic Service Area (GSA) where more than 70% of the original wetland habitats have been adversely affected by historic development (Anon 1978). The restoration of tidal marshes, which have been lost as a result of a variety of anthropogenic factors, is a desirable fisheries management outcome for the lower Fraser River estuary. Creation of intertidal brackish marsh within this GSA will provide high-quality habitat at a prime estuarine location for juvenile salmonids, other fish species, birds, and other wildlife that utilize the lower Fraser River. As a result, the Project is anticipated to improve overall productivity within the GSA.

Site selection for this Project was based on factors outlined in the Working Agreement (2012) including need, habitat productivity, site location, feasibility and cost, sustainable habitat creation, ownership and tenure, and consideration towards First Nations and communities.

2.0 PROJECT LOCATION

The Site is located near the City of Richmond, immediately north of the Steveston North Jetty in the Steveston Bend Reach of the South Arm of the Fraser River (**Figure 1** and **Figure 2**). The Site is located offshore from Steveston Village on Sturgeon Bank. Sturgeon Bank is located along the seaward edge of the Fraser River delta.

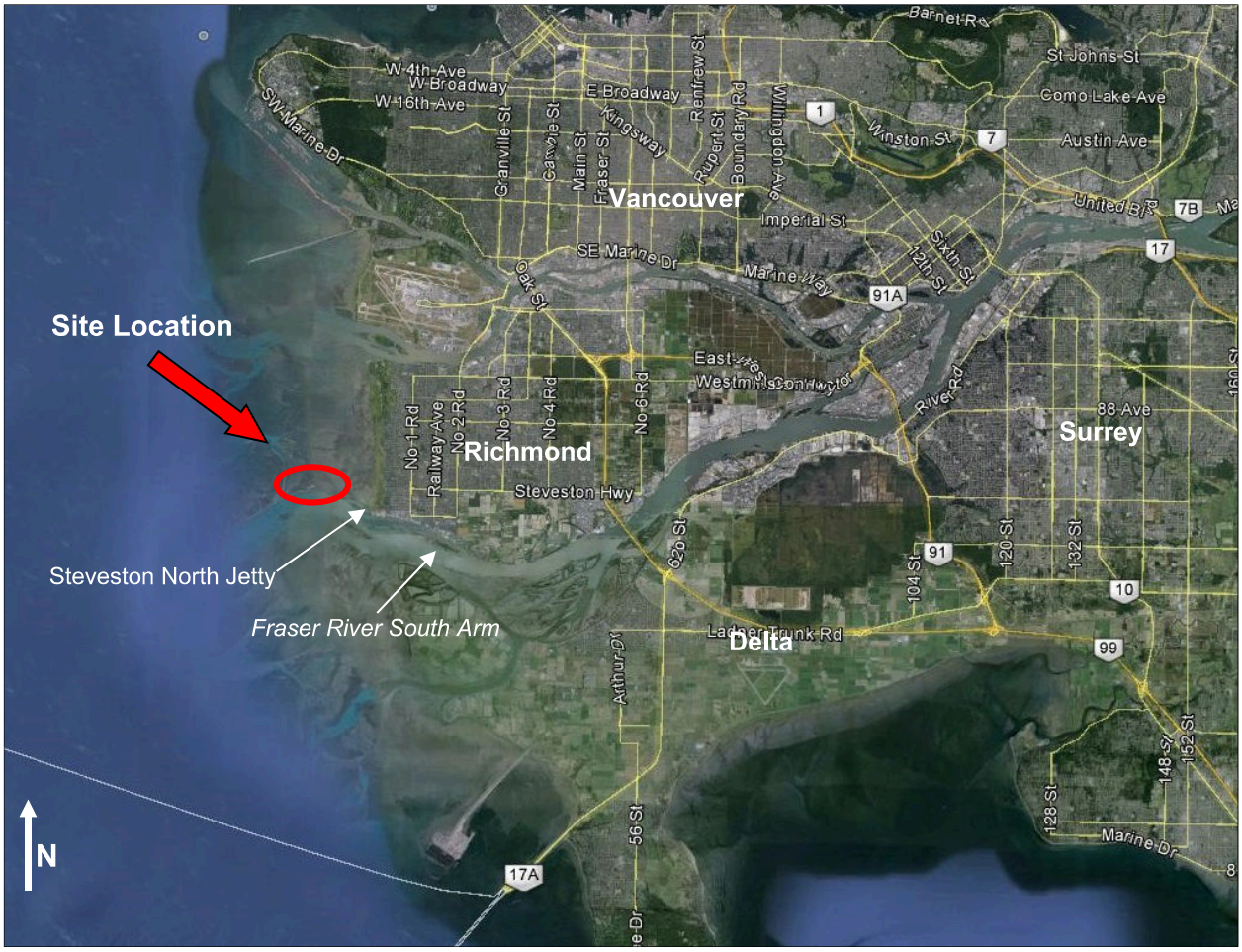


Figure 1 South Arm Jetty Tidal Marsh Project Site – Regional Setting (Google Earth Maps)

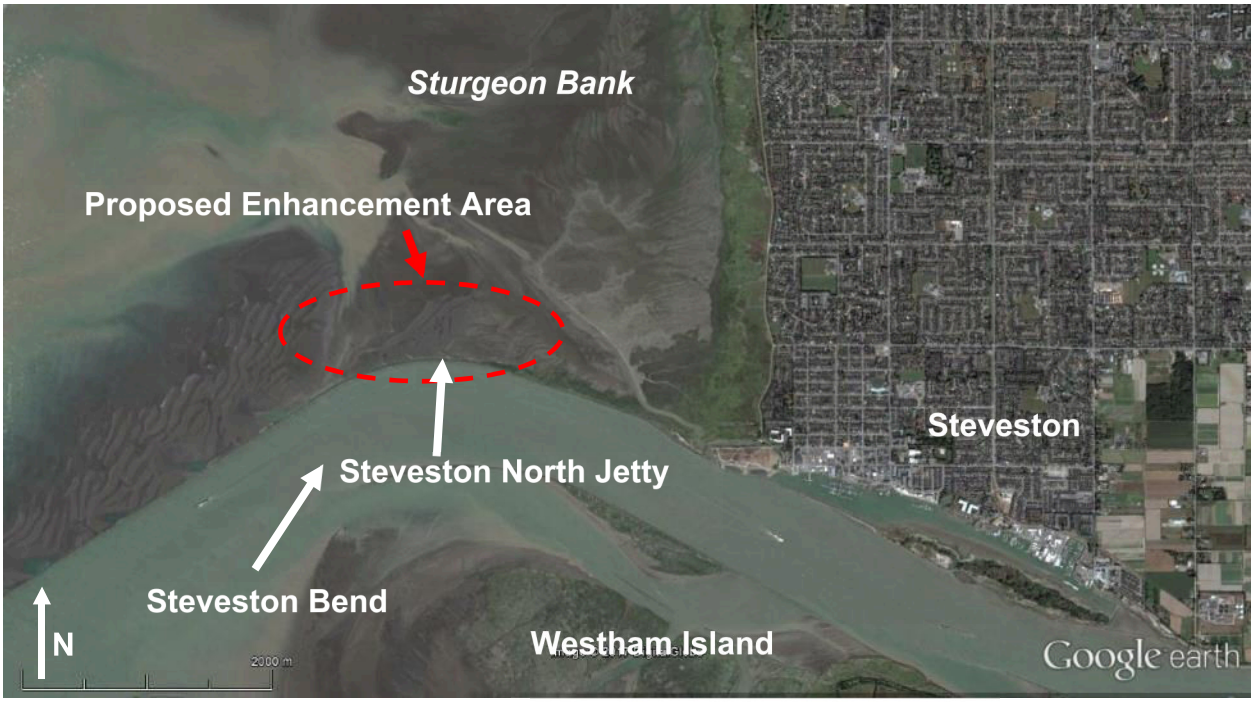


Figure 2 South Arm Jetty Tidal Marsh Project Site – Site Location (Google Earth Maps)

3.0 SITE HISTORY

The lower Fraser River estuary is a highly modified system with large sections of shoreline being used for industrial purposes. River training, in combination with annual navigation dredging, has decreased the river's delivery of sediments to Sturgeon Bank to well below historic levels (Golder and Hemmera 2014). The Steveston North Jetty, along the southern boundary of the Site, was constructed between 1911 and 1933. The jetty was installed to help stabilize the Fraser River entrance channel and to prevent erosion and the meandering of the northerly limits of the river (DFO 2014). The Site itself is not subject to frequent industrial or commercial use, aside from maintenance and repair of the jetty and navigation aids.

3.1 PREVIOUS HABITAT ENHANCEMENT INITIATIVE

In 1980, an experimental habitat enhancement initiative was undertaken within the boundaries of the Site (immediately north of the Steveston North Jetty) in an attempt to create habitat while beneficially using dredged material. Prior to this initiative, the habitat enhancement site was characterized as an unvegetated sandflat (**Photo 1**) (Envirocon 1980). To understand background conditions at the site and generate data on existing algae, invertebrate and fish communities on the flats adjacent to the jetty, field data programs were undertaken at the site in 1978 and 1979. Observations from these field programs indicated that the sand/mudflat offered mid-range habitat values relative to other habitats observed at Sturgeon Bank (Envirocon 1980).

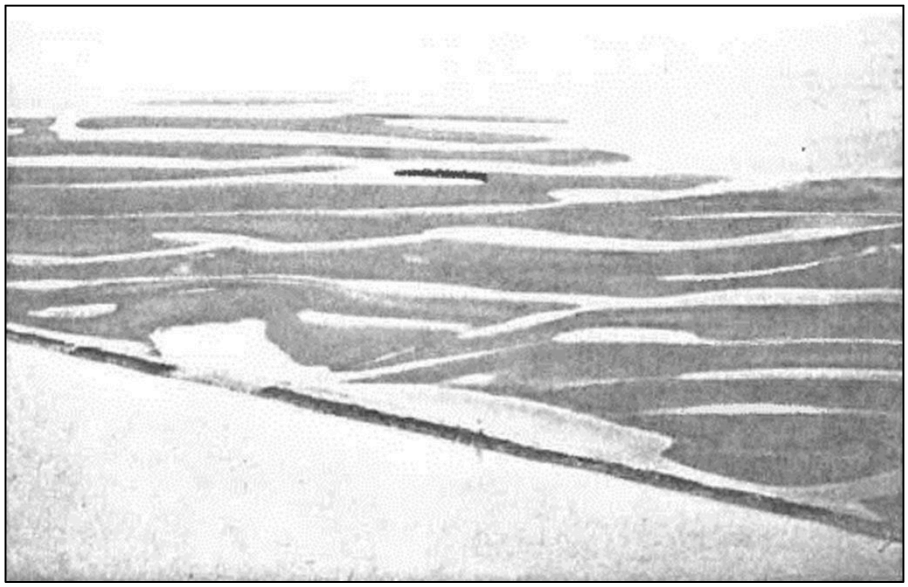


Photo 1 Aerial View of the Site Prior to the Experimental Habitat Enhancement Initiative in 1980 (View Facing Northwest, Envirocon 1980)

Between February and March 1980, approximately 40,000 m^3 of dredged material (consisting of sand and silt) from lower Fraser River maintenance dredging program was placed within the existing boundaries of the Site. The spoil was placed to a maximum height of 2.3 m geodetic datum (GD) at an approximate slope of 5% (or 1:20). Following initial substrate settlement, marsh plugs consisting of Lyngbye's sedge (*Carex lyngbyei*) and American bulrush (*Schoenoplectus americanus*), were transplanted between March and April 1980 (Envirocon 1980).

The site reportedly supported vegetation for several years (Sean Boyd, pers. comm.). However, as the project did not include wave protection, the fill material dispersed with observational data from 1990 suggesting that no vegetation was present at the site (FREMP 2017). Currently there is no vegetation present at the former project site (**Photo 2**).

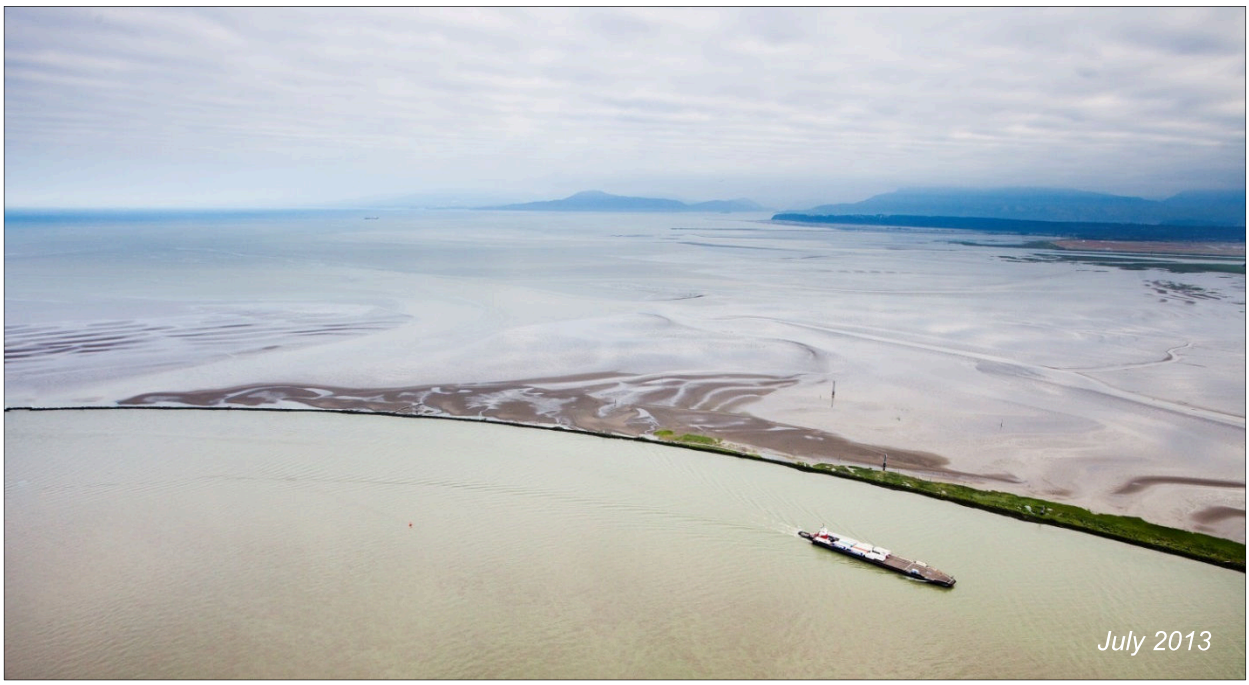


Photo 2 Aerial View of the Site (Facing North, W. Jans 2013)

4.0 PROPOSED WORKS

The Project proposes to create low intertidal brackish marsh and cobble beach habitat on the north side of the Steveston North Jetty. The Project is anticipated to have a maximum width of approximately 400 m and a maximum berm length of approximately 1,700 m (**Figure 3**). The Site encompasses an area of approximately 400,000 m^2 (40 ha) (**Figure 4A**).

The Project design is anticipated to connect to existing marsh platforms along the Site's southern boundary and eastern limit, although design for the Project has not been finalized (**Figure 4B**). Containment structures will be installed to protect the new marsh and contain the fill material within Site boundaries. Sand and silt material from maintenance dredging in the Fraser River will then be placed to raise the existing substrate to elevations between approximately 0.0 and 0.9 m GD. After a settlement period, brackish-tolerant plant species will be established on the marsh platform through a combination of plant installation and natural revegetation (**Section 5.3.2.2**).

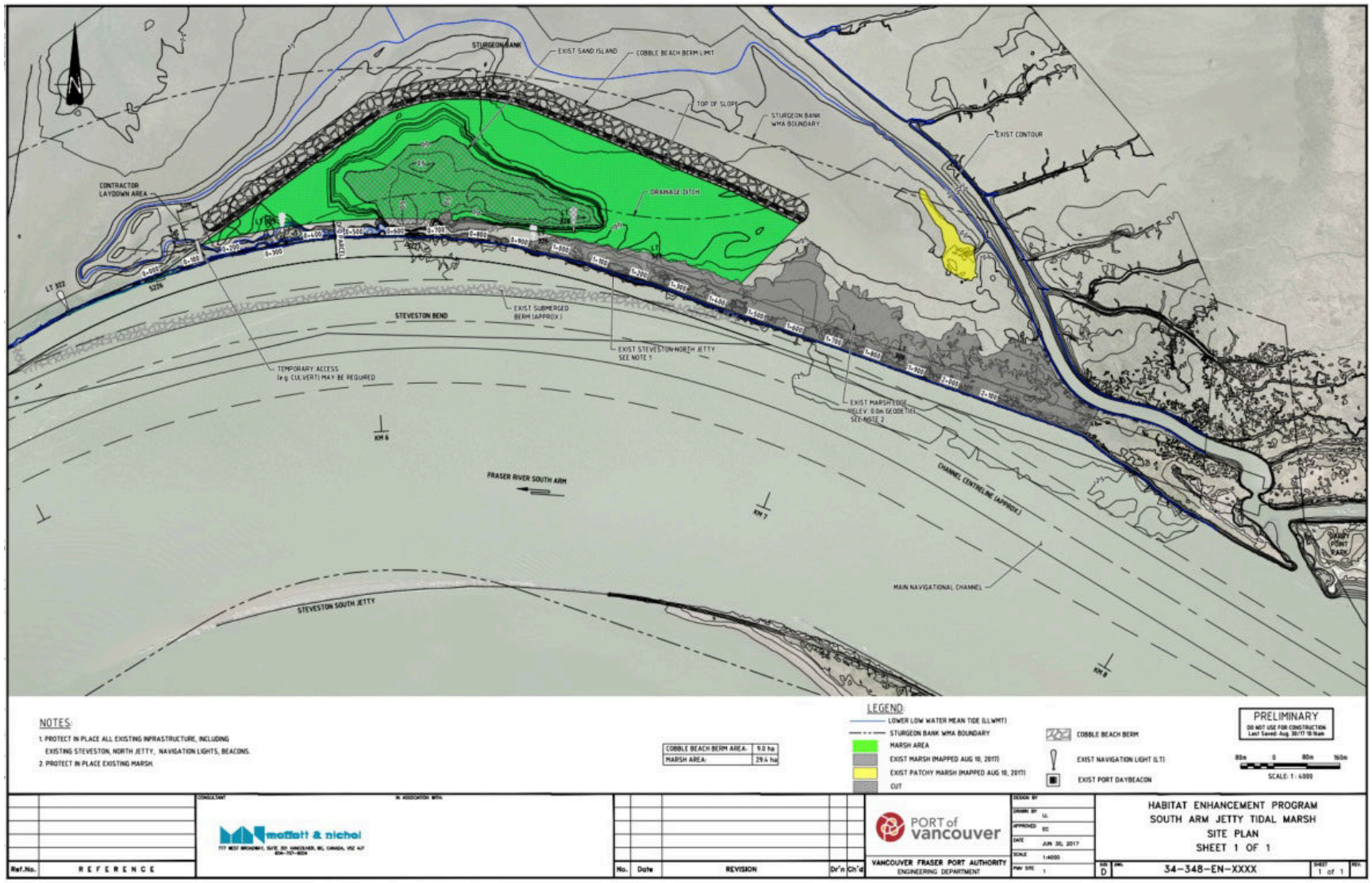


Figure 3 Proposed Design for the South Arm Jetty Tidal Marsh Project



Figure 4 South Arm Jetty Tidal Marsh Project Site: A) Existing Site Conditions, B) Rendering Concept Showing Potential Conditions at the Site Following Enhancement Works

5.0 BIOPHYSICAL CONDITIONS

Biophysical information on the Site was gathered from a desktop-based review and field studies undertaken at the Site between 2012 and 2017. The following databases were consulted during an online review:

- Fraser River Estuary Management Program and Burrard Inlet Environmental Action Program Habitat Atlas
- E-Fauna BC database
- Richmond Interactive Map
- BC Species and Ecosystems Explorer
- DFO's Aquatic Species at Risk database
- Fisheries Information Summary System
- iMap BC database

A general description of the existing and post-enhancement conditions at the Site is provided for each of the following categories: Physical Conditions, Habitat, Fish, and Wildlife (**Sections 5.2** to **5.5**, respectively). Descriptions of potential at-risk species and ecosystems that could potentially be encountered at or near the Site are also provided for each of **Section 5.3** to **5.5**. The federal Committee on the Status of Endangered Wildlife in Canada (COSEWIC) provides designations for species based on biological information that parallels the provincial ranking scheme. Species that are classified as at risk (i.e., Extirpated, Endangered, Threatened or Special Concern) by COSEWIC are reviewed by the Minister of the Environment and Governor in Council and, pending a decision by the Governor in Council, may subsequently be added to Schedule 1 of the federal Species at Risk Act (SARA). Species listed under Schedule 1 of SARA benefit from the legal protection afforded, and the mandatory recovery planning required, under SARA. Provincial at-risk species and ecosystems are assigned by the B.C. Conservation Data Centre (CDC) to either Red or Blue lists. Red-listed species or ecosystems are either Extirpated (i.e., no longer exist in the wild in BC, but do occur elsewhere), Endangered (i.e., facing imminent extinction or extirpation) or Threatened (i.e., likely to become Endangered if limiting factors are not reversed) in BC. Blue-listed species or ecosystems are described as "Special Concern" (i.e., sensitive or vulnerable to human activities or natural events) in the province.

5.1 GENERAL SITE DESCRIPTION

The Site lies within the Strait of Georgia Marine Ecosection which consists of a broad, relatively shallow estuarine basin extending to the Fraser River estuary. This ecosection consists of protected waters dominated by intertidal, nearshore, epipelagic and mesopelagic zones (Demarchi 2011).

The Site is also located directly adjacent to the Coastal Douglas Fir Moist Maritime (CDFmm) biogeoclimatic subzone (**Figure 5**). The CDFmm subzone is limited to the south coast of BC and includes several islands in the Strait of Georgia, a small portion of southeastern Vancouver Island, and a narrow strip of the adjacent

mainland. The CDFmm subzone occurs at elevations of less than 150 m, and is typified by warm, dry summers and mild, wet winters (Nuszdorfer et al. 1991). The mean annual temperature in the CDFmm subzone is 9.2 to 10.5°C and the mean annual precipitation ranges from 647 to 1,263 mm (Nuszdorfer et al. 1991).

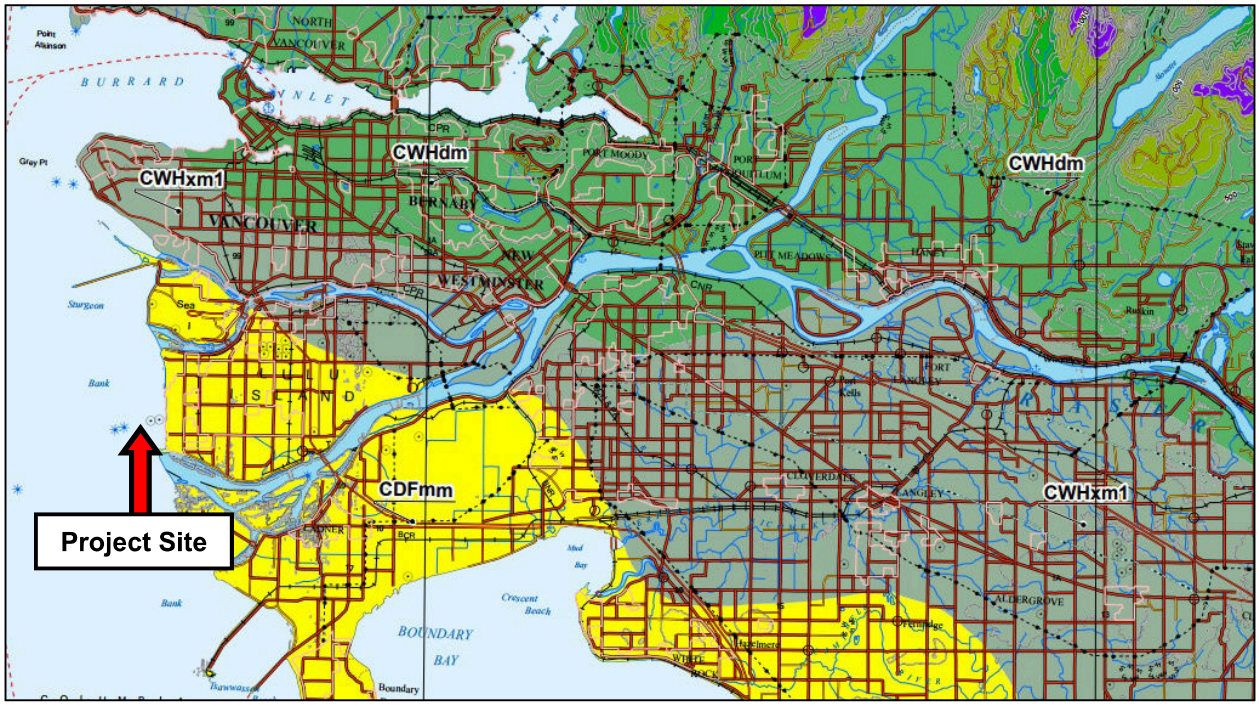


Figure 5 Biogeoclimatic Subzones of Metro Vancouver – Site Location in the Coastal Douglas Fir Moist MaritimeSubzone (MFLNRO 2016)

The Site is adjacent to the Sturgeon Bank Wildlife Management Area (WMA), a 5,152 ha protected area designated under Section 4 of the B.C. *Wildlife Act* (MFLNRO 2017, **Figure 6**). This WMA was designated in 1998 for the conservation of critical, internationally significant habitat for resident, migrating, and wintering waterfowl and shorebird populations, as well as for the preservation of important fish habitats (MFLNRO 2017). The Site is close to the shoreline of the City of Richmond, which is regionally designated as an Environmentally Sensitive Area and is west of Garry Point Park, a popular recreational area (**Figure 7**).

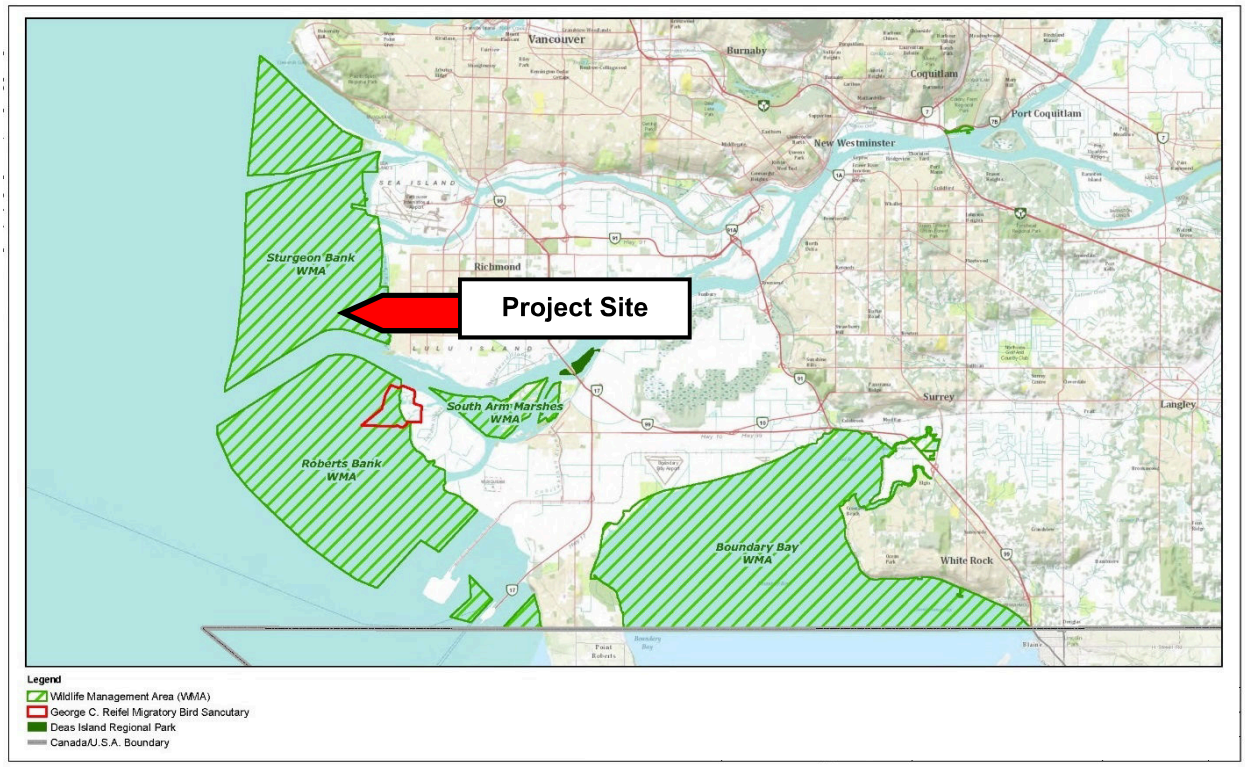


Figure 6 Sturgeon Bank Wildlife Management Area in Relation to the Site

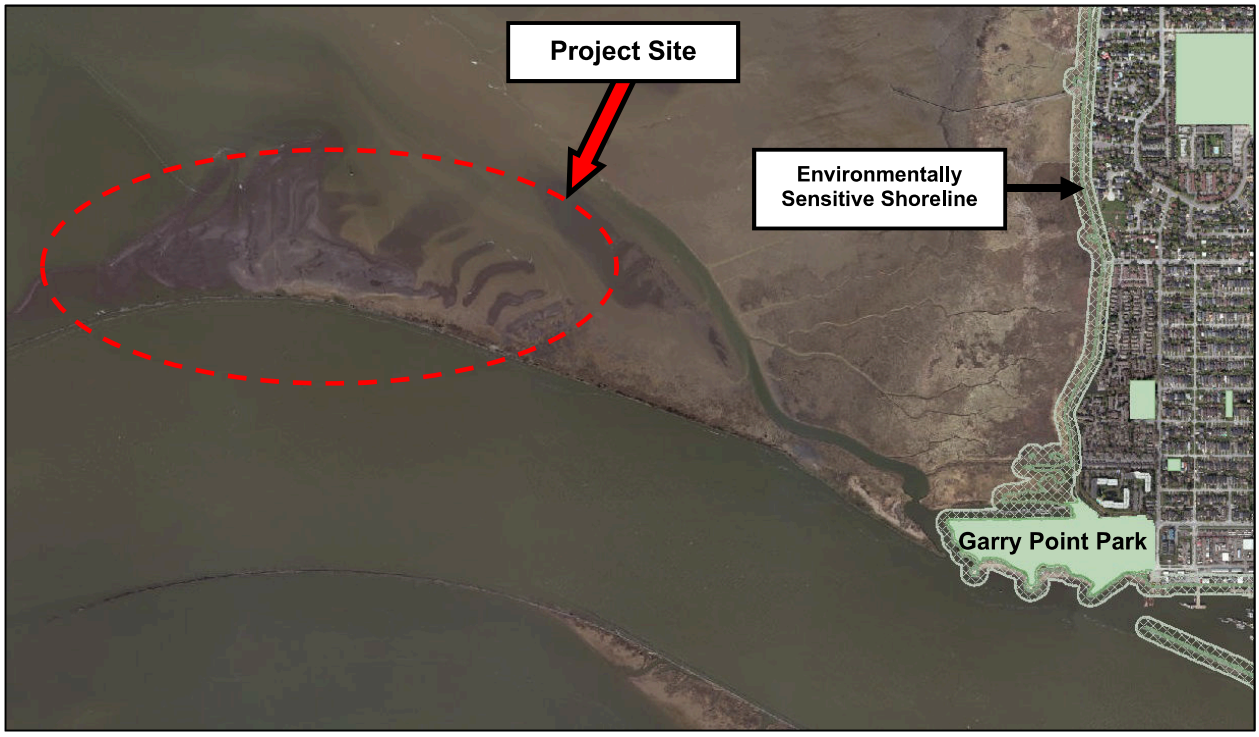


Figure 7 Parks and Environmentally Sensitive Areas Located near the Site (Richmond 2017)

5.2 PHYSICAL CONDITIONS

5.2.1 Existing Conditions

The Site is located on southern Sturgeon Bank which was formed from sediments transported by a combination of wind-waves, tidal currents, and discharge from the Fraser River. The processes of refraction, shoaling and wave-breaking play significant roles in the development of wind waves approaching the Site due to the extensive nature of the intertidal flats (Levings 1980). Small sand dunes and ripples are evident throughout much of the Site indicating that the sand substrate is mobile (**Photo 2**). Some silt and clay substrates are evident at the eastern end of the Site (Trivedi 2017).

The Site is separated from the South Arm of the Fraser River by the Steveston North Jetty. The jetty is permeable and can be described as a rock rubble mound, which in conjunction with the Albion Wall and the Steveston South Jetty, narrows the width of the Fraser River to increase channel bottom scour and improve sediment conveyance to the Strait of Georgia. The crest elevation of the jetty was designed to be at "3/4 tide" to allow free entrance of the flood tide to Sturgeon Bank, but to confine flows sufficiently to scour the channel bottom and decrease the need for maintenance dredging (DFO 2014). Some low points in the jetty exist to allow water exchange between the Fraser River and Sturgeon Bank during lower flows. A scour and drainage channel (Garry Slough/Scotch Pond) is evident near the western end of the site, adjacent to the jetty (GLW 2017).

Medium to fine grained sand that is largely submerged at high tide, is still present at the Site as a result of a previous enhancement project utilizing Fraser River dredge spoil (**Section 3.1**). This dredged sand is relatively well drained and has no visible organic content (**Photo 3**; Trivedi 2017). A small portion of the Site (near the eastern end) is also characterized by a surficial layer of mud, underlain by coarser sand substrates (**Photo 4**). A small, narrow marsh platform exists immediately north of the Steveston North Jetty (located between approximately 0.2 to 0.9 m GD, **Photo 5**) along the southern perimeter of the Site (Hemmera 2014, M&N and GLW 2014). In general, surficial sediments across the Site range from mud at the east end transitioning to sand throughout the majority of the Site (**Figure 8**).

Creosote-wood pilings and navigation towers are scattered throughout the Site (**Photo 6**), and concrete pipe pilings are also present in several areas (Hemmera 2014). Some of these concrete piles are embedded within the sand, whereas others are stacked against the jetty. The embedded pilings were placed at the western border or seaward edge of the previous enhancement effort in an attempt to contain the sand and protect the site from wave action (**Photo 7**; Hemmera 2014, M&N and GLW 2014).

Freshwater inputs from the Fraser River and marine tidal inputs from the Strait of Georgia influence the salinity regime of the Site. Discrete measurements of surface salinity at the Site from April and May 1980, indicated that salinity varied from 11 to 20 ppt (Envirocon 1980). Measurements of ponded water on the Site from May 11, 2017, showed salinities ranging from approximately 4 to 15 ppt (GLW 2017). Based on this information, the Site appears to be in a moderately brackish (mesosaline) environment. Wave and salinity modelling of the Site was undertaken by Moffatt and Nichol in 2017.



Photo 3 View of the Existing Sandflat near the West End of the Site with Evidence of Sand Ripples (Facing East, Hemmera 2017)



Photo 4 Mudflat Showing Biofilm Layer overlying Loamy Sand Textured Sediments near the Eastern End of the Site (Hemmera 2017)



Photo 5 Marsh Bordering the Steveston North Jetty (Facing West, Hemmera 2017)

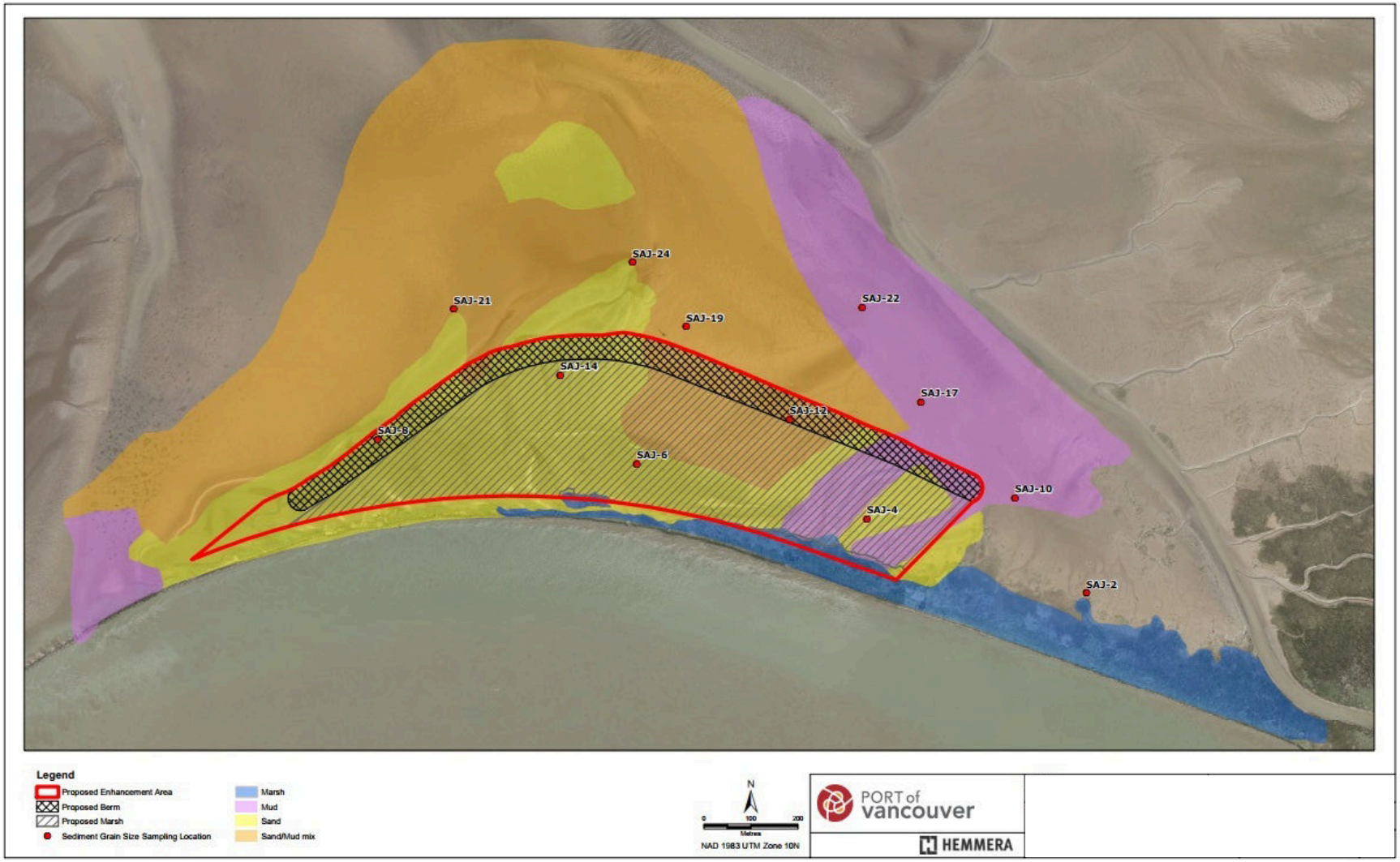


Figure 8 Map Showing Approximate Areas of Surficial Sediment Layers at the Site (2014 Data with 2017 Sediment Sampling Points)



Photo 6 Erosion Control Structures (Concrete Pilings) at the Western Limit of the Site (Facing Southeast, Hemmera 2017)



Photo 7 Concrete Pipe Pilings Located Within the Scour Channel Immediately North of the Steveston North Jetty (Facing West, Hemmera 2017)

5.2.2 Post-Enhancement Conditions

An elevated marsh bench is proposed to be constructed of Fraser River dredge spoils contained behind a cobble berm. The elevation of the marsh bench will be raised to approximately 0.0 to 0.9 m GD. To promote drainage, tidal channels may be excavated throughout the marsh (M&N and GLW 2014). The marsh platform will be designed to support brackish tidal species and target elevations will require filling in some portions of the site and excavation in areas that are currently too high. The tidal marsh platform will mimic existing marsh platforms that are forming along the north side of the jetty.

5.3 HABITAT

5.3.1 Habitat Classification

Shorelines within the Fraser River estuary were classified in 2016 according to the relative values of their habitat features (FREMP 2017). The shoreline classification system was created from an inventory of habitat types in the estuary, including features such as mudflats, marshes, and riparian habitats. The relevant shoreline habitat classifications are described below (FREMP 2002):

- **Red (High Productivity) Habitat:** Includes productive and diverse habitat features that support critical fish and wildlife functions on-site or as part of a more regional context, and/or areas where habitat compensation works have been previously constructed to offset habitat losses.
- **Yellow (Moderate Productivity) Habitat:** Includes habitat features that are of moderate value in structure or diversity due to existing conditions (e.g., surrounding land uses or productivity) and support moderate fish and wildlife functions.
- **Green (Low Productivity) Habitat:** Includes areas where habitat features and functions are limited due to existing conditions (e.g., developed for port or other urbanized uses).

Although the shoreline of the Site was not classified, nearby shorelines (e.g., marshes and tidal flats) around Sturgeon Bank were classified as high productivity habitat (**Figure 9**).

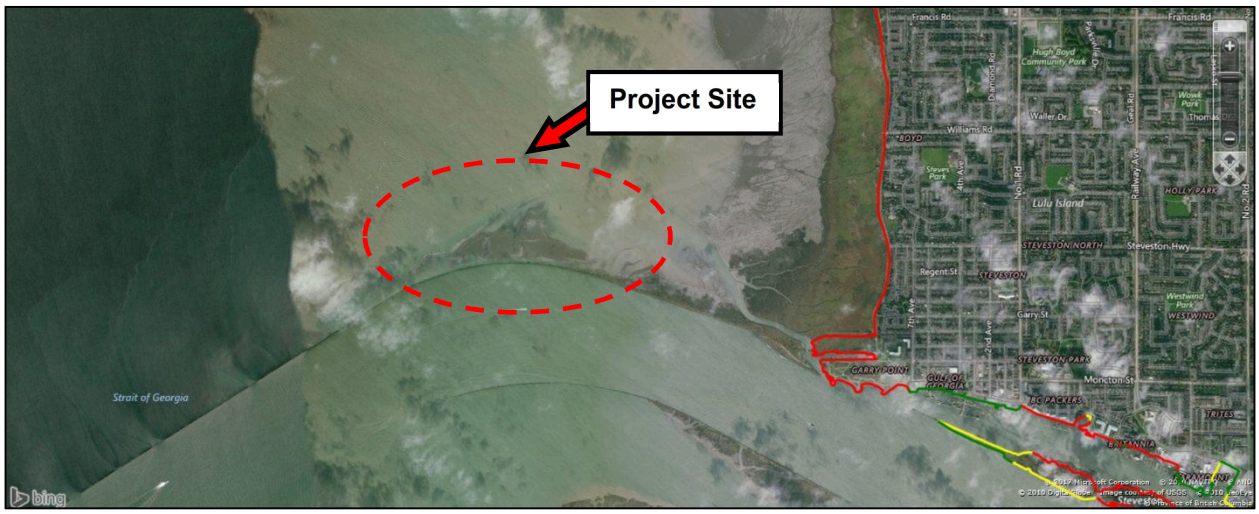


Figure 9 2016 Shoreline Classification Near the Site, Richmond, BC (FREMP 2017)

5.3.2 Fish and Wildlife Habitat

5.3.2.1 Existing Habitats

The Site consists of intertidal sand and mudflat and brackish marsh platforms (**Photo 3 and Photo 4**). The tidal flats are largely unvegetated, with sporadic occurrences of invasive Japanese eelgrass (*Zostera japonica*) in wetted depressions and shallow tidal channels. Areas adjacent to existing tidal marsh exhibit bulrush colonization adjacent to the marsh edge (**Photo 8**, Hemmera 2014, GLW 2017). Rockweed (*Fucus distichus*), sea lettuce (*Ulva* spp.) and barnacles were observed colonizing concrete debris and jetty substrates (**Photo 9**). An intertidal brackish marsh is present along the southeastern end of the Site, extending up to 150 m in width in some locations (M&N and GLW 2014).



Photo 8 **Emergent Bulrush Colonizing the Sandflat Near the Steveston North Jetty (View Facing West, Hemmera 2017)**



Photo 9 **Colonization of Concrete Debris at the Site by Barnacles, Rockweed and Sea Lettuce (Hemmera 2017)**

In October 2014 and June 2017, sediment samples were collected across the Site for biofilm analysis to aid with the assessment of the current value of habitat for foraging shorebirds. In 2014 the samples were assessed for biofilm biomass indicators including chlorophyll *a* and fucoxanthin, and in 2017 the samples were assessed for chlorophyll a and fatty acids. To provide context for analysis of biofilm biomass at the Site, data from a reference location on Roberts Bank north of the Roberts Bank terminal causeway (where biofilm sampling was previously undertaken), was used for comparison (Hemmera and Advisian 2017, Hemmera 2018). The analysis indicated that the Site possessed low levels of biofilm biomass when compared to the reference site on Roberts Bank. While chlorophyll *a* abundances measured across the SAJ Site during the June 2017 study (mean: 40.0 mg/m^2) were higher than abundances measured in October 2014 (mean: 28.8 mg/m^2), results from both sampling events showed lower chlorophyll *a* abundances than at the Roberts Bank reference site in April and May of 2016 (mean: 57.3 mg/m^2; Hemmera and Advisian 2017) and 2017 (mean: 57.0 mg/m^2; Hemmera 2018). In comparison, higher chlorophyll *a* levels at Roberts Bank in 2016 and 2017 corresponded to higher total fatty acid abundance (2016 mean: 818 mg/m^2 and 2017 mean: 651 mg/m^2) relative to the Site (2017 mean: 339 mg/m^2). Results from this study provides support to indicate that there is lower biofilm abundance, and fatty acid and chlorophyll *a* abundance, at the Site relative to Roberts Bank. The results of the analysis are provided in **Appendix A.**

Sampling undertaken in the late 1970s at the Site and surrounding Sturgeon Bank (**Section 3.1**) indicated that benthic and planktonic algae growth decreased in proximity to Steveston North Jetty. Higher densities of algae were typically found closer to marine influences. The major types of benthic and planktonic algal organisms identified were green seaweeds (*Cladophora* spp. and *Ulva* spp.) and diatoms (*Melosira* spp.) (Envirocon 1980).

5.3.2.2 Post-Enhancement Conditions

The Project is anticipated to result in the establishment of up to approximately 30 ha of brackish tidal marsh and a 10 ha of cobble berm which would increase the overall productivity of the Site. Marsh habitat at the Site would be established through a combination of nursery stock transplants of native species and natural colonization and vegetative growth. Potential transplant species are presented in **Table A**.

Table A Potential Marsh Transplant Species for South Arm Jetty Marsh Project

Scientific Name	Common name
Schoenoplectus pungens	American bulrush
Bolbochoenus maritimus	seacoast bulrush
Schoenoplectus tabernaemontani	soft-stem bulrush
Carex lyngbyei	Lyngbye's sedge
Juncus arcticus	Baltic rush
Triglochin maritima	seaside arrowgrass

5.3.3 Vegetation and Plant Communities

5.3.3.1 Existing Conditions

Although a detailed vegetation inventory was not undertaken at the Site, existing vegetation species were observed and recorded during field visits undertaken in 2013 and 2017 (Hemmera 2014, GLW 2017). Based on the field visits, the tidal flats were observed to be largely unvegetated, with a few patches of invasive Japanese eelgrass in wetted depressions and shallow tidal channels. Tidal marsh colonization, primarily by young emergent American bulrush (*Schoenoplectus pungens*), was observed adjacent to the existing marsh edge (Hemmera 2014, GLW 2017).

The existing marsh is dominated by American bulrush with stands of Baltic rush (*Juncus balticus*) and Lyngbye's sedge occurring at higher elevations particularly adjacent to the jetty. Other species documented within the marsh included seaside arrowgrass (*Triglochin maritima*), Pacific silverweed (*Potentilla anserina*), seacoast bulrush (*Bolboschoenus maritimus*), soft-stem bulrush (*Schoenoplectus tabernaemontani*) and tufted hairgrass (*Deschampsia cespitosa*) (Hemmera 2014, GLW 2017).

A search of the online provincial BC Species and Ecosystems Explorer database indicated that 34 at-risk vegetation species potentially occur in the CDFmm subzone (MOE 2017a; **Appendix B: Table B1**). **Table B** presents the single listed plant species (Henderson's checker mallow, *Sidalcea hendersonii*) with potential to currently occur at or near the site given existing (pre-enhancement) conditions, based on known geographic distributions and habitat associations. While a detailed vegetation inventory was not undertaken within marsh habitat near the Site, no listed vegetation species were observed during field assessments within the sand and mudflat habitats. Physical conditions (primarily high salinity) may be a limiting factor for potential presence of Henderson's checker mallow.

Table B Listed Plant Species in the CDFmm Subzone with Potential to Occur at the Site (MOE 2017a)

Scientific Name	Common Name	Provincial Listing[1]	Comments	Post-Enhancement Effects
Sidalcea hendersonii	Henderson's checker-mallow	Blue	A wetland species known to occur in estuaries and tidal flats. Known to occur on nearby Woodward Island, approximately 5 km from the Site (Klinkenberg 2017).	Enhancement works may provide more suitable habitat for this species. Existing and post-enhancement conditions may be too brackish or saline for this species

Notes: [1]Blue = Special Concern, Red = Extirpated, Endangered or Threatened

Due to their rarity on the landscape, the occurrence of at-risk ecosystems in the region is restricted to mature seral-stage mature or old-growth forest (i.e., structural stages 6 and 7 (McLennan and Ronalds 2000), wetlands, and unique ecosystems such as beach dunes. As the Site is located within an intertidal area that sustains unvegetated sand and mudflats, listed plant communities are unlikely to occur within the direct footprint of the Site. Several at-risk wetland ecosystems do, however, have the potential to be present in the marsh bordering the Site. In addition, marsh establishment following completion of the Project, has the potential to establish or expand at-risk wetland ecosystems. Post-construction monitoring of marsh success, including species composition, will ultimately determine if these communities become established at the Site.

A number of listed estuarine and wetland ecosystems occur in the CDFmm subzone (**Appendix B: Table B2**). The rankings highlight species and ecological communities that have particular threats, declining population trends, or restricted distributions that indicate that they require special attention. A subset of these communities, with potential to occur near the Site, is presented in **Table C** (MOE 2017a).

Table C Listed Wetland Ecosystems in the CDFmm Subzone with Potential to Occur at the Site (MacKenzie and Moran 2004, MOE 2017a)

Scientific Name	English Name	Provincial Listing[1]	Comments	Post-Enhancement Effects
Bolboschoenus maritimus var. paludosus	seacoast bulrush	Red	This community occurs in estuaries of the Georgia Depression in low-lying areas of the high marsh where soils are flooded or at least saturated at low tide and have high salinity. While seacoast bulrush has been documented in the marsh adjacent to the Site, the current elevation within the footprint of the Site is generally too low to support this community.	Enhancement works are anticipated to provide more suitable habitat for this ecosystem.
Deschampsia cespitosa ssp. *beringensis - Hordeum brachyantherum*	tufted hairgrass - meadow barley	Red	This community occurs in the upper intertidal zone throughout the BC coast. While tufted hairgrass was observed in the marsh adjacent to the Site, the current elevation within the footprint of the Site is generally too low to support this community.	Enhancement works are not anticipated to affect habitat for this community. Final design elevations would be too low to promote this community.
Distichlis spicata var. spicata	seashore saltgrass	Red	This community is found mainly in estuaries of the Georgia Depression. Seashore saltgrass occurs at the lower limit of estuary vegetation on fine-textured, poorly drained sediments that are flooded for prolonged periods by brackish water. While there is potential for this community to be present in the adjacent marsh, seashore saltgrass was not observed during any of the Site assessments.	Enhancement works have the potential to provide more suitable habitat for this ecosystem.
Eleocharis palustris	common spike rush	Blue	This community occurs in freshwater and brackish tidal reaches of large coastal rivers and estuaries. While there is potential for this community to be present in the adjacent marsh, common spike rush was not observed during any of the Site assessments.	Enhancement works have the potential to provide more suitable habitat for this ecosystem.
Juncus arcticus - Plantago macrocarpa	arctic rush - Alaska plantain	Red	This community is found in the Georgia Depression and southern coast and mountains within weakly brackish environments. Estuarine meadow species (*Juncus*) have been observed within the marsh adjacent to the Site. While there is potential for this community to be present within the adjacent marsh, it was not observed during any of the Site assessments.	Enhancement works have the potential to provide more suitable habitat for this ecosystem.
Ruppia maritima	beaked ditch-grass	Red	This community is common throughout coastal BC. It can occur in brackish tidal mudflats within lower estuarine marshes. While there is potential for this community to be present in the adjacent marsh, beaked ditch-grass was not observed during any of the Site assessments.	Enhancement works have the potential to provide more suitable habitat for this ecosystem.

Scientific Name	English Name	Provincial Listing[1]	Comments	Post-Enhancement Effects
Sarcocornia pacifica - Glaux maritima	American glasswort - sea-milkwort	Red	This community occurs in the Georgia Depression and outer coastal areas where there is daily and prolonged flooding by strongly brackish water. Given the Fraser River freshwater influence at the Site, it is unlikely that this community would be found at or near the Site.	Enhancement works are not anticipated to affect habitat for this community. Salinity levels at the Site are likely too low to support this community.

Notes: [1] **Red =** includes any ecological community that is designated as Extirpated, Endangered, or Threatened in British Columbia

5.3.3.2 Post-Enhancement Conditions

The proposed enhancement works will result in the addition of up to 30 ha of tidal brackish marsh habitat and 10 ha of cobble beach habitat. Marsh creation may create physical conditions that are suitable for some of the listed species and ecosystems presented in **Table B** and **Table C**, although the brackish conditions and target marsh elevation at the Site may not be suitable for some of them. It is anticipated that the cobble beach berm will provide attachment sites for algae which will provide habitat and productive inputs for fish and birds.

5.4 FISH

5.4.1 Existing Conditions

Fish use within the Fraser River estuary and Sturgeon Bank is well-documented (Greer et al. 1980, Conlin et al. 1982, Gordon and Levings 1984, Levings 2004, Archipelago 2014). The estuary, including the Project site, provides year-round habitat for freshwater and marine resident fish, along with migration, rearing, and overwintering habitat for anadromous fish, including species of commercial, recreational and Aboriginal (CRA) value. Examples of CRA species that rely on the Fraser River estuary, including Sturgeon Bank, during different stages of their life cycle include: Pacific salmon and trout (*Oncorhynchus* spp.), char (*Salvelinus* spp.), sturgeon (*Acipenser* spp.), and eulachon (*Thaleichthys pacificus*) (**Table 1**).

In the late 1970s and early 1980s, multiple fish sampling programs were undertaken which documented fish use of sandflats along Sturgeon Bank and the Project site (Envirocon 1980, Greer et al. 1980, Conlin et al. 1982, Gordon and Levings 1984, Wiley 1984). CRA fish using the Project site and Sturgeon Bank, include: chinook, chum, coho (*O. kisutch*) and sockeye (*O. nerka*) salmon, eulachon and smelt (Envirocon 1980). Chum salmon, Pacific herring (*Clupea pallasii*), Pacific staghorn sculpin (*Leptocottus armatus*), Pacific sand lance (*Ammodytes hexapterus*), starry flounder (*Platichthys stellatus*) and redside shiner (*Richardsonius balteatus*) have been captured in areas overlapping the Project site (Greer et al. 1980). Wiley (1984) completed sampling in the unvegetated sandflat areas at the Project site and at the Albion Jetty to the south and documented Dolly Varden (*Salvelinus malma*), steelhead (*O. mykiss*), coho salmon, sockeye salmon, Pacific herring, surf smelt (*Hypomesus pretiosus*), starry flounder, threespine stickleback (*Gasterosteus aculeatus*), Pacific staghorn sculpin, snake prickleback (*Lumpenus sagitta*), Pacific sand lance, arrow goby (*Clevelandia ios*), penpoint gunnel (*Apodichthys flavidus*), shiner perch (*Cymatogaster aggregata*), and redside shiner, in addition to unidentified chub, suckers, lamprey and whitefish.

Multi-seasonal sampling was also undertaken at Steveston Pit, located approximately one-kilometre northwest of the Project site, between April 1980 and June 1981 (Conlin et al. 1982, Gordon and Levings 1984). Steveston Pit is a relict river channel that cuts through the southern Sturgeon Bank sandflat and provides estuarine refuge for fish along Sturgeon Bank during low tides (Conlin et al. 1982, Gordon and Levings 1984). The results from 80 seine net hauls indicate that the most abundant fish species sampled

(approximately 1,000+ individuals) were threespine stickleback, shiner perch, chinook salmon, starry flounder and Pacific herring. Other common fish species sampled (100+ individuals) were Pacific sand lance, Pacific staghorn sculpin, surf smelt, snake prickleback and capelin (*Mallotus villosus*).

More recent inventories of fish species present at nearby Roberts Bank indicate that sandflat habitats to the south are used by a wide range of species, including flatfish such as starry flounder, and forage fish such as Pacific sand lance (Hemmera and Precision 2007, Archipelago 2014). Recent sampling at the northern end of Sturgeon Bank documented pink salmon fry use of tidal channels within a tidal marsh habitat enhancement site (Palm 2016).

Several listed marine and freshwater fish species occur at or near the Site (MOE 2017a). Those that have the potential to occur at or near the Site are presented in **Table D**.

Table D Fish Species of Concern with the Potential to Occur at the Site (MOE 2017a)

Scientific Name	English Name	Provincial Listing[1]	SARA[2]	COSEWIC[3]	Comments	Potential to Occur Post-Enhancement
Acipenser medirostris	Green sturgeon	Red	1-SC (2006)	SC (2013)	Habitat preferences are poorly understood, but it is unlikely that these fish would use the Site as they are primarily observed in marine waters off the BC coast.	Unlikely to be noticeably affected by the creation of marsh habitat.
Acipenser transmontanus	White sturgeon - Lower Fraser River population	Red	Not listed	T (2012)	Have been observed near the Site and juveniles, which prefer shallow water depths, could potentially use the mudflat or marsh habitats at the Site. They have been reported to occur at the mouth of the South Arm of the Fraser River (iMap 2017).	Unlikely to be noticeably affected by the creation of marsh habitat.
Cetorhinus maximus	Basking shark – Pacific population	Not listed	1-E (2010)	E (2007)	Habitat preferences are not well understood, but it is a pelagic fish that is known to utilize surface waters, primarily for feeding (e.g., zooplankton) (DFO 2011). Sightings in Canadian Pacific waters are very rare and the Project site is not located in an area of historical abundance (DFO 2011).	Unlikely to be noticeably affected by the creation of marsh habitat.
Hexanchus griseus	Bluntnose sixgill shark	Not listed	1-SC (2009)	SC (2007)	This shark is primarily a deep water benthic species and is distributed throughout much of Canadian Pacific waters including the Strait of Georgia, offshore of the Project Site. Due to its known habitat preferences, it is unlikely that this fish would utilize the shallow intertidal Project site (DFO 2012).	Unlikely to be noticeably affected by the creation of marsh habitat.
Hybognathus hakinsoni	Brassy minnow	Blue	Not listed	Not listed	A species that is known to occur in the brackish, slow-moving waters of the Fraser River estuary (McPhail 2007). Brassy minnow have been documented during sampling conducted immediately north of the Site on Sturgeon Bank (Conlin et al. 1982).	An increase in primary productivity at the Site is anticipated to increase habitat values for this species.
Oncorhynchus clarkii clarkii	Cutthroat trout, *clarkii* subspecies	Blue	Not listed	Not listed	The Site may currently be used by anadromous cutthroat trout as the estuarine marshes around and at the edges of the Site may provide some coastal feeding and overwintering habitats. The species has been well documented in the South Arm of the Fraser River.	An increase in primary productivity at the Site is anticipated to increase habitat values for this species.

Scientific Name	English Name	Provincial Listing[1]	SARA[2]	COSEWIC[3]	Comments	Potential to Occur Post-Enhancement
Oncorhynchus kisutch – pop. 7	Coho salmon – Interior Fraser population	Not listed	Not listed	T (2016)	Juvenile Interior Fraser River coho salmon migrate downriver and spend some time in the Fraser estuary (COSEWIC 2016). Coho salmon have been documented during sampling conducted immediately north of the Site on Sturgeon Bank (Conlin et al. 1982).	An increase in primary productivity at the Site is anticipated to increase habitat values for this this species.
Oncorhynchus nerka	Sockeye salmon – Cultus Lake population	Yellow	Not listed	E (2016)	Fraser sockeye smolt are known to move quickly through the Fraser estuary into the Strait of Georgia (COSEWIC 2003*a*). There is potential that sockeye could temporarily utilize the Site during migration.	An increase in primary productivity at the Site is anticipated to increase habitat values for this species.
Salvelinus confluentus - coastal lineage	Bull trout – coastal lineage	Blue	Not listed	SC (2012)	The Site may currently be used by anadromous bull trout as the estuarine marshes around and at the edges of the Site may provide some coastal feeding and overwintering habitats. The species has been documented in the South Arm of the Fraser River, but anadromous forms have not been well studied.	An increase in primary productivity at the Site is anticipated to increase habitat values for this species.
Squalus suckleyi	North Pacific spiny dogfish	Not listed	N t listed	SC (2011)	This fish utilizes a variety of habitat including intertidal, estuarine and surface waters (COSEWIC 2011). It has potential to utilize the site, however habitat is not believed to be a direct factor affecting population trends (COSEWIC 2011).	Unlikely to be noticeable affected by the creation of marsh habitat.
Thaleichthys pacificus	Eulachon – Fraser River population	Blue	Not listed	E (2011)	Eulachon are predominantly a marine species that returns to freshwater systems, including the lower Fraser River, to spawn. Spawning habitat is not currently present at the Site. However, eulachon larvae may utilize tidal marsh habitat before moving offshore.	An increase in primary productivity at the Site may increase habitat values for this species.

Notes: [1] Red = Endangered or Threatened, Blue = Special Concern
[2] Schedule 1 = federal species at risk
[3] E = Endangered, T = Threatened, SC = Special Concern

Although green sturgeon (*Acipenser medirostris*) were listed in **Table D**, sightings of green sturgeon are very rare. Little is known about green sturgeon habitat use in Canada. Rearing and spawning by this anadromous species has not been recorded in Canada, although the species may forage along the marine coast of British Columbia (COSEWIC 2004). Due to the low likelihood of occurrence at the Site, the Project is not anticipated to noticeably impact this species.

The lower Fraser population of white sturgeon (*A. transmontanus*) occur in the South Arm of the Fraser River and its estuary. Juvenile sturgeon, which utilize shallow water depths, are known to occur in areas 3 to 15 m deep with slow to moderate water velocities (e.g., bottom velocities of 0.1 to 0.5 m/s), and fine substrates (e.g., silt and silty sand) in side channels, side pools, backwaters, and mainstem channels (Glova et al. 2008). Portions of the Site as well as existing tidal channels on Sturgeon Bank and areas fronting Westham Island, may be used by juvenile white sturgeon. However, due to the existing shallow elevation of the Site, it is not anticipated that the Project will noticeably affect this species.

Both coastal cutthroat trout (*O. clarkii clarkii*) and bull trout (*Salvelinus confluentus*) are likely to occur at or near the Site. Anadromous forms of both species are likely to use the estuary as rearing and migratory habitat. Coastal cutthroat trout are provincially Blue-listed as they are susceptible to disturbance that impairs habitat quality, in addition to other factors such as angling pressure (Costello 2008). The coastal lineage of bull trout is also provincially Blue-listed due to factors such as habitat fragmentation and degradation of habitat quality (Hammond 2004). Although both species may currently use the Site, the creation of high quality marsh habitat at the Site is anticipated to increase habitat value for both species.

Eulachon are an anadromous forage fish species considered to be culturally valuable to a number of First Nation communities on the BC coast. Locally, the Fraser River eulachon population has experienced a dramatic decline in population. This population is currently provincially Blue-listed and considered Endangered by COSEWIC. Due to unsuitable habitat conditions (Lewis et al. 2002), eulachon spawning would not occur at the Site either before or after proposed enhancement activities. Estuarine rearing of this species is poorly understood but establishment of marsh habitat and an increase in primary productivity at this Site is anticipated to have a positive impact on this species.

5.4.2 Post-Enhancement Conditions

Although existing sand and mudflats at the Site will be converted to intertidal brackish marsh, potentially resulting in a loss of useable habitat for fish such as starry flounder, proposed tidal channels will still provide habitat for flatfish that may utilize the Site during high tides. The Project will create more complex, productive high value habitat for salmonids, thus increasing overall primary productivity at the Site as well as contributing to the detritus-based food web. Project benefits will also extend to other fish species, as at least 80 species of fish are known to use the Fraser River estuary near Richmond (see **Appendix C: Table C1** for a list of potential species present at or near the Site).

5.5 WILDLIFE

5.5.1 Existing Conditions

The Fraser River estuary is recognized as a key stop-over and wintering area for millions of migratory waterfowl and shorebirds as well as numerous resident bird species (Butler and Campbell 1987; WHSRN 2009). It is likely that some of these species utilize the Site and, more broadly, Sturgeon Bank. A list of bird species observed at the Reifel Migratory Bird Sanctuary, located approximately 3 km southeast of the Site, is presented in **Appendix C**: **Table C2** (BCWS 2017). Hemmera also undertook shorebird dropping surveys in 2012 and 2013 to document general habitat use by shorebirds within the Fraser River estuary. To supplement this previous data, site-specific field surveys were undertaken in 2014 and 2015 to assess baseline shorebird and waterfowl use of the Site.

The shorebird dropping surveys were undertaken between April and August 2014 to coincide with the northward adult and southward juvenile shorebird migrations. Observations of shorebird and waterfowl abundances were also recorded during these surveys. In general, the existing unvegetated sand and mudflat habitats near the Site were found to provide value for a variety of different water birds, including shorebirds. While the survey results showed inconsistent trends in the differences between dropping densities within and adjacent to the Site; the dropping densities at the Site were always similar to or less than those observed across the broader area of southern Sturgeon Bank in 2012 and 2013. However, the results suggest that habitat at the Site is of intermediate, or less than intermediate, quality relative to the rest of the estuary. Data from the shorebird surveys is available in **Appendix D**.

Algal mats and infaunal organisms provide foraging opportunities for numerous bird species. To augment the data obtained during the shorebird dropping surveys, sediment samples were collected for biofilm analysis at the Site. The results from the analysis are summarized in **Section 5.3.2.1**. The detailed biofilm analysis is available in **Appendix A**.

Avian abundance surveys were also undertaken at the Site between December 2014 and March 2015. The purpose of the surveys was to document baseline bird use (i.e., abundance and behavior) within and adjacent to the Site during the winter period. The surveys assessed bird use of the sand and mudflat habitat under both exposed and inundated conditions. The results indicated that in the context of the Fraser River estuary, the Site appears to be most important for gulls, followed by swans and is less important for other avian taxa. Data from these surveys is available in **Appendix E**.

A detailed inventory of wildlife within the marsh surrounding the Site was not undertaken, however, these areas are known to provide high quality habitat for a variety of species. Terrestrial species are not as likely to utilize the Site due to its isolated nature and frequent inundation. However, harbour seals (*Phoca vitulina*) are commonly observed in the area and could access the Site (Butler and Campbell 1987). Common wildlife

species representative of the CDFmm subzone within estuaries, shallow bays, intertidal and sub-tidal marine ecosystems are listed in **Table E** (Nuszdorfer et al. 1991).

Table E Common Wildlife Species of the CDF Zone within Estuaries, Shallow Bays, Intertidal and Subtidal Marine Ecosystems (Nuszdorfer et al. 1991)

	Representative Species Likely to Occur Near the Site
Mammals	mink (*Neovison vison)*, river otter (*Lontra canadensis)*, harbour seal (*Phoca vitulin)*
Birds	sharp-shinned hawk (*Accipiter striatus*), turkey vulture (*Cathartes aura*), red-throated loon (Gavia stellate), yellow-throated loon (*Gavia adamsii*), trumpeter swan (*Cygnus buccinators*), Canada goose (*Branta canadensis*), Brant (*Branta bernicla*), Barrow's goldeneye (*Bucephala islandica*), black scoter (*Melanitta Americana*), surf scoter (*Melanitta perspicillata*), white-winged scoter (*Melanitta deglandi*), mallard (*Anas platyrhynchos*), American wigeon (*Anas Americana*), lesser scaup (*Aythya affinis*), green-winged teal (*Anas carolinensis*), glaucous-winged gull (*Larus glaucescens*), California gull (*Larus californicus*), northwestern crow (*Corvus caurinus*)

The Site does not appear to host a diverse or high density infaunal community (Hemmera 2014). However, some sampling undertaken in 2013 at the Site found patches of invasive juvenile purple varnish clam (*Nuttallia obscurata*, **Photo 8**). Purple varnish clams are known to occupy upper intertidal zones on local beaches. During a May 2017 site visit, barnacles were also observed colonizing concrete debris along the western ends of the Site (**Photo 9**). Previous benthic invertebrate sampling undertaken in the late 1970s at the Site and surrounding Sturgeon Bank (**Section 3.1**, Envirocon 1980) found that:

- Epibenthic density was generally highest adjacent to the North Steveston Jetty with density decreasing with distance from the jetty. Density was also higher near marine influences with density decreasing in the easterly direction. Major types of epibenthic organisms reportedly sampled within the area included mysids, amphipods, decapods (e.g., sand shrimp (*Crangon* spp.) and comb jellies (ctenophores).
- Meiofauna, predominantly nematodes, were found between sand grains. Other major groups of meiofauna sampled included oligochaetes and copepods. In general, higher densities of meiofauna were found adjacent to the Steveston North Jetty.
- Macrobenthos were generally low in density adjacent to the Steveston North Jetty with densities increasing with distance from the jetty. Polychaetes (e.g., bristle worms (*Pygospio elegans* and *Eteone longa*) were most abundant followed by bivalves (primarily Baltic macoma (*Macoma balthica*). Amphipods (crustaceans) were the least abundant of the macrobenthic invertebrates observed.



Photo 10 Invasive Purple Varnish Clams Observed at the Site (Hemmera 2013)

Fifty listed wildlife species are known to occur in the CDFmm subzone within Metro Vancouver Regional District (**Appendix B: Table B3**). **Table F** indicates only those species from **Table C3** that have been identified as having potential to occur at the Site. As a note, the provincially red-listed western grebe (*Aechmophorus occidentalis*) has been sighted at Westham Island (iMap BC 2013) even though it is not one of the species listed as occurring in the Metro Vancouver CDFmm subzone (**Table F**). Western grebe is a diving waterbird that feeds on fish and invertebrates. Another at-risk species that is not listed is Steller sea lion (*Eumetopias jubatus*). Steller sea lions are the only listed pinniped species that occur in the Fraser River estuary. When not in the water, Steller sea lions prefer to haul-out on secluded rocky islands and rocky ledges (COSEWIC 2003*b*).

Table F Listed Wildlife Species of the CDFmm Subzone with a Potential to Occur at the Site (MOE 2017a)

Scientific Name	English Name	Provincial Listing[1]	SARA Schedule[2]	COSEWIC[3]	Comments[4]	Post-Enhancement Effects
Birds						
Ardea herodias fannini	great blue heron, *fannini* subspecies	Blue	1-SC (2010)	SC (2008)	Species forage for fish near and/or at the Site. They roost nearby at Reifel Bird Sanctuary with nearest nesting colony is approximately 10km away at Point Roberts	Benefit: possible increase in prey abundance
Falco peregrinus anatum	peregrine falcon, *anatum* subspecies	Red	1-SC (2012)	NAR (2017)	May forage for birds over the Site	No effect
Hirundo rustica	barn swallow	Blue	1-T (2017)	T (2011)	May forage for flying insects over the Site. They nest under man made coverings close to a source of mud which is used to construct their nests	Benefit: possible increase in prey abundance
Hydroprogne caspia	Caspian tern	Blue	Not listed	NAR (1999)	May forage for fish at the Site during high tide	Benefit: possible increase in prey abundance
Phalacrocorax auritus	double-crested cormorant	Blue	Not listed	NAR (1978)	May forage for fish at or near the Site during high tide	Benefit: possible increase in prey abundance
Progne subis	purple martin	Blue	Not listed	Not listed	May be found foraging for flying insects over the Site	Benefit: possible increase in prey abundance

Notes: [1]Red = Endangered or Threatened, Blue = Special Concern
[2]Schedule 1 = federal species at risk
[3]T = Threatened, SC = Special Concern, NAR = Not at Risk
[4]Species information was taken from The Birds of North American Online 2013 and E-Fauna BC 2013

5.5.2 Post-Enhancement Conditions

The Project is proposed to convert a largely unvegetated intertidal flat into productive brackish marsh. Pioneer low marsh and portions of the Site that sustain productive mudflat will largely be avoided. Conversion of the existing sand and mudflat will result in the loss of some habitat that is currently used for loafing and foraging by waterfowl and shorebirds. As such, existing uses by shorebirds and waterbirds are expected to change as a result of the Project. However, the Site is located along the southern edge of Sturgeon Bank where extensive intertidal mudflat habitat is available, and it is located near mudflats present at Roberts Bank, Boundary Bay, and Sea Island. Given the availability of nearby mudflat habitats, the creation of additional intertidal marsh at the Site is not anticipated to have a significant impact on species that rely on mudflats.

Listed wildlife species occurrences and use of the Site is not anticipated to be negatively affected by the Project. Current potential use of the Site by listed species for critical life history functions is considered to be relatively low. Insect-foraging species may benefit from additional insect production resulting from increased marsh area and productivity. Listed fish-eating species, such as great blue heron (*Ardea herodias fannini*) and double-crested cormorant (*Phalacrocorax auritus*), may also benefit from the Project (e.g., during salmon rearing).

6.0 CONCLUSION

The Project is anticipated to create high-value intertidal brackish marsh habitat that will provide long-term benefits for salmon stocks that depend upon the Fraser River estuary for rearing, along with other fish and wildlife species such as waterfowl and wading birds. Expansion of the intertidal marsh is anticipated to contribute to the following ecological functions:

- Increasing primary productivity;
- Supplementing the detritus-based food web;
- Creating intertidal habitat for benthic and drift invertebrates that are important prey items for juvenile salmonids and other fish;
- Providing refuge for juvenile salmonids as they utilize shoreline habitats in the lower Fraser River estuary prior to out-migrating to the Strait of Georgia and the Pacific Ocean;
- Increasing habitat diversity by converting sandflat into productive intertidal marsh; and
- Creating marsh habitat for waterfowl feeding, nesting, loafing, and refuge.

7.0 CLOSURE

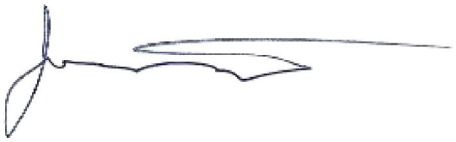
We sincerely appreciate the opportunity to have assisted you with this project and if there are any questions, please do not hesitate to contact the undersigned by phone at 604.669.0424.

Report prepared by:
Hemmera Envirochem Inc.



Mikaela Davis, M.Sc.
Project Biologist

Report peer reviewed by:
Hemmera Envirochem Inc.



Jim Roberts, R.P.Bio.
Project Director, Senior Biologist

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9.0 STATEMENT OF LIMITATIONS

This report was prepared by Hemmera, based on fieldwork and/or research conducted by Hemmera, for the sole benefit and exclusive use of Vancouver Fraser Port Authority. The material in it reflects Hemmera's best judgment in light of the information available to it at the time of preparing this Report. Any use that a third party makes of this Report, or any reliance on or decision made based on it, is the responsibility of such third parties. Hemmera accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this Report.

Hemmera has performed the work as described above and made the findings and conclusions set out in this Report in a manner consistent with the level of care and skill normally exercised by members of the environmental science profession practicing under similar conditions at the time the work was performed.

This Report represents a reasonable review of the information available to Hemmera within the established Scope, work schedule and budgetary constraints. The conclusions and recommendations contained in this Report are based upon applicable legislation existing at the time the Report was drafted. Any changes in the legislation may alter the conclusions and/or recommendations contained in the Report. Regulatory implications discussed in this Report were based on the applicable legislation existing at the time this Report was written.

In preparing this Report, Hemmera has relied in good faith on information provided by others as noted in this Report and has assumed that the information provided by those individuals is both factual and accurate. Hemmera accepts no responsibility for any deficiency, misstatement or inaccuracy in this Report resulting from the information provided by those individuals.

The liability of Hemmera to Vancouver Fraser Port Authority shall be limited to injury or loss caused by the negligent acts of Hemmera. The total aggregate liability of Hemmera related to this agreement shall not exceed the lesser of the actual damages incurred, or the total fee of Hemmera for services rendered on this project.

APPENDIX A
Biofilm Report

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11 February 2015

Proj. No.: 307071-00719
File Loc.: Burnaby

Hemmera Envirochem Inc.
18th floor, 4730 Kingsway
Burnaby, BC
V5H 06C

Attention: Jim Roberts, Project Biologist, Fisheries

Dear Mr. Roberts:

RE: PROPOSED CONVERSION OF AN AREA ALONGSIDE THE SOUTH ARM JETTY, STEVESTON, BC

1. INTRODUCTION

Port Metro Vancouver's (PMV's) Habitat Enhancement Program is proposing to convert an area along the South Arm Jetty at Sturgeon Island, in Steveston, BC into brackish marsh (the Project). The Project would involve converting an existing un-vegetated intertidal area (predominantly sand and mudflat) (Figure A) into a brackish marsh. This would be accomplished through construction of a containment berm followed by the placement of fill material to the appropriate elevation for establishment of intertidal marsh vegetation. The Project would extend approximately 2.5 km west, along the north jetty, to a maximum distance of approximately 400 m north onto Sturgeon Bank. The Project would result in the creation of approximately 44 ha of intertidal marsh habitat.

Shorebird dropping surveys were conducted by Hemmera at the Sturgeon Island site during the spring and summer of 2014, coinciding with the anticipated peak migration periods for Western Sandpiper (*Calidris mauri*). The objectives of these surveys were to document shorebird usage of sandflats and mudflats within the proposed South Arm Jetty Tidal Marsh Project site (Sturgeon Island) and to compare usage in the area to previous observations of usage in other intertidal areas of the Fraser River estuary. In order to augment the analysis of shorebird use data obtained during the shorebird dropping surveys, sediment samples were also collected for the purpose of biofilm analysis and the results are presented in this report. Information on biofilm will help in the assessment of the current value of this habitat and the potential benefits or drawbacks of a habitat enhancement project.

This technical letter presents the results of the biofilm samples collected at the Sturgeon Island site. Measured values are provided and compared between previous observed biofilm levels at Roberts Bank, namely the high biofilm density (referred to as the Upper Intertidal) and low biofilm density (referred to as Canoe Passage) (WorleyParsons, 2014b) (Figure A).

EcoNomics



Figure A Habitat Enhancement Program Sampling Sites

2. METHODS

2.1 Sampling Location

The proposed site for habitat enhancement was chosen based on a combination of factors, including site location, potential for improvement to habitat productivity values, feasibility, cost, ownership/tenure and considerations towards First Nations and surrounding communities (Hemmera, personal communication). The proposed enhancement site is located at the southern end of Sturgeon Bank, immediately to the north of the Fraser River; this site is separated from the Fraser River by a jetty which stabilizes the riverbed throughout the Fraser River delta (Figure A).

A total of 11 samples (ten samples plus one duplicate) were collected on October 3, 2014 (Table A) at the coordinates presented in Table B.

Table A Sampling Time and Tide Information

Date	Sampling Time	Location	Field Personnel	Low Tide	
				Time	Height (m)
October 3	7:30 – 11:30	Sturgeon Island	Catherine Blais (WorleyParsons) Toby St. Clair (Hemmera)	7:37	0.8*

Note: * indicates values taken from Steveston Station #7607 (Government of Canada, 2014)

Table B Sampling Coordinates for the Sturgeon Island site

Sample Name	UTM X	UTM Y
HEP SJ-1	483864	5442930
HEP SJ-2	483691	5442682
HEP SJ-3	483184	5442704
HEP SJ-4	483907	5442466
HEP SJ-5	483451	5442508
HEP SJ-6	483841	5442193
HEP SJ-7	482986	5442326
HEP SJ-8	484315	5442076
HEP SJ-9	483422	5442382
HEP SJ-10	483301	4552333

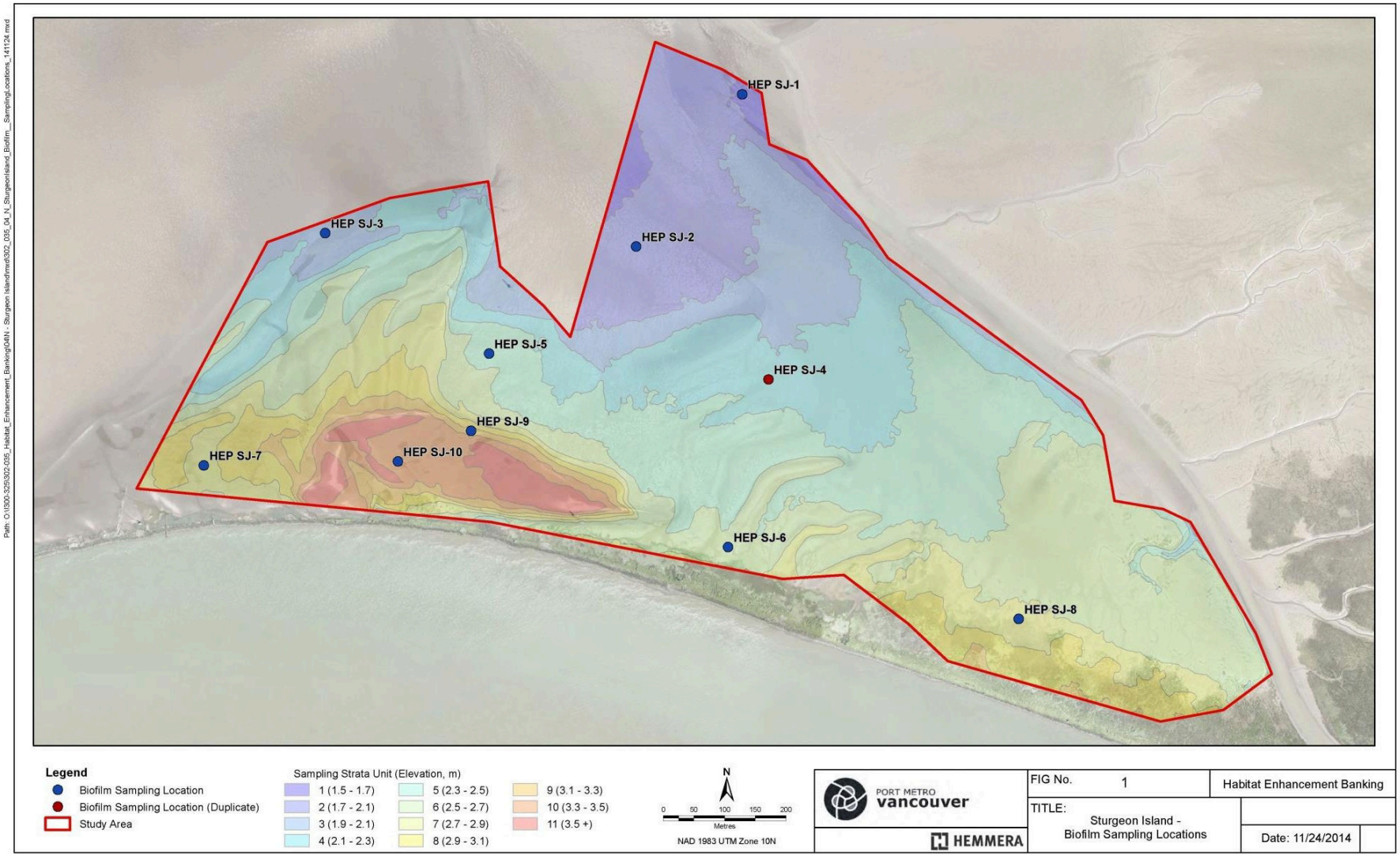


Figure B Sampling Locations at Sturgeon Island in Steveston, BC

2.2 Sampling Methodology

Sampling techniques and analytical methodology followed those used in previous assessments of biofilm within the Fraser River estuary. Detailed methodologies can be found in the *Roberts Bank Terminal 2 technical data report, biofilm annual variability* report (WorleyParsons, 2014b).

The sampling location coordinates were provided by Hemmera and uploaded to a handheld GPS for use by field personnel to locate individual sampling locations. Sediment sampling was conducted using a modified 2.75 cm diameter syringe core to collect the first two millimetres of ten separate randomly-selected sediment cores within a 1 m^2 quadrat. All ten cores, each with a surface area of 5.94 cm^2, were placed within one black 60 mL centrifuge tube to create a composite sample. Each tube was labeled and placed in an individual amber sealable bag with a second label. The samples were stored in a handheld cooler with dry ice and transferred to a -80ºC freezer at the end of the day. The samples were held in a -80ºC freezer until transferred to the laboratory for analysis; this occurred within seven days of sample collection.

A photo record was taken at each sampling quadrat to provide a visual record of each location, and is presented in Appendix 1.

2.3 Biofilm Biomass

All samples were shipped to Aquatech Enviroscience Laboratories (AEL) (Victoria, BC). Samples were placed in styrofoam coolers with dry ice and transited for less than 24 hours.

2.3.1 Sample Processing

Samples were processed at Aquatech Enviroscience Laboratories (AEL) following the steps, protocols and QA/QC procedures described in the *Roberts Bank Terminal 2 Technical Data Report, Biofilm Annual Variability* report (WorleyParsons, 2014b). Photopigment were analysed using High Performance Liquid Chromatography (HPLC) analysis. The Total Organic Carbon of biofilm samples was determined using a thermal combustion Elemental Analyzer (EA) with a continuous flow isotope ratio mass spectrometer (IRMS). Total Carbohydrate concentrations were measured by creating a phenol-sulphuric acid assay.

2.3.2 Biofilm Indicators

Although the HPLC analysis performed by the laboratory gave results for a range of pigment markers, only two were used to assess and quantify biofilm:

- ***Chlorophyll a*** (Chla) is the primary photosynthetic pigment of all oxygen-producing photosynthetic organisms and is present in all algae and cyanobacteria. The assessment of Chlorophyll *a* is a common method of estimating biomass and the potential productivity of photosynthetic organisms.
- ***Fucoxanthin*** (Fuco) is the dominant carotenoid in most algal classes of the red algal lineage and brown seaweeds. These include bacillariophytes, haptophytes, chrysophytes, raphidophytes, bolidophytes and some dinophytes. Fucoxanthin is recognized as a marker

pigment of diatoms (Wright et al., 1991), which are the dominant group identified in biofilm within the Fraser River estuary (WorleyParsons, 2014a, 2014b).

Additionally, laboratory analyses were conducted for two other biofilm biomass indicators:

- ***Total Organic Carbon*** (TOC) is the organic carbon in the sediment and a measure of organic content. Naturally-occurring organic carbon forms are derived from the decomposition of plants and animals, but can also be a result of contamination through anthropogenic activities (Schumacher, 2002).
- ***Total Carbohydrate*** (TC) is a measure of the energy absorbed by Chlorophyll *a* (as well as accessory pigments such as Fucoxanthin) that is transformed into glucose. Total Carbohydrate levels were determined based on the amount of Glucose.

2.3.3 Data Analysis

Data were delivered by AEL as parts per billion (ppb), or ng/g. For the purposes of density estimation, the concentrations were converted to density as mg/m^2. This was conducted using the following formula:

$$\text{Density of Biofilm Biomass Indicator } \left(mg/m^2\right) = \frac{Batch\ \ results\left(ng/g\right) * Sample\ \ Weight\left(g\right)}{Total\ Sample\ Area\left(cm^2\right)} * \frac{10{,}000\left(cm^2/m^2\right)}{1{,}000{,}000\left(ng/mg\right)}$$

Where:
Sample Weight = Total weight of sample (g) measured before sediment subsampling;
Total Sample Area = 59.39 cm^2 (10 cores * 5.939 cm^2/core).

A key assumption to this analysis is that only the biofilm within the top 2 mm were collected in the field (Compass Resource Management, 2013). This conversion also makes the assumption that the measured Chlorophyll *a* pigments are attributable to the microphytobenthos, which is understood to be contained within the top 2 mm of the intertidal sediments (De Brouwer & Stal, 2001; Herlory, Guarini, Richard, & Blanchard, 2004).

2.3.4 Field Duplicates

Field duplicates were collected to assess variability attributed to data collection methods. Duplicates equalled approximately 10% of the total samples collected; this equated to one duplicate for this assessment. The field duplicates were collected from the same sampling station, though a cleaned core was used to collect the sample. A comparison of the field duplicate to the sample was conducted to establish the percent variability in data due to sample collection protocols. The Relative Percent Difference (RPD) was calculated using the following formula:

$$\text{RPD} = \frac{Original\ Sample\ \ Value - Duplicate\ \ Sample\ \ Value}{\left(Original\ \ Sample\ \ Value + Duplicate\ \ Sample\ \ Value\right) \div 2} * 100\%$$

3. RESULTS

Chlorophyll *a* values at the Sturgeon Island sites ranged between 2.44 and 69.70 mg/m^2 (Table C). The lowest mean Chlorophyll *a* value was observed at sampling site HEP-SJ-9, which is located on a lower site elevation (Table B, Table C). The highest mean Chlorophyll *a* value was observed at sampling site HEP-SJ-2, which is located on a higher site elevation (Table B, Table C).

Fucoxanthin values ranged between 3.78 and 74.64 mg/m^2 (Table C). The lowest and highest values for Fucoxanthin were observed at the same sampling location as Chlorophyll *a* (Table C).

Total Organic Carbon values ranged between 5,210.85 and 16,138.32 mg/m^2 (Table C). The lowest and highest values observed for Total Organic Carbon were both on a lower site elevation, although not at the same location (Table B, Table C).

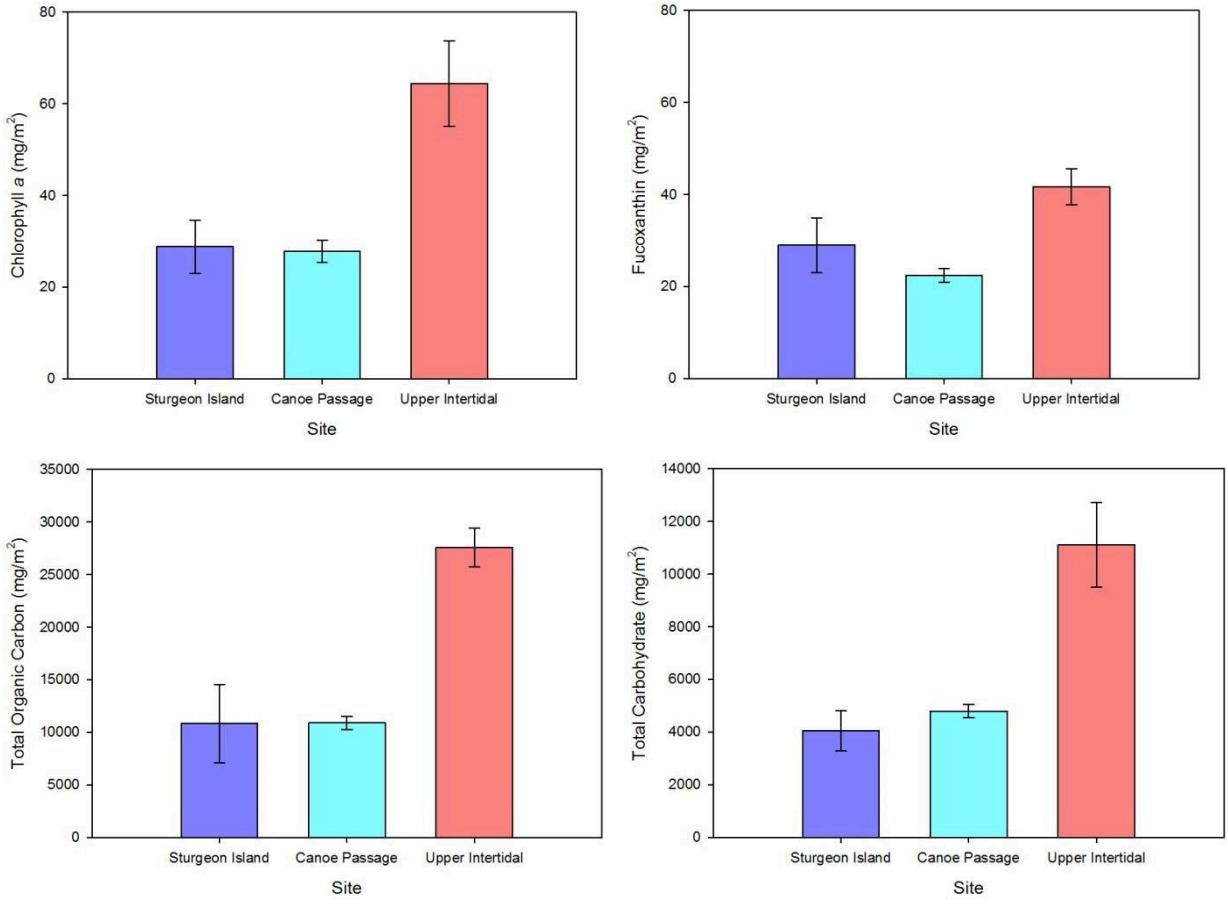
Total Carbohydrate values ranged between 600.24 and 8,781.33 mg/m^2. The highest concentration of Total Carbohydrate was found at the sampling location HEP-SJ-1, which is located in the lowest site elevation (Table B, Table C). The lowest concentration was found at the same location as minimum values for Chlorophyll *a* and Fucoxanthin (Table C).

Table C Measured Chlorophyll a, Fucoxanthin, Total Organic Carbon and Total Carbohydrate at Sturgeon Island on October 3, 2014

Sample Name	Location	Elevation Strata (m Chart Datum)	Chla (mg/m^2)	Fuco (mg/m^2)	TOC (mg/m^2)	TC (mg/m^2)
HEP SJ-1	Sturgeon Island	1.5-1.7	19.81	20.60	13,770.55	8,781.33
HEP SJ-2	Sturgeon Island	1.7-2.1	69.65	74.64	16,138.32	6,124.97
HEP SJ-3	Sturgeon Island	1.9-2.1	8.50	11.76	5,210.85	2,333.14
HEP SJ-4	Sturgeon Island	2.1-2.3	27.67	30.55	14,800.25	5,657.71
HEP SJ-5	Sturgeon Island	2.3-2.5	22.38	21.45	10,542.01	3,786.38
HEP SJ-6	Sturgeon Island	2.5-2.7	37.74	30.29	12,316.40	3,950.45
HEP SJ-7	Sturgeon Island	2.7-2.9	33.70	34.58	6,327.23	1,876.36
HEP SJ-8	Sturgeon Island	2.9-3.1	28.62	27.37	12,750.49	4,999.65
HEP SJ-9	Sturgeon Island	3.1-3.3	2.44	3.78	8,961.09	600.24
HEP SJ-10	Sturgeon Island	3.3-3.5	37.48	34.46	7,364.54	2,349.43
		Minimum	2.44	3.784	5,210.85	600.24
		Maximum	69.70	74.64	16,138.32	8,781.33
		Mean	28.80	28.95	10,818.17	4,045.96
		Standard Error of the Mean (±)	5.854	5.974	3,740.46	765.38
		Shapiro-Wilk p-value	0.408	0.065	0.728	0.85

3.1 Comparison to Roberts Bank

Following the *Roberts Bank Terminal 2 technical data report. Biofilm annual variability* report by WorleyParsons (2014b), the Roberts Bank mudflat was divided in biofilm zones for further investigation, based on the mapped distribution of biofilm density and known habitat type. Figure C presents a comparison between the values found at Sturgeon Island, and the known areas of high biofilm density (Upper Intertidal) at Roberts Bank and low biofilm density (Canoe Passage) (WorleyParsons, 2014b). All four biomass indicators for Sturgeon Island were observed to be within the same ranges as those found at Canoe Passage and much lower than those found in the Upper Intertidal zone. This indicates similarity between the Sturgeon Bank habitat and those observed in the Canoe Passage region of Roberts Bank.



Notes: error bars indicate Standard Error of the Mean

Figure C Difference in Biomass Indicators at Three Sites: Sturgeon Island, and Canoe Passage and Upper Intertidal at Roberts Bank

3.2 Quality Assurance / Quality Control

Laboratory QA/QC procedures were designed to measure process and analysis accuracy. All data used in the analysis of the biofilm indicators met the QA/QC thresholds presented in Appendix 2. One field duplicate was collected during the October 2014 sampling event to measure sampling precision. The field duplicate was collected from the same 1 m^2 sample quadrat, though different cores were used to create the composite. The field duplicates provide a measure of sampling accuracy within the quadrats, but is subject to the variable distribution of microphytobenthos. Field duplicate RPDs are presented in Table D. Larger RPD values indicate sample quadrats were not homogenous and less represented by the random core sampling method.

All field duplicates were within 12% relative percent difference (RPD), indicating suitable representation of the variability of biofilm within the 1 m^2 quadrat.

Table D Relative Percent Difference Calculation for Biofilm Indicators Field Duplicates

Sample Name	Location		Fuco (mg/m^2)	Chla (mg/m^2)	TOC (mg/m^2)	TC (mg/m^2)
HEP SJ-4	Sturgeon Island	Original	30.55	27.67	14,800.25	5657.71
		Duplicate	30.32	31.13	15,005.24	5903.46
		RDP	0.99%	-11.56%	-1.37%	-4.25%

4. DISCUSSION

Biofilm is known to occur in the Fraser River estuary (FRE) including at Sturgeon Bank, Roberts Bank, and Boundary Bay (Catherine Berris Associates Inc, 2010; Ross, 1998; WorleyParsons, 2014a, 2014b). Field sampling conducted by Hemmera in 2012 indicated increased areas of Chlorophyll *a* and Fucoxanthin at Roberts Bank, northern Sturgeon Bank, Westham Island, and eastern Boundary Bay; biofilm biomass at the Sturgeon Island site was observed to be low (WorleyParsons, 2014b). Similar findings were reported by Ross (1998), who found low sediment Chlorophyll *a* levels at the southern end of Sturgeon Bank compared to sites farther north, away from the main arm of the Fraser River.

The 2012 samples collected at Sturgeon Island (WorleyParsons, 2014a) reported Chlorophyll *a* densities between 30 to 200 mg/m^2; these were higher than the range observed in the present study which found values to range between 2 and 70 mg/m^2. Similarly, the Fucoxanthin samples collected in the Sturgeon Island area by Hemmera in 2012 (WorleyParsons, 2014a) were within a range of 40 to 120 mg/m^2, which is higher than the range observed in this study (3 and 75 mg/m^2).

The differences in data may be due to a different sampling methodology and timing. The 2012 samples were collected using a deeper sediment core, leading to the over-sampling of photopigments within the sediment. It is believed that deeper, and non-active pigments contributed to an over-estimation of biofilm biomass (Compass Resource Management, 2013, WorleyParsons (2014c)). Additionally, sampling for this study was conducted during a secondary Spring Tide. WorleyParsons (2014d) noted a distinct tidal influence with maximum biomass values occurring in conjunction with monthly maximum

tides. Additionally, the present samples were collected in early October, when day length and temperatures would have been lower compared to the optimal summer growing season noted by WorleyParsons (2014b).

In comparison to data collected at Roberts Bank, mean biofilm biomass indicators are similar to values reported at northern Roberts Bank, adjacent to Canoe Passage. The Sturgeon Island site features are similar to those of northern Roberts Bank, adjacent to Canoe Passage. Both habitats are in close proximity to the freshwater flows of the Fraser River and substrates are predominantly coarse sandy particles. The Sturgeon Island site is located against a rocky jetty extending west into Georgia Strait, creating a higher depositional area for sandier sediment (Photo A) and limiting the influence of the Fraser River South Arm.



Photo A Accumulation of Sand against the Rocky Jetty at Sturgeon Island

In an assessment of physical factors of biofilm at Roberts Bank, WorleyParsons (2014c) found increasing biofilm biomass with decreasing freshwater influence as well as with decreasing coarse sediment composition. A study undertaken by WorleyParsons (2014b) to assess the annual variability of biofilm at Roberts Bank demonstrated the change in biomass spatially. Among all biofilm zones, Canoe Passage, which has similar characteristics to Sturgeon Island, had lower annual mean Chlorophyll *a*, Fucoxanthin, Total Organic Carbon, and Total Carbohydrate densities compared to the defined biofilm zones at Roberts Bank (WorleyParsons, 2014b). Based on the understanding of biofilm biomass distributions across Roberts Bank, combined with the observed site characteristics of Sturgeon Island, biofilm biomass levels are expected to be low at Sturgeon Island under existing conditions.

5. CONCLUSION

The existing conditions of the Sturgeon Island site possess low levels of biofilm biomass compared to Roberts Bank. The proximity to the freshwater flows of the Fraser River combined with the coarse sediment size makes the existing conditions less optimal for biofilm growth. As a result, existing biofilm growth and productivity is considered to be low.

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7. CLOSING

We trust that this document satisfies your requirements and provides suitable information for your records. If you have any questions or require further details, please contact the undersigned at any time.

Regards,

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Appendix 1 Site Photos

APPENDIX 1
STURGEON ISLAND SAMPLING SITE

HEP-SJ-01



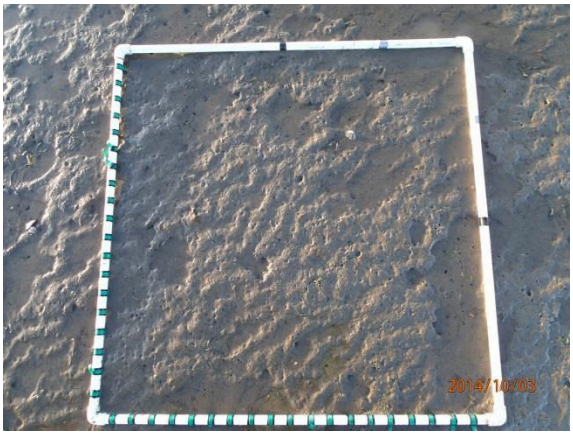
HEP-SJ-02



HEP-SJ-03



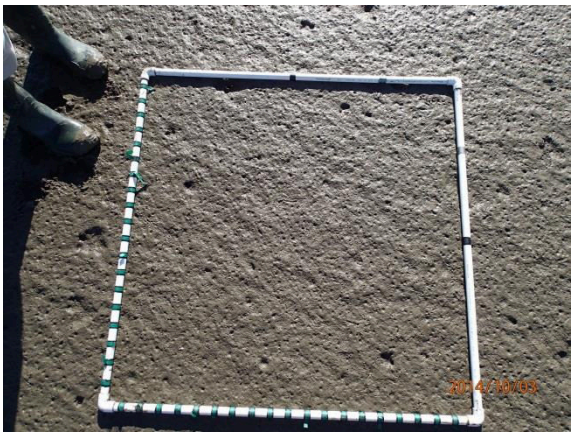
HEP-SJ-04



HEP-SJ-05



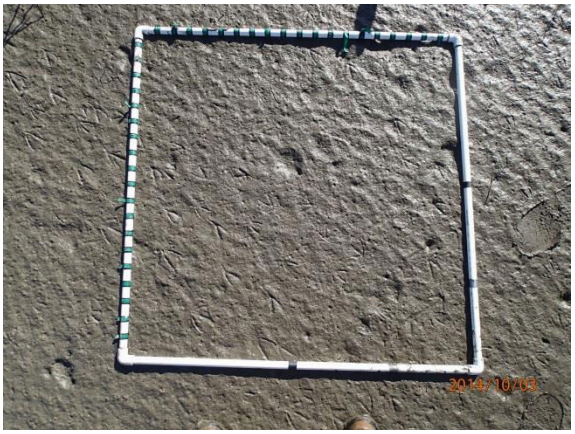
HEP-SJ-06



HEP-SJ-07



HEP-SJ-08



HEP-SJ-09



HEP-SJ-10



Appendix 2 QA / QC Thresholds

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Pigments STD Calibration Levels used for Developing the Calibration Curves

		level1	level2	level3	level4	level5	level6	level7	Original, ug/L	RT
#1	**Chlc2**	8.3	16.7	41.7	83.4	166.8	417.0	X	**834**	**3.48**
#2	**Fuco**	9.0	18.0	36.0	71.0	143.0	286.0	571.0	**1141**	**5.08**
#3	**Ddx**	11.9	23.9	47.9	95.7	191.4	478.5	X	**957**	**6.89**
#4	**Sud**	25.0	50.0	100.0	180.0	350.0	800.0	1600.0	**3200**	**7.43**
#5	**Allo**	9.0	18.0	36.0	72.0	144.0	287.0	574.0	**1147**	**7.71**
#7	**Zea**	8.0	16.0	32.0	65.0	120.0	240.0	475.0	**950**	**7.95**
#8	**Lut**	11.0	26.0	44.0	88.0	175.1	320.0	700.5	**1401**	**8.27**
#9	**Cant**	9.0	18.0	35.0	70.0	140.0	280.0	560.0	**1118**	**9.79**
#10	**Chlb**	19.0	38.0	76.0	151.0	303.0	605.0	X	**1210**	**10.80**
#11	**Chla**	14.2	28.5	57.0	120.0	228.0	441.0	911.0	**1822**	**12.31**
#12	**DVCh-a**	10.7	21.4	53.6	107.1	214.2	535.5	X	**1071**	**12.55**
#13	**Echi**	8.0	16.0	31.0	62.0	120.0	220.0	408.5	**817**	**13.18**
#15	**Phta**	14.0	28.0	55.0	108.0	220.0	440.0	879.0	**3517**	**19.43**
#16	**Acar**	11.0	22.0	44.0	88.0	176.0	352.0	X	**703**	**20.30**
#17	**Beta**	14.5	29.0	58.0	72.7	145.4	363.5	X	**727**	**21.11**

Calibration Standard (CAL) – A solution prepared from dilution of a stock standard solution.
The CAL solution is used to calibrate the instrument response with respect to analyte concentration or mass.
All CAL were prepared using Original STD individual pigment solutions.
Seven concentration levels were prepared using serial dilutions of Original STD solution of each pigment.
The dilution factor of each sequential dilution is 2, the solution used for dilution is Acetone/Methanol at 90/10 ratio.
The calibration created for each pigment individually was detector response versus concentration of a pigment in CAL solution (ug/L).
A calibration curve constructed for each individual pigment is a linear regrassion with a typical coefficient of dtermination >0.9.

Sud- Sudan is used as Internal Refence STD added to a sample extract at a known amount (typically in a range between 400 to 1200 ug/L) just prior to HPLC analysis to varify the accuracy of the injection volume.

RT – Retention Time of an analytes on a chromatogram (min).

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HPLC Performance-verification using CALCHK

	Analyte	CALCHK ug/L	Low WL -15%	High WL +15%	HEP_1-33 CALCHK,%
#2	**Fuco**	800.0	680.0	920.0	94.9%
#4	**Sud**	800.0	680.0	920.0	99.6%
#9	**Cant**	250.0	212.5	287.5	100.6%
#11	**Chla**	500.0	425.0	575.0	98.9%

na- not applicable

Sud- Sudan is used as Internal Refence STD added to a sample extract at a known amount (typically in a range between 400 to 1200 ug/L) just prior to HPLC analysis to varify the accuracy of the injection volume.
Warning Limit (WL) for Sud is +/-15%

Calibration Check Standard (CALCHK) – A mid-point calibration solution that is analyzed periodically in a sample set to verify that the instrument response to the analyte has not changed during the course of analysis.
CALCHK is analyzed for every batch os samples. It is analyzed first, before the sample batch, so to verify calibration. If CAKCHK is not +/-15% of the expected concentration for any analyte, then the instrument must be recalibrated. CALCHK is calculated and presented in % Recovery compared to the expected concentration.
Warning Limit (WL) for CALCHK is +/-15% for each individual Pigment Analyte

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HPLC Performance-verification using sample duplicate

		RT, min	HEP_1-33 Dup.Reproduce., %
#1	**Chlc2**	**3.48**	96.5
#2	**Fuco**	**5.08**	97.3
#3	**Ddx**	**6.89**	100.9
#4	**Sud**	7.43	101.4
#5	**Allo**	**7.71**	na
#7	**Zea**	**7.95**	104.5
#8	**Lut**	**8.27**	91.0
#9	**Cant**	**9.79**	95.6
#10	**Chlb**	**10.80**	102.9
#11	**Chla**	**12.31**	87.7
#12	**DVCh-a**	**12.55**	111.6
#13	**Echi**	**13.18**	90.7
#15	**Phta**	**19.43**	92.4
#16	**Acar**	**20.30**	109.4
#17	**Beta**	**21.11**	na

RT – Retention Time of an analytes on a chromatogram (min).

Duplicate Reproducibility- *is verified using a sample that is treated exactly the same throughout field and laboratory procedures.*
Analyses of duplicate sample give a measure of the precision associated with the sample preparation procedures, as well as analytical determination.

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HPLC Performance-verification using Pigments STD spiked into a sample matrix.

	#		SPK-level ug/L	RT	Low WL, -30%	High WL, +30%	HEP_1-33 %
#2	1	**Fuco**	500.0	**5.08**	350.0	650.0	87.8
#9	2	**Cant**	600.0	**9.79**	420.0	780.0	99.7
#11	3	**Chla**	500.0	**12.31**	350.0	650.0	105.8

Matrix Spike Recovery -a sample with pre-determined levels of analytes (analyzed in duplicate) is used. Known amounts of 3 Pigments are added prior to extraction and analytical procedures. This QA/QC is used as a measure of both sample extraction and analytical determination procedures.

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HPLC Performance-verification using Pigments STD as surrogates spiked into a MBSR sample followed by SamplePrep procedure.

		SPK-level ug/L	RT	HEP_1-33 Surrogate Recov., %
#2	**Fuco**	800.0	**5.08**	104.2
#5	**Sud**	800.0	**7.43**	102.2
#9	**Cant**	250.0	**9.79**	103.8
#11	**Chla**	500.0	**12.31**	111.9
#1	**Chlc2**	0.0	**3.48**	ND
#3	**Ddx**	0.0	**6.89**	ND
#5	**Allo**	0.0	**7.71**	ND
#7	**Zea**	0.0	**7.95**	ND
#8	**Lut**	0.0	**8.27**	ND
#9	**Cant**	0.0	**9.79**	ND
#10	**Chlb**	0.0	**10.80**	ND
#12	**DVCh-a**	0.0	**12.55**	ND
#13	**Echi**	0.0	**13.18**	ND
#15	**Phta**	0.0	**19.43**	ND
#16	**Acar**	0.0	**20.30**	ND
#17	**Beta**	0.0	**21.11**	ND

ND--Non detectable.

Method Blank-Spike Recovery (MBSR) – A blank sample (empty glass tube) that is treated exactly as a sample including exposure to all glassware, equipment, solvents, reagents, internal reference standards (Sud at 400-1200 ug/L), and surrogates (Fuco, Cant, Chla at the concentrations 640, 200, 400 ug/L, respectively). The MBSR is used to determine if method analytes or other interferences are present in the laboratory environment, reagents, or apparatus. If the MBSR value of the analytes other than Fuco, Sud, Cant and Chla constitute 10% or more of the analyte level determined in a sample, the contamination must be corrected and fresh samples must be analyzed when acceptable MBSR values have been obtained. The % Recovery of the surrogates (Fuco, Cant, Chla) must be within +/-20%. At least one MBSR is analyzed with each sample batch.

MBSR expected concentrations: Fuco, Sud, Cant and Chla - 640 800, 200 and 400, respectively.

APPENDIX B

Listed Species and Ecosystems of the CDFmm Subzone

Table B1 At-risk Plant Species within the CDFmm Subzone (MOE 2017a)

Scientific Name	Common Name	BC List[1]	SARA[2]	COSEWIC[3]	Potential to Occur
Alsia californica	California asia moss	Blue			Very Unlikely
Bidens amplissima	Vancouver Island beggarticks	Blue	1-SC (2003)	SC (2001)	Very Unlikely
Brachythecium holzingeri	Holzinger's brachythecium moss	Blue			Very Unlikely
Carex feta	green-sheathed sedge	Blue			**Unlikely**
Carex interrupta	green-fruited sedge	Red			Very Unlikely
Claytonia washingtoniana	Washington springbeauty	Red			Very Unlikely
Discellium nudum	flag-moss	Red			Very Unlikely
Erigeron philadelphicus var. *glaber*	salt marsh Philadelphia daisy	Red			Very Unlikely
Fissidens ventricosus	fissidens moss	Blue			Very Unlikely
Lupinus rivularis	streambank lupine	Red	1-E (2005)	E (2002)	Very Unlikely
Navarretia intertexta	needle-leaved navarretia	Blue			Very Unlikely
Nephroma occultum	cryptic paw	Blue	1-SC (2007)	T (2006)	Very Unlikely
Physcomitrium immersum	immersed bladder-moss	Red			Very Unlikely
Physcomitrium pyriforme	common bladder-moss	Blue			Very Unlikely
Platyhypnidium riparioides	riparian beaked-moss	Blue			Very Unlikely
Pseudephemerum nitidum	delicate earth-moss	Red			Very Unlikely
Sidalcea hendersonii	Henderson's checker-mallow	Blue			**Unlikely**
Syntrichia laevipila	twisted oak moss	Blue	1-SC (2005)	SC (2014)	Very Unlikely

Notes: [1] Red = Endangered or Threatened, Blue = Special Concern
[2] Schedule 1 = federal species at risk
[3] E = Endangered, SC = Special Concern
[4] Very unlikely = Site is just outside species range or it is inside the species range but site habitat is not thought to be tolerable, Unlikely = Site is within range and habitat at site is not preferred but may be tolerable, Possible = Site is within range and habitat is preferred

Table B2 At-risk Wetland Ecosystems within the Metro Vancouver CDFmm Subzone (BC Ministry of Environment 2013)

Scientific Name	English Name	Provincial Listing[1]	Potential to Occur[2]
Alnus rubra / *Carex obnupta* [*Populus trichocarpa*]	red alder / slough sedge [black cottonwood]	Red	Unlikely
Alnus rubra / Lysichiton americanus	red alder / skunk cabbage	Red	Unlikely
Bolboschoenus maritimus var. paludosus	seacoast bulrush	Red	**Likely**
Carex lasiocarpa - Rhynchospora alba	slender sedge - white beak-rush	Red	Unlikely
Deschampsia cespitosa ssp. *Beringensis -Hordeum brachyantherum*	tufted hairgrass - meadow barley	Red	**Probable**
Deschampsia cespitosa ssp. beringensis - Symphyotrichum subspicatum	tufted hairgrass - Douglas' aster	Red	Unlikely
Distichlis spicata var. spicata	seashore saltgrass	Red	**Probable**
Dulichium arundinaceum	three-way sedge	Red	Unlikely
Eleocharis palustris	common spike-rush	Blue	**Probable**
Juncus arcticus - Plantago macrocarpa	arctic rush - Alaska plantain	Red	**Probable**
Menyanthes trifoliata - Carex lasiocarpa	buckbean - slender sedge	Blue	Unlikely
Myrica gale / Carex sitchensis	sweet gale / Sitka sedge	Red	Unlikely
Pinus contorta / Sphagnum spp.	lodgepole pine / peat-mosses CDFmm	Red	Unlikely
Populus tremuloides / Malus fusca / Carex obnupta	trembling aspen / Pacific crab apple / slough sedge	Red	Unlikely
Rhododendron groenlandicum / Kalmia microphylla / Sphagnum spp.	Labrador tea / western bog-laurel / peat-mosses	Blue	Unlikely
Ruppia maritima	beaked ditch-grass	Red	**Probable**
Salix sitchensis - Salix lasiandra var. *lasiandra / Lysichiton americanus*	Sitka willow - Pacific willow / skunk cabbage	Red	Unlikely
Sarcocornia pacifica - Glaux maritima	American glasswort - sea-milkwort	Red	Unlikely
Schoenoplectus acutus	hard-stemmed bulrush Deep Marsh	Blue	Unlikely
Thuja plicata / Polystichum munitum - Lysichiton americanus	western redcedar / sword fern - skunk cabbage	Blue	Unlikely
Typha latifolia	common cattail	Blue	Unlikely

Notes: [1] Red = Endangered or Threatened, Blue = Special Concern
[2] Unlikely = site is just outside species range or it is inside the species range but site habitat is not thought to be tolerable, Probable = site is within range and habitat at site is not preferred but may be tolerable, Likely = site is within range and site habitat is preferred

Table B3 At-risk Wildlife Species within the Metro Vancouver CDFmm Subzone (MOE 2017a)

Scientific Name	English Name	Provincial Listing[2]	SARA Schedule[3]	COSEWIC[4]	Potential to Occur Comments[4]
Birds					
Accipiter gentilis laingi	Northern Goshawk, *laingi* subspecies	Red	1-T (2003)	T (2013)	Not very likely at the Site; this species prefers mature forests and old growth forest. No nearby nesting sites.
Ardea herodias fannini	Great Blue Heron, *fannini* subspecies	Blue	1-SC (2010)	SC (2008)	Species forage for fish near and/or at the Site; roost nearby at Reifel Bird Sanctuary; nearest nesting colony is ~10km away at Point Roberts
Asio flammeus	Short-eared Owl	Blue	1-SC (2012)	SC (2008)	Not likely found at the Site currently; this species is an open grassland and marshland specialist
Botaurus lentiginosus	American Bittern	Blue	Not listed	Not listed	Not likely found at the Site currently; this species is tied to wetlands with tall emergent vegetation (e.g. cattails) year-round
Brachyramphus marmoratus	Marbled Murrelet	Blue	1-T (2003)	T (2012)	May forage for fish at the Site during high tide
Buteo lagopus	Rough-legged Hawk	Blue	Not listed	NAR (1995)	Not likely found at the Site; rodent prey not likely to access this intertidal habitat.
Butorides virescens	Green Heron	Blue	Not listed	Not listed	May forage fish at the Site, although it is unlikely
Chordeiles minor	Common Nighthawk	Yellow	1-T (2010)	T (2007)	May forage for flying insects over the Site
Coccothraustes vespertinus	Evening Grosbeak	Yellow	Not listed	SC (2016)	Not likely found at the Site currently; this species is often found in forested regions, especially at higher elevations
Contopus cooperi	Olive-sided Flycatcher	Blue	1-T (2010)	T (2007)	Not likely found at the Site; this species forages and breeds in forest openings
Cypseloides niger	Black Swift	Blue	Not listed	E (2015)	Not likely found at the Site; this species is usually found in hilly or mountainous areas
Falco peregrinus anatum	Peregrine Falcon, *anatum* subspecies	Red	1-SC (2012)	NAR (2017)	May forage for birds over the Site
Hirundo rustica	Barn Swallow	Blue	1-T (2017)	T (2011)	May forage for flying insects over the Site; nest under man made coverings close to a source of mud which is used to construct their nests
Hydroprogne caspia	Caspian Tern	Blue	Not listed	NAR (1999)	May forage for fish at the Site during high tide
Megascops kennicottii kennicottii	Western Screech-Owl, *kennicottii* subspecies	Blue	1-SC (2005)	T (2012)	Not likely found at the Site; this species is primarily associated with riparian or low elevation forests

Scientific Name	English Name	Provincial Listing[2]	SARA Schedule[3]	COSEWIC[4]	Potential to Occur Comments[4]
Nycticorax nycticorax	Black-crowned Night-heron	Red	Not listed	Not listed	Not likely found at the Site currently; this species may forage for fish in marshes
Patagioenas fasciata	Band-tailed Pigeon	Blue	1-SC (2011)	SC (2008)	Not likely found at the Site; this species typically breeds and feeds in open areas within forests or in suburban gardens and parks
Phalacrocorax auritus	Double-crested Cormorant	Blue	Not listed	NAR (1978)	May forage for fish at site during high tide; between fishing it often spends time perched on man-made structures over or near water
Progne subis	Purple Martin	Blue	Not listed	Not listed	May be found foraging flying insects over the Site
Tyto alba	Barn Owl	Blue	1-SC (2003)	T (2010)	Not likely found at the Site currently; prey not likely to access the Site.
Mammals					
Corynorhinus townsendii	Townsend's Big-eared Bat	Blue	Not listed	Not listed	Not likely found at the Site; this species forages over forests, grasslands, shrub thickets and riparian areas with limited human disturbances
Lepus americanus washingtonii	Snowshoe Hare, *washingtonii* subspecies	Red	Not listed	Not listed	Not likely found at the Site; habitat generally includes non-fragmented adequately sized riparian woodlands
Mustela frenata altifrontalis	Long-tailed weasel, *altifrontalis* subspecies	Red	Not listed	Not listed	Not likely found at the Site currently; this species may be found in open habitats often near marshes and riparian areas and can tolerate close proximity to humans
Myodes gapperi occidentalis	Southern Red-backed Vole, *occidentalis* subspecies	Red	Not listed	Not listed	Not likely found at the Site; this species is generally associated with mature forest cover with high levels of structural diversity and large woody debris
Oreamnos americanus	Mountain Goat	Blue	Not listed	Not listed	Not likely found at the Site; Site is outside of range in alpine and subalpine habitat
Sorex rohweri	Olympic Shrew	Red	Not listed	Not listed	Not likely found at the Site; this species is associated with dry riparian habitat around streams and wetlands with high levels of structural diversity and deep organic soil layers
Sorex trowbridgii	Trowbridge's Shrew	Blue	Not listed	Not listed	Not likely found at the Site; this species prefer upland areas away from water

Scientific Name	English Name	Provincial Listing[2]	SARA Schedule[3]	COSEWIC[4]	Potential to Occur Comments[4]
Amphibians					
Rana aurora	Northern Red-legged Frog	Blue	1-SC (2005)	SC (2015)	Not likely found at the Site; this species is associated with structurally complex wetlands with slow moving waters relatively free of urban and agricultural runoff
Reptiles and turtles					
Chrysemys picta pop. 1	Painted Turtle - Pacific Coast Population	Red	1-E (2007)	T (2016)	Not likely found at the Site; this species is associated with slow-moving, permanent water bodies
Invertebrates					
Allogona townsendiana	Oregon Forestsnail	Red	1-E (2005)	E (2013)	Not likely found at the Site; this species is typically found in forested habitats
Callophrys eryphon sheltonensis	Western Pine Elfin, *sheltonensis* subspecies	Blue	Not listed	Not listed	Not likely found at the Site; typically found in natural pine woods and evergreen forests
Callophrys johnsoni	Johnson's Hairstreak	Red	Not listed	Not listed	Not likely found at the Site; typically found in old-growth coniferous forests
Carychium occidentale	Western Thorn	Blue	Not listed	Not listed	Not likely found at the Site; typically found in forested areas with rich leaf litter
Cryptomastix devia	Puget Oregonian	Red	1-XX (2004)	XT (2013)	Extirpated species. Not likely found at the Site; typically found in forest and mature forests
Danaus plexippus	Monarch	Red	1-SC (2003)	E (2016)	Not likely found at the Site; typically found in grasslands and shrub habitats
Epargyreus clarus californicus	Silver-spotted Skipper, *californicus* subspecies	Red	Not listed	Not listed	Not likely found at the Site; typically found in forests, grasslands and shrub habitats
Euphyes vestris	Dun Skipper	Blue	1-T (2003)	T (2013)	Found in a variety of habitats including seasonally flooded stream banks and areas adjacent to swamps and streams. It has some potential to occur in the marsh adjacent to the Site.
Galba bulimoides	Prairie Fossaria	Blue	Not listed	Not listed	Although this species is found in marsh and mud areas it is typically found in prairie habitats and as such it is not likely to be found at the Site.
Galba dalli	Dusky Fossaria	Blue	Not listed	Not listed	This is a freshwater snail that is typically found along flowing and impounded rivers in inland areas. Brackish conditions at the Site may preclude the presence of this mollusk.

Scientific Name	English Name	Provincial Listing[2]	SARA Schedule[3]	COSEWIC[4]	Potential to Occur Comments[4]
Haliotis kamtschatkana	Northern Abalone	Red	1-E	E (2009)	Not likely found at the Site; typically found in kelp beds in the low intertidal and shallow subtidal zones.
Omus audouini	Audouin's Night-stalking Tiger Beetle	Blue	Not listed	T (2013)	Not likely found at the Site; typically found in terrestrial environments
Ophiogomphus occidentis	Sinuous Snaketail	Blue	Not listed	Not listed	Not likely found at the Site; typically found in montane habitats
Parnassius clodius claudianus	Clodius Parnassian, *claudianus* subspecies	Blue	Not listed	Not listed	Not likely found at the Site; typically found in open forests and meadows and around rocky outcrops
Physella propinqua	Rocky Mountain Physa	Blue	Not listed	Not listed	Not likely found at the Site; typically found in permanent, cool water habitats (most often lakes)
Physella virginea	Sunset Physa	Blue	Not listed	Not listed	The habitat needs of this species is not well known but it occurs in shallow freshwater habitats. Brackish conditions at the Site may preclude the presence of this snail species.
Planorbula campestris	Meadow Rams-horn	Blue	Not listed	Not listed	A rare species in southern BC that is not likely found at the Site; typically found in vegetated vernal ponds, swamps and flooded portions of permanent water bodies
Icaricia saepiolus insulanus	Greenish Blue, *insulanus* subspecies	Red	1-E (2003)	E (2012)	Not likely found at the Site; typically found in upland forests, grasslands and agricultural areas
Speyeria zerene bremnerii	Zerene Fritillary, *bremnerii* subspecies	Red	Not listed	Not listed	Not likely found at the Site; typically found in upland forests, grasslands or anthropogenic habitats
Sphaerium striatinum	Striated Fingernailclam	Blue	Not listed	Not listed	This freshwater clam exists in mud, sand, gravel and rock substrates and is most abundant at water depths of less than 2 m. Brackish conditions at the Site may preclude the presence of this snail species
Sympetrum vicinum	Autumn Meadowhawk	Blue	Not listed	Not listed	This dragonfly species could potentially be found in the marsh adjacent to the Site. This species is found in ponds, slow streams and lakes with dense, emergent vegetation (Klinkenberg 2017).

Notes:
[1] Red = Endangered or Threatened, Blue = Special Concern, Yellow = Not at Risk
[2] Schedule 1 = federal species at risk, Schedule 3 = Species under consideration for Schedule 1
[3] E = Endangered, T = Threatened, SC = Special Concern, NAR = Not at Risk, XT = Extirpated, C = Candidate for upcoming assessment, DD = Data deficient
[4] Species information was taken from The Birds of North American Online 2013 and E-Fauna BC 2013

APPENDIX C

Common Species of Richmond, BC

Table C1 List of Species Known to Occur in Areas at and Adjacent to the Project Site

Fish Species	Recorded Presence
Lampreys – Family Petromyzonidae	
River lamprey (*Lampetra ayresii*)	Fraser River – Migratory – Brackish & Freshwater
Western Brook Lamprey (*Lampetra richardsoni*)	Fraser River - Resident – Freshwater
Pacific Lamprey (*Entosphenus tridentatus*)	Fraser River - Migratory - Brackish & Freshwater
Sturgeon – Family Acipenseridae	
White Sturgeon (*Acipenser transmontanus*) • Lower Fraser population: Threatened (COSEWIC) & Red-listed (CDC)	Fraser River - Semi-resident - Marine, Brackish & Freshwater
Green Sturgeon (*Acipenser medirostris*) • Special Concern (COSEWIC) & Red-listed (CDC)	Fraser River - Semi-resident – Marine
Herring – Family Clupeidae	
American Shad (*Alosa sapidissima*)	Fraser River - Migratory – Marine & Brackish
Pacific Herring (*Clupea harengus*)	Fraser River - Semi-resident – Marine
Smelts – Family Osmeridae	
Capelin (*Mallotus villosus*)	Fraser River - Resident – Marine
Eulachon (Thaleichthys pacificus) • Fraser population: Endangered (COSEWIC) & Blue-listed (CDC)	Fraser River - Migratory - Marine, Brackish & Freshwater
Longfin Smelt (*Spirinchus thaleichthys*)	Fraser River - Migratory - Marine, Brackish & Freshwater
Surf Smelt (*Hypomesus pretiosus*)	Fraser River - Migratory – Marine
Whitefishes – Family Coregonidae	
Mountain Whitefish (*Prosopium williamsoni*)	Fraser River - Semi-resident - Brackish & Freshwater
Sandlances – Family Ammodytidae	
Pacific Sand Lance (*Ammodytes hexapterus*)	Fraser River- Resident – Marine
Salmon and Trout – Family Salmonidae	
Bull Trout (*Salvelinus confluentus*) • Coastal lineage: Special Concern (COSEWIC) & Blue-listed (CDC)	Fraser River - Migratory - Marine, Brackish & Freshwater
Chinook Salmon (*Oncorhynchus tshawytcha*)	Fraser River - Migratory - Marine, Brackish & Freshwater
Chum Salmon (*Oncorhynchus keta*)	Fraser River - Migratory - Marine, Brackish & Freshwater
Coho Salmon (*Oncorhychus kisutch*) • Interior Fraser population: Threatened (COSEWIC)	Fraser River - Migratory - Marine, Brackish & Freshwater
Cutthroat Trout *(Oncorhynchus clarkii clarkii)* • Coastal population: *Blue-Listed (*CDC*)*	Fraser River - Migratory - Marine, Brackish & Freshwater
Dolly Varden (*Salvelinus malma*)	Fraser River - Semi-resident - Brackish & Freshwater

Fish Species	Recorded Presence
Pink Salmon (*Oncorhynchus gorbuscha*)	Fraser River - Migratory - Marine, Brackish & Freshwater
Rainbow (Steelhead) Trout (*Oncorhynchus mykiss*)	Fraser River - Migratory - Marine, Brackish & Freshwater
Sockeye *Salmon (Oncorhynchus nerka)* • Cultus population: Endangered (COSEWIC)	Fraser River - Migratory - Marine, Brackish & Freshwater
Dogfish Sharks - Family Squalidae	
Spiny Dogfish (*Squalus suckleyi*)	Fraser River - Resident - Marine
Suckers – Family Catostomidae	
Largescale Sucker (*Catostomus macrocheilus*)	Fraser River - Resident - Brackish & Freshwater
Codfishes - Family Gadidae	
Pacific Tomcod (*Microgadus proximus*)	Fraser River - Resident - Marine
Minnows – Family Cyprinidae	
Common Carp (*Cyprinus carpio*)	Fraser River - Resident - Brackish & Freshwater Note: Exotic species
Goldfish (*Carassius auratus*)	Irrigation drainage channels of Richmond Note: Exotic species
Redside Shiner (*Richardsonius balteatus*)	Fraser River - Resident - Brackish & Freshwater
Northern Pikeminnow (*Ptychocheilus oregonensis*)	Fraser River - Resident - Brackish & Freshwater
Peamouth (*Mylocheilus caurinus*)	Fraser River - Resident - Brackish & Freshwater
Leopard Dace (*Rhinichthys falcatus*)	Fraser River - Resident - Brackish & Freshwater
Longnose Dace (*Rhinichthys cataractae*)	Fraser River - Resident - Freshwater
Brassy Minnow (*Hybognathus hankinsoni*) • Pacific population: Blue-listed (CDC)	Fraser River - Resident - Freshwater
Catfishes – Family Ictaluridae	
Brown Bullhead (*Ameiurus nebulosus*)	Fraser River - Resident - Brackish & Freshwater Note: Exotic species
Sticklebacks – Family Gasterosteidae	
Threespine Stickleback (*Gasterosteus aculeatus*)	Fraser River - Migratory - Marine, Brackish & Freshwater
Pipefishes - Family Syngnathidae	
Bay Pipefish (*Syngnathus leptorhynchus*)	Fraser River - Resident - Marine
Basses and Sunfishes – Family Centrarchidae	
Black Crappie (*Pomoxis nigromaculatus*)	Fraser River - Resident - Brackish & Freshwater Note: Exotic species
Pumpkinseed (*Lepomis gibbosus*)	Irrigation drainage channels of Richmond Note: Exotic species

Fish Species	Recorded Presence
Surfperches – Family Embiotocidae	
Pile Perch (*Rhacochilus vacca*)	Fraser River - Resident - Marine
Shiner Perch (*Cymatogaster aggregata*)	Fraser River - Resident - Marine
Striped Seaperch (*Embiotoca lateralis*)	Fraser River - Resident - Marine
Gobies - Family Gobiidae	
Arrow Goby (*Clevelandia ios*)	Fraser River - Resident - Marine
Pricklebacks – Family Stichaeidae	
High Cockscomb (*Anoplarchus purpurescens*)	Fraser River - Resident - Marine
Snake Prickleback (*Lumpenus sagitta*)	Fraser River - Resident - Marine
Slender Cockscomb (*Anoplarchus insignis*)	Fraser River - Resident - Marine
Gunnels - Family Pholidae	
Crescent Gunnel (*Pholis laeta*)	Fraser River - Resident - Marine
Penpoint Gunnel (*Apodichthys flavidus*)	Fraser River - Resident - Marine
Saddleback Gunnel (*Pholis ornata*)	Fraser River - Resident - Marine
Greenlings – Family Hexagrammidae	
Kelp Greenling (*Hexagrammos decagrammus*)	Fraser River - Resident - Marine
Masked Greenling (*Hexagrammos octogrammus*)	Fraser River - Resident - Marine
Whitespotted Greenling (*Hexagrammos stelleri*)	Fraser River - Resident - Marine
Sculpins – Family Cottidae	
Buffalo Sculpin (*Enophrys bison*)	Fraser River - Resident - Marine
Coastrange Sculpin (*Cottus aleuticus*)	Fraser River – Resident – Marine, Brackish & Freshwater
Great Sculpin (*Myoxocephalus polyacanthrocephalus*)	Fraser River - Resident - Marine
Manacled Sculpin (*Synchirus gilli*)	Fraser River - Resident - Marine
Mosshead Sculpin (*Clinocottus globiceps*)	Fraser River - Resident - Marine
Pacific Staghorn Sculpin (*Leptocottus ormatus*)	Fraser River - Resident - Marine
Padded Sculpin (*Artedius fenestralis*)	Fraser River - Resident - Marine
Prickly Sculpin (*Cottus asper*)	Fraser River - Resident - Marine
Rosylip Sculpin (*Ascelichthys rhodorus*)	Fraser River - Resident - Marine, Brackish & Freshwater
Saddleback Sculpin (*Oligocottus rimensis*)	Fraser River - Resident - Marine
Sharpnose Sculpin (*Clinocottus acuticeps*)	Fraser River - Resident - Marine
Silverspotted Sculpin (*Blepsias cirrhosus*)	Fraser River - Resident - Marine
Smoothhead Sculpin (*Artedius lateralis*)	Fraser River - Resident - Marine
Spinynose Sculpin (*Asemichthys taylori*)	Fraser River - Resident - Marine
Tadpole Sculpin (*Psychrolutes paradoxus*)	Fraser River - Resident - Marine
Tidepool Sculpin (*Oligocottus maculosus*)	Fraser River - Resident - Marine

Fish Species	Recorded Presence
Toadfishes - Family Batrachoididae	
Plainfin Midshipman (*Porichthys notatus*)	Fraser River - Resident - Marine
Poachers - Family Agonidae	
Sturgeon Poacher (*Podothecus accipenserinus*)	Fraser River - Resident - Marine
Snailfishes - Family Liparidae	
Lobefin Snailfish (*Liparis greeni*)	Fraser River - Resident - Marine
Tidepool Snailfish (*Liparis florae*)	Fraser River - Resident - Marine
Lefteye Flounders - Family Bothidae	
Pacific Sanddab (*Citharichthys sordidus*)	Fraser River - Resident - Marine
Speckled Sanddab (*Citharichthys stigmaeus*)	Fraser River - Resident - Marine
Righteye Flounders – Family Pleuronectidae	
Butter Sole (*Isopsetta isolepis*)	Fraser River - Resident - Marine
C-O Sole (*Pleuronichthys coenosus*)	Fraser River - Resident - Marine
English Sole (*Parophrys vetulus*)	Fraser River - Resident - Marine
Flathead Sole (*Hippoglossoides elassodon*)	Fraser River - Resident - Marine
Rock Sole (*Lepidopsetta bilineata*)	Fraser River - Resident - Marine
Sand Sole (*Psettichthys melanostictus*)	Fraser River - Resident - Marine
Starry Flounder (*Plaitichthys stellanus*)	Fraser River - Resident - Marine

Table C2 Regularly Occurring Bird Species at the George C. Reifel Migratory Bird Sanctuary

Red-throated Loon	Sharp-shinned Hawk	Thayer's Gull	Golden-crowned Kinglet
Pacific Loon	Cooper's Hawk	Glaucous-winged Gull	Ruby-crowned Kinglet
Common Loon	Northern Goshawk	Glaucous Gull	Townsend's Solitaire
Pied-billed Grebe	Red-tailed Hawk	Caspian Tern	Swainson's Thrush
Horned Grebe	Rough-legged Hawk	Common Tern	Hermit Thrush
Red-necked Grebe	American Kestrel	Marbled Murrelet	American Robin
Eared Grebe	American Pipit	Eurasian Collared Dove	Varied Thrush
Western Grebe	Peregrine Falcon	Rock Pigeon	Bohemian Waxwing
Double-crested Cormorant	Gyrfalcon	Band-tailed Pigeon	Cedar Waxwing
Brandt's Cormorant	Ring-necked Pheasant	Barn Owl	Northern Shrike
Pelagic Cormorant	Virginia Rail	Great Horned Owl	European Starling
American Bittern	Sora	Snowy Owl	Cassin's Vireo
American White	American Coot	Barred Owl	Hutton's Vireo
Great Blue Heron	Sandhill Crane	Long-eared Owl	Warbling Vireo
Green Heron	Black-Bellied Plover	Short-eared Owl	Red-eyed Vireo
Black-crowned Night-Heron	American Golden Plover	Northern Saw-whet Owl	Orange-crowned Warbler
Trumpeter Swan	Semipalmated Plover	Common Nighthawk	Nashville Warbler
Tundra Swan	Killdeer	Black Swift	Yellow Warbler
Mute Swan	American Avocet	Vaux's Swift	Yellow-rumped Warbler
Greater White-fronted Goose	Greater Yellowlegs	Anna's Hummingbird	Black-throated Gray Warbler
Lesser Snow Goose	Lesser Yellowlegs	Rufous Hummingbird	Townsend's Warbler
Ross' Goose	Willet	Belted Kingfisher	Black-and-white Warbler
Emperor Goose*	Solitary Sandpiper	Red-breasted Sapsucker	Northern Waterthrush
Brant	Spotted Sandpiper	Downy Woodpecker	MacGillivray's Warbler
Canada Goose	Whimbrel	Hairy Woodpecker	Common Yellowthroat
Cackling Goose	Long-billed Curlew	Northern Flicker	Wilson's Warbler
Wood Duck	Hudsonian Godwit	Pileated Woodpecker	Western Tanager
Green-winged Teal	Bar-tailed Godwit	Olive-sided Flycatcher	Black-headed Grosbeak
Mallard	Marbled Godwit	Western Wood-Pewee	Evening Grosbeak
Northern Pintail	Ruddy Turnstone	Willow Flycatcher	Pine Grosbeak
Blue-Winged Teal	Black Turnstone	Hammond's Flycatcher	Spotted Towhee
Cinnamon Teal	Red Knot	Pacific-slope Flycatcher	American Tree Sparrow
Northern Shoveler	Sanderling	Eastern Phoebe	Chipping Sparrow
Gadwall	Semipalmated Sandpiper	Say's Phoebe	Savannah Sparrow
Eurasian Wigeon	Western Sandpiper	Western Kingbird	Fox Sparrow
American Wigeon	Least Sandpiper	Eastern Kingbird	Song Sparrow
Canvasback	Baird's Sandpiper	Horned Lark	Lincoln's Sparrow
Redhead	Pectoral Sandpiper	Purple Martin	Swamp Sparrow
Ring-necked Duck	Sharp-tailed Sandpiper	Tree Swallow	White-throated Sparrow
Greater Scaup	Dunlin	Violet-green Swallow	Golden-crowned Sparrow
Lesser Scaup	Stilt Sandpiper	Northern Rough-winged Swallow	White-crowned Sparrow
Long-tailed Duck	Short-billed Dowitcher	Bank Swallow	Dark-eyed Junco
Black Scoter	Long-billed Dowitcher	Cliff Swallow	Red-winged Blackbird
Surf Scoter	Common Snipe	Barn Swallow	Western Meadowlark
White-winged Scoter	Wilson's Phalarope	Steller's Jay	Yellow-headed Blackbird
Common Goldeneye	Red-necked Phalarope	Northwestern Crow	Brewer's Blackbird
Bufflehead	Parasitic Jaeger	Common Raven	Brown-headed Cowbird
Hooded Merganser	Franklin's Gull	Black-capped Chickadee	Bullock's Oriole
Common Merganser	Bonaparte's Gull	Mountain Chickadee	Purple Finch
Red-breasted Merganser	Mew Gull	Chestnut-backed Chickadee	House Finch
Ruddy Duck	Ring-Billed Gull	Bushtit	Red Crossbill
Turkey Vulture	California Gull	Red-breasted Nuthatch	Common Redpoll
Osprey	Herring Gull	Brown Creeper	Pine Siskin
Bald Eagle		Bewick's Wren	American Goldfinch
Northern Harrier		House Wren	House Sparrow
		Pacific Wren	Merlin
		Marsh Wren	Mourning Dove

APPENDIX D

Shorebird Dropping Surveys

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hemmera.com

Proposed South Arm Jetty Tidal Marsh Project
Shorebird Droppings Surveys – Northward and Southward Migrations of 2014

Report Date	January 17, 2015
Survey Dates & Times	Shorebird droppings surveys were conducted to quantify foraging use by migratory shorebirds in and adjacent to the proposed South Arm Jetty Tidal Marsh Project (**Photograph 1**). Surveys were conducted in 2014 during migratory periods of the most abundant shorebird in the estuary: the western sandpiper (*Calidris mauri*). Survey dates were selected around the anticipated peak of each migratory period and times were centered around low tides: • Northward Migration: May 2 (11:00-15:00), May 3 (12:00-16:00) • Southward Adult Migration: July 15 (12:15-17:15), July 16 (12:45-17:45) • Southward Juvenile Migration: August 27 (11:30-16:00), August 28 (12:30-17:00)
Weather & Tidal Conditions	All surveys were conducted under calm conditions with wind speeds below 25 km/hour and in the absence of medium to heavy rain. Surveys were centered on day-time low tides, so the first half of each survey was conducted during a falling low tide and the latter half of each survey was conducted during a rising low tide. The following is a detailed summary of the weather conditions (general conditions and temperature) and tides on each of the survey dates, for the associated times: • May 2, 2014 – mostly cloudy; average temperature: 19° C; low tide of 1.1 at 14:19, high tide of 4.4 at 21:56 • May 3, 2014 – Cloudy with light rain showers; average temperature: 12° C; low tide of 1.2 at 14:58, high tide of 4.4 at 21:56 • July 15, 2014 – Clear; average temperature: 22°; C low tide of 1.0 at 14:14, high tide of 4.7 at 21:23 • July 16, 2014 – Clear; average temperature: 23° C; low tide of 1.4 at 15:01, high tide of 4.7 at 22:01 • August 27, 2014 – Mainly clear; average temperature: 24° C; low tide of 1.8 at 13:15, high tide of 4.2 at 19:50 • August 28, 2014 – Mostly cloudy; average temperature: 22° C; low tide of 2.1 at 13:46, high tide of 4.2 at 20:11

	Weather data from Government of Canada hourly climate data for Vancouver International Airport: http://climate.weather.gc.ca/climateData/hourlydata_e.html?timeframe=1&Prov=BC&StationID=51442&hlyRange=2013-06-11%7C2014-06-11&cmdB1=Go&Year=2014&Month=3&Day=31&cmdB1=Go# Tide data from Government of Canada 7 days tidal predictions for Sand Heads: http://www.waterlevels.gc.ca/eng/station?type=0&date=2014%2F03%2F31&sid=7594&tz=PDT&pres=1
Survey Area	Port Metro Vancouver's (PMV's) Habitat Enhancement Program – Proposed South Arm Jetty Tidal Marsh Project and adjacent areas on Sturgeon Bank The proposed enhancement site is located on the north bank of the South Arm of the Fraser River, on the south side of Sturgeon Bank. The proposed enhancement area (including berm) runs approximately 2.5 km along the South Arm Jetty and extends to a maximum distance of approximately 400 m north into Sturgeon Bank, encompassing a gross total area of approximately 55 ha (**Figure 1**). Surveys were conducted across the most eastern 1600 m of the proposed enhancement area within intertidal habitat and extended up to 800 m north of the jetty to include intertidal areas adjacent to the proposed enhancement site (**Figures 2, 3, and 4**). The survey area was bounded on the north and east sides by a tidal channel originating from the Fraser River and was bounded on the west by the tideline during surveys (**Figure 1**, **Photographs 2 and 3**).
Survey Team	Toby St. Clair, MSc (Hemmera Biologist); Tanya Katamay-Smith, BSC, BIT (Hemmera Biologist); Sarah Weiss BSc (Hemmera Environmental Coordinator); Gillian Anderson BSc (Contract Biologist); Lanaye Baxter BSc (Contract Biologist)
Scope of Work	The proposed enhancement project would involve converting an existing un-vegetated intertidal area (predominantly sand- and mudflat) into a more productive brackish marsh. This would be accomplished through construction of a containment berm followed by the placement of fill material to the appropriate elevation for establishment of intertidal marsh vegetation. The Project would result in the creation of approximately 43.6 ha of high-quality intertidal marsh habitat. The purpose of dropping surveys is to document baseline shorebird use within and in proximity to the area proposed for marsh habitat creation. Reconnaissance-level bird surveys were conducted on April 27, 2014 to confirm the presence of shorebirds in the study area, prior to the study's commencement. Additional surveys were conducted to verify the presence of birds at Sturgeon Bank before each droppings survey. Droppings surveys of the South Arm Jetty follow the same methods applied during migratory periods of western sandpipers in 2012 and 2013 as part of baseline studies conducted by Hemmera to document habitat use of the Fraser River Estuary (FRE) by shorebirds. These studies were conducted to assess habitat use throughout the Fraser River Estuary (FRE), but did not provide comprehensive coverage of the area adjacent to the South Arm Jetty due to site access issues.
Survey Methods	The intensity and distribution of bird use across the study area was assessed by counting shorebird droppings at low tide within all sand-/mudflat habitat in the study area. All droppings smaller than the size of a quarter were considered to be shorebird droppings. Droppings were counted within fifteen 1 m^2 quadrats at sampling stations located every 50 meters along transects.

	To standardize sampling at each station, ten of the quadrats were sampled perpendicular to transects (i.e. five on each side of the transect), and five quadrats were sampled along the transect bearing (**Figure 5**). Data were recorded on Android smartphones using Pendragon Forms software (Pendragon Forms VI 2012) or on paper datasheets. The field crew was comprised of a team of two surveyors. Surveyors conducted droppings surveys on parallel transects spaced at least 100 m apart. Transects were conducted following non-declinated bearings of 0 (North) or 180 (South) degrees to fit the orientation and shape of the study area. Droppings measurements were taken every 50 m until transects intersected marsh vegetation, tide line (including tidal channel), or the study area boundary. An average of eight transects were conducted each day across the survey area. To avoid biasing sample effort towards the survey area edges (e.g. marsh edge, tidal channel or tide line), only the first transect began at the marsh edge (Photographs 4 and 5). For subsequent transects, the first sample station was located directly east/west (270 or 90 degrees) from a sample station on the previous transect. Surveyors also recorded estimates of the number of shorebirds and species composition observed in the study area on each survey day.
Results	Inverse distance weighted (IDW) interpolation was used to generate spatially smoothed illustrations of dropping densities recorded within each migratory period (**Figures 2, 3, and 4**). The IDW interpolation approximated dropping densities at a resolution of 5 m^2 across the study area using weighted by distance averages of the twelve nearest survey stations (the standard number used for IDW interpolation across baseline studies of the FRE). Since samples were most often collected within 50 m of one another, the distance within which twelve sites were sampled was generally 300 m or less. To limit the extent of interpolation into unsampled areas while allowing for the majority of areas to conform to the standard of averaging across twelve survey sites, 300 m was set as a maximum distance limit for interpolation. When fewer than twelve sites were present within 300 m, only the sites within that distance were averaged for interpolation. The results of IDW interpolation are presented in **Figures 2, 3, and 4** for each of the three migratory periods. Interpolations from survey results describe shorebird foraging use in 93-98% of the proposed enhancement area across migratory periods (**Figures 2, 3, and 4**). Summary statistics of dropping density records within and adjacent to the proposed Habitat Enhancement Area (HEA) are provided in **Table 1** and mean dropping densities are plotted with standard errors within **Figures 2, 3, and 4**. For comparison, the same summary statistics and plots are also provided from surveys conducted across the southern half of Sturgeon Bank during 2012 and 2013. Results are presented separately for each migratory period. Survey results from the northward migration found dropping densities within the proposed HEA that were similar to the average across southern Sturgeon Bank in 2012 and 2013. Dropping densities in the area adjacent to the proposed HEA were slightly lower than within the HEA or across southern Sturgeon Bank during this period **(Figure 2)**. Survey results from the southward migration of adult western sandpipers found low dropping densities both within and adjacent to the HEA relative to densities observed across southern Sturgeon Bank in previous years (**Figure 3**). Results from the southward migration of juvenile western sandpipers found dropping densities within the proposed HEA that were similar to the average across southern Sturgeon Bank, and relatively higher dropping densities in the study area adjacent to the proposed HEA (**Figure 4**).

	Estimates of shorebird numbers observed during each survey are provided in **Table 2**. Shorebirds observed within the study area include western sandpiper, least sandpiper (*Calidris minutilla*) greater yellowlegs (*Tringa melanoleuca)*, killdeer (*Charadrius vociferous*), sanderling (*Calidris alba*), and black-bellied plover (*Pluvialis squatarola*). Other birds observed within the study area include mallard (*Anas platyrhynchos*), northern pintail (*Anas acuta*), green-winged teal (*Anas crecca*), American widgeon (*Anas americana*), Canada goose (*Branta Canadensis*), great blue heron (*Ardea herodius*), bald eagle (*Haliaeetus leucocephalus*), peregrine falcon (*Falco peregrinus*), double-crested cormorant (*Phalocrocorax auritus*), mew gull (*Larus canus*), glaucous-winged gull (*Larus glaucescens*), and ring-billed gull (*Larus delawarensis*).
Summary & Recommendations	Survey results show inconsistent trends in the differences between dropping densities within and adjacent to the proposed HEA; however, dropping densities within the proposed HEA were always similar to or less than those observed across the broader area of southern Sturgeon Bank in 2012 and 2013. Surveys conducted in 2012 and 2013 found intermediate dropping densities at southern Sturgeon Bank relative to other areas in the Fraser River Estuary (FRE). Thus, results suggest that habitat within the proposed HEA is of intermediate or less than intermediate quality relative to the rest of the estuary, depending on the migratory period. Two caveats to this conclusion must be recognized: 1) Given that surveys during 2014 were conducted during the peak of each migration and surveys in 2012 and 2013 included the tails of the migration when fewer shorebirds were present, results may over-estimate the quality of habitat within the study area relative to other areas of the FRE; 2) Given the small sample size of surveys in 2014 (n=2 in each migration period), results from this study have a higher potential to be influenced by anomalous records (i.e., sampling bias) and mean density records are less likely to be representative of the true mean relative to results from the 2012 and 2013 studies. The most common bird observed during surveys was the western sandpiper; however, during the northward migration, dunlin comprised substantial proportions of flocks (Table 2). Black-bellied plovers, yellowlegs, least sandpipers, sanderling, and killdeer were all observed in the study area on multiple survey days; however, these species were present in such small numbers (a few dozen at most) that they are unlikely to have made significant contributions to overall dropping distributions. Dropping densities during the southward migration therefore reflect use from western sandpipers, while densities from the northward migration reflect use by both western sandpipers and dunlin. Shorebird abundances and species were recorded between droppings surveys whenever foraging shorebird flocks were noticed by field staff, not according to any standardized protocols. Consequently, these records are potentially incomplete with regard to total abundances and the total number of species using the study area. Despite this limitation, the abundance records offer a sample of species composition which is useful in estimating the proportions of the more abundant species (e.g., dunlin and western sandpiper), and confirms the presence of the species listed above. Some consideration of potential impacts from proposed habitat enhancement works on areas with high habitat quality near the study area is also warranted. Previous surveys of shorebird abundance and droppings demonstrate that habitat on the northeast side of the tidal channel that bounds this study's survey area supports the highest densities of birds and droppings at Sturgeon Bank. While not within the proposed enhancement project's footprint, potential influences on tidal currents and freshwater flows in adjacent areas warrants consideration. For instance, tidal currents and freshwater flows control sediment and nutrient deposition as well as salinity could affect the abundance and composition of shorebird prey.

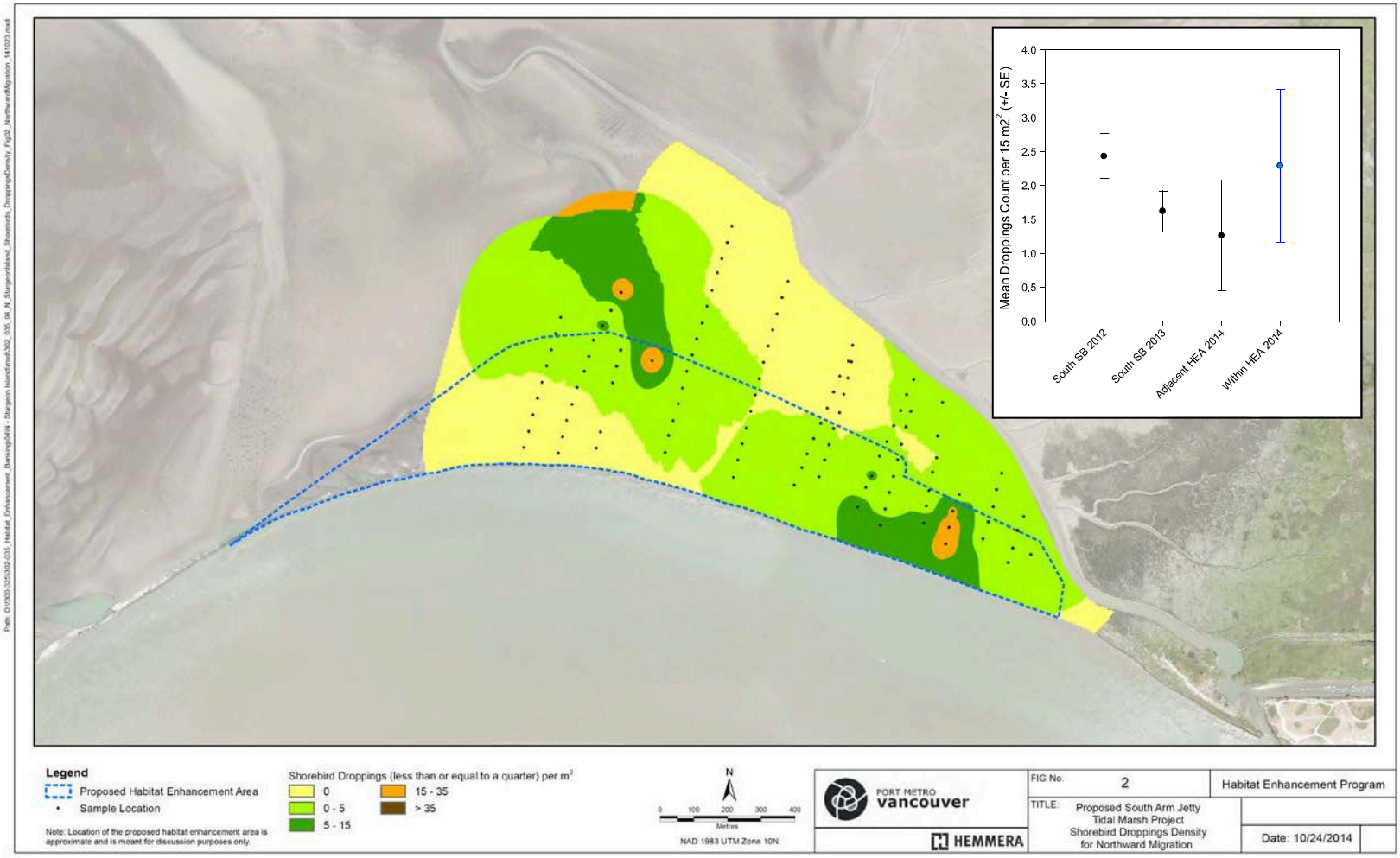
	Further review of the project proposal by a fluvio-geomorphologist was undertaken, in order to assess the potential for impacts to tidal currents, flow rates, and sedimentation. The project's design engineer (Moffatt and Nichol Engineers, or M&N) was asked to provide this follow-up assessment. M&N notes that deposition and erosion of sediments on Sturgeon Bank are driven by a combination of tidal currents, freshwater flows and wind driven waves. Potential changes to these physical processes as a result of project construction were evaluated by M&N using numeric models. The project's proposed cobble beach berm and containment structure were designed to limit the effect they have on tidal current and fresh water flow patterns. Overall the proposed project has little to no change to the physical processes which drive deposition and erosion outside of the immediate vicinity of the proposed project. Some minor changes in current speeds are probable, less than 0.1 m/s, but these are considered within the numeric model accuracy.

Figures

Figure 1. Proposed South Arm Jetty Tidal Marsh Project Area

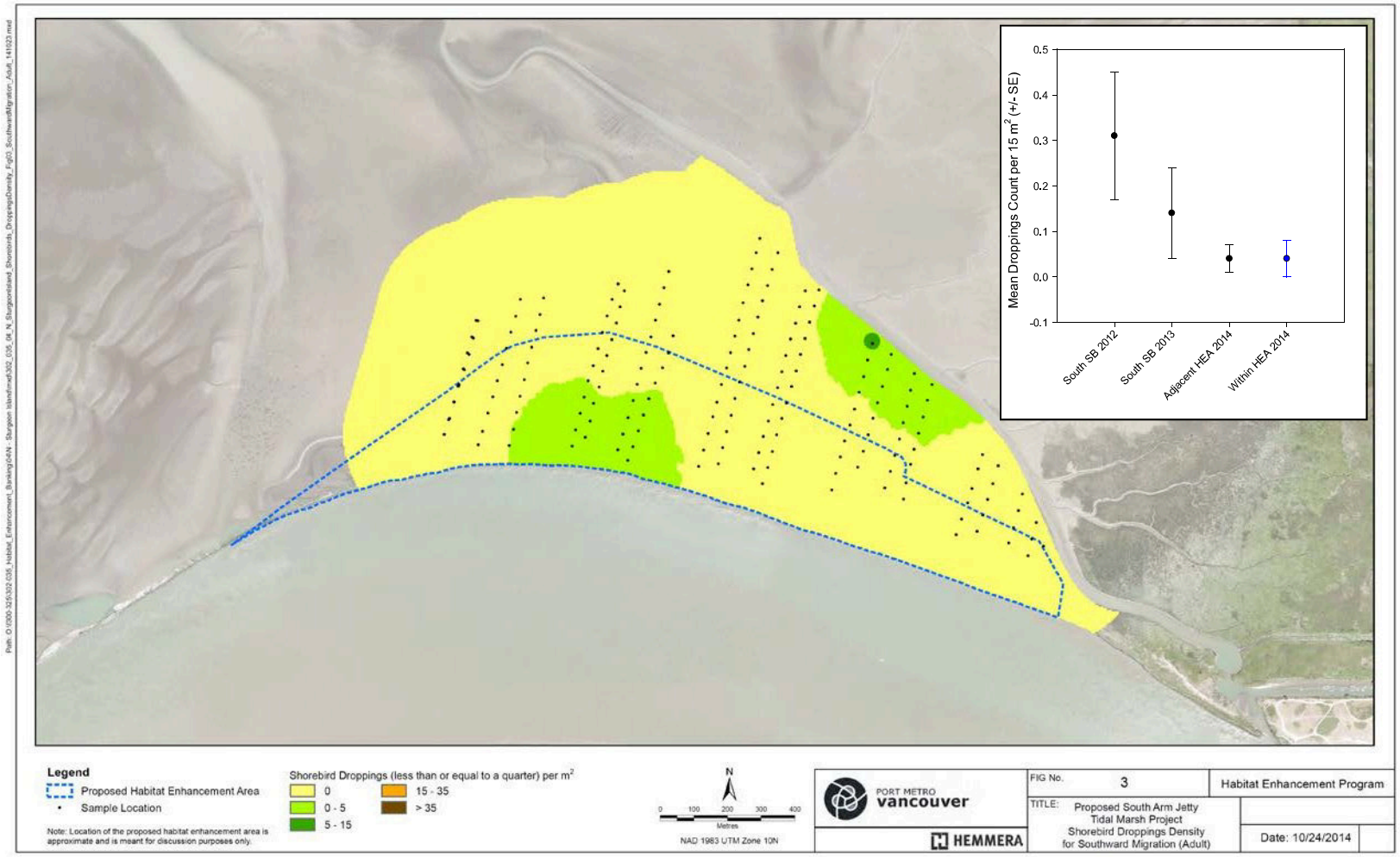


Figure 2. Shorebird Dropping Densities Adjacent to the South Arm Jetty during the Northward Migration of Western Sandpipers and Dunlin



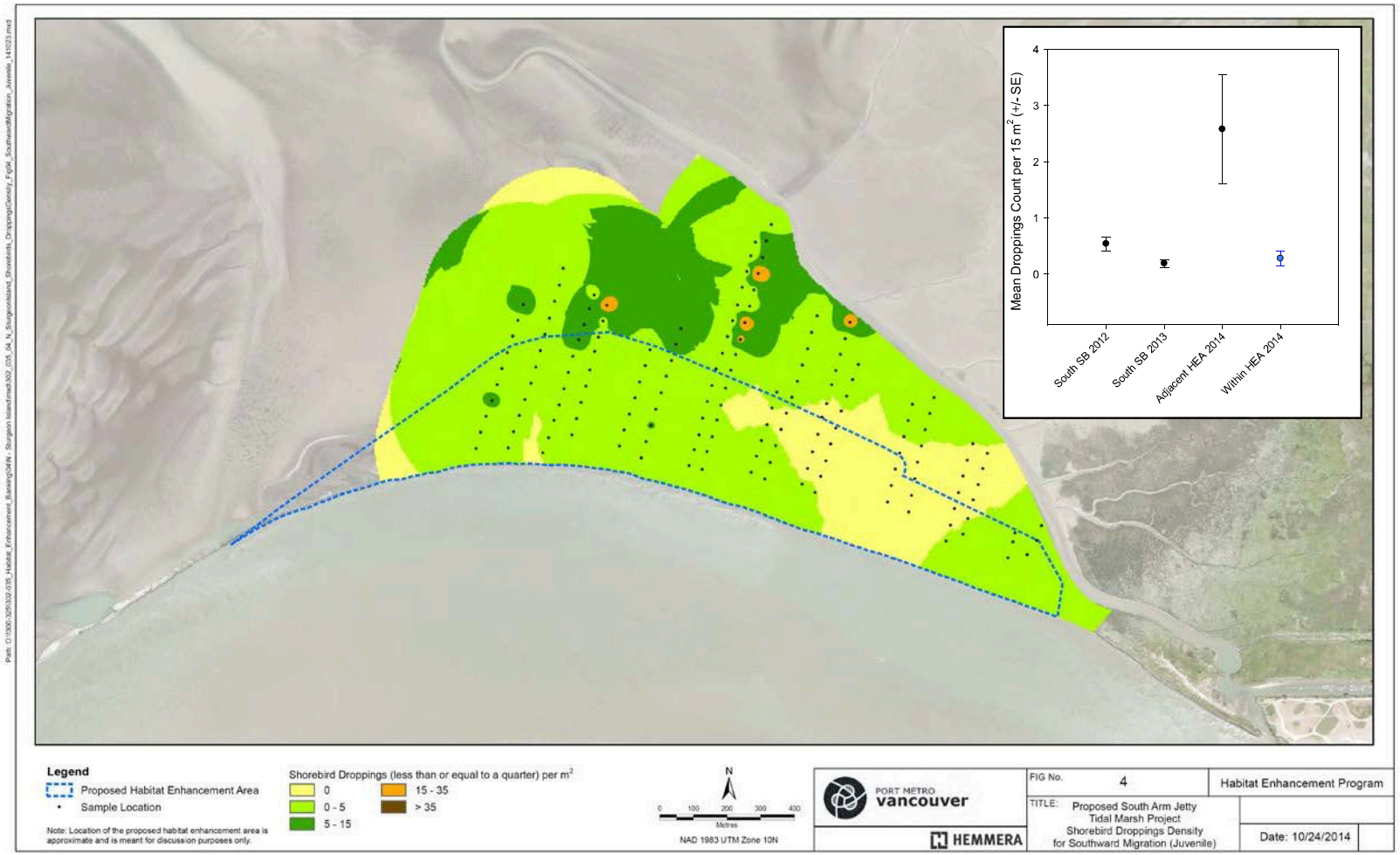
Notes: Areas south of sample locations, on the north side of the jetty were covered by sedges and other marsh vegetation and are unlikely to support foraging use by sandpipers (Photographs 4 and 5). Interpolation of dropping densities into this area is, therefore, considered inaccurate.

Figure 3. Shorebird Dropping Densities Adjacent to the South Arm Jetty during the Southward Migration of Adult Western Sandpipers



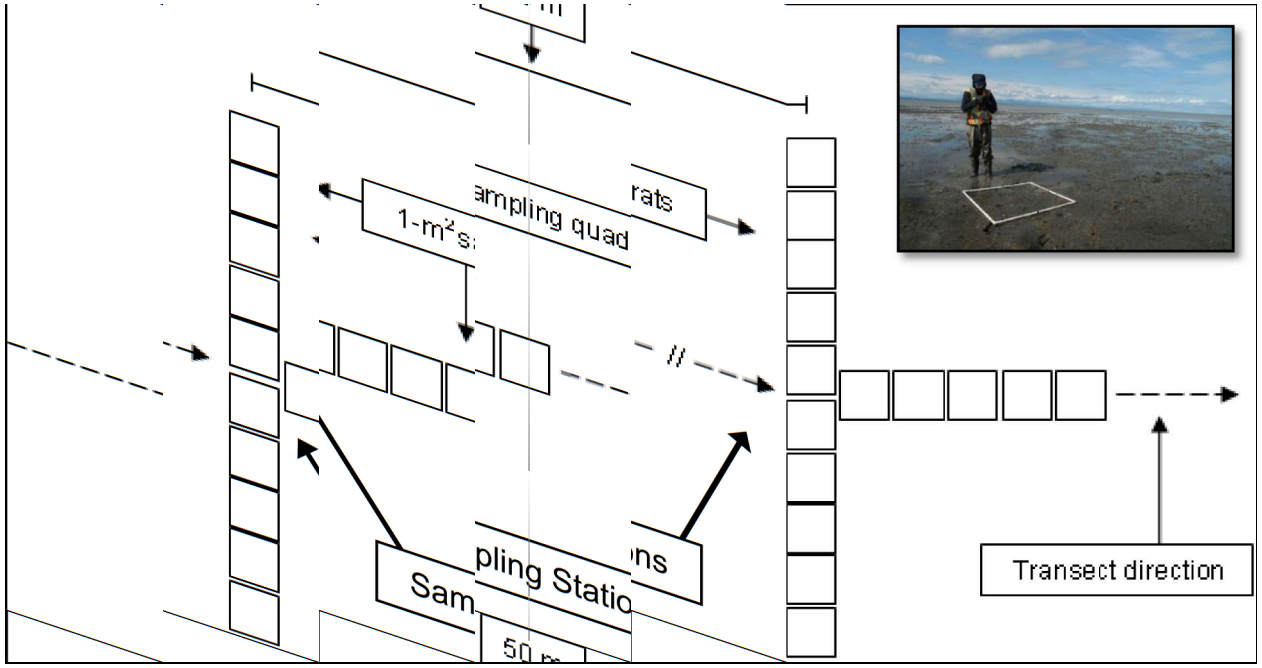
Notes: Areas south of sample locations, on the north side of the jetty were covered by sedges and other marsh grasses vegetation are unlikely to support foraging use by sandpipers (Photographs 4 and 5). Interpolation of dropping densities into this area is, therefore, considered inaccurate.

Figure 4. Shorebird Dropping Densities Adjacent to the South Arm Jetty during the Southward Migration of Juvenile Western Sandpipers



Notes: Areas south of sample locations, on the north side of the jetty were covered by sedges and other marsh vegetation and are unlikely to support foraging use by sandpipers (Photographs 4 and 5). Interpolation of dropping densities into this area is, therefore, considered inaccurate.

Figure 5. Schematic of Sampling Design at each Station to Assess Shorebird Use of the Intertidal Sand and Mudflats. Inset Photograph Shows a Biologist Inspecting a 1-m^2 Quadrat for Shorebird Droppings



Tables

Table 1. Summary Statistics of Dropping Densities within and adjacent to the Proposed Habitat Enhancement Area Relative to Dropping Densities Observed within the Southern Half of Sturgeon Bank in 2012 and 2013

Migration	Area	Sample Size	Mean Dropping Densities	Standard Deviation	Standard Error
Northward	South Sturgeon Bank 2012	681	2.43	8.53	0.33
	South Sturgeon Bank 2013	528	1.62	6.84	0.30
	Adjacent HEA 2014	27	1.26	4.20	0.81
	Within HEA 2014	35	2.29	6.66	1.13
Southward Adult	South Sturgeon Bank 2012	356	0.31	2.63	0.14
	South Sturgeon Bank 2013	130	0.14	1.19	0.10
	Adjacent HEA 2014	47	0.04	0.20	0.03
	Within HEA 2014	45	0.04	0.30	0.04
Southward Juvenile	South Sturgeon Bank 2012	456	0.54	2.63	0.12
	South Sturgeon Bank 2013	295	0.19	1.20	0.07
	Adjacent HEA 2014	36	2.58	5.84	0.97
	Within HEA 2014	40	0.28	0.85	0.13

Table 2. Estimates of Shorebird Numbers Observed Foraging within the Study Area during Droppings Surveys

Date	Shorebirds
May 2	500 (70% WESA, 30% DUNL)
May 3	1500 (Species unknown)
July 15	No Shorebirds
July 16	1570 Western Sandpipers
August 27	3000 Western Sandpipers
August 28	No shorebirds

Photographs



Photo 1. Western sandpipers foraging in the study area, adjacent to the proposed habitat enhancement area during the southward migration of juvenile western sandpipers (August 27, 2014).



Photo 2. Sand-/mudflat habitat north of the South Arm Jetty: View facing northeast from the marsh edge from near the northern boundary of the study area, as defined by the tidal channel originating from the South Arm of the Fraser River.



Photo 3. Sand-/Mudflat habitat north of the South Arm Jetty: View facing north/northwest from the marsh edge with the north and north-western boundary of the study area defined by the rising tide and the tidal channel originating from the South Arm of the Fraser River, respectively.



Photo 4. East-facing view of the South Arm Jetty and marsh from the approximate middle of the southern boundary of the proposed habitat enhancement area.



Photo 5. West-facing view of the South Arm Jetty and marsh from the approximate middle of the southern boundary of the proposed habitat enhancement area.

APPENDIX E

Avian Abundance Surveys

HEMMERA | 20 YEARS 1994–2014

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Proposed South Arm Jetty Tidal Marsh Project
Avian Abundance Surveys – Winter 2014/2015

Report Date	May 5, 2015
Rationale and Overview	As part of Port Metro Vancouver's Habitat Enhancement Program, the creation of a brackish tidal marsh is proposed at the South Arm Jetty site near Steveston, B.C. The area where the project would be located is characterized by un-vegetated intertidal habitats (predominantly sand- and mudflat). Adjacent to the proposed enhancement site are brackish tidal marshes fringing the jetty to the south and additional un-vegetated flats and shallow sub-tidal channels to the north (**Figure 1**). The project would help restore brackish tidal marsh habitat in the Sturgeon Bank area, where considerable areas of natural marsh have been lost over the past several decades. The proposed enhancement project would involve converting the existing un-vegetated intertidal habitats into more biologically productive brackish tidal marsh. This would be accomplished through construction of a containment berm, followed by the placement of fill material to the appropriate elevation for establishment of intertidal marsh vegetation. The project would result in the creation of approximately 43.6 ha of brackish tidal marsh habitat. The purpose of the avian abundance surveys is to document baseline bird use (i.e., abundance and behavior) during the winter period within and adjacent to the area proposed for marsh habitat creation.
Survey Dates & Times	Reconnaissance efforts to determine appropriate survey techniques, timing, and survey area boundaries were conducted on December 12, 2014. Subsequently, seven surveys were conducted from December 27, 2014 to March 25, 2015. One survey was conducted in December, and two surveys were conducted during each of the subsequent three months (see the weather and tidal conditions section below for exact dates). Surveys were scheduled and conducted during the lowest daytime tides. These tidal conditions were selected to assess bird use of sand-/mudflat habitat under both exposed and inundated conditions.
Weather & Tidal Conditions	All surveys were conducted during time periods characterized by wind speeds less than 30 km/hour. With the exception of the final survey, surveys were also conducted under dry conditions (i.e. no precipitation). As surveys were centered on peak daytime low tides, the first half of each survey was conducted during a falling low tide, with the latter half of each survey conducted during a slack low tide or rising low tide. The following is a detailed summary of weather conditions (general conditions and

	temperature) and tides during each of the survey dates, for the associated times: • December 27, 2014 – Clear; average temperature: 5° C; low tide: 2.5 m at 16:54 • January 12, 2015 – Cloudy; average temperature: 7° C; low tide: 2.3 m at 17:20 • January 26, 2015 – Clear; average temperature: 7° C; low tide: 1.8 m at 15:52 • February 11, 2015 – Cloudy; average temperature: 8° C; low tide: 2.1 m at 16:07 • February 24, 2015 – Clear; average temperature: 10° C; low tide: 1.6 m at 16:06 • March 13, 2015 – Cloudy; average temperature: 10° C; low tide: 1.6 m at 17:51 • March 25, 2015 – Cloudy with rain showers; average temperature: 10° C; low tide: 1.3 m at 16:22 Weather data from Government of Canada hourly climate data for Vancouver International Airport: http://climate.weather.gc.ca/climateData/hourlydata_e.html?timeframe=1&Prov=BC&StationID=51442&hlyRange=2013-06-11%7C2014-06-11&cmdB1=Go&Year=2014&Month=3&Day=31&cmdB1=Go# Tide data from Government of Canada 7 days tidal predictions for Sand Heads: http://www.waterlevels.gc.ca/eng/station?type=0&date=2014%2F03%2F31&sid=7594&tz=PDT&pres=1
Survey Areas	Port Metro Vancouver's (PMV's) Habitat Enhancement Program – South Arm Jetty Tidal Marsh, Steveston, BC. The proposed enhancement site is located on the southwest end of Sturgeon Bank, west of Steveston and Garry Point Park (**Figure 1**). The site was divided into three survey areas, east (S1), central (S2), and west (S3).
Survey Team	Toby St. Clair, Biologist (Hemmera); Andrew Venning, Biologist (Hemmera)
Survey Methods	Survey direction was alternated each survey (east to west vs. west to east) to reduce the potential for bias related to time of day or tidal cycle. Surveys were conducted from the South Arm of the Fraser River via boat on days when the tide did not expose sufficient un-vegetated intertidal habitat to provide for access on foot (i.e., low tide >2.1 m). Surveys were conducted by walking the sand- and mudflats on days with lower tides. Boat surveys were conducted from the boat deck within approximately 10 m of the jetty (**Photo 1**). Walking surveys were conducted from the sand- and mudflats with the observer walking half-way between the jetty and the tideline. A single surveyor conducted 30-minute surveys within each of three survey areas (**Figure 1).** Binoculars and a spotting scope were used to identify and count all birds detected visually in survey areas within 1,000 m of the jetty. To improve identification and count accuracy on mudflats, the observer moved through or along the edge of the survey area, during surveys. Large flocks were approached to improve count accuracy when time allowed. The following information was recorded for each bird observed during surveys: species, number, estimated distance from the jetty, habitat (marsh, exposed sand-/mudflat, inundated flats) and behavior.
Results and Discussion	***Overview*** This report provides baseline information on the number of birds observed utilizing marsh, exposed sand-/mudflats and inundated flats in and adjacent to the proposed South Arm Jetty Tidal Marsh Project area (**Tables 1, 2, 3, 4, 5 and 6**) and describes the relative abundance of species and species groups within those habitats (**Figures 2 and 3**). Surveys indicate that the most abundant types of birds in the study area during winter are gulls and ducks, followed by inconsistent numbers of shorebirds, and lower

but more consistent numbers of bald eagles (*Haliaeetus leucocephalus)* and swans (*Cygnus* spp) (**Table 1; Figures 2 and 3**). Great blue herons (*Ardea herodius*) were also occasionally present. Bird abundance and species composition within the overall study area varied to some extent temporally (**Table 1**) as well as by habitat type (**Figures 4 and 5**) and survey area (**Figures 6 and 7**).

Overall Abundances

Average abundances recorded during this study are reported here and compared to abundances reported across the Fraser River Estuary (FRE) in previous years, to provide an indication of the study area's importance to birds in the context of the local region (i.e., Roberts and Sturgeon Banks) and the estuary as a whole. The most abundant species groups in the study area were ducks and gulls with means of 710 and 689 individuals, respectively (**Table 1**). These numbers represent approximately 6% (ducks) and 67% (gulls) of total abundances recorded at Roberts and Sturgeon Banks during the 2012/2013 winter (ca. 11,500 and 1,000 individuals, respectively: Hemmera 2014a). Furthermore, these numbers represent approximately 1% (ducks) and 10% (gulls) of abundances recorded across the entire FRE (i.e., Roberts Bank, Sturgeon Bank, and Boundary Bay) during the 1989/1990 winter (averages of 81,000 and 7,000 individuals, respectively: Butler and Vermeer 1994) (**Figures 8 and 9**).

Over-wintering dunlin comprise the large majority and most important population of over-wintering shorebirds in the FRE. Abundances of dunlin in the FRE typically range between 40,000 to 60,000 individuals (Hemmera 2014); consequently, the project area typically hosts less than 1% of dunlin overwintering in the FRE. Other shorebird species were found in similarly low proportions of FRE abundances.

Mean abundances of bald eagles, great blue herons, and swans were 3.6, 2.1, 6.6 individuals (**Table 1**). These abundances represent 7%, 5%, and 15% of averages observed across Sturgeon Bank and Roberts Bank during the 2012/2013 (50.0, 39.5, and 43.0 individuals, respectively: Hemmera 2014)(**Figure 8**). Abundances of great-blue herons and swans in the study area represent 2% and 5% of average abundances observed across the FRE during the 1989/1990 winter (were 94.5 and 123.8 respectively: Butler and Vermeer 1994) (**Figure 9**). No estimates were provided for bald eagles during 1989/1990.

Thus, in the context of the estuary, the study area appears to be most important for gulls, followed by swans and is less important for other avian taxa.

Temporal Variation

Swans and bald eagles were present in fairly consistent numbers across surveys **(Table 1).** Duck abundances were also generally consistent across the winter 2014/2015 period, with the exception of green-winged teals which were far more abundant during surveys conducted in February and March than in earlier months **(Table 2)**. In contrast, gull numbers were substantially lower in the later surveys as compared to the earlier surveys. Thus, results indicate that the study area is used most by gulls in the early winter, whereas green-winged teal use the site more in the late winter.

Shorebird and heron numbers were generally low with relatively high numbers observed during the final survey.

Temporal trends help to inform interpretation of mean abundance estimates and confidence intervals. For gulls, the wide degree of uncertainty around means appears to

be the result of the temporal decline in numbers, while for shorebirds and herons it is the result of a single day of high abundances during the final survey date (**Table 1**). As a result, this examination of temporal trends informs us that for herons and shorebirds, the mean is inflated relative to typical numbers observed in the study area. Also, while gull abundances in the study area were variable across surveys, numbers are fairly predictable in any given period of the winter.

Habitat Type

Exposed Sand-/Mudflat

The cumulative abundance of bird species observed in exposed sand-/mudflat habitat is presented in **Table 3**. The most abundant species groups in these un-vegetated habitats were dabbling ducks, gulls, and shorebirds comprising 30% (2,255 individuals), 44% (3,383), and 25% (1,940) of cumulative abundances (7,618), respectively. The most abundant dabbling ducks observed in mudflat habitat were green-winged teal, American wigeon (*Anas Americana*), and northern pintail (*Anas acuta*), comprising 61% (1,270), 21% (442), and 11% (231) of ducks identified to species (cumulative abundance: 2,090). The glaucous-winged gull (*Larus glaucescens*) was the most abundant bird observed on exposed sand-/mudflat habitat, comprising 86% (3,166) of identified gull records. Mew gulls (*Larus canus*) and ring-billed gulls (*Larus delawarensis*) were the next most abundant gulls, comprising 8% and 4% of the remaining gull records, respectively. Shorebird records were generally low (<50), with the exception of one flock of 1,850 dunlin (*Calidris alpina*). Low numbers (e.g., <30 cumulative records) of great blue herons, bald eagles, and swans were also observed in exposed sand-/mudflat habitat during surveys.

Existing Marsh

The cumulative abundance of bird species observed in existing marsh habitat is presented in **Table 4**. The most abundant species group observed in existing marsh habitat was dabbling ducks which comprised 97% (368) of cumulative records from marsh habitat (378). American wigeon and green-winged teal (*Anas crecca*) comprised 87% (317) and 13% (49) of dabbling duck records, respectively. The only other birds observed in existing marsh habitat were four glaucous-winged gulls, one great-blue heron, four bald eagles, and one unidentified shorebird. Dense vegetation and uneven terrain in existing marsh habitat may have limited bird detections relative to exposed and inundated flats. Consequently, numbers presented for avian abundances in marsh habitat represent minimum potential abundances.

Inundated Flats

The cumulative abundance of each species observed on inundated flats is presented in **Table 5**. The most abundant species groups in this habitat were ducks (diving and dabbling) and gulls which comprised 62% (2,406) and 37% (1,434) of cumulative bird records (3,853) in that habitat. The majority of ducks identified to species in marine/inundated habitat were mallards (*Anas platyrynchos*) (46%: 509 of 1,101) and northern pintail (34%: 372 of 1,101); however, 54% of ducks observed could not be identified to species due to detection limitations such as distance from observers. All identified gulls recorded in marine/inundated habitat were glaucous-winged gulls; however, 16% of gulls were also unidentified. Apart from ducks and gulls, thirteen great-blue heron, three bald eagles, and ten swans were recorded in marine/inundated habitat.

Survey Area

Cumulative bird abundances indicate that gulls were most abundant in the central (S2) and west (S3) survey areas, whereas ducks and swans were most abundant in the east (S1) survey area and least abundant in the west (S3) survey area (**Figures 6 and 7**). Shorebirds had far greater cumulative abundances in the west (S3) survey area; however, the large majority of those records were from a single flock. The location and behavior of one large flock is not necessarily representative of a species' or species group's overall preferences. In contrast, gull, duck, raptor, and swan observations were made from many small flocks on multiple survey days. Thus, the observations of shorebird distributions across the survey areas are considered less representative of overall use than those of other species and species groups. Raptors showed no apparent preference for any of the habitats, likely because perching structures (e.g., pilings) were available in all survey areas.

Behavior

Some of the species observed in this study demonstrated what appeared to be distinct behaviors in each of the different habitat types (**Tables 3, 4 and 5**). For instance, dabbling ducks were more commonly observed feeding on the inundated flats than in exposed sand-/mudflat habitat where they were more often observed resting. Ducks and gulls in the marsh habitat exclusively exhibited resting behaviors (e.g., loafing/resting, standing), suggesting that this area is used more as a roosting site than for feeding. In contrast, raptors were primarily observed perching in all habitat types, and shorebirds were only observed feeding or resting in exposed sand-/mudflat habitat.

Distance from shore

Distance of birds to the jetty (**Table 6**) appears to have been influenced by both habitat preference and tidal height. Birds were generally closer to shore during periods with relatively high tides, while birds that were most often recorded in the water on inundated flats (i.e., diving ducks) were generally reported further from shore. Consequently, the distances recorded from shore cannot be used directly to separate the habitat use within the proposed enhancement site from habitat use outside of this area. For example, diving ducks generally were not observed feeding within the proposed enhancement site during these low tide surveys; however, diving ducks are likely to feed in this area at higher tides. Similarly, birds feeding on exposed sand-/mudflats were generally observed close to the jetty and within the proposed enhancement site as this was the area most often exposed. Habitat use of exposed sand-/mudflat would, however, be expected to extend further distances from the jetty during lower daytime tides when available (e.g., spring, summer, and fall).

Caveats and survey limitations

Results from this study describe habitat use of the study area during the lowest daytime high tides in the winter of 2014/2015. As described above, this survey period was selected to assess bird use of the sand-/mudflat habitat under both exposed and inundated conditions to provide the best possible indication of overall (i.e., both nocturnal and diurnal) use.

Average daytime tides during the winter are typically higher than those selected for observation during these surveys, which tended to be the lowest available tides. Diurnal bird abundances and species composition in the study area are, therefore, likely to differ somewhat from those reported here. For instance, shorebirds and dabbling ducks generally feed in shallow water or exposed conditions and the study area is therefore expected to host fewer numbers of these species under more typical daytime

	conditions. Furthermore, diving ducks are likely more abundant during more typical daytime tides. During winter, the lowest tides in the FRE occur at night. Surveys of habitat use during diurnal low tides were the most practical and cost-effective indicator of habitat use under low tide conditions; however, nocturnal habitat use is also likely to vary somewhat from what was observed during this study. For example, shorebirds typically do not aggregate in such large flocks at night as during the day; consequently, more consistent small numbers of shorebirds might be expected under nocturnal conditions. Additionally, this study describes habitat use in the Project area during the winter which will differ relative to use occurring during migratory or breeding periods in the spring, summer, and fall. For example, greater numbers of great-blue herons were observed in all habitat types (marsh, exposed intertidal and inundated intertidal) during reconnaissance surveys of the study area in the spring. While there is seasonal variation in habitat use in the Project area, the winter period supports the highest numbers of most waterfowl species in the FRE, and is, therefore, the most important period for those birds. Apart from the spring and summer migrations of shorebirds, wintering waterfowl exhibit the most concentrated avian foraging use that occurs in the FRE (BirdLife International 2015). Shorebird use of the study area during migratory periods was previously assessed and is presented under separate cover (Hemmera 2014a, b). ***Next steps*** With completion of bird surveys during the 2014/15 winter and finalization of this survey report, baseline overwintering bird use (i.e., abundance and behavior) has been established. Furthermore, in combination with previous survey work that assessed shorebird use and habitat values within the study area, establishment of a baseline of the most important components of bird use and the most important bird habitat values can also be considered complete. Although further pre-enhancement bird survey work is not recommended at this time, consideration may be given at a future date towards an assessment of bird use following the successful establishment of new tidal marsh habitats.
Literature Cited	BirdLife International, Bird Studies Canada, and Nature Canada. 2015. Important Bird Area Site Summary: Boundary Bay - Roberts Bank - Sturgeon Bank (Fraser River Estuary) - Delta, Richmond, Surrey, White Rock, British Columbia. Online Database. <http://www.ibacanada.ca/site.jsp?siteID=BC017>. Butler, R., and K. Vermeer. 1994. The abundance and distribution of estuarine birds in the Strait of Georgia, British Columbia. Occasional Paper No. 83E, Canadian Wildlife Service, Environment Canada, Ottawa, ON. Hemmera. 2014a. Roberts Bank Terminal 2 Technical Data Report Coastal Birds: Abundance and Distribution of Over-wintering Shorebirds in the Fraser River Estuary. Technical Data Report, Prepared by Hemmera Envirochem Inc. for Port Metro Vancouver, Vancouver, B.C. Hemmera. 2014b. Proposed South Arm Jetty Tidal Marsh Project: Shorebird Dropping Surveys – Northward and Southward Migrations 2014. Technical Report, Prepared by Hemmera Envirochem Inc. for Port Metro Vancouver, Vancouver, B.C.

Tables

Table 1. Mean average and daily avian abundances in the study area during winter 2014/2015 surveys

Species Group	27/12/2014	12/01/2015	26/01/2015	11/02/2015	24/02/2015	13/03/2015	25/03/2015	Mean	Standard Deviation	95% Confidence Interval
Ducks	333	883	752	990	557	1012	510	719.6	260.2	192.8
Gulls	791	1623	1321	542	380	102	62	688.7	596.8	442.1
Herons	1	0	0	0	0	1	13	2.1	4.8	3.6
Raptors	3	5	6	2	2	2	5	3.6	1.7	1.3
Shorebird	46	0	0	0	2	10	1883	277.3	708.2	524.7
Swans	2	10	10	10	8	6	0	6.6	4.1	3.1
Total	*1176*	*2521*	*2089*	*1544*	*949*	*1133*	*2473*	*1697.9*	*659.2*	*488.3*

Table 2. Daily abundances of dabbling and unknown ducks in the study area during winter 2014/2015 surveys

Species		27/12/2014	12/01/2015	26/01/2015	11/02/2015	24/02/2015	13/03/2015	25/03/2015
American wigeon	*Anas americana*	110	169	140	126	145	165	66
Gadwall	*Anas strepera*	0	0	0	0	3	0	0
Green-winged teal	*Anas crecca*	14	0	0	472	148	355	354
Mallard	*Anas platyrhynchos*	73	126	25	10	36	305	8
Northern pintail	*Anas acuta*	26	110	30	50	223	105	60
Northern shoveler	*Anas clypeata*	0	0	0	6	0	55	14
Unknown dabbling duck	-	*1174*	*2521*	*2089*	*1544*	*941*	*1133*	*2465*

Table 3. Cumulative abundance of bird **s**pecies observed on exposed sand-/mudflats in the study area during winter 2014/2015

Species Group (Total # of individuals)	Common Name	Latin Name	Survey Area			Grand Total	Principal Behaviours
			S1	S2	S3		
Dabbling Ducks (2255)	American wigeon	*Anas americana*	260	162	20	442	Loafing/resting, standing, walking
	Gadwall	*Anas strepera*	3	0	0	3	Loafing/resting
	Green-winged teal	*Anas crecca*	1067	203	0	1270	Loafing/resting, walking, standing
	Mallard	*Anas platyrhynchos*	44	29	0	73	Standing, walking
	Northern pintail	*Anas acuta*	13	218	0	231	Walking, feeding, standing
	Northern shoveler	*Anas clypeata*	66	5	0	71	Loafing/resting, walkinig
	Unknown dabbling duck	-	155	10	0	165	Standing, feeding, loafing/resting
Diving Ducks (0)	Barrow's goldeneye	*Bucephala islandica*	0	0	0	0	-
	Greater scaup	*Aythya marila*	0	0	0	0	-
	Red-breasted merganser	*Mergus serrator*	0	0	0	0	-
Gulls (3383)	California gull	*Larus californicus*	25	0	0	25	Standing
	Glaucous-winged gull	*Larus glaucescens*	66	569	1325	1960	Standing, walking, loafing/resting
	Herring gull	*Larus smithsonianus*	1	2	1	4	Standing, feeding
	Mew gull	*Larus canus*	2	117	66	185	Walking, standing
	Ring-billed gull	*Larus delawarensis*	50	48	0	98	Standing, walking
	Unknown gull	-	279	540	292	1111	Standing, walking, landing
Herons (1)	Great-blue heron	*Ardea herodius*	0	0	1	1	Standing
Raptors (18)	Bald eagle	*Haliaeetus leucocephalus*	2	7	9	18	Perched, standing, landing
Shorebirds (1940)	Black-bellied plover	*Pluvialis squatarola*	0	2	0	2	Walking
	Dunlin	*Calidris alpina*	25	0	1895	1920	Walking, feeding, standing
	Greater yellowlegs	*Tringa melanoleuca*	10	8	0	18	Standing, walking
Swans (26)	Trumpeter/Tundra swan	*Cygnus buccinator/columbianus*	24	2	0	26	Feeding, standing, walking
Grand Total			2092	1922	3609	7623	NA

Note: Principal behaviors list the three most common behaviors in order of abundance, except in cases where only one or two behaviors were observed

Table 4. Cumulative abundance of bird **s**pecies observed in existing marsh in the study area during winter 2014/2015

Species Group (Total #)	Common Name	Latin Name	Survey Area			Grand Total	Principal Behaviors
			S1	S2	S3		
Dabbling Ducks (368)	American wigeon	*Anas americana*	170	147	0	317	Standing, landing, loafing/resting
	Gadwall	*Anas strepera*	0	0	0	0	-
	Green-winged teal	*Anas crecca*	49	0	0	49	Landing, taking off, walking
	Mallard	*Anas platyrhynchos*	1	0	0	1	Standing
	Northern pintail	*Anas acuta*	1	0	0	1	Loafing, resting
	Northern shoveler	*Anas clypeata*	0	0	0	0	-
	Unknown dabbling duck	-	0	0	0	0	-
Diving Ducks (0)	Barrow's goldeneye	*Bucephala islandica*	0	0	0	0	-
	Greater scaup	*Aythya marila*	0	0	0	0	-
	Red-breasted merganser	*Mergus serrator*	0	0	0	0	-
Gulls (4)	California gull	*Larus californicus*	0	0	0	0	-
	Glaucous-winged gull	*Larus glaucescens*	2	0	2	4	Standing
	Herring gull	*Larus smithsonianus*	0	0	0	0	-
	Mew gull	*Larus canus*	0	0	0	0	-
	Ring-billed gull	*Larus delawarensis*	0	0	0	0	-
	Unknown gull	-	0	0	0	0	-
Herons (1)	Great-blue heron	*Ardea herodius*	1	0	0	1	Standing
Raptors (4)	Bald eagle	*Haliaeetus leucocephalus*	3	0	1	4	Perched on piling, landing
Shorebirds (1)	Black-bellied plover	*Pluvialis squatarola*	0	0	0	0	-
	Dunlin	*Calidris alpina*	0	0	0	0	-
	Greater yellowlegs	*Tringa melanoleuca*	0	0	0	0	-
	Unknown shorebird	-	0	1	0	1	Standing
Swans (8)	Trumpeter/Tundra swan	*Cygnus buccinator/columbianus*	8	0	0	8	Standing
Grand Total			235	148	3	386	NA

Note: Principal behaviors list the three most common behaviors in order of abundance, except in cases where only one or two behaviors were observed

Table 5. Cumulative abundance of birds observed on inundated flats in the study area during winter 2014/2015

Species Group (Total #)	Common Name	Latin Name	Survey Area			Grand Total	Principal Behaviours
			S1	S2	S3		
Dabbling Ducks (1071)	American wigeon	*Anas americana*	4	122	36	162	Swimming, loafing/resting, feeding
	Gadwall	*Anas strepera*	0	0	0	0	-
	Green-winged teal	*Anas crecca*	22	2	0	24	Swimming
	Mallard	*Anas platyrhynchos*	100	40	369	509	Swimming, loafing/resting, feeding
	Northern pintail	*Anas acuta*	40	25	307	372	Swimming, feeding
	Northern shoveler	*Anas clypeata*	4	0	0	4	Swimming
Diving Ducks (30)	Barrow's goldeneye	*Bucephala islandica*	1	0	0	1	
	Greater scaup	*Aythya marila*	0	0	17	17	Landing, swimming
	Red-breasted merganser	*Mergus serrator*	0	5	7	12	Swimming
Unknown duck		-	140	690	483	1313	Swimming, feeding, loafing/resting
Gulls (1434)	California gull	*Larus californicus*	0	0	0	0	-
	Glaucous-winged gull	*Larus glaucescens*	6	422	774	1202	Swimming, loafing/resting
	Herring gull	*Larus smithsonianus*	0	0	0	0	-
	Mew gull	*Larus canus*	0	0	0	0	-
	Ring-billed gull	*Larus delawarensis*	0	0	0	0	-
	Unknown gull	-	0	180	52	232	Swimming, loafing/resting
Herons (13)	Great-blue heron	*Ardea herodius*	1	0	12	13	Standing, hunting
Raptors (3)	Bald eagle	*Haliaeetus leucocephalus*	0	2	1	3	Perched
Shorebirds (0)	Black-bellied plover	*Pluvialis squatarola*	0	0	0	0	-
	Dunlin	*Calidris alpina*	0	0	0	0	-
	Greater yellowlegs	*Tringa melanoleuca*	0	0	0	0	-
Swans (12)	Trumpeter/Tundra swan	*Cygnus buccinator/columbianus*	2	10	0	12	Swimming, feeding
Grand Total			320	1498	2050	3876	NA

Note: Principal behaviors list the three most common behaviors in order of abundance, except in cases where only one or two behaviors were observed

Table 6. Cumulative abundance records from bird surveys at 100 meter intervals of distance to the jetty during winter 2014/2015

Species Group (Total #)	Common Name	Distance to the Jetty (m)										Total
		0-100	150-200	250-300	350-400	450-500	550-600	650-700	750-800	850-900	950-1000	
Dabbling Ducks (3529)	American wigeon	367	120	212	8	22	4	41	85	50	12	921
	Gadwall	0	0	3	0	0	0	0	0	0	0	3
	Green-winged teal	8	48	90	145	51	213	460	0	270	58	1343
	Mallard	33	20	0	137	91	6	16	170	20	90	583
	Northern pintail	71	25	0	51	75	55	49	50	120	108	604
	Northern shoveler	0	0	64	0	0	4	2	5	0	0	75
Diving Ducks (30)	Barrow's goldeneye	0	0	0	0	0	1	0	0	0	0	1
	Greater scaup	0	0	0	15	0	2	0	0	0	0	17
	Red-breasted merganser	0	0	0	7	0	0	5	0	0	0	12
Unknown duck		50	0	15	70	143	12	286	112	50	740	1478
Gulls (4821)	California gull	0	0	0	0	0	0	0	0	0	25	25
	Glaucous-winged gull	29	10	33	385	832	566	1157	30	90	34	3166
	Herring gull	2	0	0	0	1	1	0	0	0	0	4
	Mew gull	2	0	0	30	31	39	83	0	0	0	185
	Ring-billed gull	50	30	7	0	11	0	0	0	0	0	98
	Unknown gull	120	170	20	145	140	89	290	187	32	150	1343
Herons (15)	Great-blue heron	1	0	0	0	0	1	1	0	0	12	15
Raptors (25)	Bald eagle	8	2	3	7	0	3	0	0	1	1	25
Shorebirds (1941)	Black-bellied plover	0	0	0	0	0	2	0	0	0	0	2
	Dunlin	0	0	45	1850	0	0	0	0	0	25	1920
	Greater yellowlegs	0	10	0	6	0	0	0	2	0	0	18
	Unknown shorebird	1	0	0	0	0	0	0	0	0	0	1
Swans (36)	Trumpeter/Tundra swan	2	12	4	8	18	2	0	0	0	0	46
Total		744	447	496	2864	1415	1000	2390	641	633	1255	11885

Figures

Figure 1. Study area and survey areas

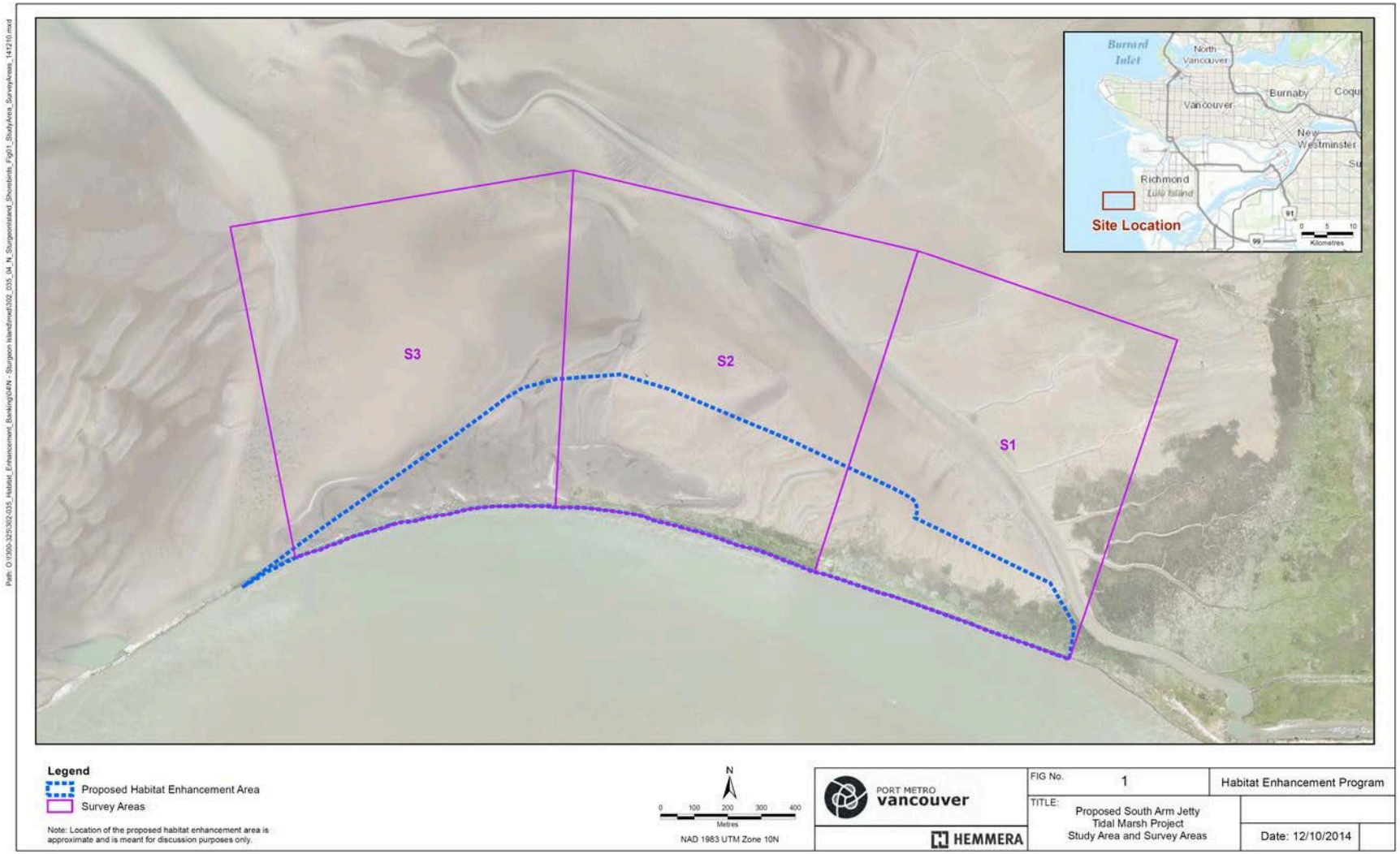


Figure 2. Mean abundance and 95% confidence intervals for ducks, gulls, and shorebirds during winter 2014/2015 surveys

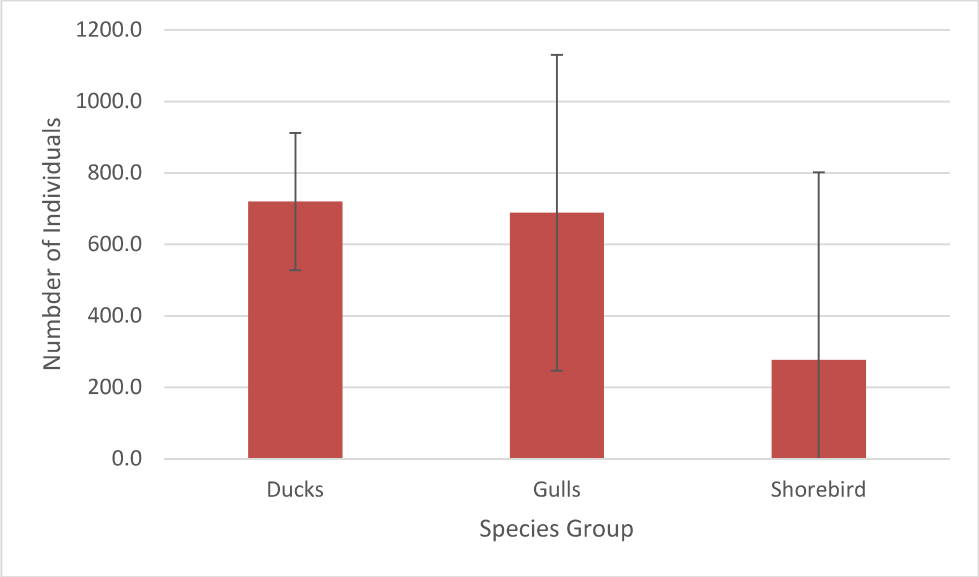


Figure 3. Mean abundance and 95% confidence intervals for herons, raptors, and swans during winter 2014/2015 surveys

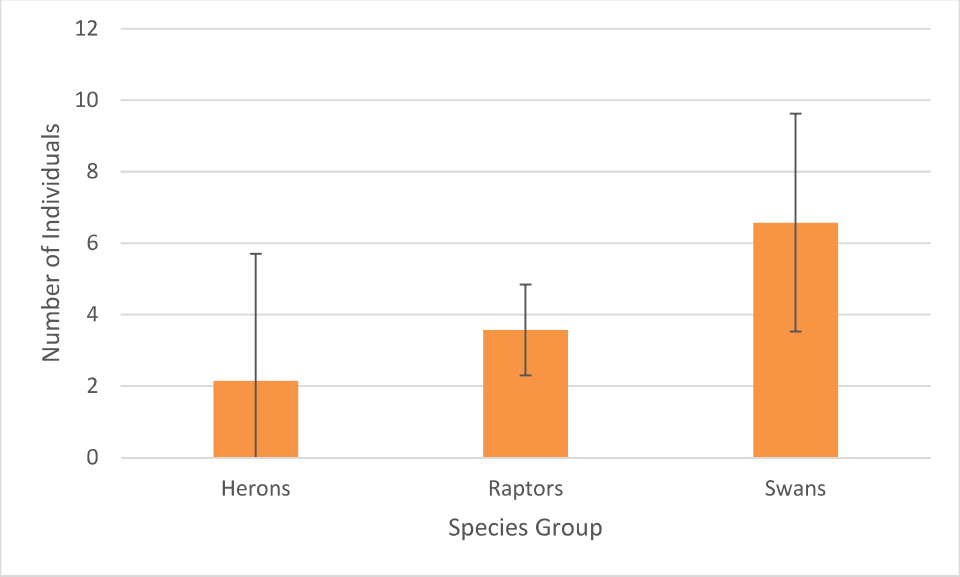
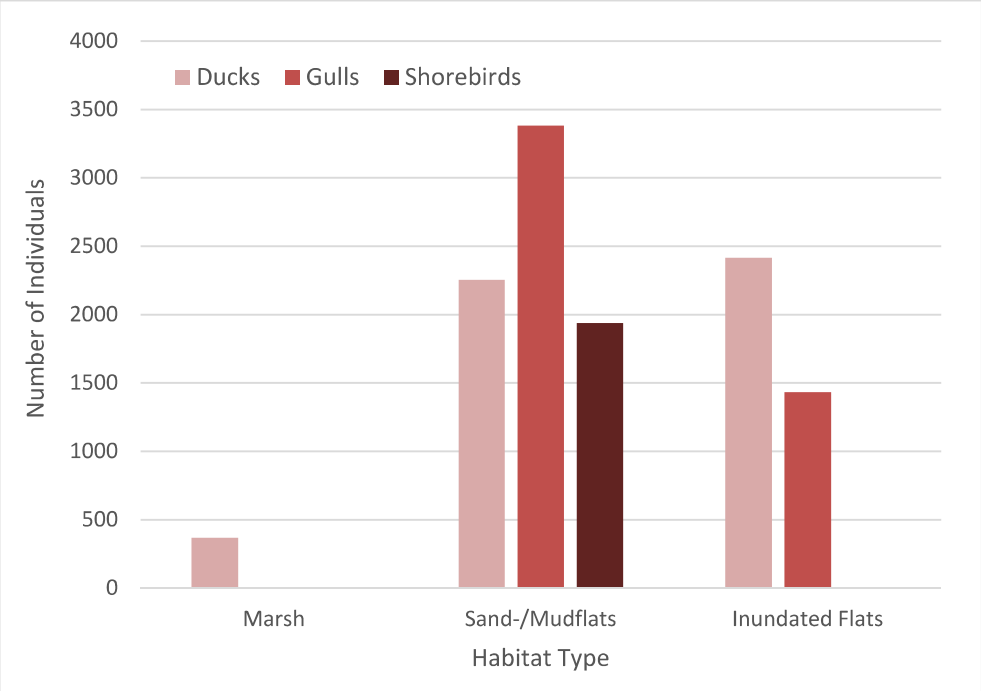
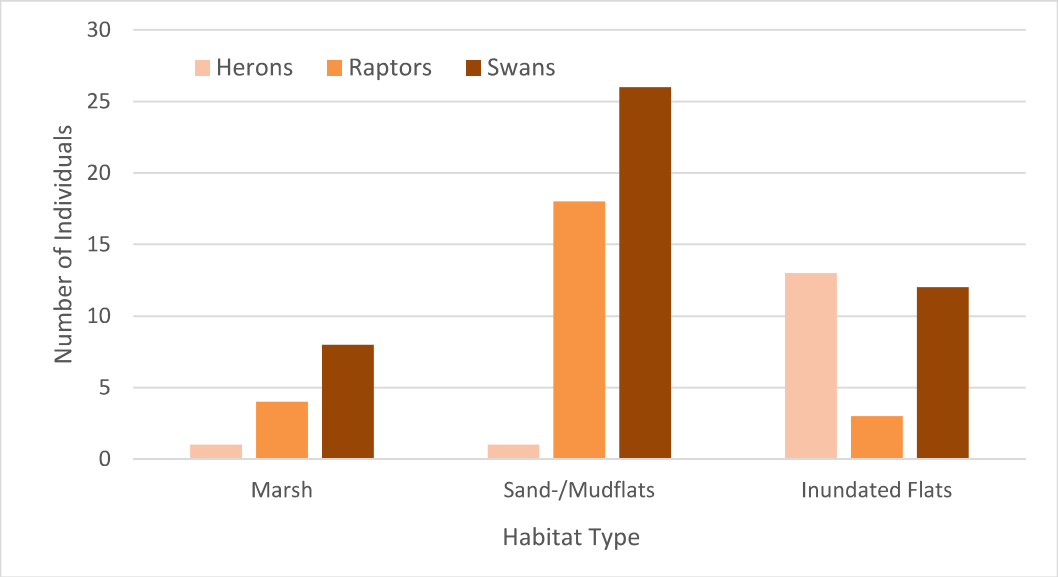


Figure 4. Cumulative abundance of ducks, gulls, and shorebirds by habitat types during winter 2014/2015 surveys



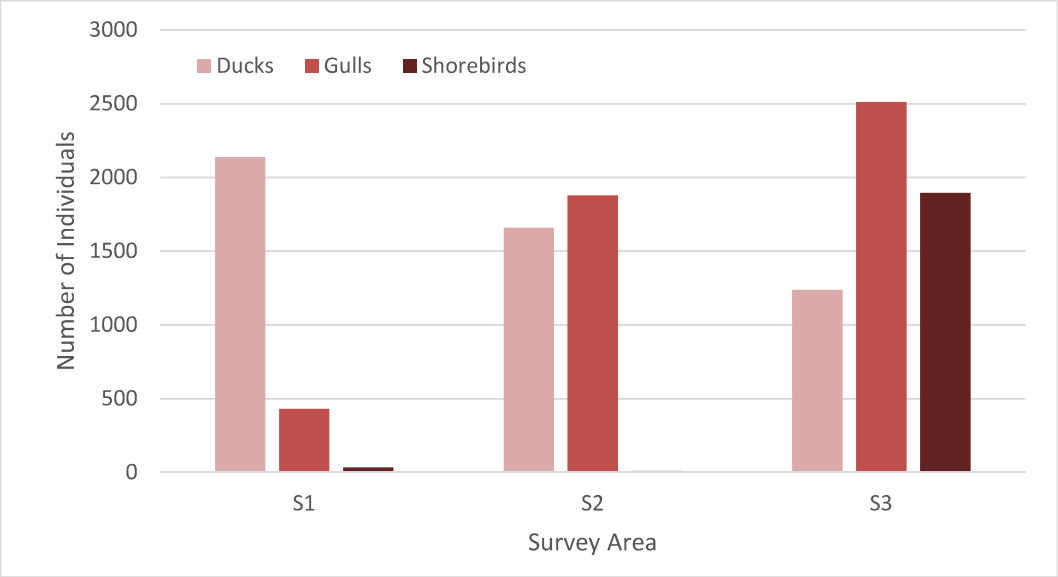
Note: Shorebird abundances in mudflat habitat are largely comprised of a single flock of 1,850 individuals

Figure 5. Cumulative abundance of herons, raptors and swans by habitat types during winter 2014/2015 surveys



Note: Raptors were observed perched above habitat types, not using them directly

Figure 6. Cumulative abundance of ducks, gulls, and shorebirds by survey area during winter 2014/2015 surveys



Note: Shorebird abundances in survey area S3 are largely comprised of a single flock of 1,850 individuals

Figure 7. Cumulative abundance of herons, raptors and swans by survey area during winter 2014/2015 surveys

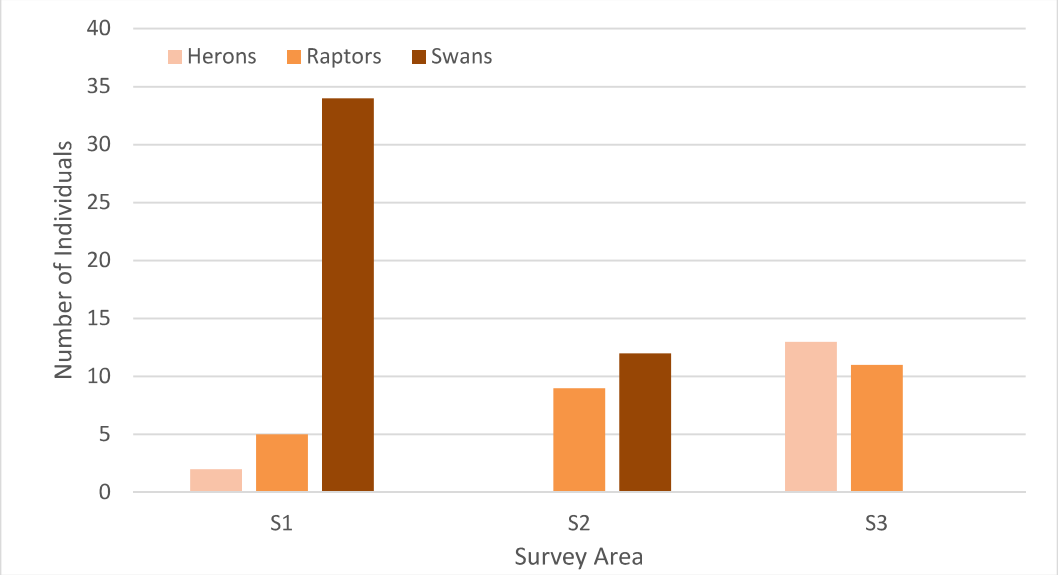
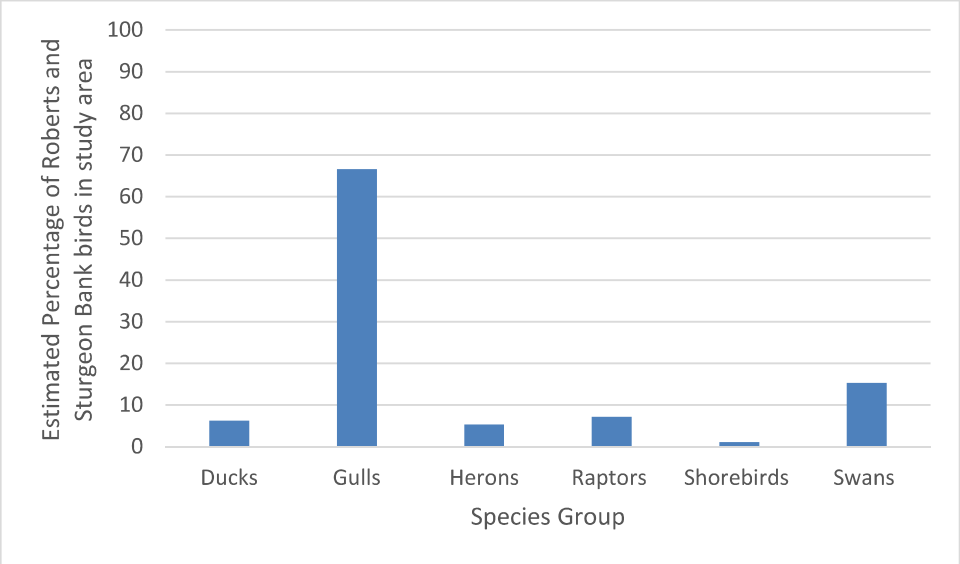
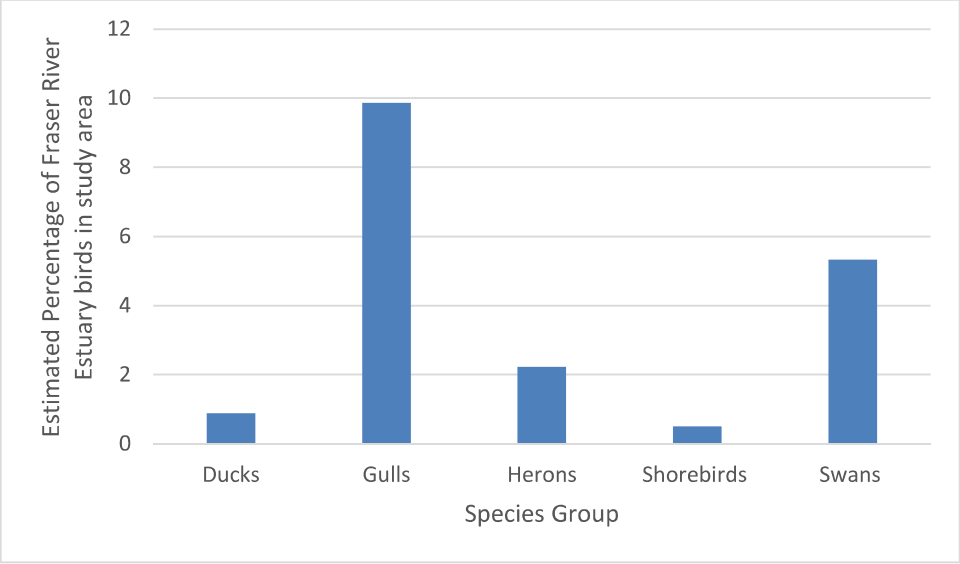


Figure 8. Estimated proportions of birds in the study area during winter 2014/2105 surveys relative to total abundances at Roberts and Sturgeon Banks



Note: Percentages determined by dividing average survey results from 2013/14 by the average of abundances recorded between December 2012 and March 2013.

Figure 9. Estimated proportions of birds in the study area during winter 2014/2105 surveys relative to total abundances in the Fraser River Estuary



Note: Percentages determined by dividing average survey results from 2013/14 by the average of monthly abundances recorded from December 1989 through March 1990.

Photographs



Photo 1. Observer surveying the study area from a boat deck from the South Arm of the Fraser River on the south side of the jetty

Appendix IR2020-1.1-A10

Geotechnical Assessment – Phase 2
Habitat Enhancement: South Arm Jetty Tidal Marsh, Richmond, BC

DRAFT REPORT

February 28, 2014

GEOTECHNICAL ASSESSMENT

Phase 2 Habitat Enhancement: South Arm Jetty Tidal Marsh, Richmond, BC

Submitted to:
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Report Number: 1314470047-002-R-Rev0

Distribution:Distribution:

1 e-Copy - Moffatt and Nichol
1 e-Copy - Golder Associates Ltd.

Golder Associates

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Figure 2: Approximate Test Hole Locations

1.0 INTRODUCTION

As requested, Golder Associates Ltd. (Golder) has carried out a geotechnical assessment for the Phase 2 proposed habitat compensation sites located at the South Arm Jetty, Richmond, BC. The assessment was requested by Moffatt and Nichol (MN) on behalf of Port of Metro Vancouver (PMV). The development of the habitat compensation sites involves site grading and fill placement as required to achieve a ground surface elevation suitable for the support of habitat.

The geotechnical assessment was carried out on the basis of a desktop geotechnical study and limited site reconnaissance. This report presents the anticipated geotechnical conditions and preliminary comments on geotechnical considerations for design and construction of the habitat compensation sites. All elevations discussed within this report are referenced to Geodetic Datum.

The assessment of the South Arm Jetty is being carried out as a part of a larger habitat compensation project which includes additional Phase 1 and Phase 2 sites at various locations. The reports for other sites have been issued under separate cover, grouped by Phase and geographic location.

The work on this report has been carried out in accordance with Golder proposal for Phase 2 sites dated March 15, 2013. The work has been completed in accordance with the terms and conditions outlined in the Reciprocal Master Service Agreement for consulting services between MN and Golder dated March 11, 2011 and associated work order dated March 20, 2013.

The scope of this report is limited to geotechnical aspects of the proposed site development, and does not include any provision for environmental services such as the investigation, testing or assessment of the potential presence or impact of soil or groundwater contamination at the site, archeological or biological considerations or other hydrogeological services including but not limited to sediment transportation, erosion and/or scouring potential of the proposed developments.

This report should be read in conjunction with the ***"Important Information and Limitations of This Report"*** that follows this text. The reader's attention is specifically drawn to this information as it is essential for the proper use and interpretation of this report.

2.0 SITE AND PROPOSED DEVELOPMENT DESCRIPTION

2.1 South Arm Jetty Tidal Marsh

The proposed Sturgeon Bank site is located at South Arm Jetty Tidal Marsh at the mouth of the South Arm of the Fraser River as shown on the Key Plan, Figure 1. The site comprises of a sandflat zone; it is unvegetated, intertidal with shallow subtidal areas comprising medium to fine sand substrates that occur along the outer delta below mean water level. The sand flats are generally exposed to waves and high energy oceanographic conditions so the sands can be quite mobile are constantly being reworked (GL Williams & Associates 2006).

Drawings are included in Appendix B of M&N's Design Report. The sketch indicates the habitat compensation will involve construction of a marsh bench at Elevation 0.0 m, requiring up to 1.0 m of fill thickness to be placed over a width up to 320 m and an area of approximately 43.6 ha. In addition, an embankment will be constructed at the northern edge of the habitat enhancement area including up to 3 m of fill placement. It is understood that the grade fill will be sourced from Fraser River maintenance dredging operations and that about 238,000 m^3 of fill volume will be required.

3.0 SITE RECONNAISSANCE

A Golder representative attended a site viewing by boat of the Sturgeon Bank, on March 11, 2013, with representatives from MN and PMV. Site photographs were taken during the viewing.

4.0 REVIEW OF AVAILABLE INFORMATION

4.1 Regional Surficial Geology

Surficial geology information published by the Geological Survey of Canada (ref: Map 1486A dated 1979) indicates that the area is underlain by the following sequence of deposits:

- **Fraser River Sediments** comprising of:
  - Overbank silty to silt clay loam normally less than 2 m thick; overlying
  - Deltaic and distributary channel fill of interbedded fine to medium sand about 15 m thick; overlying
  - Estuarine interbedded fine sand to clayey silt, between 10 m to 185 m thick; overlying
- Up to approximately 400 m thickness of competent glacial and pre-glacial soils; overlying
- Bedrock.

4.2 Aerial Photographs

A review of historical aerial photographs, dating from 1938 through to 2004, was carried out. A summary of key review findings are presented in Table 1.

Table 1: Summary of Historical Aerial Photograph Review

Year	Sturgeon Bank – Key Findings
1938	Albion Dike No. 2 has yet to be constructed. No sandbar has formed
1946	No Change
1963	Albion Dike No. 2 has been constructed. The sandbar is beginning to form against the Dike.
1969	The sandbar is similar to the present day albeit with a slightly shallower configuration.
1976	The sandbar is similar to the present day configuration.
1982	The sandbar is similar to the present day configuration; however, it appears sediment is beginning to accrete to the west of the sandbar.
1989	A second sandbar has formed against Albion Dike No. 2. The second sandbar is a mirror image of the existing sandbar and together the two sandbars form a ribbon shape.
1994	The second sand bar is not present. The sandbar is similar to the present day configuration.
2004	The sandbar is similar to the present day configuration.

4.3 Previous Geotechnical Investigations

A review of available geotechnical reports in the vicinity of the Sites was carried out as summarized below.

Golder 1991

Golder carried out a geotechnical investigation at the South Arm Jetty Site in 1991. The investigation was for a proposed river channel training structure (ref: Golder Report No. 902-1222 titled "Report to Public Works Canada on Geotechnical Investigation Proposed River Channel Training Structure" dated March 1991). A total of eight boreholes (BH) and two dynamic cone penetration tests (PT) were put down to depths of up to 30 m below the river bed at the locations shown on Figure 2.

Golder 1992

Golder carried out a subsequent geotechnical investigation at the South Arm Jetty Site later in 1991 to test fill that had been placed for the above-mentioned river training structure (ref: Golder Report No. 902-1222 titled "Geotechnical Testing River Training Structure" dated January 1992). A total of eight Becker Penetration Tests (BPT) and 2 sampled open Becker boreholes (BO) were put down.

Golder 2009-2011

Golder previously carried out a geotechnical investigation approximately 8 km southwest of the Site. The investigation included a total of four test pits, four auger holes, one seismic cone penetration test and one cone penetration test. Standpipe piezometers were installed in selected augerholes. In addition, a test fill embankment was constructed and monitored over six months at site. The test fill included the installation and monitoring of 20 settlement gauges and comprised two zones as follows:

- A lower fill embankment constructed to approximately 1.5 m to 2 m above original site grade, measuring approximately 200 m by 100 m in plan; and
- A higher (upper) fill embankment constructed to approximately 4.5 m to 5 m above original site grade, measuring 50 m by 50 m.

This test embankment is considerable distance from the Site, however, it has been included herein since it is within the same geological sequence and represents a trail response of the deposits to fill placement.

5.0 INFERRED SITE CONDITIONS

The Golder 1991 investigation was carried out in close proximity to the South Arm Jetty Site and indicated minor surficial sand deposits over an extensive sequence of soft to firm normally consolidated to lightly overconsolidated, weak and compressible silt to depths of greater than 30 m below the existing river bed.

Very Loose to Loose Sand and Silty Sand

A surficial deposit of micaceous sand to silty sand was commonly encountered within 1 to 4 m of the existing river bed and is inferred to represent transient alluvial channel deposits. *In-situ* and laboratory testing indicated the following:

- Sieve analysis indicated the material consisted predominantly of medium sand, with some fine and coarse sand, and up to 20 per cent silt sizes.
- Dynamic Cone Penetration Test (DCPT) blow counts indicate the upper 3 to 5 m were particularly loose.

Soft to Firm Silt

An extensive deposit of soft to firm silt was encountered at all borehole locations either underlying the surficial sand stratum or at river bed level. The silt was thinly laminated and contained interbeds of sand and silty sand. The deposit was considered very weak and sensitive. *In-situ* and laboratory testing indicated the following:

- Standard Penetration Tests (SPT) blow counts ranged from less than 1 to a maximum of 5 blows per 300 mm penetration.
- Undrained shear strengths ranged from 15 to 24 kPa. Remoulded shear strengths in the ranged from 7 to 11 kPa. These values are indicative of high sensitivities.
- Moisture contents of samples typically ranged from 30 to 40 percent and were generally at, or above, the Liquid Limit. Plasticity Indices ranged from 9 to 13.
- A consolidated undrained triaxial test carried out on a sample of silt obtained at a depth of 6.5 m below river bed level showed an effective friction angle of 37 degrees with almost zero effective cohesion. Coefficients of consolidation in the range of 0.002 to 0.004 cm^2/s were recorded.
- A consolidation test carried out on a sample of silt obtained at a depth of approximately 3 m below river bed level indicated it was moderately compressible with a compression index of about 0.3 and a coefficient of consolidation of approximately 0.004 cm^2/s.

Firm Silt, Some Clay

At depths ranging from 19 to 25 m below existing river bed level the silt deposit was observed to become firmer, with less sandy interlayers and is inferred to be a marine silt deposit. *In-situ* and laboratory testing indicated the following:

- Moisture contents were slightly less than in the overlying deposit and were sometimes less than the Liquid Limit. Plasticity Indices ranged from 9 to 13.
- SPT blow counts ranged from 2 to a maximum of 8 blows per 300 mm penetration.
- Undrained shear strengths were approximately 30 kPa.

- One consolidation test carried out on a sample of silt obtained at a depth of approximately 19.5 m below river bed level indicated it was moderately compressible with a compression index of about 0.3 and a coefficient of consolidation of approximately 0.004 cm^2/s.

6.0 GEOTECHNICAL CONSIDERATIONS

The following briefly summarizes significant geotechnical design and construction considerations for the proposed habitat compensation embankments common to both sites:

- The subgrade soils comprise an extensive sequence of deltaic and estuarine deposits that are inferred to extend to depths in the order of 100 m below ground surface. These soils include weak and moderately compressible, near-surface silt to clayey silt deposits, extensive loose to compact sand deposits and an interlayered sequence of silt, sand and clayey silt soils.
- Development at the South Arm Jetty will require the placement of permanent grade fills of thickness up to 1.0 m over a wide area and up to 3 m over the proposed embankment area.
- The placement of these fills will cause consolidation of the underlying fine-grained subgrade soils.
- Sequencing should consider specifying limitations on the thickness of fill placed in any single lift; each lift placement should be separated from the next by a waiting period to allow strength gain and dissipation of pore water pressures in the underlying deposits.
- There may be difficulties in controlling and monitoring the nature of the fill placement due constraints associated with dredging and submerged fill placement.
- The low-plastic silt and extensive loose sand deposits are susceptible to soil liquefaction during strong seismic (earthquake) shaking, which will result in loss of soil strength.

6.1 Settlement of Compressible Deposits

As described in Section 4.3, a test fill embankment was constructed at a project 8 km from this Site. Settlement measured at gauges installed within a fill embankment indicated the following order of magnitude of settlement:

- 1.5- to 2-m-fill thickness: approximately 50 to 150 mm over the first 6 month period with an additional 25 mm over the following 18 month period.
- 4.5- to 5-m-fill thickness: approximately 60 to 250 mm over the same 6 month period with an additional 25 mm over the following 18 month period.

One-dimensional settlement calculations were carried out for the South Arm Jetty using the available information from the 1991 and 1989 Golder reports, respectively. The limitation of these calculations is that the thickness of the compressible deposits needed to be assumed, as it was not determined in any of the investigation holes. On the basis of regional geological information, the full depth of compressible deposits was assumed to extend to a depth of some 100 m below river bed level. These calculations indicate settlement in the order of 350 mm could be expected in the compressible deposits in response to 4 m of fill placement.

Based on the performance of the test fill embankment (with the assumption that similar behavior may be expected at the South Arm Jetty) and in conjunction with settlement calculations based on soil properties from the 1991 and 1989 investigations, settlement at the South Arm Jetty Site could be expected as follow:

- Areas with up to 1 m of fill placement: in the order of 50 mm could be expected to occur during the construction period with secondary consolidation of about 25 mm to 100 mm over the design life of the habitat embankment (assumed at 25 years); and
- Areas with up to 3 m of fill placement: in the order of 100 to 300 mm could be expected to occur during the construction period. Secondary consolidation of about 25 mm to 100 mm over the design life of the habitat embankment (assumed at 25 years) could be expected. However, based on the review of the aerial photographs, the area appears to be a dynamic environment. It is possible that at some time in history the land reclamation area may have been loaded with sand that has subsequently been scoured away. This may have imparted a preloading effect. If this is in fact the case, the settlements observed at the Site in response to site development, may be much smaller than those predicted above.

It should be noted that GL Williams & Associates have indicated that the entire delta area is subsiding in response to the ongoing inputs of sand as well as the process of dewatering and degassing of sediments and is likely most pronounced in the sandflats where the most recently deposited sediments occur.

6.2 Settlement of Dredged Sand Fill

In addition to settlement of the native compressible deposits described above, the dredged fill will also settle under its own self weight. This will occur concurrent with the construction process and therefore will not have an impact on design details, but will be an important consideration for volume calculations. The amount of settlement that could be expected within the dredged sand fill is a function of placement methods, as well as the type of material used. Assuming a relatively clean Fraser River Sand (say less than 15% fraction passing the 75 μm sieve) settlement in the order of 5 to 10 percent of the fill height could be expected.

6.3 Staged Fill Placement

The general purpose of staged fill placement is to allow sequential strength gain of the underlying compressible soils by administering a waiting period between lifts to allow dissipation of excess pore pressures induced by the fill, and to avoid overstressing the underlying fine-grained soils. The consequence of placement of fill in an uncontrolled manner (without staging) may result in failure of the underlying soils resulting in lateral movements at and beyond the toe of the fill affecting construction.

Construction using staged loading should be implemented. It is recommended to plan for staging of placement of fill in lifts no thicker than about 0.5 m.

6.4 Stability Assessment

Slope stability analyses were conducted for the embankment along the northern boundary to the Site using limit equilibrium methods with the commercially available computer software program SLOPE/W of the GeoStudio 2007 (Version 7.17) package by GEO-SLOPE International Ltd. Stability analyses were carried out under static loading conditions and did not consider seismic (earthquake) loading effects. The slope stability analyses were carried out using Modified Bishop's Method. The calculated FOS against failure of the proposed embankment was calculated to be greater than 1.5.

6.5 Suitability of Dredge Materials as Reclamation Fill

Generally, dredged and placed sand with less than 10% to 15% of fines is considered suitable as engineering fill. Sand meeting this criterion is a better reclamation material for the following reasons:

- It's easier to handle.
- Drainage is good and consolidation occurs quickly.
- The reclaimed land has a higher bearing capacity.
- The long-term settlements occurring within the reclaimed soils are small.

Dredged and placed sand with fines content greater than 15% could still be usable, but longer consolidation/settling times could be expected. It is anticipated that in-situ silty sands and sandy silts will lose some amount of fines during the dredging and reclamation processes followed for site development by the dredging contractor.

The amount of fines existing within the seabed deposits will be altered during the dredging and reclamation processes as the soil particles segregate during transportation and deposition into the reclamation cells. Determining the actual amount of fines that would remain in place within the reclamation area following dredging, pumping and placement of the dredgeate depends on how the reclamation work is staged and carried out and contractor's methodology, all of which are unknown at the time of preparation of this report.

6.6 Seismic Response

The soils at South Arm Jetty are expected to be potentially liquefiable under moderate to strong levels of seismic shaking. Liquefaction-induced ground movements (lateral spreading and settlement) are expected to occur during and following the cessation of shaking. Soils exhibiting clay-like behaviour are not expected to liquefy, however, they could experience cyclic softening under moderate to strong levels of shaking.

7.0 CLOSURE

We trust that the information presented in this report is sufficient for your immediate requirements. Should you have any questions or require further information, please feel free to contact us.

GOLDER ASSOCIATES LTD.

ORIGINAL SIGNED

Kieran McNally, EIT
Geotechnical Engineer

ORIGINAL SIGNED

Jo-Anne I. Perrett, P.Eng.
Associate, Senior Geotechnical Engineer

KM/JIP/sn

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8.0 REFERENCES

Fraser River Estuary Management Program Roberts and Sturgeon Bank Reach Overview, Draft Final Report GL Williams & Associates/Northwest Hydraulics Consultants September 2009

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Port Metro Vancouver Website

IMPORTANT INFORMATION AND LIMITATIONS OF THIS REPORT

Standard of Care: Golder Associates Ltd. (Golder) has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practising under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this report. No other warranty, expressed or implied is made.

Basis and Use of the Report: This report has been prepared for the specific site, design objective, development and purpose described to Golder by the Client. The factual data, interpretations and recommendations pertain to a specific project as described in this report and are not applicable to any other project or site location. Any change of site conditions, purpose, development plans or if the project is not initiated within eighteen months of the date of the report may alter the validity of the report. Golder cannot be responsible for use of this report, or portions thereof, unless Golder is requested to review and, if necessary, revise the report.

The information, recommendations and opinions expressed in this report are for the sole benefit of the Client. No other party may use or rely on this report or any portion thereof without Golder's express written consent. If the report was prepared to be included for a specific permit application process, then upon the reasonable request of the client, Golder may authorize in writing the use of this report by the regulatory agency as an Approved User for the specific and identified purpose of the applicable permit review process. Any other use of this report by others is prohibited and is without responsibility to Golder. The report, all plans, data, drawings and other documents as well as all electronic media prepared by Golder are considered its professional work product and shall remain the copyright property of Golder, who authorizes only the Client and Approved Users to make copies of the report, but only in such quantities as are reasonably necessary for the use of the report by those parties. The Client and Approved Users may not give, lend, sell, or otherwise make available the report or any portion thereof to any other party without the express written permission of Golder. The Client acknowledges that electronic media is susceptible to unauthorized modification, deterioration and incompatibility and therefore the Client cannot rely upon the electronic media versions of Golder's report or other work products.

The report is of a summary nature and is not intended to stand alone without reference to the instructions given to Golder by the Client, communications between Golder and the Client, and to any other reports prepared by Golder for the Client relative to the specific site described in the report. In order to properly understand the suggestions, recommendations and opinions expressed in this report, reference must be made to the whole of the report. Golder cannot be responsible for use of portions of the report without reference to the entire report.

Unless otherwise stated, the suggestions, recommendations and opinions given in this report are intended only for the guidance of the Client in the design of the specific project. The extent and detail of investigations, including the number of test holes, necessary to determine all of the relevant conditions which may affect construction costs would normally be greater than has been carried out for design purposes. Contractors bidding on, or undertaking the work, should rely on their own investigations, as well as their own interpretations of the factual data presented in the report, as to how subsurface conditions may affect their work, including but not limited to proposed construction techniques, schedule, safety and equipment capabilities.

Soil, Rock and Groundwater Conditions: Classification and identification of soils, rocks, and geologic units have been based on commonly accepted methods employed in the practice of geotechnical engineering and related disciplines. Classification and identification of the type and condition of these materials or units involves judgment, and boundaries between different soil, rock or geologic types or units may be transitional rather than abrupt. Accordingly, Golder does not warrant or guarantee the exactness of the descriptions.

Special risks occur whenever engineering or related disciplines are applied to identify subsurface conditions and even a comprehensive investigation, sampling and testing program may fail to detect all or certain subsurface conditions. The environmental, geologic, geotechnical, geochemical and hydrogeologic conditions that Golder interprets to exist between and beyond sampling points may differ from those that actually exist. In addition to soil variability, fill of variable physical and chemical composition can be present over portions of the site or on adjacent properties. **The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report.** The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.

Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities (traffic, excavation, groundwater level lowering, pile driving, blasting, *etc.*) on the site or on adjacent sites. Excavation may expose the soils to changes due to wetting, drying or frost. Unless otherwise indicated the soil must be protected from these changes during construction.

Sample Disposal: Golder will dispose of all uncontaminated soil and/or rock samples 90 days following issue of this report or, upon written request of the Client, will store uncontaminated samples and materials at the Client's expense. In the event that actual contaminated soils, fills or groundwater are encountered or are inferred to be present, all contaminated samples shall remain the property and responsibility of the Client for proper disposal.

Follow-Up and Construction Services: All details of the design were not known at the time of submission of Golder's report. Golder should be retained to review the final design, project plans and documents prior to construction, to confirm that they are consistent with the intent of Golder's report.

During construction, Golder should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not materially differ from those interpreted conditions considered in the preparation of Golder's report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in Golder's report. Adequate field review, observation and testing during construction are necessary for Golder to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, Golder's responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

Changed Conditions and Drainage: Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that Golder be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that Golder be employed to visit the site with sufficient frequency to detect if conditions have changed significantly.

Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. Golder takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the system.



LEGEND

- PREVIOUS BOREHOLE LOCATION
- PROPOSED SITE (APPROXIMATE LOCATION)
- MAJOR ROAD
- LOCAL ROAD
- RAILROAD

1 0 1

SCALE 1:50,000 KILOMETRES

REFERENCE

TRANSPORTATION FEATURES OBTAINED FROM THE PROVINCE OF BRITISH COLUMBIA.
IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS PUBLISHED BY MICROSOFT CORPORATION, REDMOND, WA, APRIL 2013.
INSET DATA OBTAINED FROM E.S.R.I.
DATUM: NAD83 PROJECTION: UTM ZONE 10

PROJECT

MOFFATT & NICHOL
HABITAT ENHANCEMENT
SOUTH ARM JETTY TIDAL MARSH

TITLE

KEY PLAN

Golder Associates

PROJECT	13-1447-0047		FILE No.	
DESIGN	JP	26 Feb. 2014	SCALE AS SHOWN	REV. 0
GIS	MH	26 Feb. 2014		
CHECK				
REVIEW				

FIGURE: 1

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LEGEND

- PREVIOUS TEST HOLE (APPROXIMATE LOCATION)
- PROPOSED SITE (APPROXIMATE LOCATION)
- MAJOR ROAD
- LOCAL ROAD
- RAILROAD

1 0 1

SCALE 1:50,000 KILOMETRES

REFERENCE

TRANSPORTATION FEATURES OBTAINED FROM THE PROVINCE OF BRITISH COLUMBIA.
IMAGERY OBTAINED FROM BING MAPS FOR ARCGIS PUBLISHED BY MICROSOFT CORPORATION, REDMOND, WA, APRIL 2013.
INSET DATA OBTAINED FROM E.S.R.I.
DATUM: NAD83 PROJECTION: UTM ZONE 10

PROJECT

MOFFATT & NICHOL
HABITAT ENHANCEMENT
SOUTH ARM JETTY TIDAL MARSH

TITLE

APPROXIMATE TEST HOLE LOCATIONS

Golder Associates

PROJECT	13-1447-0047		FILE No.	
DESIGN	JP	26 Feb. 2014	SCALE AS SHOWN	REV. 0
GIS	MH	26 Feb. 2014		
CHECK				
REVIEW				

FIGURE: 2

N:\Bur-Graphics\Projects\2013\1447\13-1447-0047\GIS\Mapping\MXD\General\Figure-2_Approximate_Test_Hole_Locations_r20140226.mxd

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