PIER Phase 2 Report

MCIP15330

City of Surrey

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PIER: Prioritizing Infrastructure and Ecosystem Risk from Coastal Processes in Mud Bay

There are numerous ways in which future climate change is going to influence Canadian municipalities—City of Surrey has long recognized the need to explore the multifaceted climate change impacts and to proactively reduce the vulnerability of the community. As a result, the City has been engaging in comprehensive planning for forthcoming climate change; currently one of the main areas of focus is the coastal floodplain of the City and the adjacent lands. This project, Prioritizing Infrastructure and Ecosystem Risk from Coastal Processes in Mud Bay (PIER), represents the work dedicated to identifying and assessing vulnerabilities of the shoreline infrastructure and the natural environment to future impacts of sea level rise and other climate change impacts in Mud Bay, prioritizing high risk areas, and recommending actions to reduce the identified risks.

Predicted consequences of climate change in the Surrey coastal area include rising sea and groundwater levels, coastal squeeze, increased shoreline erosion, saltwater intrusion, higher levels and duration of floods, and increased risk of dyke breaching. Current coastal dykes are highly vulnerable: previous work estimated that for present conditions, the existing Colebrook Dyke (north side of Mud Bay) has a design return period of 22 years, whereas the sheltered area along Nicomekl is protected to above the 200 year design standard. As a result of sea level rise, these values will reduce over time with overtopping occurring annually (return period of less than a year) at all locations by 2070. With the purpose of further investigating and evaluating current and future impacts of predicted climate change on these areas, and identifying short- to long-term adaptation options, the Coastal Flood Adaptation Strategy (CFAS) is being developed through a participatory, community-driven planning process.

CFAS is a higher-level plan that will evaluate coastal flood impact the entire floodplain area of Surrey and assess possible large-scale adaptation actions. More detailed analysis of the historic and current state of the natural environment in the Mud Bay study area is needed in order to both better understand the risks of climate change effects on specific existing shoreline infrastructure (in particular, sea dykes), coastal natural habitats and species, and to inform area-wide adaptation. The City has developed PIER based in part from stakeholder feedback received in CFAS.

A good understanding of ongoing and future impacts to Mud Bay is necessary to identify specific adaptation options that maximize protection of environmental, economic, and social values. While the City has good information on the land vulnerable to sea level rise, the data on offshore and nearshore conditions are currently limited. Offshore data on natural processes in Mud Bay collected through PIER will help us understand vulnerabilities of coastal grey infrastructure, identify priority areas for risk mitigation, and propose actions to address the identified risks; with the end goal of reducing the vulnerability of coastal flood control infrastructure and protecting the communities in Mud Bay and Crescent Beach that depend on their service.

Mud Bay is part of Boundary Bay within the Fraser River Delta—estuarine habitats, such as salt marshes, found there provide important ecosystem services. Flood control is an example of a crucial regulating ecosystem service of floodplains, tidal marshes and estuaries, which provide act as natural storage reservoirs and limit the damage of storm surges and tidal waves by reducing the water's speed and height. Such ecosystem functions supplement man-made flood control infrastructure and protect it from erosion and similar natural processes. Estuaries are, however, particularly vulnerable to climate change through processes such as coastal squeeze and shoreline erosion. Therefore, PIER also includes gathering data on green infrastructure and environmental vulnerabilities and prioritizing areas for protection that will help the City develop adaptation strategies that maximize protection of both grey and green infrastructure in the study area. In the final phase of PIER, a plan for future periodic monitoring will also be developed. This plan will allow for tracking of sedimentary conditions and identification accretion or erosion trends; through these, infrastructure risks will be regularly re-evaluated and addressed with adaptive management practices. PIER is a standalone project with separate deliverables designed to address data gaps identified through CFAS to-date and to improve adaptation decision making in the broader CFAS and support regulatory approvals needed for implementation.

PIER Phase 1

Phase 1 consisted of desktop literature analysis and mapping. 12 km of shorelines, riverbanks, and dykes were evaluated for the risk of erosion due to sea level rise and for potential future habitat disturbance; the obtained data was presented in a map form. A literature review of data relating to the intertidal habitats in Mud Bay was conducted. Shoreline inventory and mapping was verified with a field review. A coastal geomorphology study that explored the literature on historic and current sedimentary conditions of Mud Bay and their implications for flood adaptation strategies was conducted. Phase 1 report is available upon request.

PIER Phase 2

Phase 2 advanced the work accomplished in the previous phase, through continuing estuary monitoring, eelgrass mapping and evaluation, ecosystem vulnerability risk analysis and exploration of potential mitigation approaches, and preparations for wave monitoring.

This report summarizes the work done in Phase 2 and consists of the following elements:

- **Chapter 1**: Preliminary Report on Mud Bay Nutrient Loading Effects on Eelgrass Bed Health
- **Chapter 2**: Mud Bay Eelgrass Mapping and Monitoring Report
- **Chapter 3**: Monitoring Phase 2 Memo
- **Chapter 4**: Framework for Environmental Vulnerability
- **Chapter 5**: Ecosystem Vulnerability Workshop Summary and Notes
- **Chapter 6**: Wave and Wind Monitoring Plan
- **Chapter 7**: Wave and Wind Monitoring RFQ

Chapter 1

Preliminary Report on Mud Bay Nutrient Loading Effects on Eelgrass Bed Health

Preliminary Report On Mud Bay Nutrient Loading Effects On Eelgrass Bed Health

Prepared On:
November 4, 2018

Prepared for:
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EXECUTIVE SUMMARY

Between April 2018 and September 2019 FOSBS and UBC are carrying out eelgrass monitoring and experiments to fill known data gaps on biodiversity within eelgrass beds in Boundary Bay. In part, this project will inform the City of Surrey's Coastal Flood Adaptation Strategy by informing ecosystem risk prioritization in Mud Bay. The productivity of estuaries, such as Mud Bay, will change in response to climate change related patterns of precipitation; precipitation driven runoff may alter ocean temperature, salinity, turbidity, and inputs of terrestrially-derived nutrients washed into the ocean (Harley et al 2006, Scavia et al. 2002).

To identify impacts of nutrient loading on eelgrass beds, an indicator species for estuarine habitat, a field experiment is being conducted by UBC researchers and Friends of Semiahmoo Bay Society between April 2018 and September 2019. Nutrient treatments have been applied in eelgrass beds and are being monitored for changes to eelgrass bed structure (physical and biological community). The objectives of this experiment are to: a) Set a baseline ecosystem status of Mud Bay eelgrass beds including measures of water quality, primary producer abundance, eelgrass density, macroalgal biomass, and sediment characteristics, b) Determine whether the eelgrass ecosystems in Mud Bay and Crescent Beach are experiencing negative impacts nutrient pollution, and c) Catalyze and inform a discussion on a conservation planning/management framework for climate adaptation in Mud Bay and Boundary Bay.

Initial sampling has been completed and sample processing is still underway. Preliminary results have found Mud Bay eelgrass beds, suspected to already be subject to higher nutrient loading from the Serpentine and Nicomekl Rivers, have a lower shoot density (shoots/m^2) than Crescent Beach eelgrass beds. As well, Crescent Beach eelgrass bed shoot density decreased when nutrients were applied, whereas Mud Bay bed densities remained unaffected. Mud Bay may already be subject to nutrient loading at a scale where the field experiment concentration applied did not have an effect. Increased nutrient loading in Mud Bay and Boundary Bay as a potential result of climate change might alter eelgrass bed structure and community composition, thereby affecting the estuaries productivity. Further analysis of other sampling parameters will help inform whether a shift in eelgrass beds from nutrient loading is certain and may indicate what types of changes to expect. The experiment is on track with final results expected in 2019.

STUDY BACKGROUND

As the transition zone between freshwater and marine environments, estuaries are particularly vulnerable to climate change and sea level rise. Estuarine habitats, particularly salt marshes and eelgrass beds, provide significant ecosystem services such as nutrient cycling, water filtration, fish habitat and carbon sequestration (Beck et al. 2001; Campbell 2015; Orth et al. 2006). Unfortunately, these habitats have undergone precipitous declines worldwide (Campbell 2015 Crooks et al. 2011).

Climate change and sea level rise adaptation requires assessment and planning for both infrastructure and ecosystems components. The City of Surrey is leading a project funded by the Federation of Canadian Municipalities to prioritize infrastructure and ecosystem risk in Mud Bay. The City has partnered with Ducks Unlimited Canada (DUC), Friends of Semiahmoo Bay Society (FOSBS), and ecologists at University of British Columbia (UBC), each of which has expertise in the ecological components of Mud Bay. Between April 2018 and September 2019 FOSBS and UBC are carrying out eelgrass monitoring and experiments to fill known data gaps on biodiversity within eelgrass beds in Boundary Bay as it related to water quality and pollution. Estuarine productivity will change in response to climate change related patterns of precipitation; precipitation driven runoff may alter ocean temperature, salinity, turbidity, and inputs of terrestrially-derived nutrients washed into the ocean (Harley et al 2006, Scavia et al. 2002).

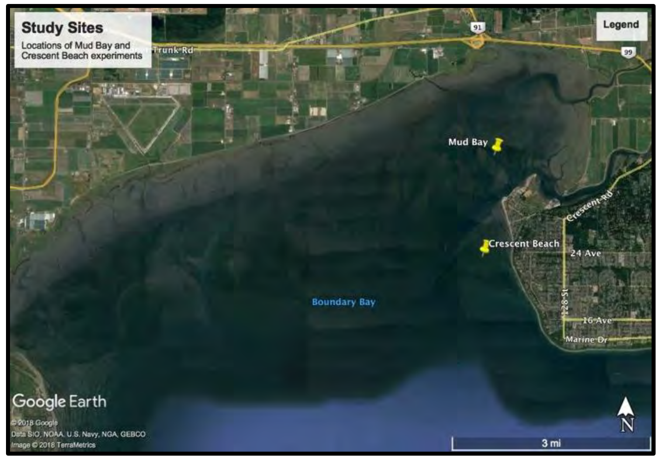

Figure 1 Map of Boundary Bay with pins at the two study locations. 1) Mud Bay (46.066840, -122.890244) and 2) Crescent Beach (46.044783, -122.894224) eelgrass beds.

The eastern portion of Mud Bay is part of Boundary Bay within the Fraser River Delta, an estuary designated as a wetland of international importance under the Ramsar Convention. The project area is also part of the Boundary Bay Wildlife Management Area (WMA), which provides an important stopover on the extensive Pacific Flyway migration route. There are no comparable sites along the Pacific Coast between California and Alaska. The value and importance of Boundary Bay is also recognized internationally as an Important Bird Area by Bird Life International, and a site of hemispheric importance by the Western Hemisphere Shorebird Reserve Network.

Considering the renowned importance of the project area and the critical role of eelgrass in estuarine ecosystems, there has been little research on eelgrass in Boundary Bay/Mud Bay. Eelgrass, Zostera, provides essential habitat to juvenile salmon, macroalgal and invertebrate resources, and provide the surface area for over 400 species of epiphytic algae, which form the basis of the food web for juvenile salmon and other fish (Phillips 1984). Zostera beds in British Columbia are disproportionately important compared to other habitats because they "salmon highways" and home to over 80% of commercially important fish and shellfish species (Durance 2012; Wright et al. 2014). In addition, eelgrass helps to stabilize coastlines and buffers coastal communities like those adjacent to Mud Bay from effects of climate change such as increased storm energy and erosion. These habitats may be degraded by a suite of human pressures, including nutrient enrichment from the Nicomekl and Serpentine rivers. However, linking habitat degradation to specific human pressures and corresponding impact to focal species is not simple. A framework of research, monitoring and direct communication with local communities is recommended to inform climate change and sea level rise adaptation planning. Here we use a bottom-up ecological approach, with the goal of linking predictors of Zostera bed health, with a focus on nutrient loading, to impacts on trophic structure and support.

OBJECTIVES

- *Set a baseline ecosystem status of Mud Bay eelgrass beds including measures of water quality, primary producer abundance, eelgrass density, macroalgal biomass, and sediment characteristics;*

- *Determine whether the eelgrass ecosystems in Mud Bay and Crescent Beach are experiencing negative impacts nutrient pollution;*

- *Catalyze and inform a discussion on a conservation planning/management framework for climate adaptation in Mud Bay and Boundary Bay*

METHODS

Increased macroalgal abundance in seagrass systems can indicate a shift to nutrient-enriched systems. As the macroalgae grows and photosynthesizes, it also respires and ultimately senescence, as the macroalgae increases and then senesces, light to seagrass and epiphytes is attenuated. This can ultimately result in a system dominated by detrital material and sediment with a microalgae film. Biota measured in this experiment will indicate whether such shifts are occurring in response to nutrient enrichment.

Sites

All surveys and experiments occurred in two eelgrass beds in Boundary Bay (Figure 1). The first is in Mud Bay at the outflow of the Nicomekl and Serpentine rivers, predicted to be subject to high disturbance and nutrient load. For comparison an eelgrass beds in Crescent Beach was also selected for monitoring and experimental methods because it is predicted to be a high flow site with lower nutrient loads and potentially less impacted eelgrass beds than Mud Bay.

Experimental design

To identify nutrient thresholds nutrient treatments (300 gram bundles of slow release Scott's Osmocote fertilizer) were applied to 8 experimental plots at both Mud Bay and Crescent Beach, for a total of 16 experimental "+N" plots. Plot were staked with 1 piece of rebar in center, down approximately 1.5 m into the sediment. Each plot will be sampled 6 times over the course of the experiment using a 50 cm equilateral triangle oriented by compass bearing. Each site has 8 additional plots as "controls", with no nutrient addition. Osmocote or other slow release fertilizer is often used in ecological research to simulate the effect of nutrient enrichment (eutrophication) from human impacts because it releases incremental amounts over time and is localized to within 1 meter before the effect dissipates, resulting in no long term or large-scale impacts (Fong and Zedler 1993). Figure 2 shows a schematic of each plot and describes the sampling schedule.

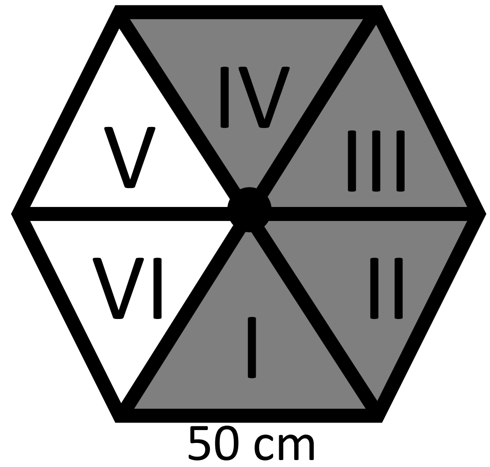

Figure 2 Plot schematic and sampling schedule. June 2018 (I), July 2018 (II), August 2018 (II), September 2018 (IV), June 2019 (V), September 2019 (VI). Shaded segments indicate that they are already completed.

Table 1 Experimental design of plots

Treatment	Site	Replicates
+Nutrients	Mud Bay	8
Ambient (Control)	Mud Bay	8
+Nutrients	Crescent Beach	8
Ambient (Control)	Crescent Beach	8

Sampling

Throughout summer 2018, sampling was completed for seagrass characteristics, invertebrates and water quality at each site (Mud Bay and Crescent Beach) for each treatment (+N, or Control – *no treatment*). This included:

1) Water: A Quatro Yellow Strings Instrument (YSI) was used to measure water for dissolved oxygen, turbidity, pH, temperature, and salinity at each site. Two additional water samples were collected per site to analyze chlorophyll-a and nutrient concentrations in the water column.
2) Key Biotic indicators: from the triangular area for each sampling period (as shown in Figure 2) we collected all seagrass, algae and invertebrates. This included all above ground biomass/shoots of seagrass, detritus, epiphytes, macroalgae, and invertebrates > 500 µm.
3) Sediment samples from each plot for chlorophyll-a concentration and organic content analysis.

4) Light and temperature was measured at 15 min intervals from May-September using Onset HOBO meters.

Mud Bay was sampled in May, June, and August 2018, with nutrient enrichment treatments placed on June 28, 2018. Crescent Beach was sampled in May, June, July and August 2018 and treatments were placed on June 25, 2018. In May 2019, sampling after 1-year will occur and nutrient treatments will be removed. Recovery will be measured by sampling at the end of the peak growing season in August 2019.

PRELIMINARY RESULTS

Currently available data (as of Sept 30, 2018) includes YSI water quality data, light and temperature readings, above ground abundance of eelgrass, detritus and macroalgal abundance and diversity are available for the May-July sampling periods.

Shoot Density

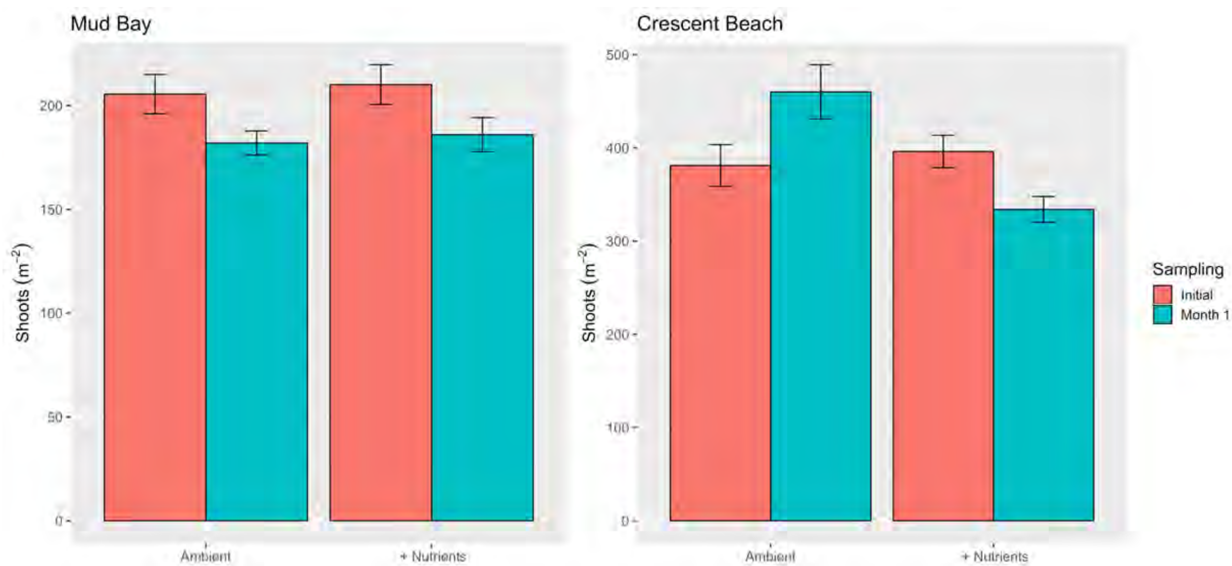

Figure 3 Shoot density measured as number of Zostera marina shoots per m2 area at Mud Bay (L) and Crescent Beach (R). Averages are shown for the initial sampling in June (red) and after 1 month of nutrient enrichment in July (blue).

Figure 5 Zostera marina shoots in Mud Bay

Zostera marina (shown in) shoot density (Shoots m^{-2}) at Crescent Beach (>350 shoots/m2) is double that of Mud Bay (~200 shoots/m2). At Mud Bay there was no difference between shoot density in nutrient enriched (+Nutrients) and control (Ambient) plots over the first month of the experiment. However, at Crescent Beach shoot density increased from June (initial) to July (1 Mon th) 2018 in control plots but decreased in plots that were nutrient enriched (Figure 4).

Macroalgae

There was an increase in macroalgal biomass (g m^{-2}) from June to July, however the effect of nutrient enrichment was not significant at either site. Further analysis is required as a sum of all macroalgal biomass may not be best indicator for the effects of nutrtient enrichment to overall macroalgal abundance (i.e. Species morphology may be an influencing factor). The average number of macroalgal species found in each plot, increased from 0-1 species to 2- 3 species on average for both sites (Figure 4).

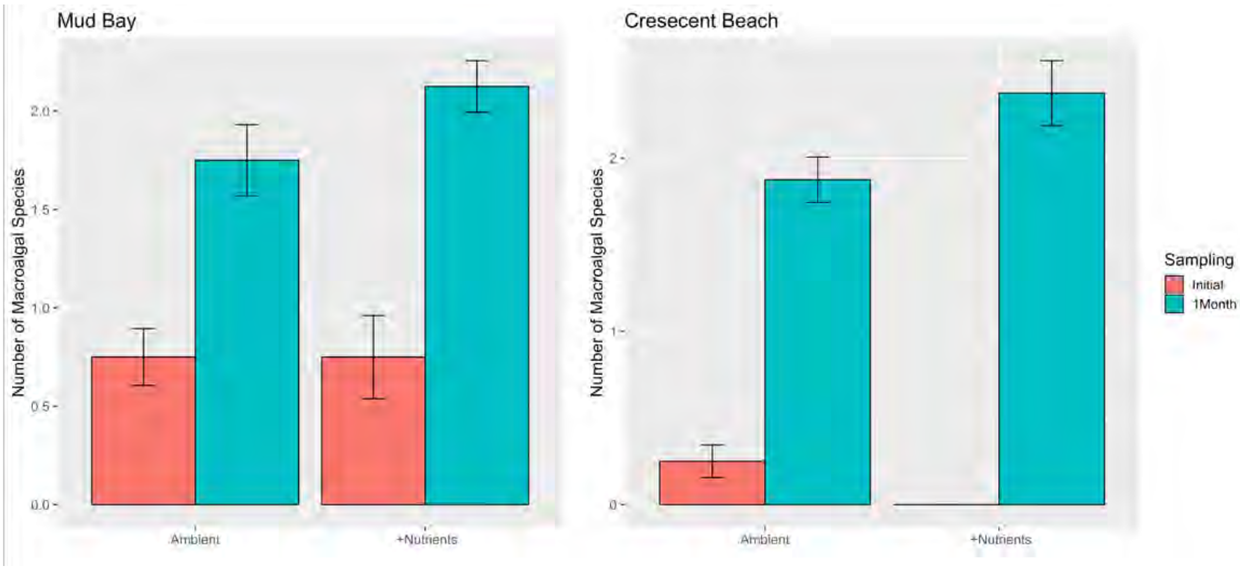

Figure 6 Macroalgal species abundance measured as number of species per plot at Mud Bay (L) and Crescent Beach (R). Averages are shown for the initial sampling in June (red) and after 1 month of nutrient enrichment in July (blue).

Detritus

As for shoot density, the amount of detritus (g m-2) in each plot was 2-3 times greater at Crescent Beach than Mud Bay. Detritus includes unattached, senesscing eelgrass and since shoot density is higher at Crescent Beach so is the amount of detritus. At Mud Bay and Crescent Beach, detritus increased from June to July (Figure 5). Nutrient enrichment at Crescent Beach had significantly higher detritus than Mud Bay sites. On average, nutrient enriched plots also had more detrital material in July at Mud Bay, but this was not a signficant effect.

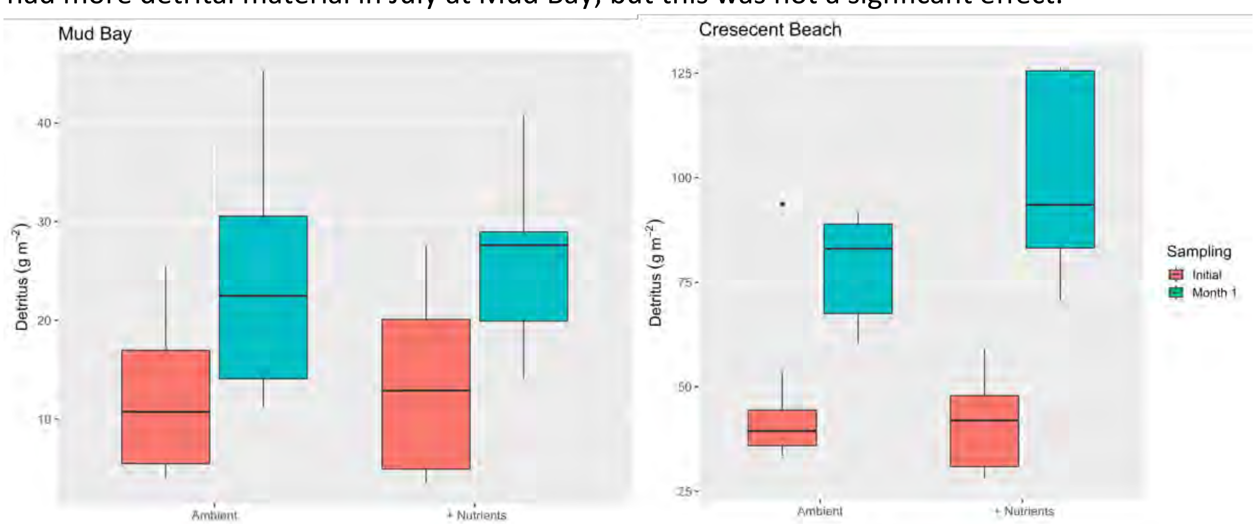

Figure 7 Detrital abundance measured as grams per m2 in each plot at Mud Bay (L) and Crescent Beach (R). Averages are shown for the initial sampling in June (red) and after 1 month of nutrient enrichment in July (blue).

Discussion

The results above are preliminary results and the following is preliminary discussion on these early findings.

- Mud Bay eelgrass beds, suspected to already be subject to higher nutrient loading from the Serpentine and Nicomekl Rivers, have a lower shoot density (shoots/m^2) than Crescent Beach eelgrass beds.
- Crescent Beach eelgrass bed shoot density decreased when nutrients were applied, whereas Mud Bay bed densities remained relatively unaffected. Mud Bay may already be subject to nutrient loading at a scale where the field experiment concentration applied did not have an effect.
- Increased nutrient loading in Mud Bay and Boundary bay as a potential result of climate change might alter eelgrass bed structure and community composition, thereby affecting the estuaries productivity

Next steps

1) August samples of above ground biomass (eelgrass, detritus, macroalgae) are being processed, completion is expected in early November 2018.

2) Invertebrate diversity and abundance is currently being processed and is expected to be completed in Jan 2019. Shifts in invertebrate diversity may occur as a function of the shift from eelgrass to macroalgal and detritus domination which will be measured as a shift from grazers dependent on seagrass epiphytes to detritivores (worms, filter feeders).

3) Water samples will be processed for nutrient and chlorophyll-a concentration and sediment samples will be processed for chlorophyll-a. Water and sediment will be processed from mid-November 2018 – January 2019. With this data we can validate whether nutrient concentration and chlorophyll-a (phytoplankton) is higher at Mud Bay than Crescent Beach as predicted because of the influence of nutrient enrichment from the Serpentine and Nicomekl rivers. Chlorophyll-a concentration in the sediments will be used to indicate if there is an ecosystem shift to domination by benthic microalgae as the system is disturbed.

4) Finally, percent nitrogen and phosphorus in the tissue collected of macroalgae and eelgrass will be measured January-April 2019 pending funding and laboratory prep assistance. Percent nitrogen and phosphorus in plant tissues is often used as a more reliable measure of nutrient loading into an estuary as nutrients are taken up by the plants from the water column. Therefore, water column measures are not a good indicator of total nitrogen or phosphorus loading.

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Joy Zedler and Fong, short term effect of osmocote in experiments

Water column and nutrients in plant tissues—Lauri Green, Martha Sutula
Phase shift/detrital process

Chapter 2

Mud Bay Eelgrass Mapping and Monitoring Report

11/18/2018

Mud Bay Eelgrass Mapping and Monitoring

Report to City of Surrey

Matthew Christensen
FRIENDS OF SEMIAHMOO BAY SOCIETY

Acknowledgements

This work could not have been undertaken without the support and leadership of local community members and subject matter experts. SeaChange Marine Conservation Society worked tirelessly to collect the boat mapping data and collate detailed, clear field data records. UBC post-doctoral fellow Dr.Sarah Joy Bittick and her team of researchers diligently collected and processed eelgrass samples. Dr. Mary O'Connor's Lab at UBC provided an opportunity to have researchers and citizen scientists collaborate. Support from the City of Surrey has enabled the eelgrass mapping work of FoSBS to take a new breath. The City's continual support of FoSBS has enabled countless opportunities for community environmental education and engagement in project activities.

Funding that made this work possible includes Environment and Climate Change Canada-Environmental Damages Fund, the Province of BC Ministry of Sports, Recreation and Culture, the Federation of Canadian Municipalities through the City of Surrey's Prioritizing Infrastructure and Ecosystem Risk in Mud Bay.

Project Partners

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Sea Change
MARINE CONSERVATION SOCIETY

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1. Introduction

The City of Surrey is leading a project funded by the Federation of Canadian Municipalities to prioritize infrastructure and ecosystem risk in Mud Bay. The City has partnered with Ducks Unlimited Canada (DUC), Friends of Semiahmoo Bay Society (FOSBS), and ecologists at University of British Columbia (UBC), each of which has expertise in the ecological components of Mud Bay. Between Summer 2016 and Summer 2018 FOSBS worked with UBC and SeaChange to carry out eelgrass mapping and monitoring on eelgrass beds in Mud Bay.

Eelgrass beds are present in the lower tidal and subtidal areas of Boundary Bay and Mud Bay (Kellerhals and Murray 1969, Bird and Cleugh 1979, Baldwin and Lovvorn 1994, City of Surrey 2008, BirdLife International 2018). These beds have been noted as the richest sites in terms of biomass of invertebrates in the Bays, providing very important feeding grounds for waterfowl (Kellerhals and Murray 1969, Baldwin and Lovvorn 1992, 1994). Eelgrass beds in the bay include both native eelgrass species, *Zostera marina*, and introduced dwarf eelgrass, *Zostera japonica* (Harrison and Dunn 2004). Introduced dwarf eelgrass has increased the total eelgrass coverage in the Bay (Harrison and Dunn 2004). This is expected to have a beneficial effect on species such as mallard, American wigeon, and brant goose, which eat the leaves, but could have a negative effect on shorebirds (e.g. sandpiper spp.) which feed on un-vegetated mudflats (Harrison and Dunn 2004).

This project builds on eelgrass mapping efforts to date. Boat-based eelgrass mapping was completed using an underwater camera and mapping software to interpolate data points, informing the total extent and relative abundance of eelgrass in Mud Bay and Boundary Bay. Foot-based sampling was conducted to quantify abundance and eelgrass bed health.

2. Methods

2.1. Field Methods

2.1.1. Foot-based Sampling

Sites

All surveys and experiments occurred in two eelgrass beds in Boundary Bay (Figure 1). The first is in Mud Bay at the outflow of the Nicomekl and Serpentine rivers (yellow box), and the second at Crescent Beach for comparison (red box).

Sampling

Plots were staked with 1 piece of rebar in center, down approximately 1.5 m into the sediment. Eight plots at each site were sampled 3 of times with a 50 cm equilateral triangle oriented by compass bearing. Mud Bay was sampled in May, June, and August 2018 and Crescent Beach was sampled in May, June, and July 2018. Shoot density, leaf length and leaf width were measured during each sampling interval for each plot.

Figure 1. Study sites and plots locations for eelgrass mapping

2.1.2. Boat-based Mapping

Surveys were done by boat equipped with a depth sounder, Trimble and/or Garmin gps. An underwater camera was towed behind the boat and connect to a live video monitor on board the boat. The boat ran transects perpendicular to shore, approximately 200 m apart. The transects covered the full extent of eelgrass detected and no beds were found beyond the reaches of the transects. Points were collected along the transects and visual observations at each point were recorded on field data sheets. Attributes recorded include:

Table 1. Boat based eelgrass data collected

Attribute	Description
Waypoint	*The number or name of the waypoint*
Depth	*Depth reading from depth sounder*
Presence	*Edge of Bed, Inside of Bed or None*
Form	*Flat or Fringing*
Distribution	*Continuous or Patchy*
Substrate Type	*Primary, Secondary and/or Tertiary*
Percent Cover	*Visual Estimate of % cover*
Tide	*Slack Tide or Running Tide*
Visibility	*Low, medium or high*
Comments	*Any notes or comments*

Form can be either fringing or flat. Fringing beds are those that occur as relatively narrow bands usually on gentle slopes and Flat beds are more expansive beds covering large areas such as tidal flats. Distribution can be either patchy or continuous. Patchy beds are those that contain isolated groups or patches of plants. Beds that are not patchy, were classified as continuous; a bed that had a few bare patches was classified as continuous.

2.2. Analysis

Two approaches to mapping were used, distance-based aggregation of like (same attributes) data points to generate polygons and a spatial analysis of points using kriging to interpolate points to a raster. Both methods required the creation of point feature classes from field data sheets be entered into a spreadsheet and then joined to the spatial data files from the GPS/GNSS device used during field data collection. Sites are classified as either Mud Bay or Crescent Beach (Figure 1).

2.2.1. Foot-based

Shoot Density

Eelgrass shoot densities useful indicators of environmental change responding to environmental change over time (Phillips et al. 1983, Olesen et al. 1994). The number of shoots in the sampling unit was multiplied by the number of sampling units to make one metre squared to determine shoot density. All plots were averaged together to get mean shoot density for each site.

Leaf Area Index

Leaf area indices are often used to estimate the productivity of eelgrass and the amount of habitat available for colonization by epifauna. The LAI is calculated according to the following formula:

LAI = mean shoot length x mean shoot width x mean density of shoot /m2

LAI is potentially more sensitive to environmental stress than is a parameter such as leaf width since it integrates both density and area (Neckles, 1994). Five measures of leaf width and five measures of leaf length were averaged to get mean leaf width and mean leaf width for each plot.

2.2.2. Boat-based

Distance-based Aggregation

Attribute fields, specifically Presence, Bed Type and Percent Cover, were each used to group points into polygons. See Table 2 for a list of eelgrass attribute fields and associated attribute combinations. All points that had the same Bed Type attribute were grouped together. For example if points 1 through 5 were observed to have a "Continuous, Flat" bed type then those points were grouped together if they were within a defined distance.

Table 2. Attribute fields used for eelgrass bed analysis

Field	Description
Transects	*All points*
Presence	*Detected (inside & edge) or not detected*
Bed Type	*1 of 4 combinations of Form and Distribution: "Continuous, Flat", "Continuous, Fringing", "Patchy, Flat", or "Patchy, Fringing"*
Percent Cover	*If present, then 1 of 3 percent cover categories : "<25", "26-75", or ">75"*

To generate polygons based on point data, points were buffered radially 30 meters and point feature class were split by attributes to separate feature classes (ie. All 26_75 % cover class buffered points as one independent attribute feature class). Each attribute feature class was spatially aggregated based on 250 m distance to create polygons for each attribute class. Barriers of alternate attribute options for the same attribute type were included in the buffer analysis to prevent the aggregation from overlapping alternate attribute point observations that were within 250 meters of two like attributes points. Manual edits were completed as a part of a visual inspection of the data aggregation. The polygons of spatially aggregated attribute types were merged to create one feature class for all polygons of each attribute type (ie. Percent Cover, Bed Type).

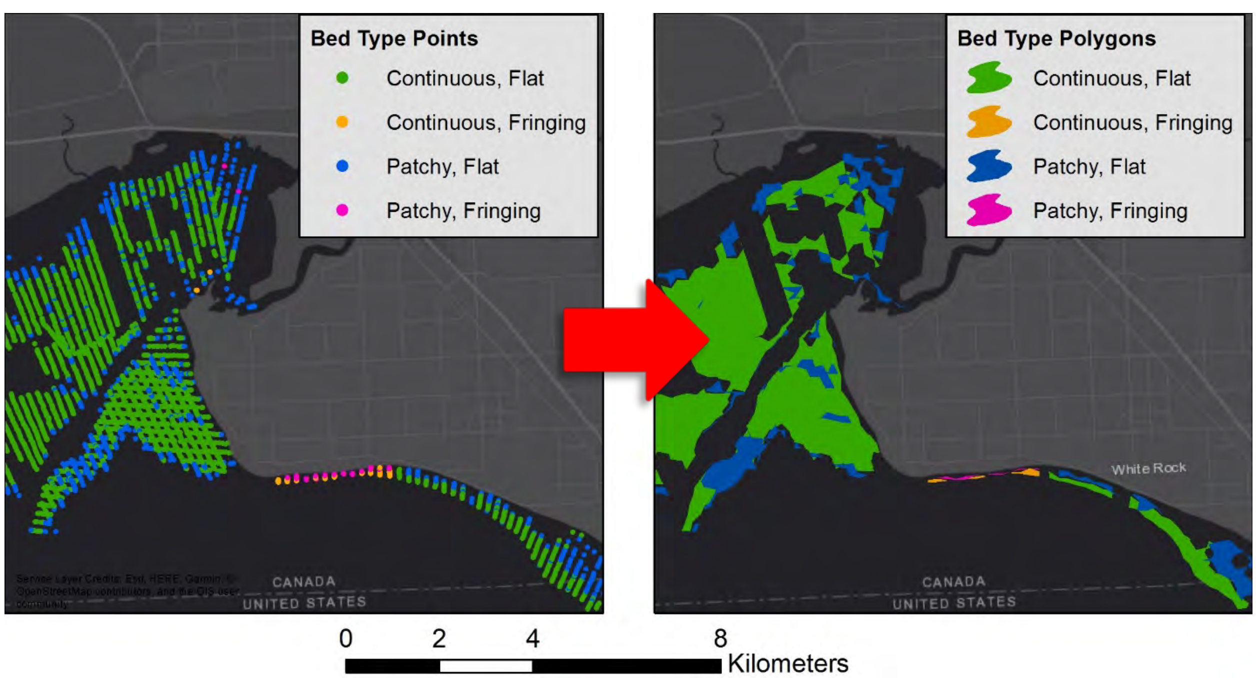

Figure 2. Example of attribute and distance-based point aggregation to polygons

Interpolation

Kriging was used to generate the best unbiased prediction of intermediate values (the spaces between points in a transect and between transects). Kriging is a geostatistical approach to interpolate points for which the interpolated values are modeled by a Gaussian process using determined prior covariances.

Table 3. Bed characteristic values assigned for interpolation

Bed Characteristics					
Form	**Value**	**Distribution**	**Value**	**Cover**	**Value**
NULL	000	NULL	000	NULL	000
None	001	None	010	0%	100
Patchy	002	Fringing	020	<25%	200
Continuous	003	Flat	030	25-75%	300
				>75%	400

All point data was merged into one feature class and each attribute type was assigned a unique number value (Table 3). Form and distribution were combined to create one unique value for each combination (Table 4). R was used to fit the data to a model and determine its covariances for kriging as shown in Figure 3 (R Core Team, 2018).

Table 4. Value for form and distributions combinations

Form, Distribution	**Form + Distribution Value**
Null, Null	0
None, None	11
Patchy, Fringing	22
Continuous, Flat	33
Patchy, Flat	32
Continuous, Fringing	23

Then using ArcGIS 10.4, in the Spatial Analyst toolbox, the kriging tool was used. Ordinary kriging was selected and spherical semivariogram model was selected based on the results shown in Figure 2. A surface raster is generated as well as a variance raster which is the predicted variance of the modelled surface raster.

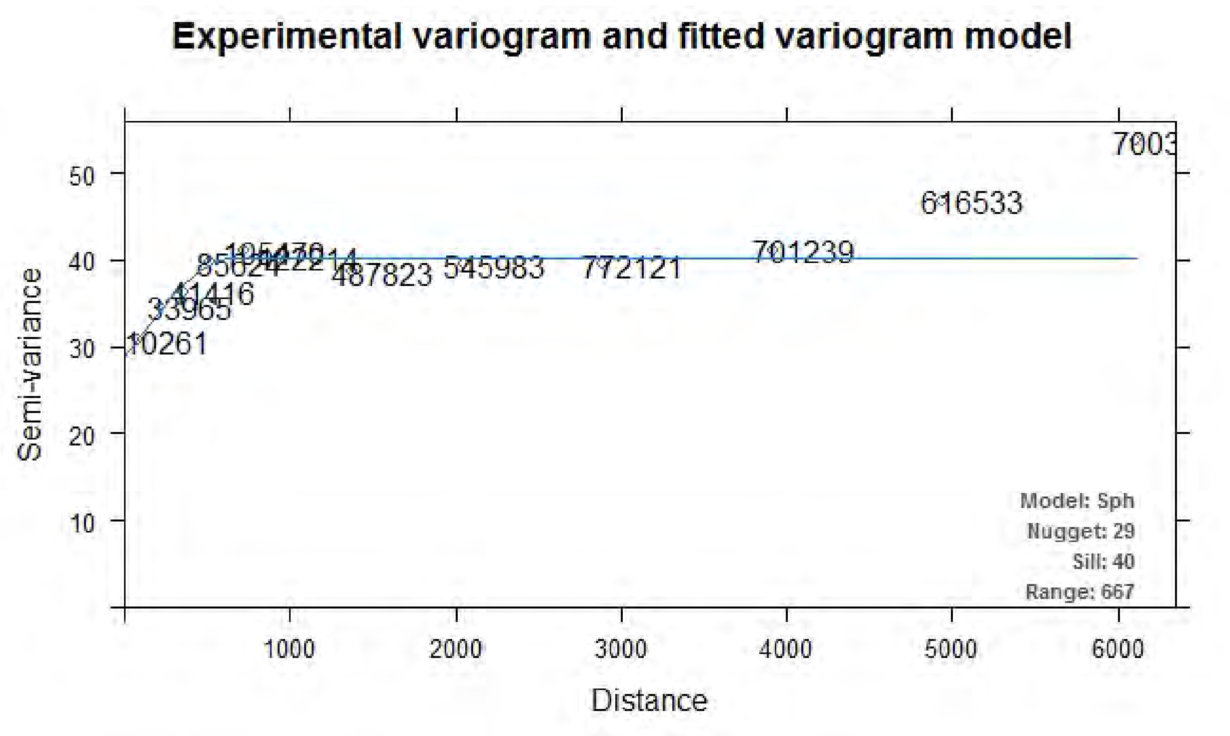

Figure 3. Semivariogram model for bed type with best fit for interpolation.

3. Results & Discussion

3.1.1. Foot-based sampling

Shoot Density

Zostera marina (Figure 4) shoot density (Shoots/ m^2) at Crescent Beach (>350 shoots/m^2) was double that of Mud Bay (~200 shoots/m^2).

Leaf Width, Shoot Length and LAI

Leaf width was higher in all three months at Mud Bay compared to Crescent Beach. Shoots were longer on average for all three months in Mud Bay compared to Crescent Beach. Mean LAI was higher in Mud Bay than at Crescent Beach for the first two sampling intervals and only lower in the third sampling interval, although there was no significant difference in the LAI between sites for any sampling period. LAI

Figure 4. *Zostera marina* shoots in Mud Bay

is supposed to reflect changes in available seagrass habitat and thus diversity and abundance of species. This should be verified Mud Bay and Crescent Beach. As well, this is a snapshot in time of eelgrass bed health in Mud Bay and Boundary Bay and does not indicate what stressors may or may not be impacting each area and whether each bed is near a stressor threshold.

Table 5. Summary statistics for foot-based sampling

		Crescent Beach			**Mud Bay**		
		May n = 9	June n = 8	July n = 8	May n= 9	June n = 8	August n = 8
Shoot Density (shoots/m^2)	Minimum	128.00	157.04	208.00	128.00	129.33	144.00
	Maximum	368.00	628.16	736.00	544.00	332.55	240.00
	Mean ± Standard Deviation	280.89 ± 85.08	381.05 ± 148.60	460.00 ± 193.47	236.44 ± 130.91	205.54 ± 62.21	182.00 ± 38.19
	95% Confidence Intervals (Lower, Upper)	(225.30, 336.48)	(278.08, 484.03)	(325.93, 594.07)	(150.92, 321.97)	(162.43, 248.65)	(155.54, 208.46)
Shoot Length (cm)	Minimum	23.96	32.20	37.00	32.84	58.08	37.92
	Maximum	39.60	47.70	55.70	60.96	102.52	156.04
	Mean ± Standard Deviation	30.76 ± 5.16	37.60 ± 4.74	45.25 ± 5.92	51.02 ± 8.85	75.49 ± 16.79	82.45 ± 39.40
	95% Confidence Intervals (Lower, Upper)	(27.38, 34.13)	(34.32, 40.88)	(41.15, 49.35)	(45.23, 56.80)	(63.86, 87.12)	(55.14, 109.75)
Leaf Width (cm)	Minimum	0.32	0.36	0.28	0.34	0.48	0.40
	Maximum	0.44	0.46	0.44	0.56	0.62	0.56
	Mean ± Standard Deviation	0.38 ± 0.05	0.41 ± 0.04	0.38 ± 0.05	0.44 ± 0.06	0.55 ± 0.05	0.47 ± 0.07
	95% Confidence Intervals (Lower, Upper)	(0.35, 0.41)	(0.38, 0.43)	(0.34, 0.41)	(0.40, 0.48)	(0.51, 0.59)	(0.42, 0.52)
LAI	Minimum	1594.778	2139.500	3076.740	1786.496	3606.656	3026.304
	Maximum	5296.896	10083.430	13429.500	14373.786	13972.313	15379.302
	Mean ± Standard Deviation	3,248.46 ± 1,147.48	5,887.29 ± 2,539.68	7,930.00 ± 3,841.64	5,641.91 ± 3,928.03	8,819.86 ± 3,711.54	7,535.59 ± 4,840.75
	95% Confidence Intervals (Lower, Upper)	(2,498.79, 3,998.14)	(4,127.41, 7,647.17)	(5,267.93, 10,592.08)	(3,075.64, 8,208.17)	(6,247.94, 11,391.78)	(4,181.18, 10,890.00)

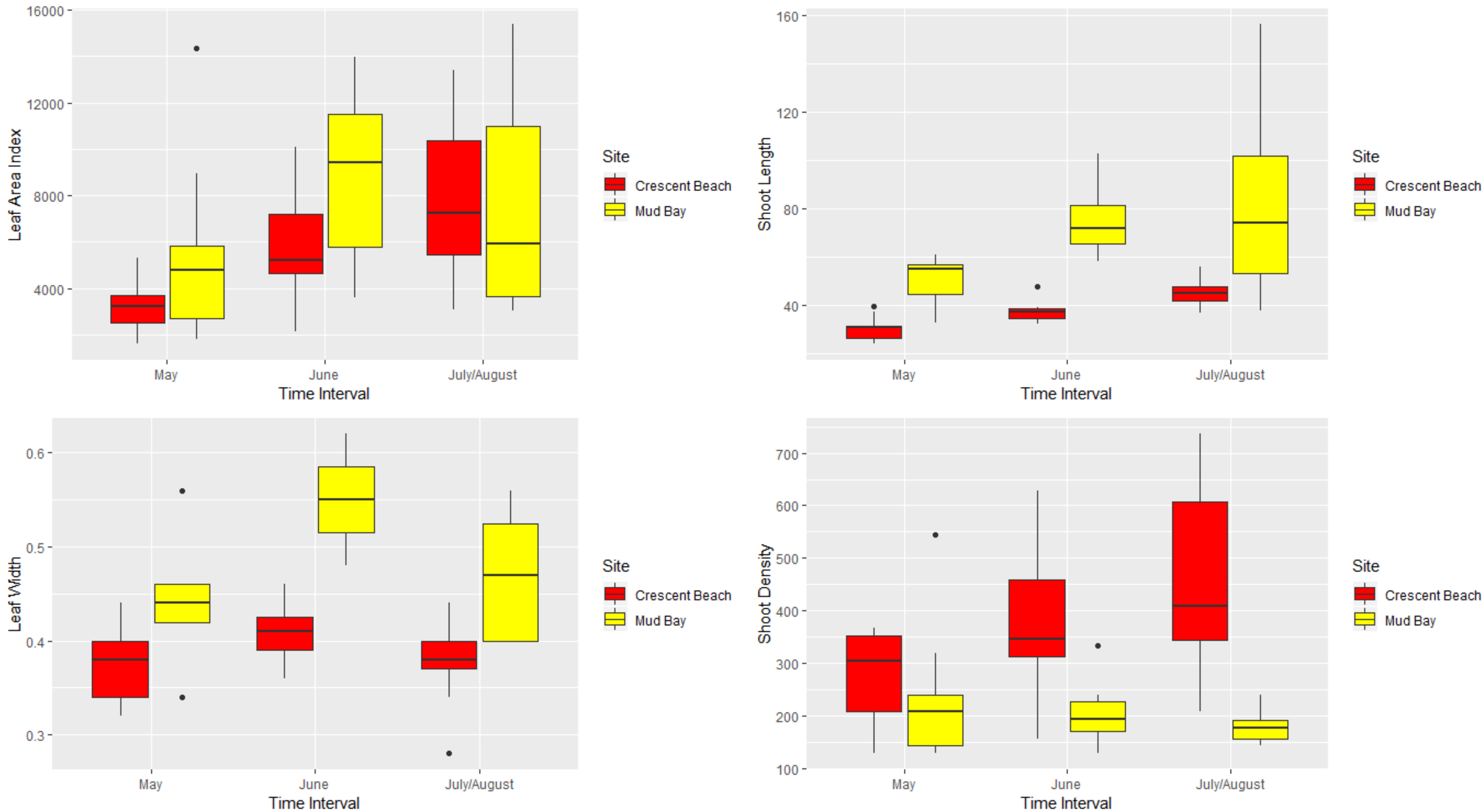

Figure 5. Foot-based sampling boxplots for Leaf Area Index (LAI), Shoot Length (cm), Leaf Width (cm) and Shoot Density at Crescent Beach and Mud Bay for 2018

3.1.2. Boat-based Mapping

Additional boat-based mapping has been undertaken by Friends of Semiahmoo Bay Society and Sea Change Marine Conservation Society outside of the study area boundary. This project builds on the previous mapping and work done by these agencies since 2016.

Distance-based Aggregation

Although this method is less scientific it does produce a representative and useful dataset of eelgrass bed extent and attributes. Repeating this analysis is likely to yield slightly different results each time. Polygons are easy to visually manipulate and to quantify bed type areal extent. Boundary Bay and Mud Bay are both dominated by Continuous, Flat beds. Change in area between years in each of Table 6 and Table 7 does not necessarily reflect a shift in the system and is likely a result of a shift in the surveyed extent. Further analysis to detect inter-annual change would require areas that were surveyed in both years be compared under the same or similar conditions (light, season, visibility).

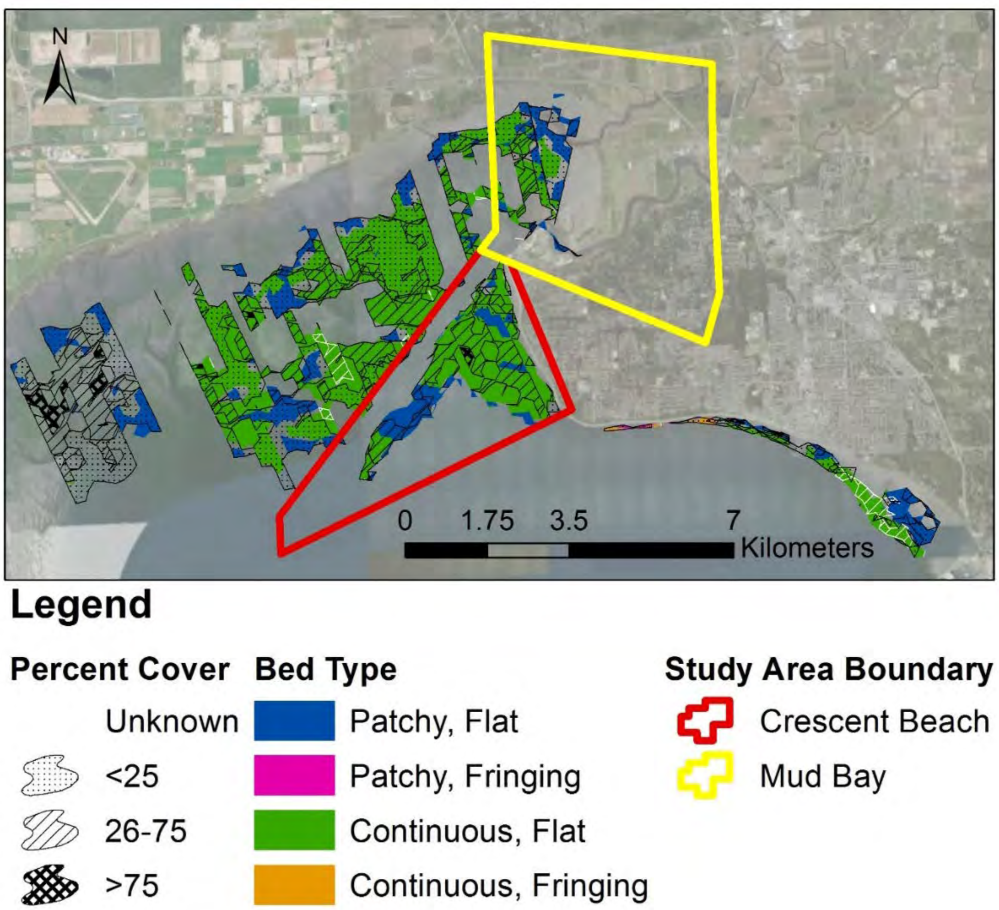

Figure 6. Map of distance-based aggregation of like attributes

Table 6. Area of eelgrass bed types in Mud Bay

Bed Type	Area (ha)	
	2016	2017
Continuous, Flat	116.76	39.23
Continuous, Fringing	0.00	0.00
Patchy, Flat	93.70	8.96
Patchy, Fringing	0.00	0.00

Table 7. Estimated area of eelgrass cover classes in Mud Bay

Percent Cover	Area (ha)	
	2016	2017
0 %	93.25	12.33
< 25%	177.39	54.96
25 - 75%	48.51	1.51
> 75%	0	0.00

Table 8. Area of eelgrass bed attributes at Crescent Beach

Bed Type	Area (ha)		Percent Cover	Area (ha)	
	2016	2017		2016	2017
Continuous, Flat	510.39	328.3	0 %	20.59	44.55
Continuous, Fringing	0.00	0.00	< 25%	65.69	0.73
Patchy, Flat	36.13	118.8	25 - 75%	71.65	205.11
Patchy, Fringing	0.00	0.00	> 75%	0.01	5.81

Interpolation

Interpolation appears to be the most robust method for analyzing the boat-based field mapping of eelgrass. The methods and results are repeatable and provide predicted variance of the interpolated dataset. The output is a raster dataset that can be used in statistical comparison to future mapping of similar data type collection. A power analysis could be performed to determine the sample size required for an area to produce a large and accurate enough raster for comparison at one to several sites in Boundary Bay, including Mud Bay, to monitor eelgrass beds. As with distance-based aggregation, interpolation determined Continuous, Flat beds to be dominant in Boundary Bay and Mud Bay. Mud Bay has more Patchy, Flat beds in the upper intertidal. Quantification of bed attribute areal extent is not as straightforward as the polygons from distance-based aggregation. Interpolation results in a gradient of attribute values; classifying the range for each attribute type will require further analysis. Bed type interpolation is shown with the confidence in Figure 7; lower predicted variance equals higher confidence. Figure 9 shows what the interpolation looks like compared to the sample point data.

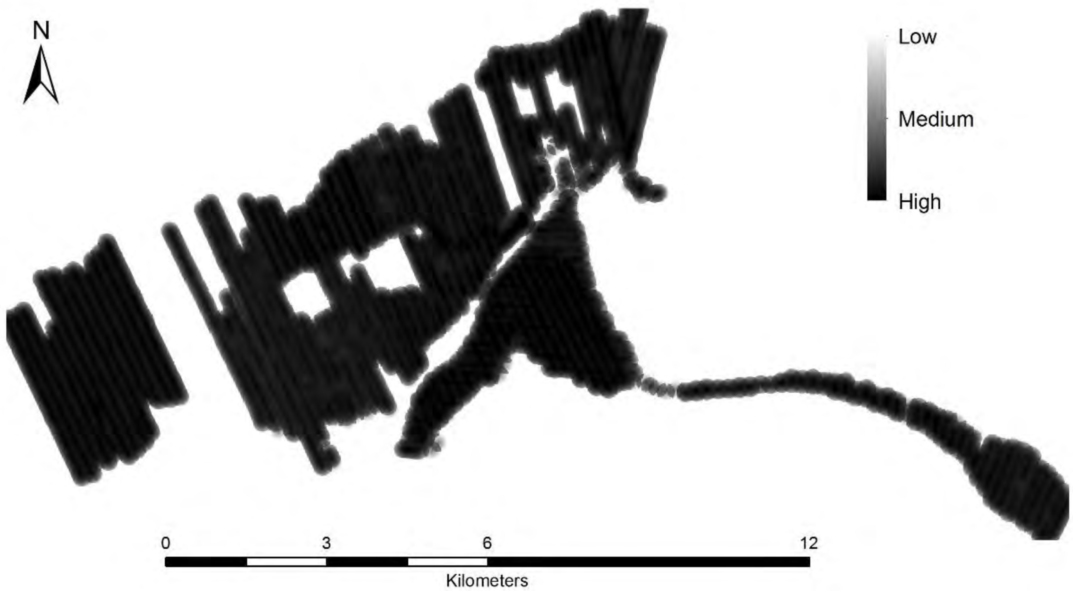

Figure 7. Bed type interpolation confidence

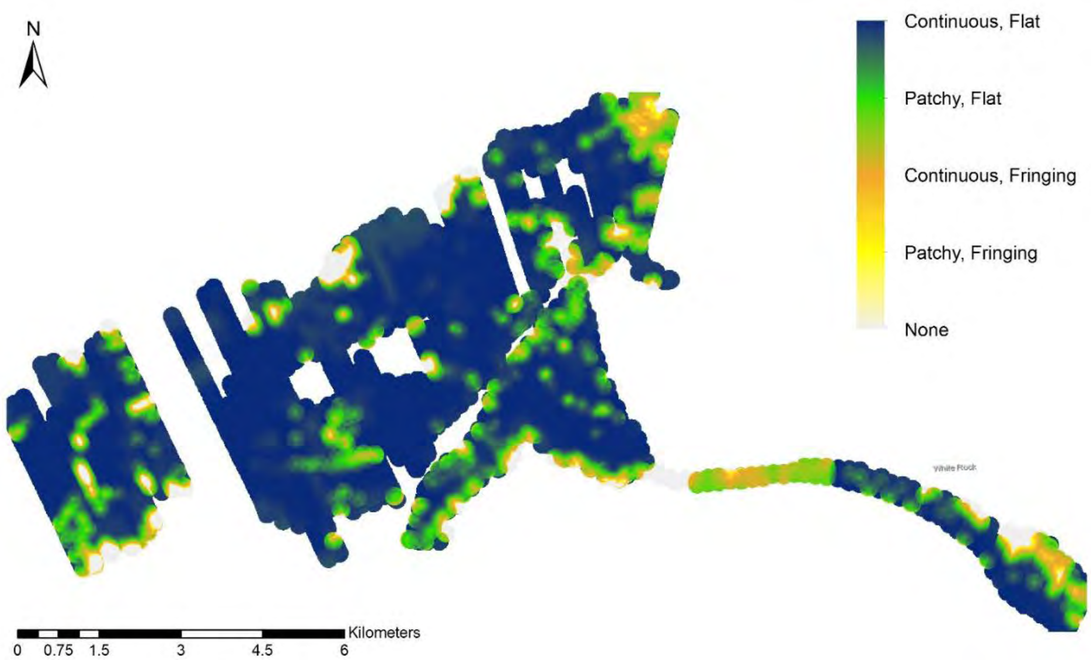

Figure 8. Interpolation map for bed type attribute points

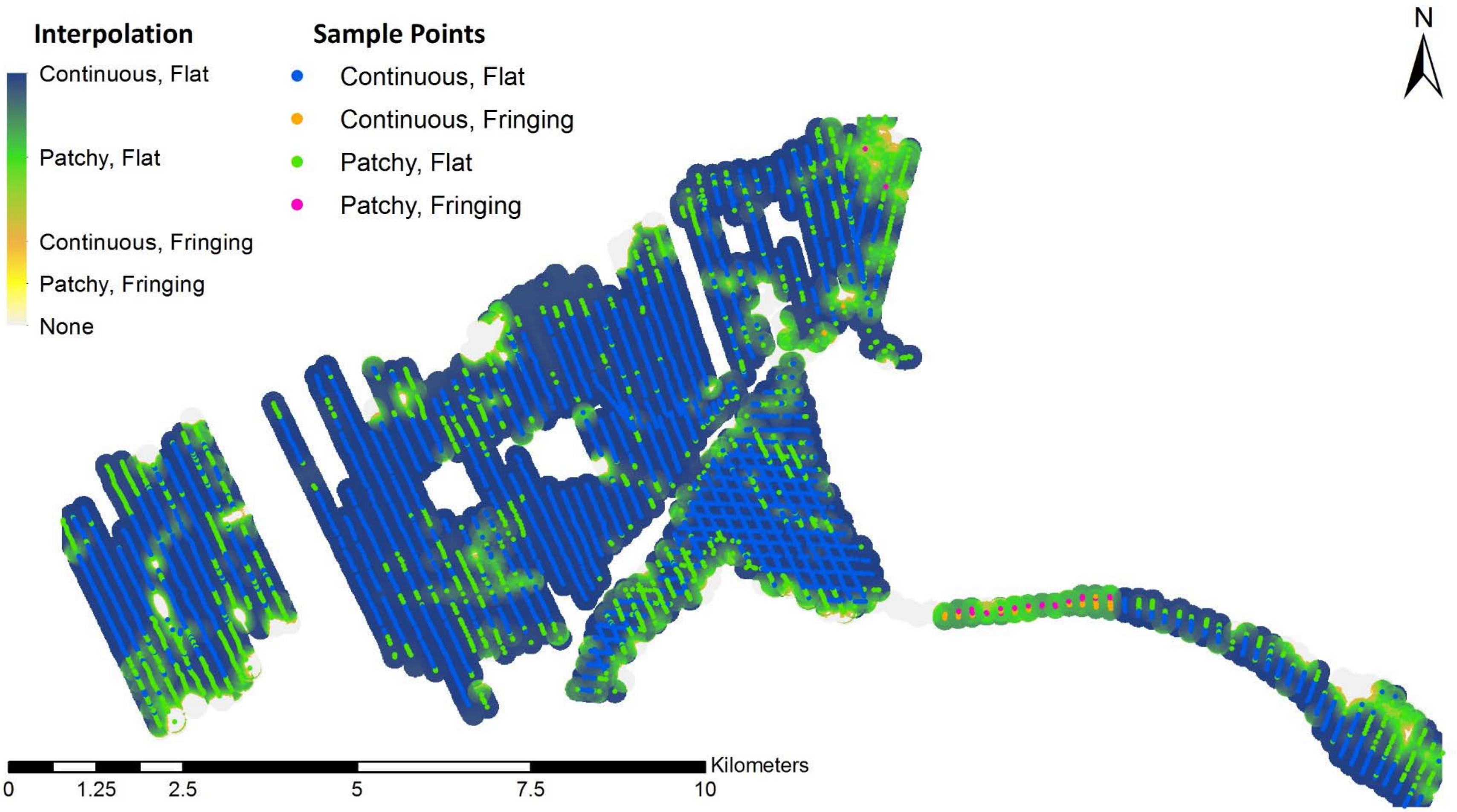

Figure 9. Sample points shown over interpolation

4. Summary and Recommendations for Future Work

Figures 7 through 9 have a few blank areas which should be noted. The long straight gaps in the transect data are due to either an inability to complete transects because of tide and weather conditions or field datasheets were lost during the surveys. Follow up mapping should investigate these data discrepancies to determine non-presence or if detected, then survey to complete the dataset. Confirmed non-presence areas should be clearly marked in future map products. The blank spaces that resemble holes are either sand bars or bare patches where eelgrass was not detected. Further investigation into why eelgrass is not in these areas is recommended. There are shellfish tenure bed artifacts in the bay from the historical shellfish industry that may be part of why these bare patches exist.

Boat-based mapping provides the extent of eelgrass beds and information regarding the types of beds and their visually estimated cover. This has provided an updated baseline extent of eelgrass beds and their distribution in the study area which can be used in assessing change at the site level. Foot-based transects provide further insight into eelgrass bed health in terms of detecting and monitoring eelgrass wasting disease and changes in bed productivity. Both methods are useful for monitoring at different scales. Boat-based mapping is resource intensive and can be costly, while foot-based transects can be completed with trained citizen scientists. Boat-based mapping is more suitable to larger scale changes and is likely better suited to being completed every 5 to 10 years while foot-based sampling should be completed more frequently at the same locations to detect change over time. The high density of sampling points achieved with the boat-based transect and further field verification via foot-based transects can be used to validate a remote sensing approach using satellite imagery collected at the same time. This should be explored as an additional monitoring tool as time and resources permit.

Interpolation analysis provides more robust and repeatable mapping of eelgrass beds compared to distance-based aggregation. However, environmental modelling such as the interpolation analysis is only as robust as the factors considered in the model. This interpolation analysis did not account for changes in substrate type, bathymetry such as river beds or other environmental factors. Future analysis should explore incorporating such factors to improve the predictions of the interpolation. The percent cover interpolation had some discrepancies when compared to the original point data. This should be investigated in more detail. In general, the percent cover observed by boat-based mapping in Mud Bay was < 25%. Percent cover is more variable in subtidal mapping due to the plants movement in the water column. More emphasis is placed on location, extent and bed types with boat-based mapping. Elevation data was collected with a GNSS device, which can be paired with tide height data and sonar depth and then correlated to eelgrass presence. Eelgrass is known to have a depth range of 1.8 m above

MLLW[1] to -30 m and prefers MLLW to -6.6 m (Phillips, 1974). The study area's current range can be evaluated using the existing data and compared to similar local sites such as Robert's Bank and Sturgeon Banks. As well, depth with be a direct factor of sea level rise influencing eelgrass bed changes in the study area.

Eelgrass health is largely influenced by salinity, sediment type, current velocity, light availability, depth, temperature, pH, flushing and incident solar radiation. These environmental variables are not independent of each other. For example, the maximum depth eelgrass can grow depends on the light availability at that location. Light availability is influenced by the turbidity of the water and the turbidity of the water can be influenced by current velocity and/or sediment type. The vulnerability of eelgrass to sea level rise is difficult to determine due to the inter-related environmental variables that influence eelgrass. Increased average water levels may mean more sub-tidal habitat availability, however this may also mean increased sediment mixing and turbidity which would impact the newly available habitat's suitability. Boundary Bay eelgrass extent was modelled using exposure time (the period of time when eelgrass isn't inundated) and determined a net increase in Z. marina extent when using a 55 cm projected increase in sea level (Stronach and Dunbar, 1992). The study also recognized the limitations of a single factor model and a 55 cm increase in sea level rise is well below current day estimates. Sea level rise will directly affect the availability of subtidal habitat for native eelgrass to occupy however other factors associated with sea level rise, such as wave velocity and turbidity, will also impact eelgrass beds in Boundary Bay.

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[1] Mean lower low water - the average height of the lowest tide recorded at a tide station each day during a 19-year recording period, known as the National Tidal Datum Epoch

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6. Appendix – A : Maps of Mud Bay

6.1. Distance-based aggregation

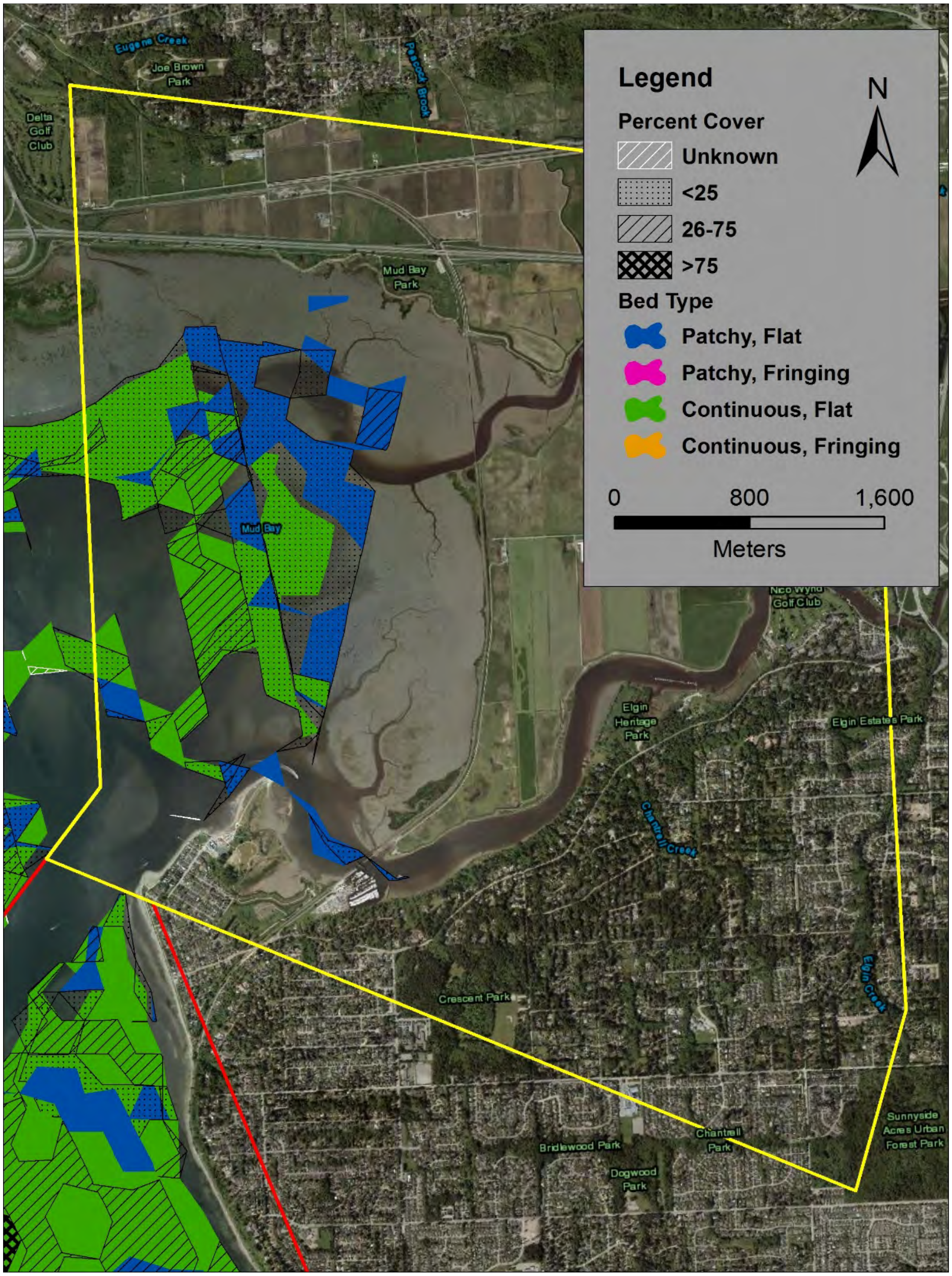

Figure 10. Map of mud bay eelgrass beds

6.2. Interpolation

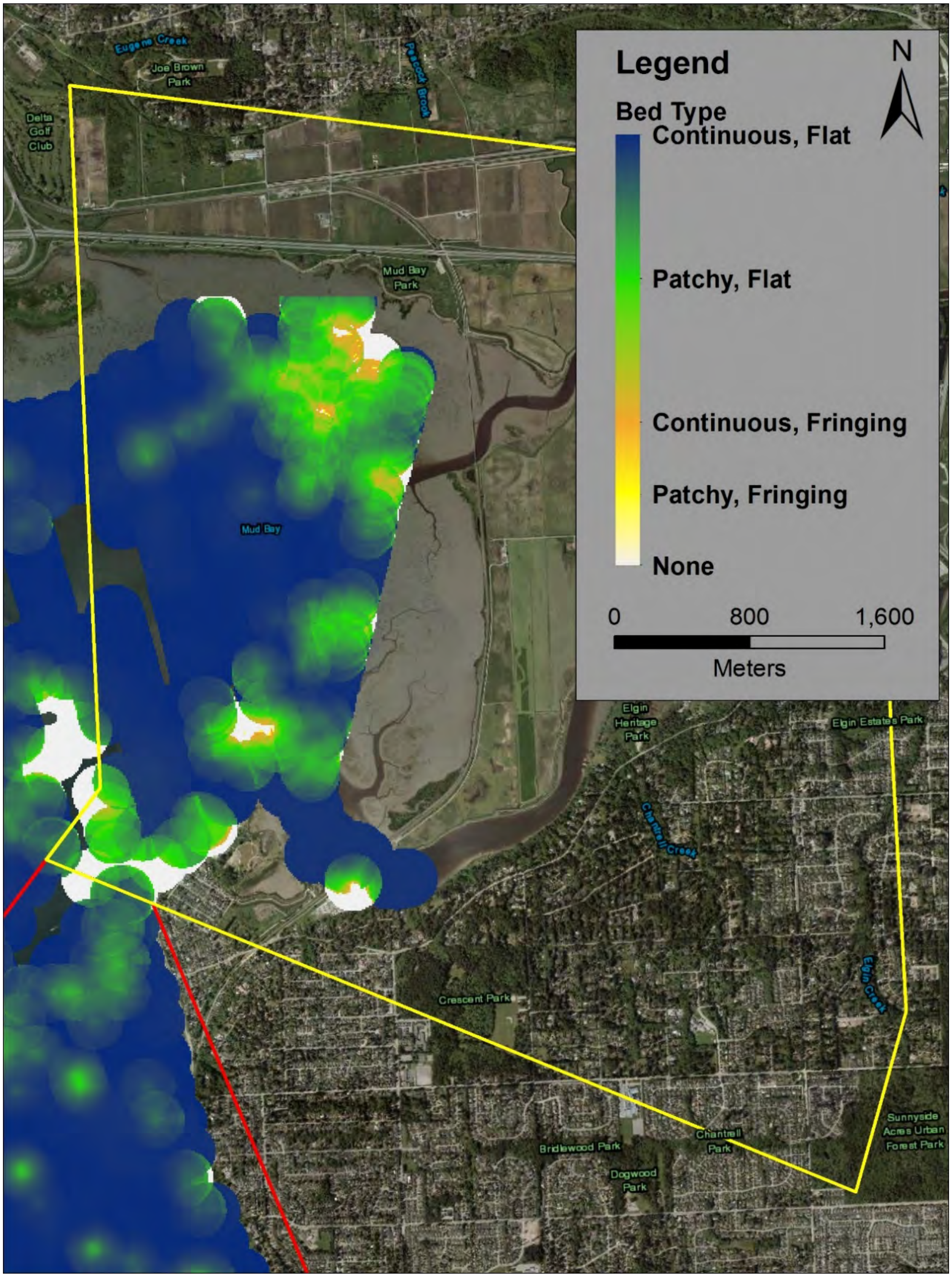

Figure 11. Bed type interpolation map for Mud Bay

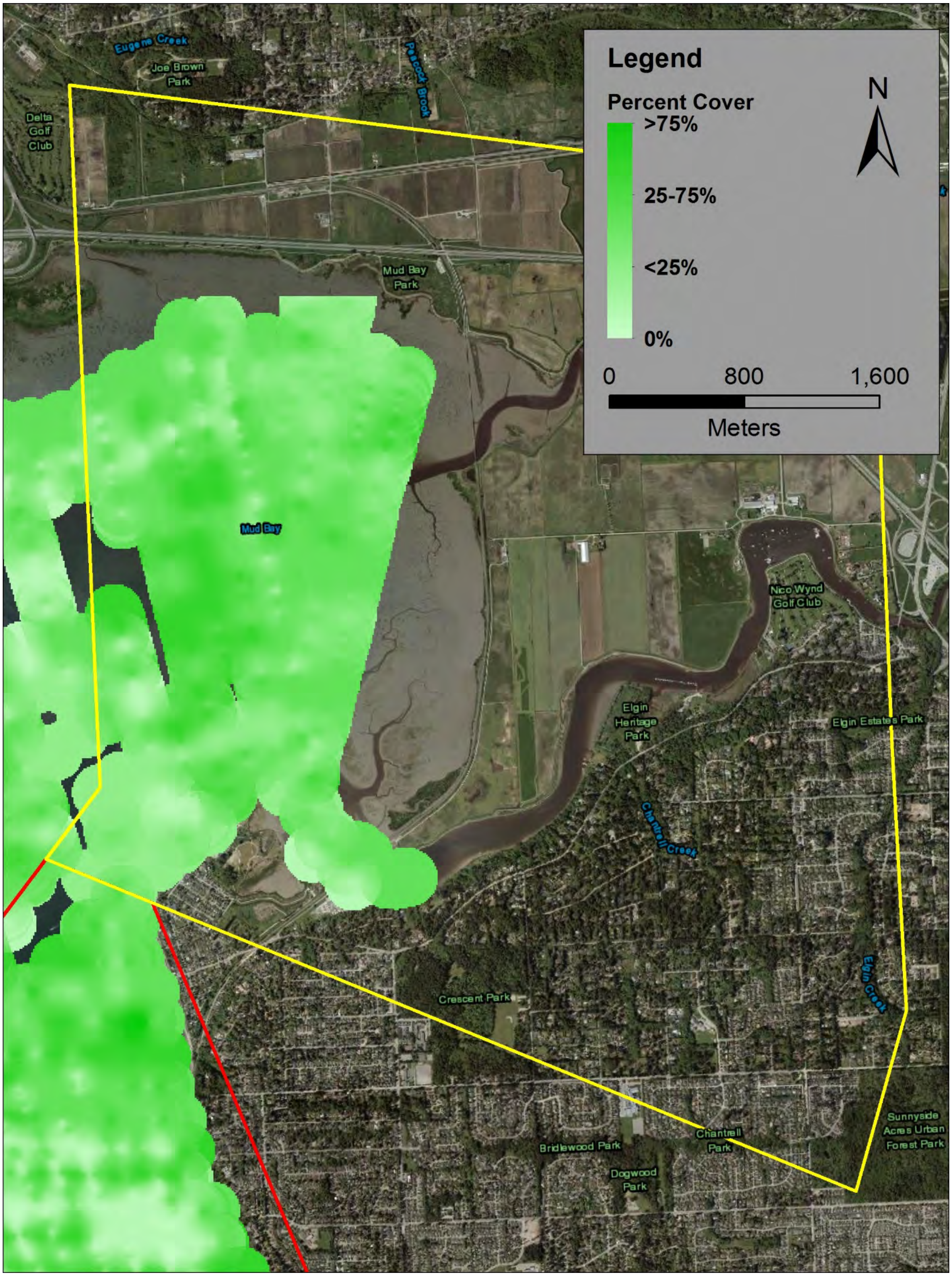

Figure 12. Percent cover interpolation map for Mud Bay

Chapter 3

Monitoring Phase 2 Memo

Date: October 26, 2018

MEMO

To Matt Osler/Tjasa Demsar
City of Surrey

From Matt Christensen
Ducks Unlimited Canada

Re: Prioritizing Infrastructure and Ecosystem Risk from Coastal Processes in Mud Bay

INTRODUCTION

The City of Surrey (CoS) has partnered with Ducks Unlimited Canada (DUC) on "Prioritizing Infrastructure and Ecosystem Risk from Coastal Processes in Mud Bay". As a part of this partnership project DUC is leading on Estuary Monitoring in Mud Bay which includes monitoring near-shore settlement, water quality data collection, habitat and wildlife data collection. This is an interim project update memo to report on the status of monitoring equipment installed and the next steps.

Figure 1 Map of Study Area and Monitoring Point Locations

METHODS

SURFACE ELEVATION

To understand the physical processes that determine elevation change and the potential for sea level rise in estuary habitats, we require precise measurements of sediment elevation in these areas. The surface elevation table (SET) developed by scientists at the United States Geological Survey (USGS) provides accurate and precise measurements of sediment elevation of intertidal areas. The rod surface elevation table (rSET), is an improved version of the original SET.

Four rSET sampling stations were installed in Mud Bay based on recommendations by Northwest Hydraulic Consultants (NHC); one was installed at the north end of Mud Bay and three more were installed at the southern extent of the study area. These stations are location at roughly the same elevation. All four stations are anchored in the sediment using a shallow benchmark platform, which consists of four three-foot long, three -inch diameter sections of aluminum pipe driven vertically into the marsh, onto which we bolted an aluminum platform with a receiving collar for the rSET instrument itself. To avoid disturbing the sediment around the sampling station, we made a platform out of an aluminum plank mounted on two step stools on which staff can kneel or crouch while taking measurements.

After mounting the instrument on the platform, measurements were taken at the four positions (bearings). The same set of bearings, with respect to the platform, will be used to repeat the measurements in the future at each monitoring point location. The instrument arm is levelled, each pin is lowered to the sediment surface and the distance from the top of the arm to the top of the pin is recorded. The mean of all 36 measurements (9 pins X 4 bearings) at a station is determined. Further details on installation and measurement can be found here: https://www.pwrc.usgs.gov/set/SET/rod.html.

Marker horizons were also placed to help distinguish between shallow subsidence and sediment accretion. Without them differences in surface elevation are assumed to be due to sediment accretion.

Figure 2 Marker Horizon

WATER

Monitoring water conditions can provide information on the degree of water circulation and tidal flushing throughout a site, which can directly affect vegetation and wildlife species using the area. The dataloggers collect water levels, water temperature and water salinity. The loggers were installed within a PVC pipe that was driven into the sediment. An RTK GPS was used to record the elevation of the top of the pipe, and a tape measure was used to record the length of the cord used to hang the device from the top of the pipe to give the datum referenced elevation of the dataloggers. The loggers provide continuous data (collected every 10 min) on water levels, temperature and salinity in Mud Bay. Dataloggers are deployed at monitoring points MB1, MB3 and MB4 as shown in Figure 1.

Level

The dataloggers measure pressure to determine water level. Corresponding barometric (air) pressure is subtracted from the pressure recorded by the datalogger in the well. The difference in pressure returns the amount of water above the sensor. The height of the water with respect to a vertical datum is then presented based on the elevation of the cap of the datalogger, less the length of the cable.

Salinity

Specific conductivity (mS/cm) is recorded by the dataloggers at 10-minute intervals. The salinity is then calculated based on the temperature and specific conductivity readings. CTD-Diver dataloggers have to different thresholds for specific conductivity, up to 30 mS/cm and up to 120 mS/cm.

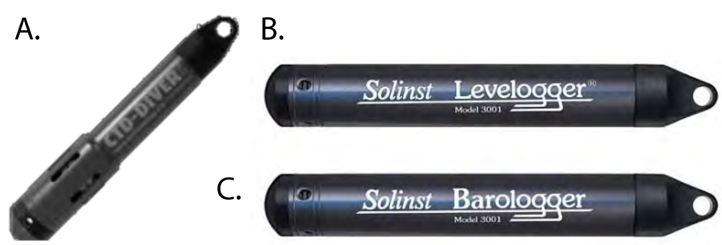

Figure 3 Installed datalogger models A. Van Essen CTD-Diver, B. Solinst Levelogger Model 3001 and C. Solinst Barologger Model 3001

WILDLIFE

Birds

Bird species and observation records for Mud Bay are available through eBird, a citizen science-based database. eBird data documents bird distribution, abundance, habitat use, and trends through checklist data collected within a simple, scientific framework. Birders enter when, where, and how they went birding, and then fill out a checklist of all the birds seen and heard during the outing. The eBird Reference Dataset (ERD) is updated once annually includes observational and checklist data, is zero-filled, and associated with a suite of landscape variables (Sullivan et al., 2009). The eBird Observation Dataset (EOD) is updated annually and made available through the Global Biodiversity Information Facility (GBIF.org, 2018). The EOD contains basic occurrence data including species, date, and location. Additional metadata associated with these observations, including sampling event data (such as effort), are not included in the EOD.

HABITAT

Tidal channel characteristics (morphology, cross section and depth,), woody debris abundance, and vegetation community extent will be measured using UAV flights.

RESULTS

SURFACE ELEVATION

Measurements were taken on January 25th and February 15th, 2018. The next measurement recordings for the rSET platforms will be in November 2018. The platforms were surveyed using a Trimble SP80 GNSS rover with network connection in July 2018. Marker horizons were installed at this time. Platform locations and measurements are shown in Table 1.

Table 1 List of rSET platform locations and measurements (CGVD28 GVRD; NAD83)

						Measurements (cm)								
Name	Latitude	Longitude	Elevation (m)	Direction	Approximate Bearing (°)	1	2	3	4	5	6	7	8	9
MB1	49.0892982	-122.8669968	1.553	5	170	22.1	21.8	22	22.3	22.9	23.9	23	23.9	23.9
				3	293	23.2	22.1	22.1	21.6	21.8	22.4	22.3	22.8	22.3
				1	2	22	21.6	22.2	22.8	22.1	21.9	21.3	20.2	20.2
				7	93	22.2	22.3	22.7	23.4	22.7	22.2	22.7	23	22.8
MB2	49.0681992	-122.8600006	1.571	3	295	*25.6*	24.7	23.4	22.8	21.8	22.2	23.5	24	23.5
				1	205	27.8	27	27.5	27	27.6	28	24.9	24.4	24.5
				7	115	22.6	22.7	22.6	23.1	24.6	26.2	25.8	23.9	22.3
				5	190	23.6	22.2	21.6	23.1	23.7	23.5	22.5	21	21.4
MB3	49.0630989	-122.8659973	1.034	3	156	22.3	22.5	22.3	22.3	21.6	21.6	21.3	21.2	21.5
				7	20	22.6	22.8	21.8	22.4	22.2	22.2	21.9	22.1	22
				1	250	22.9	22.6	22	22.2	22	22	21.9	22	21.9
				5	77	22.1	23.4	22.3	21.9	21.6	21.3	22	21.8	21.8
MB4	49.0601997	-122.8669968	1.572	7	263	23.4	23.4	23.8	23	22.4	22.2	23.3	23.4	23.7
				3	97	24	23.7	23.6	23.6	23.6	23.1	22.9	23.2	23
				5	5	22.4	22.4	22.7	22.7	22.9	23.2	23.1	23	22.6
				1	164	23.1	23.1	22.9	22.9	22.5	22	23.1	22.4	23

Figure 4 rSET platfrom (center) with four marker horizons approximately 3 meters apart

WATER

Dataloggers (as shown in Figure 3) were installed at locations MB1, MB3 and MB4 (see Figure 1). The barologger collects barometric pressure information from the site and is used to correct the water level from the level loggers by adjusting for atmospheric pressure. The barologger must stay above water at all times, so it was installed in a tree adjacent to the railway tracks.

Table 2 List of installed water level and water quality monitoring equipment locations

Elevation (m)	Feature	FeatureID	Latitude	Longitude
1.153	CTD Diver	MB1	49.08914	-122.867
0.645	CTD Diver	MB4	49.06027	-122.867
1.021	CTD Diver	MB3	49.06315	-122.866
NA	Barologger	MB-Barologger	49.0599	-122.864

In February 2018, we deployed one Solinst (Model 3001 Levelogger Junior Edge as shown in Figure 3 B.) gauge, at monitoring point location MB3 (Figure 1). In May 2018 a different model of datalogger (CTD-Diver; shown in Figure 3 A.) was deployed at both the MB3, to replace the Solinst model, and MB4 locations.

Salinity

Upon initial downloading of the data in May, we found that the logger had become laden with sediment within the PVC pipe. The two CTD-Divers that were installed in May 2018 at MB3 and MB4 were downloaded on August 30, 2018. The specific conductivity range selected for the locations during this time period was too low and subsequently the salinity data between May and August 2018 only indicates that the salinity is higher than 18.6 ppt in Mud Bay. A third CTD-Diver was installed at the MB1 monitoring point on August 30, 2018. MB1 CTD-Diver data was downloaded on October 24, 2018. Between Aug 30 and Oct 24, 2018 MB1 had a salinity range of 18.4 to 32.2 ppt.

Temperature

The temperature range of the water at MB4 and MB3 was between 13.4°C and 30.5°C. MB4 had a significant temperature spike around July 25, 2018 until August 30,2018. This is likely due to coming out of the water or becoming laden with sediments. MB3 had a temperature range of 12.6°C to 17.6°C. Between Aug 30 and Oct 24, 2018 MB1 had a temperature range of 11.7 to 19.4 °C.

Water Level

The cable length was shortened to raise the logger during each visit due to sediment intrusion into the PVC pipe. In addition, after subtracting the barometric (air) pressure measured in a nearby barometer from the total pressure measured in the loggers, we found many negative values, suggesting that the devices were incorrectly calibrated during installation. It is possible that we can correct for the calibration error and report the water level data in the future. Until then, the results are reported as they have been found. The maximum water level recorded between either February 15 to March 23, 2018 and May 19, 2018 to October 24, 2018 is 2.88 m and the minimum was -0.036 m (CGVD28 GVRD).

Table 3 Water monitoring parameters ranges based on weekly maximums and minimums

Range	Salinity (ppt)		Temperature (°C)		Water Level (m) CGVD28 GVRD	
Monitoring Point	Max	Min	Max	Min	Max	Min
CTD-MB-1	32.217	18.433	19.373	11.667	1.537	0.732
CTD-MB-3	18.567	18.567	17.643	12.610	2.640	1.390
CTD-MB-4	18.567	18.398	30.497	13.363	2.878	0.379
SOL-MB-3	NA	NA	9.206	6.984	1.820	-0.036

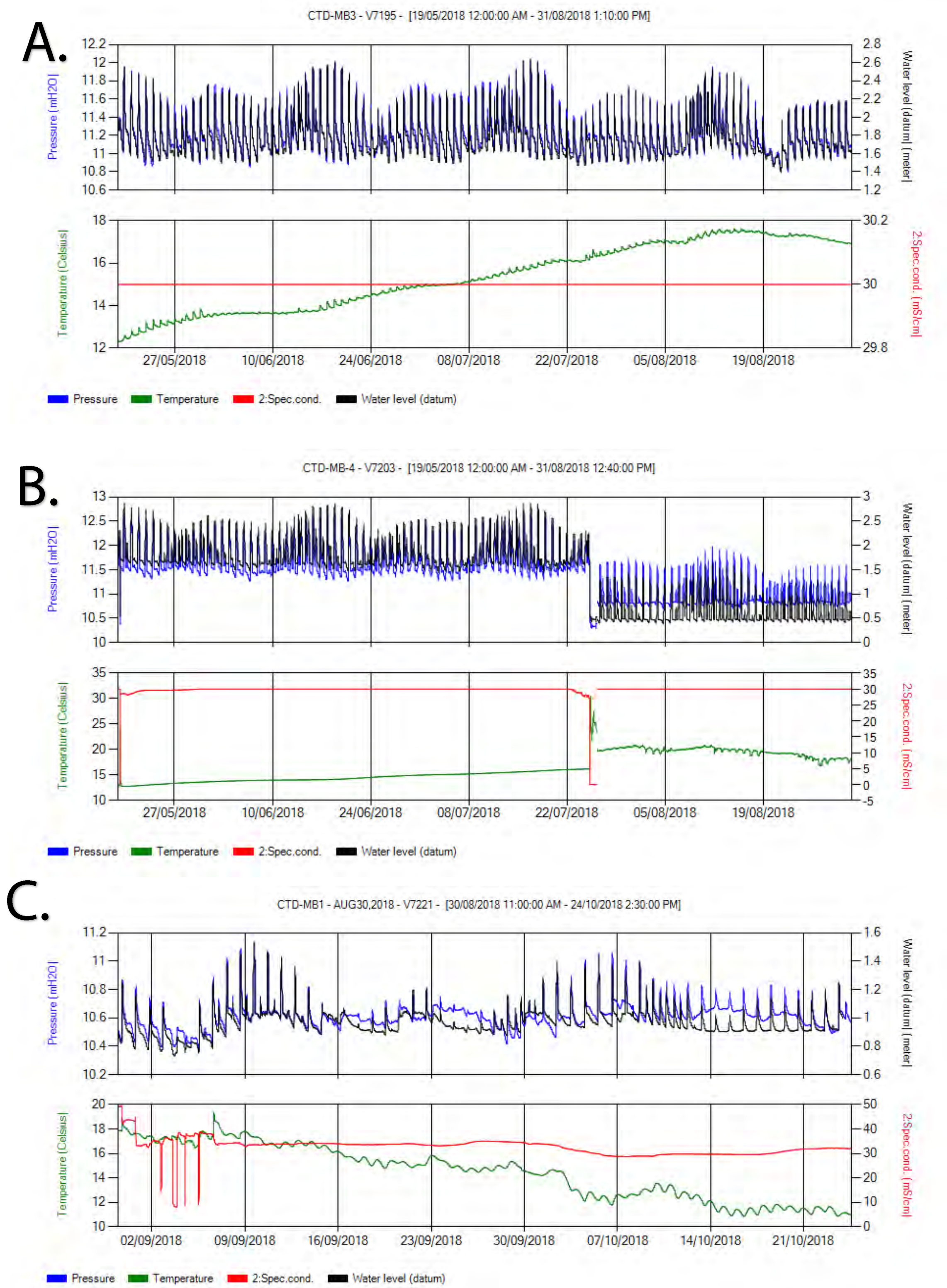

Figure 5 CTD-Diver datalogger temperature, salinity and water level . A. CTD-MB3, B. CTD-MB4, C. CTD-MB5

HABITAT

UAV flights were flown in October 2018 with preliminary mapping of vegetation communities to be available in early November 2018.

WILDLIFE

Birds

A copy of the EOD database (limited to the last five years of observation records for the study area) and the most current ERD dataset was downloaded for Mud Bay. The clements/ebird taxonomic list was cross referenced with EOD data to list species common name in the data preparation (Clements et al. 2018).

The EOD was used to create a bubble chart to show the relative number of observations of each type of bird in Mud Bay between 2013 and 2018(Figure 6). Waterfowl and shorebirds were the most observed types with waterfowl out ranking shorebirds. Mud Bay is within the Fraser River Delta, home to Canada's largest wintering waterfowl population. As a result, the number of waterfowl observations likely outranks the number of shorebird observations due to the residency time in the bay. Shorebirds may pass through in greater number but for shorter residency times. A map was also created to show the relative number of observations of each species using the study area; the locations of the bubbles are averages of the observation locations and not a reflection of the area of Mud Bay the species is frequently observed (Figure 7). The next steps will be to explore abundance using the ERD database.

Bird species frequencies downloaded from eBird and grouped into guilds as shown in XXXX. Five representative species were selected for each guild and plotted by season and/or month. Song bird frequency is the greatest in late spring to early summer (May, June and July). Waterfowl are most frequent in winter months as with raptors.

Table 4 Bird guilds and five selected representative species for each

 Songbirds	American Goldfinch American Robin Barn Swallow Violet Green Swallow White crowned sparrow	 Shorebirds	Greater Yellowlegs Killdeer Western Sandpiper Western Grebe Whimbrel
 Waterfowl	Mallard Northern Pintail Green-winged teal American Wigeon Snowgoose	 Raptors	Bald Eagle Northern Harrier Red-tailed hawk Peregrin Falcon Rough legged hawk

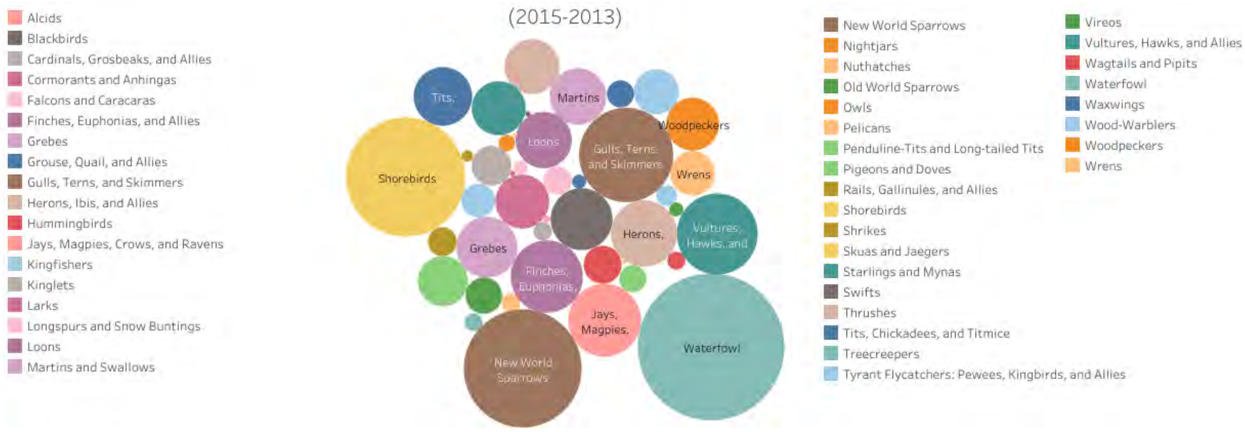

Figure 6 Bubble graph showing the number of observations of each bird type in Mud Bay, Surrey, BC

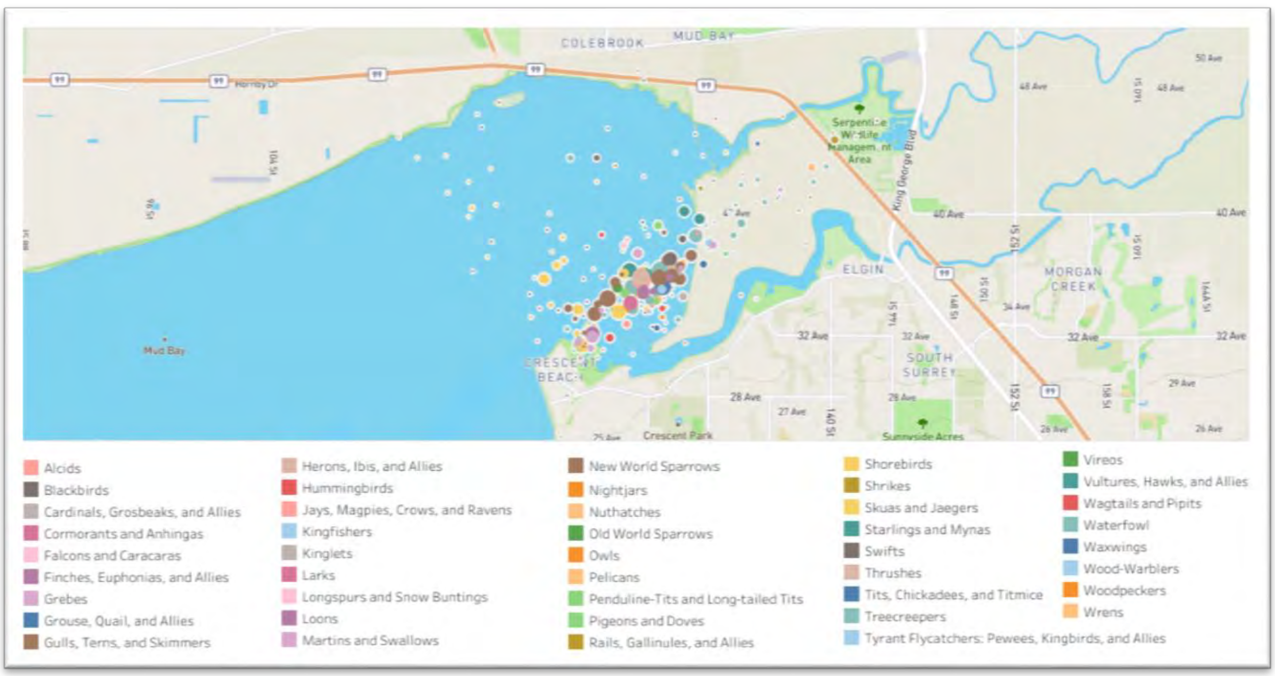

Figure 7 Map of the relative number of observations of each bird type in observed in Mud Bay, Surrey (2013-2018)

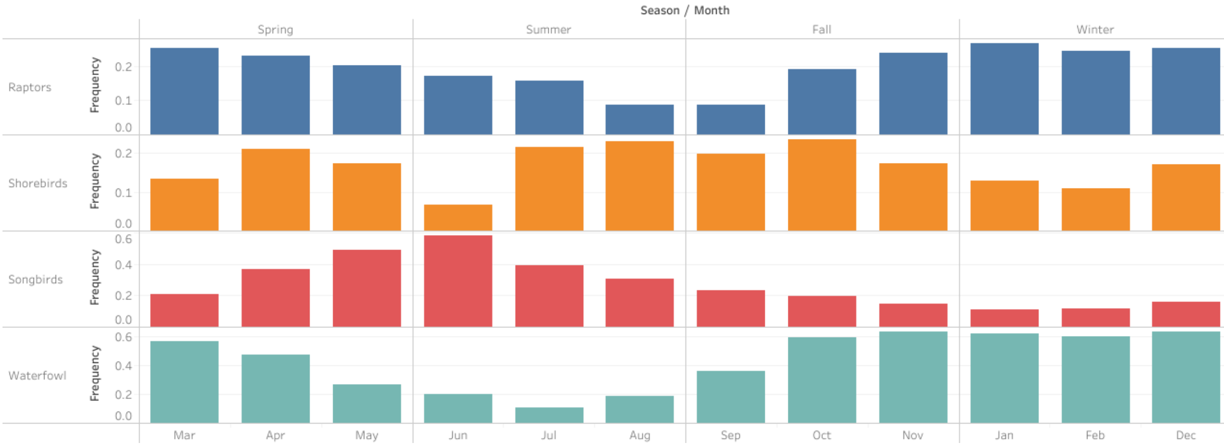

Figure 8 Frequency of bird guilds observed by season/month (consisting of 5 representative species for each) for Mud Bay, Surrey (2013-2018)

RECOMMENDATIONS

- Now that vegetation has senesced, complete rSET platform measurements in November 2018. Platforms will be easier to locate and vegetation will not be in the way of measurement rods.
- Vegetation sampling, habitat types and channel cross section measurements by Unmanned Aerial Vehicle (UAV) will collect a larger sample area and be more accurate than traditional sampling methods. Collect this information by UAV over three seasons (Fall, Winter, Spring).

DATASETS ATTACHED

- Water Level Data Merge All Excel
  - Copy of CTD_1_3_4_MergeAllTypes.xlsx
- Link to Tableau Graphs
  Chart: Guild by Season/Month
  - https://public.tableau.com/views/MudBayBirdTypeObservationFrequencySeasonmonth/BirdType_Monthly?:embed=y&:display_count=yes

  Chart : Observation Frequency by Species and Season
  - https://public.tableau.com/views/eBird-allspmudbaysites/AllSpAllSites?:embed=y&:display_count=yes

  Map: Observation Frequency by Type
  - https://public.tableau.com/views/Ebird_ObservationRecordsMaps/ColourBySpecies?:embed=y&:display_count=yes

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Clements, J. F., T. S. Schulenberg, M. J. Iliff, D. Roberson, T. A. Fredericks, B. L. Sullivan, and C. L. Wood. 2018. The eBird/Clements checklist of birds of the world: v2018. Downloaded from http://www.birds.cornell.edu/clementschecklist/download/

GBIF.org (22 October 2018) GBIF Occurrence Download https://doi.org/10.15468/dl.b3puii

Sullivan, B.L., C.L. Wood, M.J. Iliff, R.E. Bonney, D. Fink, and S. Kelling. 2009. eBird: a citizen-based bird observation network in the biological sciences. Biological Conservation 142: 2282-2292.

Chapter 4

Framework for Environmental Vulnerability

Prioritizing Infrastructure and Ecosystem Risk (PIER), Framework for Environmental Vulnerability

City of Surrey,
Surrey, BC

December, 2018
Updated March 26, 2019

Submitted to:

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1.0 Background

1.1 Coastal Flood Adaptation Strategy (CFAS)

Over the next 100 years, the effects of climate change, including sea level rise and increased precipitation, are predicted to cause wide spread flooding of the Mud Bay area as well as the lowland floodplain areas associated with the Serpentine and the Nicomekl Rivers. The City of Surrey (City) recognizes the need to reduce climate vulnerability and mitigate the expected impacts of climate change. In response to these changes, and their anticipated consequences, Surrey is developing a comprehensive Coastal Flood Adaptation Strategy (CFAS). This strategy focuses on both the current and future impacts of flooding within Surrey's coastal floodplain. As part of this project, Diamond Head Consulting evaluated potential impacts to habitats found in and east of Mud Bay that are likely to be impacted by Sea Level Rise, and potential adaptation strategies (Appendix 3).

1.2 Prioritizing Infrastructure and Ecosystem Risk (PIER)

As part of their Coastal Flood Adaptation Strategy, the City is undergoing an analysis for Prioritizing Infrastructure and Ecosystem Risk (PIER). This includes identifying vulnerability and ecosystem priorities for climate change along with their interconnection with grey infrastructure and potential sea level rise adaptation in Surrey coastal floodplains. Whereas past work focused on land based grey infrastructure through the Improving Coastal Flood Adaptation Approaches Project, this assessment focuses on the shoreline and near shore environment. This analysis will be used to clarify coastal ecosystem needs from an adaptation perspective for the Mud Bay and Crescent Beach areas and to inform and prioritize actions the City can undertake to reduce ecosystem risk.

The outcomes of this project will identify the greatest impacts that the expected sea level rise will have on ecosystem processes, habitat and wildlife species in the study area. Predicting how natural systems will react over the next 100 years is extremely complex. It is recognized up front that there is a lot of uncertainty and limitations associated with this analysis. The following report provides a summary of expert opinions on the expected environmental impacts and greatest environmental vulnerabilities as well as opportunities to mitigate the greatest impacts. This process is not meant to provide firm answers or decisions but is intended to inform an ongoing discussion on future management of the affected areas.

2.0 References

This is a cursory overview of expected impacts of expected sea level rise on the natural environmental. There have been a number of reports and studies completed that have helped to inform this assessment. These studies are establishing baseline information that will be monitored over time to help inform the understanding of ecosystems impacts from sea level rise.

- CFAS Primer Part 1: Coastal Flooding in Surrey
- CFAS Primer Part 2: Options
- Associated Engineering: Final report 2018: Improving Coastal Flood Adaptation Approaches

- Friends of Semiahmoo Bay Society 2018: City of Surrey Shoreline Assessment Mud Bay – Field Verification Report
- Ducks Unlimited 2018: Prioritizing Infrastructure and Ecosystem Risk from Coastal processes in Mud Bay - Estuary Monitoring Program
- Friends of Semiahmoo Bay Society; Joy Bitick, Sarah 2018: Preliminary Report on Mud Bay Nutrient Loading Effects on Eelgrass Bed health
- Northwest Hydraulics and the City of Surrey 2012; Serpentine, Nicomekl & Campbell Rivers – Climate Change Floodplain Review
- Diamond Head Consulting 2018: Surrey Flood Protection – Preliminary Habitat Impact Assessment Report

3.0 Methodology

The rise of sea level is predicted to have significant influence on coastal ecosystems and the species populations that inhabit them. It is however very difficult to predict with certainty what these impacts will be and to quantify them. Natural systems and processes are closely interconnected making it difficult to model all possible outcomes. Also, sea level rise will take place slowly over a long period of time. How we react and adapt to these changes will also have a major influence on these species' dynamics. The following risk assessment methods were adopted to provide a framework for evaluating the expected impacts on these natural systems and the species that rely on them.

3.1 Risk Assessment Methodology

The methodology used for this ecosystem risk assessment follows the approach used for the Gray Infrastructure Risk Assessment. This included identifying individual infrastructure assets and for each, evaluating consequence resulting from a flood (on a scale of 0-5) and multiplying this by the probability of it occurring (on a scale of 0-5). This final risk rating provided a measure of the vulnerability of infrastructure to sea level rise and flooding.

For this environmental risk assessment, a list of predicted impacts have been identified through the CFAS process (Section 3.2). A probability score out of 5 was given to each impact based on how certain it is that sea level rise will cause the effect. A description of the probability scoring is provided in Table 1.

Table 1: Probability of an impact occurring.

Probability	Description
0	Not applicable
1	Very low
2	Low
3	Moderate
4	High
5	Very high

The consequence of each impact on 10 broad species groups was considered. These scores provide a measure of how the impact would change these species relative to the current day populations. This rating is difficult to determine as there are so many variables to consider and uncertainties of how sea level rise will affect the habitat features that these species rely on. These ratings are meant to highlight these complexities and to help facilitate an ongoing discussion and future studies. A description of the consequence ratings is provided in Table 2.

Table 2: Consequence rating of the impact on species groups.

Consequence Rating		Description
0	No effect	Will have no impact on population levels
1	Very low	Insignificant or negligible effect on population levels
2	Low	May impact some individuals but will not have a significant impact on the local population levels
3	Moderate	Will have a noticeable impact on population levels. With habitat replacement/restoration it will be possible for the populations to recover
4	High	Will have a significant and permanent impact on population levels in the study area. With habitat replacement/restoration it may not be possible for populations to recover
5	Very high	Will have impacts that could potentially result in the extrication of this group from the study area

A final risk score was calculated for each species group and expected impact by multiplying the probability score of the impact occurring with the consequence score (Table 3). This risk rating helps to identify what impacts are expected to cause the greatest negative effect and should be discussed in more detail for mitigation.

Table 3: Risk rating of impacts on species groups.

Risk Rating		Description
<10	Low	Risks requiring minimal action
10-19	Medium	Risks that may require future action
20-25	High	Risks that require action

3.2 Limitations

There are limitations and uncertainties associated with this analysis. Predicting the details of climate change and sea level rise over the next 100 years, and their influence on habitat and natural processes is difficult. This framework is not intended to provide firm answers or decisions; it is intended to inform an ongoing discussion on future management of the affected areas and species.

3.3 Environmental Impacts

Under all potential management scenarios there are a number of expected effects that will have an impact on wildlife populations. The environmental effects being considered in this risk analysis include:

- **Loss of intertidal habitat:** *The intertidal zone is defined as the area between the highest high water mark and the lowest low water mark. These areas are under the influence of changing tides and provide critical habitat for both terrestrial and aquatic species. Rising sea levels will constrain this area up against diking, also known as coastal squeeze.*
- **Less exposure time of mud flats and biofilm**: *Mud flats are areas of shallow-sloped intertidal coastal wetland habitat that have accumulated large amounts of sediments deposited by tides or rivers over time. They generally support productive ecosystems, supporting both marine and terrestrial life. The mud flats of Boundary Bay are well known as important areas where large migratory flocks stop, rest, and feed to ensure they have enough energy for the rest of their migration. The amount of time mud flats will be exposed is expected to decrease with rising sea levels.*
- **Loss of existing eelgrass community**: *Eelgrass plants form dense communities on the sea bottom, forming the basis of a complex food web in estuaries and other sheltered marine areas. Eelgrass species are best adapted to specific depths. Rising sea level is expected to push eel grass communities inland and reduce their abundance when range expansion is limited.*
- **Loss of agricultural lands**: *Agricultural lands have been previously cleared and are used for farming or ranging activities. They are likely to decrease in quantity and quality through flooding, erosion, and/or dyke upgrades.*
- **Loss of old field/shrub habitat**: *Old agricultural fields are often taken over by early successions species. Old field/shrub habitat is likely to decrease through flooding, erosion, and/or dyke upgrades.*
- **Increase salinity in freshwater (Nicomekl and Serpentine) rivers**: As sea levels rise, saltwater intrusion will increase and creep further inland, increasing the *salinity in the Nicomekl and Serpentine Rivers is likely to increase and creep further inland. This would reduce the amount of freshwater habitat. The severity of this increase will depend on management strategies employed.*
- **Increase salinity in freshwater wetlands (Serpentine Fen)**: *The extent of salinity will extend inland, likely negatively affecting wetlands. This will likely alter the plant communities that are able to survive and make wetlands inhabitable to some fish and amphibians.*

There are numerous other effects that will result from sea level rise and flooding, but their influences on wildlife is uncertain and difficult to predict. These include effects such as changes to ground water levels, salination of soils, sediment transport, sedimentation of marine and freshwater ecosystems and competition from invasive species. For this risk assessment, some key and more easily understood effects have been identified to help understand impacts on wildlife and prioritise actions to mitigate them.

3.4 Species Groups

There is a wide variety of resident and migratory wildlife that inhabit the Mud bay area, all of which have different needs at different times of the year. To simplify this impact analysis, they have been considered in broad groups. It is recognized that some groups may not fall within any of these groups. However, these have been kept at a broad level so that big picture concepts are considered. Future studies and analysis will look into certain species in more detail.

- **Song Birds**: *Birds belonging to the clade Passeri of the perching birds; their vocal organs are typically developed enough to produce diverse and elaborate songs. Ex. Spotted towhee.*
- **Waterfowl Birds**: *Waterfowl birds consist of Anseriformes, which includes ducks, geese, and swans. Waterfowl birds are highly adapted to exist at the surface of aquatic ecosystems (e.g. all are web-footed). Ex. Mallard.*
- **Shorebirds**: *A bird that is frequently found along the seashore, including sandy or rocky shorelines, mudflats and shallow waters. Ex. Western sandpiper.*
- **Raptors**: *Raptors are an informal grouping of primarily land-based predators, and includes birds that primarily hunt and feed on vertebrates. They typically have excellent eyesight, curved beaks, and strong talons. Their prey are often relatively large for the size of the birds of prey. Ex. Red-tailed hawk.*
- **Terrestrial Mammals**: *This category consists of land-based mammals, which are defined as a clade of endothermic vertebrates that have, among other things, hair and mammary glands. Ex. Townsend's vole.*
- **Marine Fish**: *This category consists of fish that live in saltwater. Marine fish with freshwater life stages (anadromous fish) only have its saltwater life stage considered in this category. Ex. Coho salmon.*
- **Marine Invertebrates**: *Animals that do not have vertebrae and exist in marine environments. They often have evolved a shell or hard exoskeleton. This category includes marine zooplankton, bivalves, crustaceans, and echinoderms, among others. Ex. Littleneck clam.*
- **Freshwater Fish**: *This category consists of fish that live in freshwater. A freshwater fish with a saltwater life stage (catadromous) only has its freshwater life stage considered in this category. Ex. Cutthroat trout.*
- **Amphibians**: *Amphibians are ectothermic tetrapods of the class Amphibia. They inhabit a variety of environments including terrestrial, fossorial, arboreal or freshwater aquatic ecosystems. Generally, amphibians cannot survive in saltwater; however, there is one species of frog that survives in brackish water. Ex. Northwest Salamander.*
- **Terrestrial Invertebrates**: *Animals that do not have vertebrae and exist in terrestrial environments. Ex. Anise swallowtail.*

4.0 Analysis of Scenarios

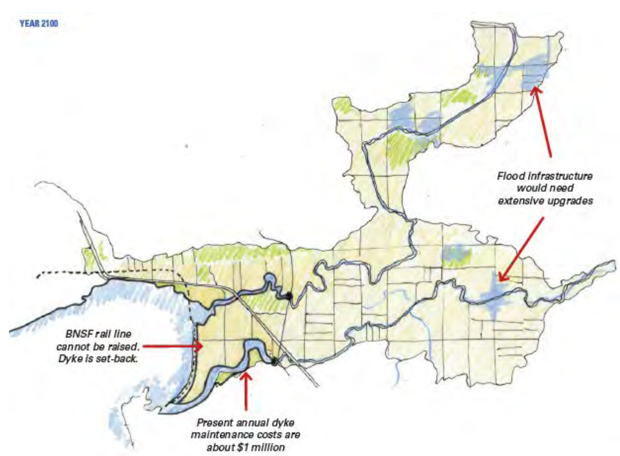
Climate change is expected to have global impacts on temperatures and precipitation patterns. Based on climate change projections, sea level is expected to rise by approximately 1 m by 2100 in Mud Bay, and winter precipitation is expected to increase in frequency and duration in the City of Surrey. Without intervention, this will cause widespread flooding of the Mud Bay area, as well as the lowland floodplain areas associated with the Serpentine and the Nicomekl Rivers.

The impact that sea level rise will have on habitat and wildlife species depends on how we intervene and manage it. The environmental impacts from a wide range of management options were evaluated by the City through the first stages of the CFAS project. Two illustrative scenarios were selected for this prioritisation analysis. The first is to continue with the status quo and to maintaining the current flood control systems where they exist today. The second is to manage a strategic retreat back to Highway 99. The following is a summary of these two options.

4.1 Current Convention: Maintain current management practices and flood control systems

There is currently a dyke at the interface of Mud Bay and the City of Surrey with a series of flood cells and pumping systems through the floodplains of the Serpentine and Nicomekl rivers. Occasional flooding occurs during King Tide events, as well as during severe storm events. Current management practices are reactive, with a focus on emergency response and recovery. This scenario assumes that these same methods for flood control will continue to be in upgraded and remain in place until 2100.

The responses to flooding will continue to be reactive and likely include emergency actions and recovery just prior to and after major storm events. Water damage will be mitigated as best as possible with sandbags and emergency pumping. Adapting to rising sea levels and storm events will include reinforcing and armoring these dikes to strengthen their position. Impacts of flooding to local residents and farmers will also be reactive. Infrastructure will be rebuilt as needed and soils will likely require amendment to mitigate the impacts of increased salinity.



4.2 Highway 99 Realignment

The second option considered as part of this risk assessment is to strategically retreat the dike barrier back to the current alignment of Highway 99. The current dike systems will be maintained but not enforced or made larger. When damages from flooding become too great, agricultural activity in the affected areas would stop and the land would be allowed to naturalize and adapt to more frequent flooding. Under this option, the impacts of coastal squeeze would not be as harsh and there is potential to slowly restore the existing agricultural areas to intertidal wetlands.

5.0 Risk Assessment

The framework was developed by professional biologists that have local experience in the City of Surrey, with input from the City. It is based on the City of Surrey's Grey Infrastructure Risk Assessment and best practices found in the literature. It was developed as a tool to promote constructive discussions with stakeholders. It is meant to be an adaptive process that will be updated through this consultation process and over time as more is learned about the impacts of sea level rise.

The probability and consequence ratings are based on an understanding of local wildlife and using professional judgement. The biologists would like to emphasize that no rigorous scientific methods were used as part of this assessment. It is expected that future analysis will continue to explore these findings and help to refine priority actions to mitigate the impacts. Decisions on how to manage for sea level rise will also consider social and economic impacts, which will also influence the effects on the environment.

The preliminary ecosystem risk assessment was completed by Diamond Head Consulting. The consequence ratings were further refined through conversations with local wildlife enthusiasts and biologists after an Ecosystem Vulnerability Workshop hosted at the Surrey City Hall. The workshop was put on by Ducks Unlimited Canada, the City of Surrey, and Diamond Head Consulting. It brought together experts from various levels of local, provincial, and federal government; environmental NGOs; environmental consultants; and academia (Ex. the City of Surrey, Metro Vancouver, the Department of Fisheries and Oceans, Nature Canada, etc.). These experts self-sorted into groups to focus on potential impacts to either birds and mammals or aquatic and terrestrial species. Due to time restrictions, the risk assessment was completed assuming Scenario #1, (Current Conventions Section 4.1.1) is adopted. General comments and discussions were then used to inform the consequence ratings for Scenario #2. The results of the ecosystem risk analysis are available in Table 4 and Table 5.

Table 4: Consequence ratings for expected environmental effects on species groups assuming Scenario #1, which continues to follow current conventions. Example indicator species are provided for each species group.

Environmental Effects	Probability	Song Birds	Waterfowl Birds	Shorebirds	Raptors	Terrestrial Mammals	Marine Fish	Marine Invertebrates	Freshwater Fish	Amphibians	Terrestrial Invertebrates
		Spotted Towee	Mallard	Western Sandpiper	Red-tailed hawk	Townsend's Vole	Coho Salmon	Littleneck Clam	Cutthroat Trout	Northwest Salamander	Anise Swallowtail
Loss of intertidal habitat	5	0	3	4	2	2	4	4	0	0	2
Less exposure time of mud flats	5	0	4	5	2	0	1	3	0	0	1
Loss of eelgrass commmunity	4	0	5	3	2	0	5	4	0	0	1
Loss of agricultural lands	3	1	2	2	4	4	1	1	1	1	3
Loss of old field/shrub habitat	3	2	2	1	4	3	1	1	1	3	3
Increase salinity in freshwater	3	1	1	0	1	1	0	0	3	5	3
Increase salinity in wetlands	3	3	4	0	2	2	0	0	2	4	4

Table 5: Risk ratings for expected environmental effects on species groups assuming Scenario #1, which continues to follow current conventions.

Environmental Effects	Song Birds	Waterfowl Birds	Shorebirds	Raptors	Terrestrial Mammals	Marine Fish	Marine Invertebrates	Freshwater Fish	Amphibians	Terrestrial Inverebrates
Loss of intertidal habitat	0	15	20	10	10	20	20	0	0	10
Less exposure time of mud flats	0	20	25	10	0	5	15	0	0	5
Loss of eelgrass commmunity	0	20	12	8	0	20	16	0	0	4
Loss of agricultural lands	3	6	6	12	12	3	3	3	3	9
Loss of old field/shrub habitat	6	6	3	12	9	3	3	3	9	9
Increase salinity in freshwater	3	3	0	3	3	0	0	9	15	9
Increase salinity in wetlands	9	12	0	6	6	0	0	6	12	12

	High Risk
	Moderate Risk
	Low Risk

Table 6: Consequence and risk ratings for expected environmental effects on species groups for Scenario #2, retreat to Highway 99. Example indicator species are provided for each species group.

Environmental Effects	Probability	Song Birds	Waterfowl Birds	Shorebirds	Raptors	Terrestrial Mammals	Marine Fish	Marine Invertebrates	Freshwater Fish	Amphibians	Terrestrial Inverebrates
		Spotted Towee	Mallard	Western Sandpiper	Red-tailed hawk	Townsend's Vole	Coho Salmon	Littleneck Clam	Cutthroat Trout	Northern Salamander	Anise Swallowtail
Loss of intertidal habitat	4	0	3	4	2	3	3	3	0	0	2
Less exposure time of mud flats	3	0	3	4	2	0	1	2	0	0	1
Loss of eelgrass commmunity	3	0	5	3	2	0	5	4	0	0	1
Loss of agricultural lands	5	1	2	2	4	4	1	1	1	1	3
Loss of old field/shrub habitat	5	2	2	1	4	3	1	1	1	3	3
Increase salinity in freshwater	3	1	1	0	1	1	0	0	4	5	3
Increase salinity in wetlands	3	3	4	0	2	2	0	0	2	5	4

Table 7: Risk ratings for expected environmental effects on species groups for Scenario #2, retreat to Highway 99.

Environmental Effects	Song Birds	Waterfowl Birds	Shorebirds	Raptors	Terrestrial Mammals	Marine Fish	Marine Invertebrates	Freshwater Fish	Amphibians	Terrestrial Inverebrates
Loss of intertidal habitat	0	12	16	8	12	12	12	0	0	8
Less exposure time of mud flats and biofilm	0	9	12	6	0	3	6	0	0	3
Loss of eelgrass commmunity	0	15	9	6	0	15	12	0	0	3
Loss of agricultural lands	5	10	10	20	20	5	5	5	5	15
Loss of old field/shrub habitat	10	10	5	20	15	5	5	5	15	15
Increase salinity in freshwater	3	3	0	3	3	0	0	12	15	9
Increase salinity in wetlands	9	12	0	6	6	0	0	6	15	12

(red)	**High Risk**
(yellow)	**Moderate Risk**
(green)	**Low Risk**

6.0 Discussion of Vulnerability Assessment and Mitigation Options

Vulnerability defined:
The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

This ecosystem risk analysis was undertaken to identify what are likely to be the most vulnerable locations and groups of species, to begin an iterative process to attempt to reduce these impacts. Based on this preliminary risk analysis, there are some high-risk environmental effects that warrant consideration for mitigation. These are discussed below along with preliminary recommendations for mitigation. This discussion assumes that Scenario #1 - Current Conventions will be adopted. This is however an adaptive process and management strategies should change as we learn more about climate change.

6.1 Loss of Exposure Time – Waterfowl and Shorebirds

The loss of exposure time for foraging associated with mud flats is identified as a highly probable, high consequence environmental effect. The greatest impact from this is expected to be to waterfowl birds, and shorebirds which rely heavily on this area as a stopover to feed and replenish their reserves for their continued migration north.

Mitigation: Monitor sediment transport in Mud Bay and design engineering interventions to promote the retention of sediment. The goal of these features will be to promote the accumulation of sediment at a similar rate as sea level rise, to maintain similar exposure areas and time. *This approach is supported by recommendations IN 1.1 and EC 3.5 from the Climate Action Strategy (CAS) – Enhance data collection and monitoring for climate impacts in Surrey (IN 1.1) and evaluate options for installing physical interventions to support ecosystems (EC 3.5).*

6.2 Loss of Eelgrass Communities – Waterfowl and Marine Fish

The loss of eelgrass plant communities is identified as a highly probable, high consequence environmental effect. The depth of the water column of Mud Bay is expected to increase, which could reduce the available habitat for eelgrass, as these plants can survive only at certain water depths. Eelgrass communities support a diversity of marine species and birds.

Mitigation: The extent of eelgrass communities and their tolerance to changing water depths should be monitored. If range expansions and more depth-tolerant species do not maintain eelgrass populations, engineering interventions could be designed to promote the retention of sediment to maintain the water column depth and light attenuation required by the eelgrass. *This approach is supported by recommendation EC 3.5 from the CAS – Evaluate options for installing physical interventions to support ecosystems.*

6.3 Loss of Intertidal Habitat – Shorebirds, Marine Fish, and Marine Invertebrates

Loss of intertidal habitat, particularly estuarine marshes, is identified as a highly probable, high consequence environmental effect. This transition zone between the marine and terrestrial habitat is highly productive and used by a wide range of species. Its loss will likely impact forage opportunities most importantly for shorebirds, marine fish and marine invertebrates, as well as mammals and waterfowl birds.

Mitigation: Promote a nature-based solutions approach to all new and rebuilt dikes where possible to enhance foreshore habitat (Appendix 2). This will help improve flood control through wave attenuation and reduce coastal erosion, while improving habitat quality and quantity. Intertidal features could be designed to help trap sediment and extend the intertidal zone out as far as possible. Dikes to be upgraded should be selected by the City after consultation with project specialists to determine the best locations, considering areas that would benefit the most and have the least impact to the engineering functionality of the dike. Ex. Green Shores, Living Dikes, etc. *This approach is supported by recommendation EC 3.5 from the Climate Action Strategy (CAS) – Evaluate options for installing physical interventions to support ecosystems.*

Acquire coastal land strategically to reduce flood risk and to enable the intertidal zone to shift inland. *This approach is supported by recommendation A-3.2 from the Biodiversity Conservation Strategy (BCS) – Identify priority natural areas for acquisition as part of GIN; and EC 1.2 from the CAS – Strategically acquire a diverse representation of ecosystem types as part of Surrey's Parks and natural areas.*

7.0 Mitigation Opportunities

7.1 Climate Action Strategy and Biodiversity Conservation Strategy Recommendations

There are a number of recommendations identified in existing City of Surrey strategies for environmental protection, enhancement, and restoration. These apply to a range of City departments, locations, and policy and planning tools. Recommendations from the Climate Action Strategy (CAS) and the Biodiversity Conservation Strategy (BCS) were reviewed to identify the ones most relevant to reducing the impact to ecosystems from the predicted effects of coastal flooding and sea level rise. Most recommendations are fairly high level and will require some additional effort to select specific actions and locations. Some of the most relevant recommendations are consolidated and summarised as:

1. **Infrastructure (CAS):** Enhance data collection and monitoring for climate impacts in Surrey (IN 1.1).
2. **Urban Trees and Landscaping (CAS):** Select tree species well adapted to Surrey's future climate projects (TR 2.1); Monitor tree survival rates (TR 2.2); increase species diversity of trees (TR 2.3).
3. **Agriculture and Food Security (CAS); Agricultural Biodiversity (BCS):** Encourage local research to identify resilient agricultural practices (AG 2.3); encourage farmers to select adaptable crop varieties (AG 2.5); and explore best practices from other communities facing similar agricultural challenges, including innovative diking technologies, growing practises in a changing climate,

etc. (AG 4.5); and from the BCS, encourage farmers to establish and protect riparian buffers on agricultural land that consider flood return levels (B-1.4); enhance dykelands with natural vegetation (trees, shrubs) in riparian areas adjacent to Nicomekl and Serpentine Rivers (B-1.6)

4. **Ecosystems and Natural Areas (CAS); Natural Areas Acquisition, Protection and Enhancement (BCS):** Identify and strategically acquire a diverse representation of ecosystem types as part of Surrey's parks and natural areas to enhance the Green Infrastructure Network (GIN), selling or trading low quality land outside the GIN where required (CAS - EC 1.2; BCS - A-3.2 & A-3.3); reduce habitat fragmentation by using and protecting the GIN (EC 1.3); enforce streamside setback standards to reduce erosion and optimize ecological health (EC 3.1); maintain stream flow affected by climate change (EC 3.3); Incorporate climate change into the City's Integrated Stormwater Management Plans (ISMPs) (EC 4.1);
5. **Planning and Development (BCS):** Create and maintain a biodiversity database to monitor change over time (A-1.7); consider incentives to restore degraded habitat during re-development (A-2.8).
6. **Green Building Standards (BCS):** Encourage developers to integrate natural biodiversity features (e.g. trees, wetlands) into development (A-4.1); Encourage use and implementation of natural drainage patterns, naturescaping, green infrastructure, and permeable surfaces to manage stormwater (A-4.6); naturalize existing and proposed stormwater detention ponds, ensure a naturalized terrestrial buffer, encourage creation of small wetlands (A-4.7).
7. **Climate Change and Biodiversity (BCS):** Preserve and restore ecosystems as an integral component of the City's climate change mitigation and adaptation strategy (C-1.2); Model and manage for predicted impacts of sea level rise to coastal foreshore and floodplain areas (C-1.3); and develop ecosystem-based adaptive strategies to manage for biodiversity and reduce dyke maintenance/construction costs associated with projected sea-level rise (C-1.4).

Additional goals and strategies supplied by the City of Surrey are provided in Appendix 1.

7.2 Current Initiatives - Nicomekl Riverfront Park Management Plan

Based on recommendations from the BCS and CAS, the City of Surrey has already begun to make strategic management decisions to reduce the impact of sea level rise. Surrey recently purchased a ~3km stretch of waterfront on the south bank of the Nicomekl River extending from Elgin Road east to 40th Avenue, making it Surrey's longest riverfront park. The Nicomekl Riverfront Park will begin to address recommendations from the CAS including EC 1.2 and 1.3 and BCS including A-3.2, A-4.6, and B-1.6 (see Appendix 1 for descriptions).

The consideration of flood risk has been a main driver behind purchasing the land and dedicating it as park land. Enhancement opportunities are being considered to provide additional and higher quality habitat for local species and to provide additional flooding capacity through the creation of wetlands and habitat islands. Recreational opportunities are being created away from the most sensitive habitats with features that are tolerant of flooding and focusing on highlighting local cultural and heritage through art and design elements.

Appendix 1 Selected Actions from City of Surrey Strategies

Strategy	Sub-Risk / Cause	Key goals identified to address impacts and increase resilience	Action / Strategy
CAS	Cross Cutting.	The following actions cut across all sectors of adaptation and are central to building a resilient community through policy integration, education, and community engagement.	CC - 0.1 Review City policies and by-laws to identify those practices that support resilience, and reinforce their implementation and enforcement.
CAS	Cross Cutting.	The following actions cut across all sectors of adaptation and are central to building a resilient community through policy integration, education, and community engagement.	CC - 0.2 Integrate climate change education and awareness into existing programs and communications, and develop new education initiatives where gaps exist for Surrey residents, businesses, and City Staff.
CAS	Cross Cutting.	The following actions cut across all sectors of adaptation and are central to building a resilient community through policy integration, education, and community engagement.	CC - 0.3 Engage residents and businesses on ways they can adapt or otherwise prepare for climate change impacts (e.g. promote sustainable drainage techniques, plant appropriate tree species, emergency preparedness).
CAS	Agriculture and Food Security.	Goal 1 - Provide Appropriate Infrastructure for Agricultural Viability (AG-1.1; AG-1.2; AG-1.3; AG-1.4).	AG 1.1 - Continue to improve lowland drainage and flood management infrastructure in keeping with the Lowland Flood Control Strategic Plan
CAS	Agriculture and Food Security.	Goal 1 - Provide Appropriate Infrastructure for Agricultural Viability (AG-1.1; AG-1.2; AG-1.3; AG-1.4).	AG 1.2 - Work with all levels of government to evaluate long-term flood management options in response to sea level rise impacts with considerations for agricultural vulnerability
CAS	Agriculture and Food Security.	Goal 1 - Provide Appropriate Infrastructure for Agricultural Viability (AG-1.1; AG-1.2; AG-1.3; AG-1.4).	AG 1.3 - Continue to enhance rainwater storage and stormwater management in all areas of Surrey, including agricultural areas
CAS	Agriculture and Food Security.	Goal 2 - Encourage Greater Diversity in Local Products and Growing Methods (AG-2.1; AG-2.2; AG-2.3; AG-2.4; AG-2.5).	AG 2.1 - Continue to work closely with the Federal Department of Fisheries and Oceans to protect fish habitat within the City
CAS	Agriculture and Food Security.	Goal 2 - Encourage Greater Diversity in Local Products and Growing Methods (AG-2.1; AG-2.2; AG-2.3; AG-2.4; AG-2.5).	AG 2.3 - Encourage local research to help identify resilient agricultural practices (e.g. mapping crop varieties to future climate scenarios; integrated pest management strategies, etc.)

CAS	Agriculture and Food Security.	Goal 2 - Encourage Greater Diversity in Local Products and Growing Methods (AG-2.1; AG-2.2; AG-2.3; AG-2.4; AG-2.5).	AG 2.5 - Encourage farmers to diversify crop selection and choose adaptable varieties (e.g. less dependent on irrigation, more resistant to saline soils)
CAS	Agriculture and Food Security.	Goal 3 - Increase Food Self-Sufficiency in the City and Region AG-3.1; AG-3.2; AG-3.3; AG-3.4; AG-3.5; AG-3.6; AG-3.7).	AG 3.4 - Encourage local research on the types and quantity of crops needed to increase self-sufficiency AG
CAS	Agriculture and Food Security.	Goal 3 - Increase Food Self-Sufficiency in the City and Region AG-3.1; AG-3.2; AG-3.3; AG-3.4; AG-3.5; AG-3.6; AG-3.7).	AG 3.5 - Encourage the restoration of pollinator-friendly habitat and housing of apiaries on private and public lands, where practical
CAS	Agriculture and Food Security.	Goal 4 - Help Farmers Build Capacity to Adapt (AG-4.1; AG-4.2; AG-4.3; AG-4.4).	AG 4.2 - Manage urban-rural interface relations as agricultural practices change and adapt
CAS	Agriculture and Food Security.	Goal 4 - Help Farmers Build Capacity to Adapt (AG-4.1; AG-4.2; AG-4.3; AG-4.4).	AG 4.3 - Explore and support best practices from other global communities that currently face challenges our agricultural system may face in the future (e.g. innovative dyking technologies, growing practices in warmer/dryer climates, etc.)
CAS	Ecosystems and Natural Areas.	Goal 1 - Optimize Space for Habitat and Species Migration (EC-1.1; EC-1.2; EC-1.3; EC-1.4).	EC 1.2 - Strategically acquire a diverse representation of ecosystem types as part of Surrey's parks and natural areas
CAS	Ecosystems and Natural Areas.	Goal 1 - Optimize Space for Habitat and Species Migration (EC-1.1; EC-1.2; EC-1.3; EC-1.4).	EC 1.3 - Reduce habitat fragmentation by using and protecting a comprehensive network of corridors and larger natural areas (hubs and sites)
CAS	Ecosystems and Natural Areas.	Goal 1 - Optimize Space for Habitat and Species Migration (EC-1.1; EC-1.2; EC-1.3; EC-1.4).	EC 1.4 - Increase public awareness, capacity, and the use of planning tools (e.g. voluntary conservation easements) to create higher habitat values on private property.
CAS	Ecosystems and Natural Areas.	Goal 2 - Actively Manage Ecological Assets (EC-2.1; EC-2.2; EC-2.3; EC-2.4; EC-2.5; EC-2.6).	EC 2.1 - Increase active management of City controlled natural areas (e.g. removal of invasive species), and encourage more active management of natural areas on Provincial, Regional, non-profit and privately owned lands
CAS	Ecosystems and Natural Areas.	Goal 2 - Actively Manage Ecological Assets (EC-2.1; EC-2.2; EC-2.3; EC-2.4; EC-2.5; EC-2.6).	EC 2.2 - Implement evolving best practices for ecosystem management in a changing climate
CAS	Ecosystems and Natural Areas.	Goal 2 - Actively Manage Ecological Assets (EC-2.1; EC-2.2; EC-2.3; EC-2.4; EC-2.5; EC-2.6).	EC 2.3 - Consider assisted migration for species whose dispersion rate is unable to keep pace with climate change (e.g. planting tree species historically suited to more Southern climates)
CAS	Ecosystems and Natural Areas.	Goal 2 - Actively Manage Ecological Assets (EC-2.1; EC-2.2; EC-2.3; EC-2.4; EC-2.5; EC-2.6).	EC 2.4 - Increase tree risk management to minimize damage and liability from dead or dying trees

CAS	Ecosystems and Natural Areas.	Goal 2 - Actively Manage Ecological Assets (EC-2.1; EC-2.2; EC-2.3; EC-2.4; EC-2.5; EC-2.6).	EC 2.5 - Partner with key organizations and the private sector to limit the sale of invasive species and promote adaptable species at local nurseries
CAS	Ecosystems and Natural Areas.	Goal 2 - Actively Manage Ecological Assets (EC-2.1; EC-2.2; EC-2.3; EC-2.4; EC-2.5; EC-2.6).	EC 2.6 - Incorporate climate change messaging in environmental education efforts, and continue to engage the public in stewardship initiatives
CAS	Ecosystems and Natural Areas.	Goal 3 - Support Viability of Highly Sensitive Ecosystems (EC-3.1; EC-3.2; EC-3.3; EC-3.4; EC-3.5).	EC 3.1 - Apply Surrey standards for streamside setbacks to accommodate potential erosion and optimize ecological health
CAS	Ecosystems and Natural Areas.	Goal 3 - Support Viability of Highly Sensitive Ecosystems (EC-3.1; EC-3.2; EC-3.3; EC-3.4; EC-3.5).	EC 3.2 - Establish Development Permit Area Guidelines for sensitive ecosystems
CAS	Ecosystems and Natural Areas.	Goal 3 - Support Viability of Highly Sensitive Ecosystems (EC-3.1; EC-3.2; EC-3.3; EC-3.4; EC-3.5).	EC 3.3 - Implement strategies to maintain stream flow affected by changing temperature and precipitation patterns
CAS	Ecosystems and Natural Areas.	Goal 3 - Support Viability of Highly Sensitive Ecosystems (EC-3.1; EC-3.2; EC-3.3; EC-3.4; EC-3.5).	EC 3.4 - Promote the development of regional cost/benefit analyses of sea level rise and flood management options that considers ecological values and protection of property and infrastructure
CAS	Ecosystems and Natural Areas.	Goal 3 - Support Viability of Highly Sensitive Ecosystems (EC-3.1; EC-3.2; EC-3.3; EC-3.4; EC-3.5).	EC 3.5 - Evaluate options for installing physical interventions to support ecosystems (e.g. construction of a breakwater)
CAS	Ecosystems and Natural Areas.	Goal 4 - Protect Ecosystem Services Through Development (EC-4.1; EC-4.2; EC-4.3; EC-4.4).	EC 4.1 - Incorporate climate change into the City's Integrated Stormwater Management Plans (ISMPs) and other efforts to integrate land use planning and stormwater management
CAS	Ecosystems and Natural Areas.	Goal 4 - Protect Ecosystem Services Through Development (EC-4.1; EC-4.2; EC-4.3; EC-4.4).	EC 4.4 - Review landscape and design guidelines to ensure they support habitat values
CAS	Flood Management & Drainage.	Goal1 - Reach Consensus on a Regional Approach to Flood Management (FL-1.1; FL-1.2; FL-1.3).	FL-1.1 Support the development of a Regional Flood Management Strategy in coordination with senior levels of government, other municipalities, and key stakeholders
CAS	Flood Management & Drainage.	Goal1 - Reach Consensus on a Regional Approach to Flood Management (FL-1.1; FL-1.2; FL-1.3).	FL-1.2 Participate in a detailed cost-benefit analysis to assess alternative options for accommodating sea level rise and coastal climate change impacts
CAS	Flood Management & Drainage.	Goal1 - Reach Consensus on a Regional Approach to Flood Management (FL-1.1; FL-1.2; FL-1.3).	FL-1.3 Encourage senior levels of government to proactively commit the capital investment for flood protection infrastructure

CAS	Flood Management & Drainage.	Goal 2 - Update Planning and Development Standards for Floodplains (FL-2.1; FL-2.2; FL-2.3; FL-2.4).	FL-2.1 Conduct detailed analysis on Surrey-specific climate impacts, including the timelines and extent of sea level rise and its related effects on flood construction levels and floodplain designations
CAS	Flood Management & Drainage.	Goal 2 - Update Planning and Development Standards for Floodplains (FL-2.1; FL-2.2; FL-2.3; FL-2.4).	FL-2.2 Develop drainage and flood control strategies based on cost-benefit analyses and site-specific needs
CAS	Flood Management & Drainage.	Goal 2 - Update Planning and Development Standards for Floodplains (FL-2.1; FL-2.2; FL-2.3; FL-2.4).	FL-2.3 Incorporate climate change into the City's Integrated Stormwater Management Plans (ISMPs) and other efforts to integrate land use planning and storm water management
CAS	Flood Management & Drainage.	Goal 2 - Update Planning and Development Standards for Floodplains (FL-2.1; FL-2.2; FL-2.3; FL-2.4).	FL-2.4 Review and revise regulatory by-laws and design standards to account for and minimize the impacts of climate change
CAS	Human Health and Safety.	Goal 1 - Collaborate with Key Partners on Improving Population Health (HS-1.1; HS-1.2; HS-1.3; HS-1.4).	HS 1.2 - Encourage health agencies and research institutions to anticipate, monitor and reduce the impact of climate change on the spread of infectious disease
CAS	Human Health and Safety.	Goal 1 - Collaborate with Key Partners on Improving Population Health (HS-1.1; HS-1.2; HS-1.3; HS-1.4).	HS 1.3 - Work with key partners to integrate climate change messaging into communication materials related to public health and safety
CAS	Human Health and Safety.	Goal 1 - Collaborate with Key Partners on Improving Population Health (HS-1.1; HS-1.2; HS-1.3; HS-1.4).	HS 1.4 - Work with health agencies to better identify and respond to the needs of vulnerable populations specific to climate-related health risks
CAS	Human Health and Safety.	Goal 2 - Minimize the Urban Heat Island Effect (HS-2.1; HS-2.2; HS-2.3; HS-2.4; HS-2.5; HS-2.6; HS-2.7).	HS 2.4 - Explore opportunities for green roofs and walls on institutional, commercial, industrial and large residential development
CAS	Human Health and Safety.	Goal 2 - Minimize the Urban Heat Island Effect (HS-2.1; HS-2.2; HS-2.3; HS-2.4; HS-2.5; HS-2.6; HS-2.7).	HS 2.7 - Increase the use of high albedo (i.e. light coloured, reflective) surfaces on buildings and pavings
CAS	Human Health and Safety.	Goal 4 - Build Emergency Response Capacity at the City (HS-4.1; HS-4.2; HS-4.3; HS-4.4).	HS 4.1 - Continue to build community capacity to respond effectively in an emergency (i.e. neighbours helping neighbours)
CAS	Human Health and Safety.	Goal 4 - Build Emergency Response Capacity at the City (HS-4.1; HS-4.2; HS-4.3; HS-4.4).	HS 4.3 - Look at gaps in emergency prevention and response, taking into account climate change impacts
CAS	Human Health and Safety.	Goal 4 - Build Emergency Response Capacity at the City (HS-4.1; HS-4.2; HS-4.3; HS-4.4).	HS 4.4 - Ensure emergency response capacity keeps pace with the need for services, given increasing climate impacts
CAS	Infrastructure.	Goal 1 - Deliver Proactive Climate Analysis and Management Practices for City Infrastructure (IN-1.1; IN-1.2; IN-1.3; IN-1.4; IN-1.5; IN-1.6).	IN 1.1 - Enhance data collection and monitoring for climate impacts in Surrey (e.g. storm events, precipitation patterns, subsidence rates, changes in water quality, etc.)

CAS	Infrastructure.	Goal 1 - Deliver Proactive Climate Analysis and Management Practices for City Infrastructure (IN-1.1; IN-1.2; IN-1.3; IN-1.4; IN-1.5; IN-1.6).	IN 1.2 - Regularly review design requirements to ensure that they adequately account for expected weather conditions due to climate change
CAS	Infrastructure.	Goal 1 - Deliver Proactive Climate Analysis and Management Practices for City Infrastructure (IN-1.1; IN-1.2; IN-1.3; IN-1.4; IN-1.5; IN-1.6).	IN 1.3 - Assess existing City infrastructure and utilities for vulnerability to climate change
CAS	Infrastructure.	Goal 1 - Deliver Proactive Climate Analysis and Management Practices for City Infrastructure (IN-1.1; IN-1.2; IN-1.3; IN-1.4; IN-1.5; IN-1.6).	IN 1.4 - Integrate climate change into the 10 year capital and servicing plans of relevant departments
CAS	Infrastructure.	Goal 1 - Deliver Proactive Climate Analysis and Management Practices for City Infrastructure (IN-1.1; IN-1.2; IN-1.3; IN-1.4; IN-1.5; IN-1.6).	IN 1.6 - Monitor and manage species composition and selection to enhance resilience of Surrey's Green Infrastructure Network
CAS	Urban Trees and Landscaping.	Goal 1 - Provide the Required Growing Environment to Sustain Trees (TR-1.1; TR-1.2).	TR 1.2 - Utilize City by-laws, standards, and permitting processes to optimize soil conditions for shade trees on public and private property (e.g. soil quality, quantity and moisture content)
CAS	Urban Trees and Landscaping.	Goal 2 - Plant Appropriate Species (TR-2.1; TR-2.2; Tr-2.3; TR-2.4).	TR 2.1 - Select tree species and planting stock from provenances that will be well adapted to Surrey's future climate projections, particularly with respect to temperature and drought increases
CAS	Urban Trees and Landscaping.	Goal 2 - Plant Appropriate Species (TR-2.1; TR-2.2; Tr-2.3; TR-2.4).	TR 2.2 - Monitor survival rate of trees planted on public property to confirm species suitability over time
CAS	Urban Trees and Landscaping.	Goal 2 - Plant Appropriate Species (TR-2.1; TR-2.2; Tr-2.3; TR-2.4).	TR 2.3 - Increase the species diversity of shade trees on public and private property
CAS	Urban Trees and Landscaping.	Goal 2 - Plant Appropriate Species (TR-2.1; TR-2.2; Tr-2.3; TR-2.4).	TR 2.3.b - Increase the species diversity of shade trees on public and private property
CAS	Urban Trees and Landscaping.	Goal 2 - Plant Appropriate Species (TR-2.1; TR-2.2; Tr-2.3; TR-2.4).	TR 2.4 - Develop an educational resource that encourages residents to plant trees which enhance species diversity (e.g. an annual "feature tree" pamphlet)
CAS	Urban Trees and Landscaping.	Goal 3 - Increase Tree Maintenance Management (TR-3.1; TR-3.2; TR-3.3; TR-3.4).	TR 3.1 - Increase tree replacement and maintenance activities (such as watering) to sustain trees, as necessary
CAS	Urban Trees and Landscaping.	Goal 3 - Increase Tree Maintenance Management (TR-3.1; TR-3.2; TR-3.3; TR-3.4).	TR 3.2 - Anticipate a growing need for tree risk assessments and abatement due to tree decline and mortality
CAS	Urban Trees and Landscaping.	Goal 3 - Increase Tree Maintenance Management (TR-3.1; TR-3.2; TR-3.3; TR-3.4).	TR 3.2b - Anticipate a growing need for tree risk assessments and abatement due to tree decline and mortality
CAS	Urban Trees and Landscaping.	Goal 3 - Increase Tree Maintenance Management (TR-3.1; TR-3.2; TR-3.3; TR-3.4).	TR 3.3 - Undertake a Pest Threat Assessment to better understand the risks to trees and ecosystems posed by changing disease vectors and invasive species
BSC	A. PLANNING AND DEVELOPMENT	A-1 BIODIVERSITY CONSERVATION STRATEGY IMPLEMENTATION	A-1.1 Integrate recommendations of the Biodiversity Conservation Strategy into the Official Community Plan and other relevant documents;

BSC	A. PLANNING AND DEVELOPMENT	A-1 BIODIVERSITY CONSERVATION STRATEGY IMPLEMENTATION	A-1.3 Work with neighbouring municipal partners and provincial and federal agencies to support biodiversity initiatives;
BSC	A. PLANNING AND DEVELOPMENT	A-1 BIODIVERSITY CONSERVATION STRATEGY IMPLEMENTATION	A-1.5 Develop training programs in relevant municipal departments to raise awareness of new biodiversity objectives;
BSC	A. PLANNING AND DEVELOPMENT	A-1 BIODIVERSITY CONSERVATION STRATEGY IMPLEMENTATION	A-1.7 Create and maintain a biodiversity database which should include habitat mapping and population surveys of identified indicator species to monitor change over time; Host an annual "bioblitz" to develop this database; Develop a bird monitoring program in coordination with community volunteers that integrates annual Christmas Bird Count data and a Summer Bird Count;
BSC	A. PLANNING AND DEVELOPMENT	A-1 BIODIVERSITY CONSERVATION STRATEGY IMPLEMENTATION	A-1.9 Incorporate the United Nations' City Biodiversity Index (when completed) to provide a global comparison of Surrey's biodiversity efforts;
BSC	A. PLANNING AND DEVELOPMENT	A-2 DEVELOPMENT PLANNING, OPPORTUNITIES, PERMIT AREAS AND MONITORING	A-2.1 Review all development applications to ensure they meet the objectives of the Biodiversity Management Area;
BSC	A. PLANNING AND DEVELOPMENT	A-2 DEVELOPMENT PLANNING, OPPORTUNITIES, PERMIT AREAS AND MONITORING	A-2.7 Implement measures to improve wildlife crossings within the GIN network to facilitate movement and reduce traffic mortality;
BSC	A. PLANNING AND DEVELOPMENT	A-2 DEVELOPMENT PLANNING, OPPORTUNITIES, PERMIT AREAS AND MONITORING	A-2.8 Consider incentives to restore degraded habitat during re-development;
BSC	A. PLANNING AND DEVELOPMENT	A-2 DEVELOPMENT PLANNING, OPPORTUNITIES, PERMIT AREAS AND MONITORING	A-2.9 Establish canopy cover targets for different land uses that will contribute towards the City wide goal of 40%;
BSC	A. PLANNING AND DEVELOPMENT	A-3 NATURAL AREAS ACQUISITION, PROTECTION AND ENHANCEMENT	A-3.1 Designate appropriate City-owned land within the GIN as protected;
BSC	A. PLANNING AND DEVELOPMENT	A-3 NATURAL AREAS ACQUISITION, PROTECTION AND ENHANCEMENT	A-3.2 Identify priority natural areas for acquisition as part of GIN;
BSC	A. PLANNING AND DEVELOPMENT	A-3 NATURAL AREAS ACQUISITION, PROTECTION AND ENHANCEMENT	A-3.3 Identify opportunities to sell City-owned land outside of the GIN and acquire higher priority land that can be integrated into GIN;
BSC	A. PLANNING AND DEVELOPMENT	A-3 NATURAL AREAS ACQUISITION, PROTECTION AND ENHANCEMENT	A-3.5 Work with land trusts and private landholders to establish voluntary conservation easements on private land;
BSC	A. PLANNING AND DEVELOPMENT	A-4 GREEN BUILDING STANDARDS	A-4.1 Explore incentives for and encourage developers to integrate natural biodiversity features (e.g. trees, wetlands) into development; Incorporate a Biodiversity Checklist (Appendix G) that will require developers to achieve a specified biodiversity target, but permit flexibility in how this can be achieved

BSC	A. PLANNING AND DEVELOPMENT	A-4 GREEN BUILDING STANDARDS	A-4.3 Maintain an updated list of recognized invasive plant species and prohibit them from use in all development landscaping;
BSC	A. PLANNING AND DEVELOPMENT	A-4 GREEN BUILDING STANDARDS	A-4.4 Incorporate targets for biodiversity such as tree cover, naturescaping and wildlife movement into applicable City Standards and Guidelines related to landscaping;
BSC	A. PLANNING AND DEVELOPMENT	A-4 GREEN BUILDING STANDARDS	A-4.6 Encourage use and implementation of natural drainage patterns, naturescaping, green infrastructure, permeable surfaces, sustainable drainage features, and Low Impact Development (LID) to manage stormwater and support biodiversity objectives;
BSC	A. PLANNING AND DEVELOPMENT	A-4 GREEN BUILDING STANDARDS	A-4.7 Naturalize existing and proposed stormwater detention ponds where possible to enhance habitat value; ensure a naturalized terrestrial buffer; Encourage creation of small wetlands associated with open drainage features;
BSC	A. PLANNING AND DEVELOPMENT	A-4 GREEN BUILDING STANDARDS	A-4.9 Promote salvage of native plants and topsoil from greenfield development sites for use in restoration and enhancement projects to support genetic diversity and local seed sources;
BSC	A. PLANNING AND DEVELOPMENT	A-4 GREEN BUILDING STANDARDS	A-4.11 Implement biodiversity strategies for active parks. Include hedgerows and canopy cover guidelines for playfields, parking lots and landscaped areas;
BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.1 Work with farming community to encourage sustainable farming practices that support food production and provide free ecosystem services (i.e. crop diversity, habitat, carbon sequestration, flood risk mitigation);
BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.2 Work with local farmers and conservationists to find ways to improve stewardship on agricultural land. Integrate and coordinate with existing agricultural programs such as the Environmental Farm Plan, Code of Agricultural Practice, Agricultural Building Setback Standards, Delta Farmland & Wildlife Trust
BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.4 Encourage farmers to establish and protect riparian buffers on agricultural land that consider flood return levels;
BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.5 Work with farm community to sustainably manage temporal and geographic distribution of fallow fields to support biodiversity, particularly migratory birds;
BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.6 Investigate potential to enhance dykelands with natural vegetation (trees, shrubs) in riparian areas adjacent to Nicomekl and Serpentine Rivers, while recognizing provincial guidelines and dyke maintenance requirements;
BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.7 Protect integrity of existing dykes; however, explore opportunities to widen the channel for re-vegetation and habitat enhancement;
BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.8 Explore incentives for private land holders to retain forest and natural habitat on non-arable land;

BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.9 Ensure windfirm forested and landscape buffers adjacent to the ALR boundary;
BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.10 Encourage hedgerows, where appropriate, adjacent to fields and row crops;
BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.11 Ensure that fencing in and around agricultural areas allows for wildlife passage in key areas;
BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.12 Develop an outreach program that teaches ecological design principles for field drainage systems and ponds. Work with farmers to retain, enhance and create wetlands in areas prone to seasonal flooding;
BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.13 Identify and protect key groundwater recharge areas, and aquifers that contribute groundwater to open channels during the summer
BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.15 Implement a program to support increased native bee production and pollination;
BSC	B. AGRICULTURAL AREAS	B-1. AGRICULTURAL BIODIVERSITY	B-1.16 Work with local farmers to restrict livestock access to natural watercourses;
BSC	C. CLIMATE CHANGE	C.1 CLIMATE CHANGE AND BIODIVERSITY	C-1.2 Preserve and restore ecosystems as an integral component of the City's climate change mitigation and adaptation strategy, particularly with regard to carbon sequestration and floodwater management;
BSC	C. CLIMATE CHANGE	C.1 CLIMATE CHANGE AND BIODIVERSITY	C-1.3 Model and manage for predicted impacts of sea level rise to coastal foreshore and floodplain areas;
BSC	C. CLIMATE CHANGE	C.1 CLIMATE CHANGE AND BIODIVERSITY	C-1.4 Develop ecosystem-based adaptive strategies to manage for biodiversity and reduce dyke maintenance/construction costs associated with projected sea-level rise;

Appendix 2 NHC Sediment Movement Report

nhc
northwest hydraulic consultants ltd

NHC Ref. No. 3004517

25 March 2019

CITY OF SURREY
Engineering Department, Utilities Division
4th Floor, 13450 104 Ave, Surrey BC
V3T 1V8

Attention: **Matt Osler, P.Eng.**
Project Engineer

Via email: mfosler@surrey.ca

Re: **Prioritizing Infrastructure and Ecosystem Risk (PIER) Framework for Environmental Vulnerability**
Preliminary Analysis of Sediment Transport within Mud Bay – Final Report

Dear Mr. Osler:

As requested, we have conducted a review of the report *Prioritizing Infrastructure and Ecosystem Risk (PIER) Framework for Environmental Vulnerability* prepared by Diamond Head Consulting and offer the enclosed preliminary analysis of sediment transport within Mud Bay as it relates to the proposed ecosystem mitigation strategies.

1 INTRODUCTION

Sea level rise is anticipated to impact ecosystem functions within Mud Bay. As part of the Coastal Flood Adaptation Strategy (CFAS), the City of Surrey is assessing potential environmental impacts and exploring mitigation options that would seek to preserve ecosystem health and function. Two of the proposed mitigation options outlined in the report *Prioritizing Infrastructure and Ecosystem Risk (PIER) Framework for Environmental Vulnerability* (to which this analysis will be appended) – promoting sediment retention and building green infrastructure – are examined in the context of sedimentation rates and the wave environment. The purpose of this letter report is to present a conceptual-level analysis of sedimentation rates and the wave environment that would be required to achieve the overall goals of: a) promoting vertical accretion of the inter-tidal portions of Mud Bay at a rate that will keep pace with the expected rise in sea level, and b) creating a softer shoreline to retain ecological function.

2 SEDIMENT RETENTION

One mitigation option that has been identified is to promote sediment retention within various inter-tidal portions of Mud Bay. Promoting sediment retention in order for vertical accretion to keep pace with sea level rise could potentially help maintain similar sediment exposure areas and time to mitigate the impacts of loss of exposure time for foraging in the mud flats (Section 6.1), loss of eelgrass communities (Section 6.2), and loss of intertidal habitat (Section 6.3). A conceptual-level consideration of geomorphic processes and the sedimentary condition of Mud Bay allows for some of the requirements associated with this mitigation option to be quantified.

2.1 Order of Magnitude Estimates

As a first step, a calculation was performed to obtain an order of magnitude estimate of the volume of sediment required to maintain similar sediment exposure as sea level rises in Mud Bay. Section 6.1 states that a possible mitigation strategy is to promote the retention of sediment, with a goal "to promote the accumulation of sediment at a similar rate as sea level rise". The City of Surrey is planning for 1 m of sea level rise by 2100.

The rate of projected sea level rise used in the BC Ministry of Environment Climate Change Adaptation Guidelines (Ausenco-Sandwell, 2011) is not expected to be linear; however, for the purpose of this analysis, NHC used a linear function to calculate a projected annual sea level rise of 1.25 cm/year (based on 1 m rise over the next 80 years). 2013 air photos were used to estimate the area occupied by salt marshes in Mud Bay (Figure 2.1) as well as the area of inter-tidal mudflats within Mud Bay that are not coincident with existing tidal channels (Figure 2.2).

These relatively extensive areas of the inter-tidal zone were considered in this preliminary analysis because they provide insight into the scale of this mitigation option; and, because alternative approaches, such as focusing on smaller localized areas to apply sediment, might result in unanticipated consequences in the tidal flat system. For example, promoting sediment accumulation in a localized area only would raise the elevation of that area relative to its surroundings, which could lead to slope steepening and increased susceptibility for erosion. If sediment is retained over large parts of Mud Bay, this reduces the limitations of local steepening on sediment retention.

From a purely geometrical perspective, in order for the salt marshes of Mud Bay to accrete vertically at the same rate as sea level rise, approximately 4,000 m^3 of sediment would need to be retained annually. To promote this rate of vertical accretion throughout the entire Mud Bay area, excluding the distributaries from the Serpentine and Nicomekl Rivers, approximately 100,000 m^3 would need to be retained annually. The present rate of sediment accumulation has not been quantified, so these volumes do not account for natural sources of sediment.

Figure 2.1 Approximate salt marsh extent in Mud Bay based on 2013 air photos.

Figure 2.2 Approximate inter-tidal area of Mud Bay.

This calculation of sediment volumes is purely based on geometry to give a sense of order of magnitude. It does not consider compaction, subsidence, or the relationship between grain size and wave energy, each of which would have a substantial impact on the amount of sediment required to be delivered to the inter-tidal area to achieve the required vertical accretion rates. The processes of compaction and subsidence, as well as losses of sediment to deep (sub-tidal) water would require a much greater volume of sediment. Additionally, sediment deposition is dependent on wave energy. Wave energy is greater further offshore where the average water depth is greater and decreases moving towards the shoreline as the average water depth decreases. Consequently, grain size fining occurs in the inland direction, in which larger grain sizes are ultimately deposited further offshore where wave energy is higher and smaller grain sizes are carried closer to the shoreline where wave energy is lower. The location where sediment delivered to Mud Bay is ultimately deposited is dependent on the wave environment, which is subject to change due to sea level rise.

2.2 Sedimentary Condition of Mud Bay

There are three primary contemporary sediment sources to Mud Bay: silt and clay delivered by the Serpentine and Nicomekl Rivers; sediment transported into the bay by longshore drift; and cliff erosion via wave action (Government of Canada, 1998; Kellerhals and Murray, 1969). The volume of sediment delivered by each of these sources is unknown; however, contemporary sediment sources represent a very small fraction of the existing sediment in Mud Bay. The majority of sediment in Mud Bay was deposited between 10,000 and 5,000 years ago, following the last glaciation. NHC's (2018) Mud Bay Coastal Geomorphology Study Draft Report suggests that over the last few years, Mud Bay has been relatively stable with respect to sedimentation and that over the last few decades, the majority of detectable changes that Mud Bay has experienced can be attributed to discrete anthropogenic disturbances. In the absence of a reliable estimate of the volume of new sediment inputs to Mud Bay, it has been assumed that the mitigation strategy would need to include a plan for importing up to 100,000 m^3 of sediment annually.

2.3 Fraser River Dredgeate

Dredgeate from the Fraser River could be a possible source of sediment to be placed at Mud Bay. Each year, sediment is dredged from the Fraser River and some of this sediment is sold and some is disposed of in deep water ocean disposal sites. It is possible that some of the sediment that is typically disposed of in the ocean could instead be delivered to Mud Bay as a sediment source. Between 1997/1998 and 2006/2007, the volume of sand dredged from the Fraser River annually, averaged over the ten-year period of record, was approximately 2,000,000 m^3 per year (FREMP, 2007). In 2006/2007, approximately 80% of dredged sand was taken to upland sites and less than 20% was disposed of in the ocean (FREMP, 2007). If this same ratio of 80:20 is applied to the average annual volume of dredgeate, this leaves approximately 400,000 m^3 of dredged material disposed into the ocean annually. The geometry-based estimated volume of sediment (100,000 m^3) required annually to match the rate of sea level rise in Mud Bay represents roughly 25% of the average volume of dredgeate (400,000 m^3) disposed of annually. Although these calculations are based on average values, the volume of sediment dredged varies each year.

Placing dredgeate from the Fraser River in Mud Bay would also require other considerations, including determining the suitable sediment grain size, predicting sediment migration under waves and currents, predicting ecological response, and navigating the regulatory process. The dredged material that is disposed of at sea is typically comprised of fine sand and finer materials; however, the sediment in Mud

Bay includes finer grain sizes, primarily silty sand in the western part of Mud Bay and clay-sized sediment in the eastern part of Mud Bay.

3 GREEN INFRASTRUCTURE

A second proposed mitigation option is to build green infrastructure to mitigate the loss of intertidal habitat (Section 6.3). It is important to consider sedimentation, as described above, as well as the wave environment in designing green infrastructure.

3.1 Wave Environment

Creating a softer shoreline can include promoting coastal vegetation in front of a dike to help reduce wave heights for flood protection while also supporting important ecological functions. This could involve promoting the expansion of existing coastal vegetation or establishing new coastal vegetation. Wave energy can impact sedimentation rates, which could affect the expansion and survival of coastal vegetation. Additionally, wave energy can impact how much erosion green infrastructure must be designed to withstand.

Based on SWAN modelling of wave heights, NHC (2012) found that wave heights and periods are expected to increase in 2100 compared to 2010 in some locations in the Boundary Bay area due to greater water depths with sea level rise. However, the modelling shows that in some cases wave height is not expected to increase between 2010 and 2100 because there are some locations where wind speed and fetch limit wave height more than depth (NHC, 2012). The local wave environment would therefore need to be considered in designing green infrastructure.

3.2 Adaptive Management

Instituting measures to promote sediment retention across the landscape of Mud Bay represents a large-scale effort and can be expected to modify the existing sediment transport dynamics, which in turn will be undergoing change induced by rising sea levels. An adaptive management approach is an increasingly accepted way to manage projects in complex and dynamic environments, applying the scientific concepts of ongoing data collection and analysis to monitor the response in the environment, and using those results to update the proposed management actions accordingly. Adaptive management also has a public and regulatory interaction, providing assurances to both that projects that may be perceived as "risky" can be managed appropriately.

A common element of an adaptive management approach is to carry out a pilot project as an initial proof of concept. An example of a pilot project in Mud Bay would be to apply sediment over a relatively small section of shoreline in which sediment is delivered via rail to promote sediment retention. The results from such a pilot project would inform later phases that consider larger scale mitigation plans, which might involve delivering dredgeate to a larger area via barge.

Some factors to consider in planning a pilot project along the shoreline in Mud Bay include identifying a suitable location for the pilot project, identifying a suitable volume of sediment, and identifying an appropriate sediment source. Monitoring would also be required so that the findings from the pilot project could be integrated into the planning of the next mitigation stage.

The selection of a location for the pilot project would need to consider several factors, including accessibility, existing vegetation, vulnerability, shoreline type, and significant wave height. Based on these criteria a section of shoreline along the conservation water lot in the southern part of Mud Bay has been identified as a suitable location for a pilot project (**Figure 3.1**). The BNSF railway runs along the shoreline at this location, so sediment could conceivably be transported to this location via rail and then delivered to the foreshore. Since this section of shoreline has an unvegetated bench, the risk of smothering existing vegetation is reduced. This section of shoreline is not armoured so it is comparatively more vulnerable than armoured areas and could stand to benefit from sediment retention to help mitigate the impacts of sea level rise. The significant wave height in this area is relatively low since this area is quite protected (Stantec Engineering, 2016). A pilot project at this site will therefore not be representative of all shoreline segments in Mud Bay but the results can be used to inform future projects at more exposed locations.

The lessons learned from the pilot project, and the trust earned by regulators and the public will inform subsequent projects that would be expected to have a large extent. One possible next step would be to deliver dredgeate sourced from the Fraser River dredging program to Mud Bay and place it over a larger area. The dredgeate would be most economically transported by barge to a location within the sub-tidal waters (water depth is a limiting factor for the barge in the intertidal area due to safety considerations) and pumped to a location further inshore. The receiving site (or sites) would be chosen as part of an overall plan that considers long-term dispersal to the foreshore via wind-generated waves and currents. Consequently, the wind and wave climate would have a big impact in the selection of a location for sediment delivery.

Figure 3.1 Shoreline classifications developed by Golder and Associates (2018) and potential location for pilot project.

3.3 References

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DISCLAIMER

Sincerely,

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25 March 2019

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Appendix 3 DHC Environmental Inventory Report

CITY OF SURREY

Surrey Flood Protection – Preliminary Habitat Impact Assessment Report

November 20, 2018

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1.0 Project Scope and Overview

Surrey's low elevation floodplains are home to a variety of natural habitats that house a rich diversity of plants, wildlife, invertebrates and other organisms. In addition to some of the Lower Mainland's most productive farmland, this area also supports young forests, fallow grass and shrub, intertidal areas, freshwater rivers and lakes and wetlands. The Nicomekl River, Serpentine River, and Little Campbell River are the major drainage systems in this area, all flowing into Boundary Bay, a globally recognized Important Bird Area (IBA). Together, these habitats support a great diversity of species, some of which are "at-risk" in British Columbia.

Surrey's original dyke system was constructed at a period coinciding with the early stages of agricultural and residential development in the City. Construction of these dykes permanently altered natural ecosystems in the area. Now, climate change is necessitating further changes to the dyke system to manage expected sea level rise over the next 100 years. This report provides a baseline analysis of the habitat types and biodiversity in Surreys lowland floodplains, agricultural areas and Mud Bay. This information can be used to assess the impact of proposed flood protection works and potential changes to existing habitat and associated species.

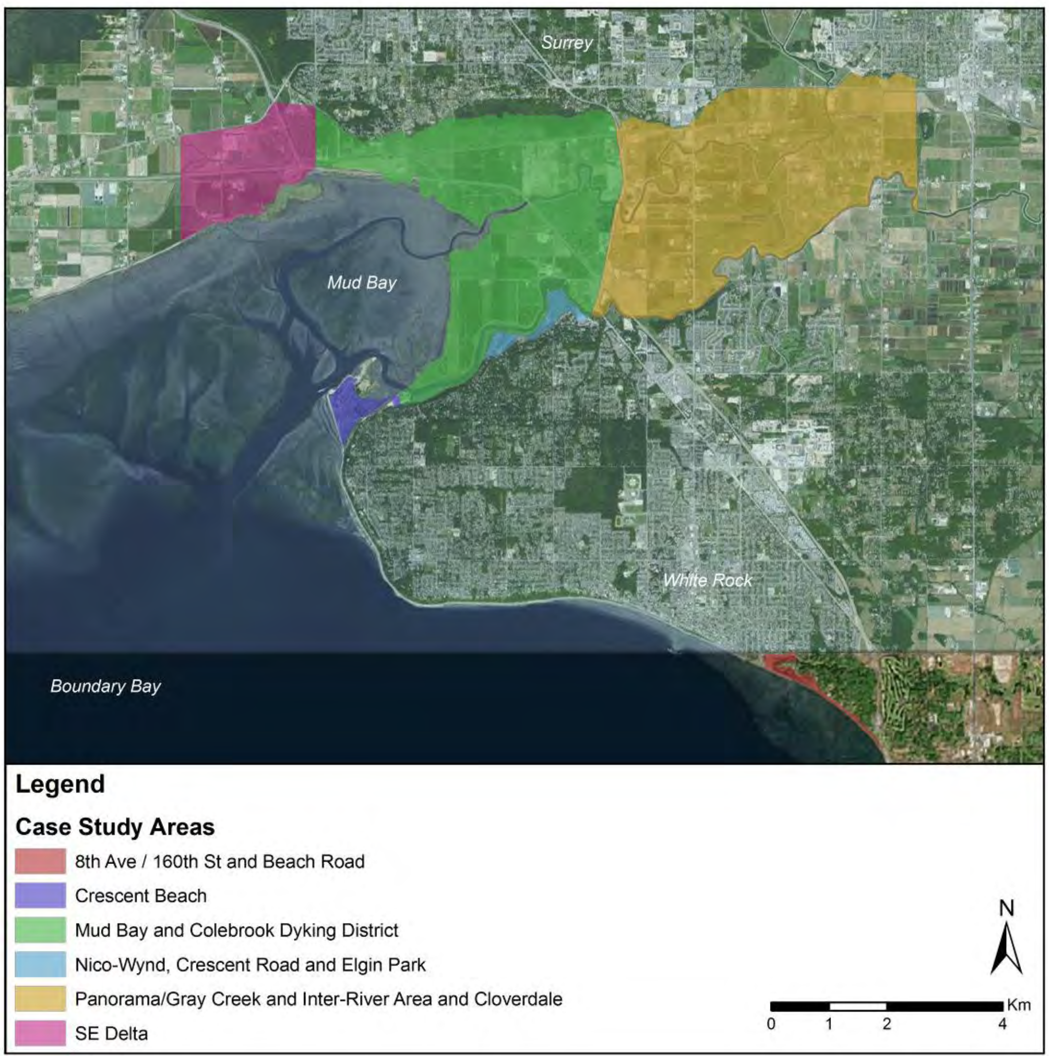

Figure 1: Map of study area.

2.0 Habitat Analysis

2.1 Habitat Types

Twelve general habitat types were defined in the study area, based on the City of Surrey Biodiversity Conservation Strategy (BCS, 2014). For the purposes of this review, some specific sub-types were combined to form more generalized types (e.g. “Agriculture Herb and Grass” and “Agricultural Row Crops” were combined into a single “Agriculture” type). The Province of British Columbia iMap Shoreline Units were used to delineate and classify marine areas. Habitat types are illustrated in Figure 2.

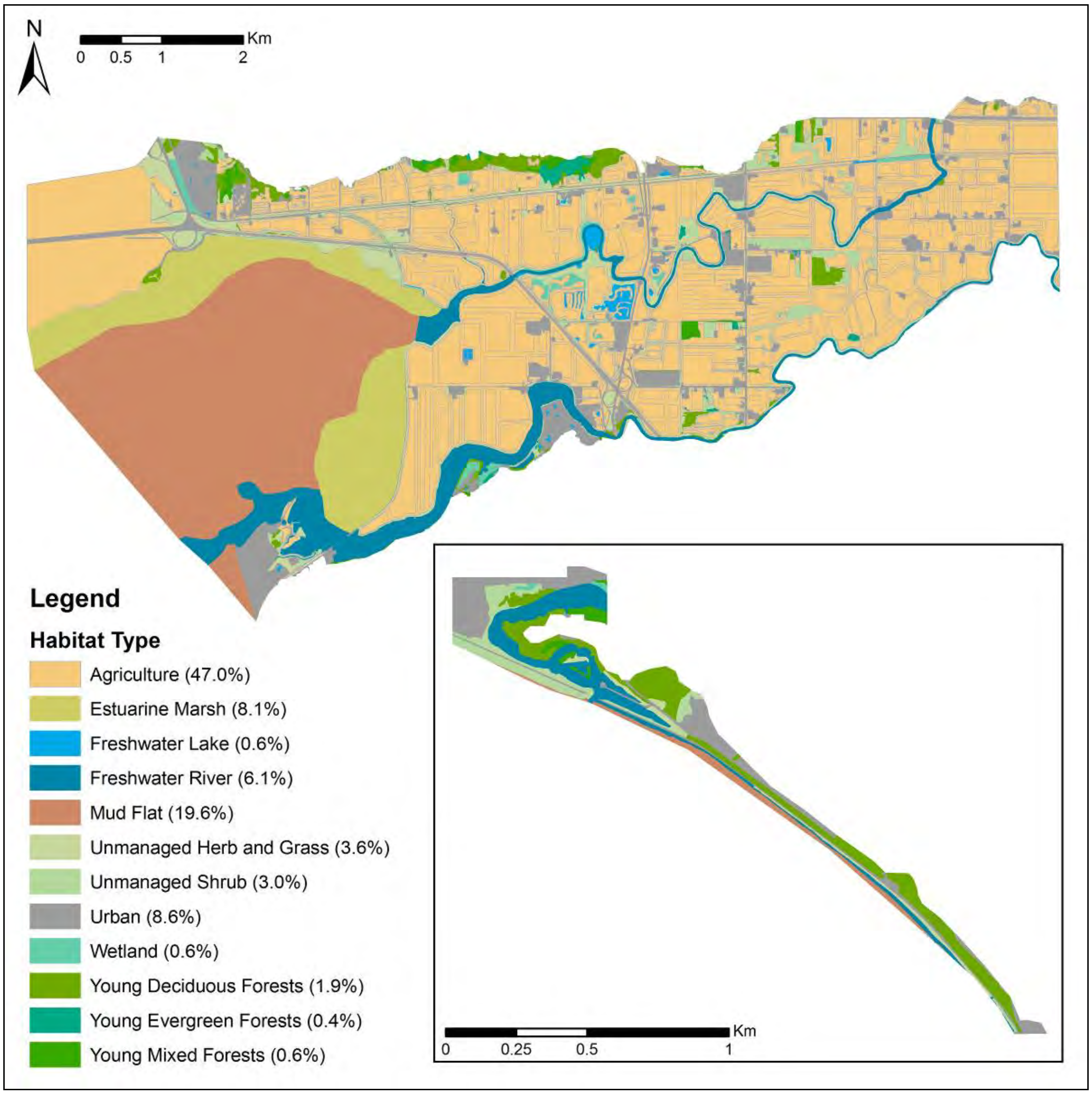

Figure 2: Map of habitat types. Inset represents the 8th Ave/160th St and Beach Road region.

2.2 Representative Species

Representative species, including iconic, common, keystone, indicator and at-risk species, associated with each habitat class are described in Table 1. These include invertebrates, fish, birds, reptiles, amphibians and mammals.

Table 1. Representative species for each habitat type and total area within the study area.

Habitat Type	Total Area (ha)	Representative Species		
		Common/Iconic	Indicator/Keystone	Species at Risk
Agriculture	2177	Peregrine Falcon (*Falco peregrinus*)	Red-tailed Hawk (*Buteo jamaicensis*)	Barn Owl (*Tyto alba*)
Estuarine Marsh	375	Herring Gull (*Larus argentatus*)	Coho Salmon (*Oncorhynchus kisutch*)	Great Blue Heron (*Aredea herodias*)
Freshwater Lake	28	Mallard (*Anas platyrhynchos*)	Cutthroat Trout (*Oncorhynchus clarkii*)	Painted Turtle (*Chrysemys picta*)
Freshwater River	281	River Otter (*Lontra canadensis*)	Beaver (*Castor canadensis*)	Nootsack Dace (*Rhinichthys catacractae /Rhinichthys sp.)*
Mud Flat	909	Littleneck Clam (*Protothaca staminea*)	Western Sandpiper (*Calidris mauri*)	Great Blue Heron (*Aredea herodias*)
Unmanaged Herb and Grass	165	Coyote (*Canis latrans*)	Anise Swallowtail (*Papilio zelicaon Lucas*)	Rough-Legged Hawk (*Buteo lagopus*)
Unmanaged Shrub	137	Song Sparrow (*Melospiza melodia*)	Spotted Towhee (*Pipilo maculatus*)	Silver-spotted Skipper (*Epargyreus clarus*)
Urban	398	Northwestern Crow (*Corvus caurinus*)	House finch (Haemorhous mexicanus)	Barn swallow (*Hirundo restica*)
Wetland	29	Red-Winged Blackbird (*Agelaius phoeniceus*)	Marsh Wren (*Cistothorus palustris*)	Northern Red-legged Frog (*Rana aurora*)
Young Deciduous Forests (5-80 years)	89	Black-Capped Chickadee (*Poecile atricapilla*)	Black-throated Gray Warbler (*Dendroica nigrenscens*)	Band-tailed Pigeon (*Patagioenas Fasciata*)
Young Evergreen Forests (5-80 years)	17	Douglas Squirrel (*Tamiasciurus douglasii*)	Brown Creeper (*Certhia Americana*)	Olive sided flycatcher (*Contopus cooperi*)
Young Mixed Forests (5-80 years)	27	Stellar's Jay (*Cyanocitta stelleri*)	Pileated Woodpecker (*Dryocopus pileatus*)	Western Screech-Owl, kennicottii subspecies (*Megascops kennicottii kennicottii*)

2.3 Biodiversity Conservation Strategy Ranking

The BCS Biodiversity ranking for different habitat types was developed using a measure of relative species diversity and current habitat suitability based on the size and connectivity of habitat patches. Biodiversity rankings fall within a range from 0 (least biodiversity value) to 120 (greatest biodiversity value), and are separated into five classes (Low, Moderately Low, Moderate, Moderately High, High). Note that marine environments including estuarine marsh and mud flat habitat types were not ranked in the BCS. These areas would likely be ranked as moderately high to high based on their known value to support a wide diversity of resident and migratory birds.

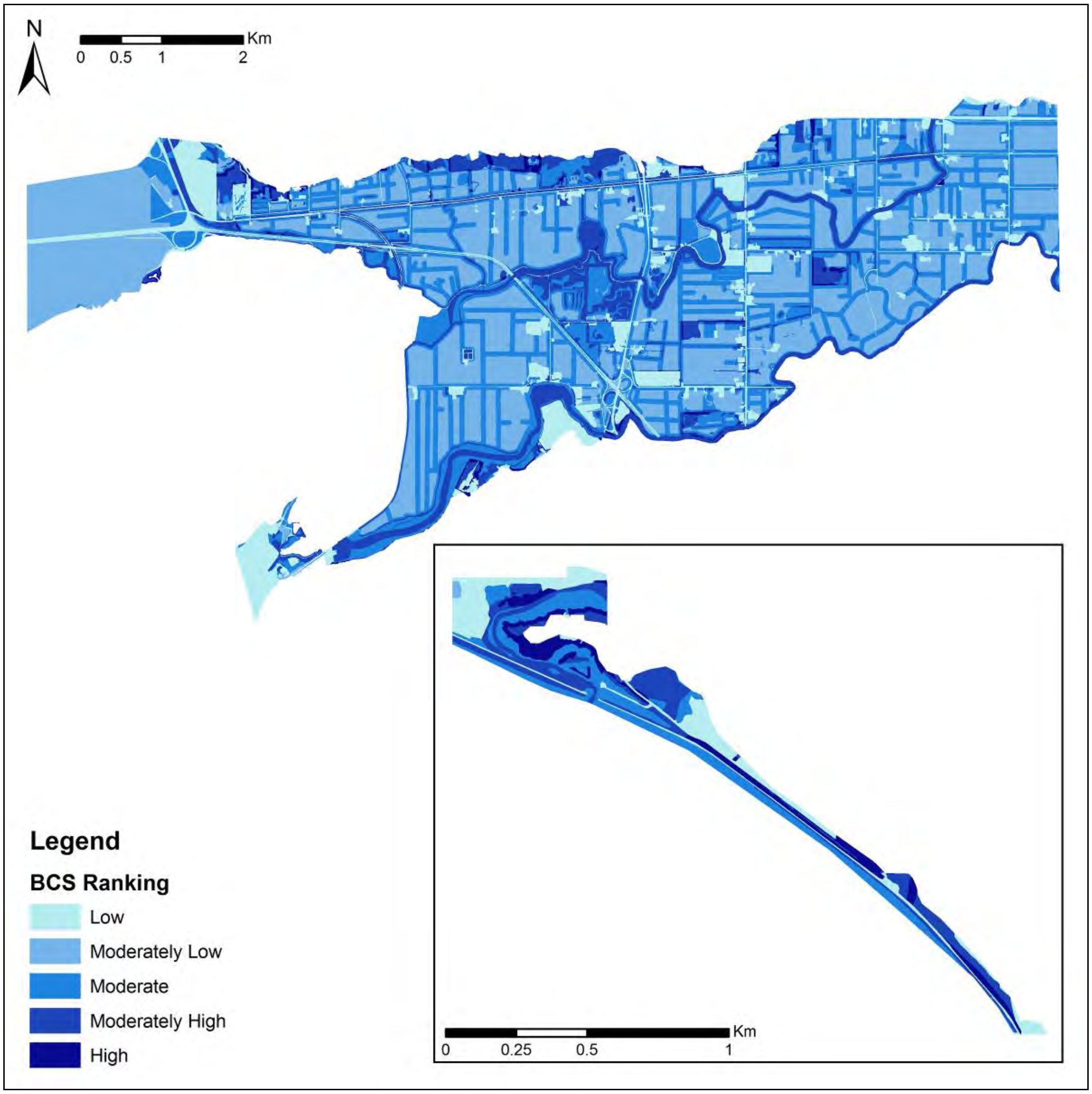

Figure 3: Map of study region with areas coded by BCS ranking. Darker areas represent areas of greater habitat value.

2.4 Species Richness Capability Ranking

Species richness capability was assessed based on the relative number of species that are potentially associated with each habitat type. For this metric, only vertebrate species were included as plant and invertebrate groups are extensive and relatively poorly described. Species were selected based on occurrence data from Surrey's BCS study and the BC Conservation Data Centre (CDC). Vertebrate species that are extinct, extirpated, or not likely to occur were not included in this assessment. Values for species richness were categorized using a five point scale (Low, Moderately Low, Moderate, Moderately High, High). Estuarine Marsh has the greatest species richness ranking (147 species), while Agriculture has the least (23 species). Urban areas are unranked; however, the estuarine marsh and mud flat habitat types are assessed.

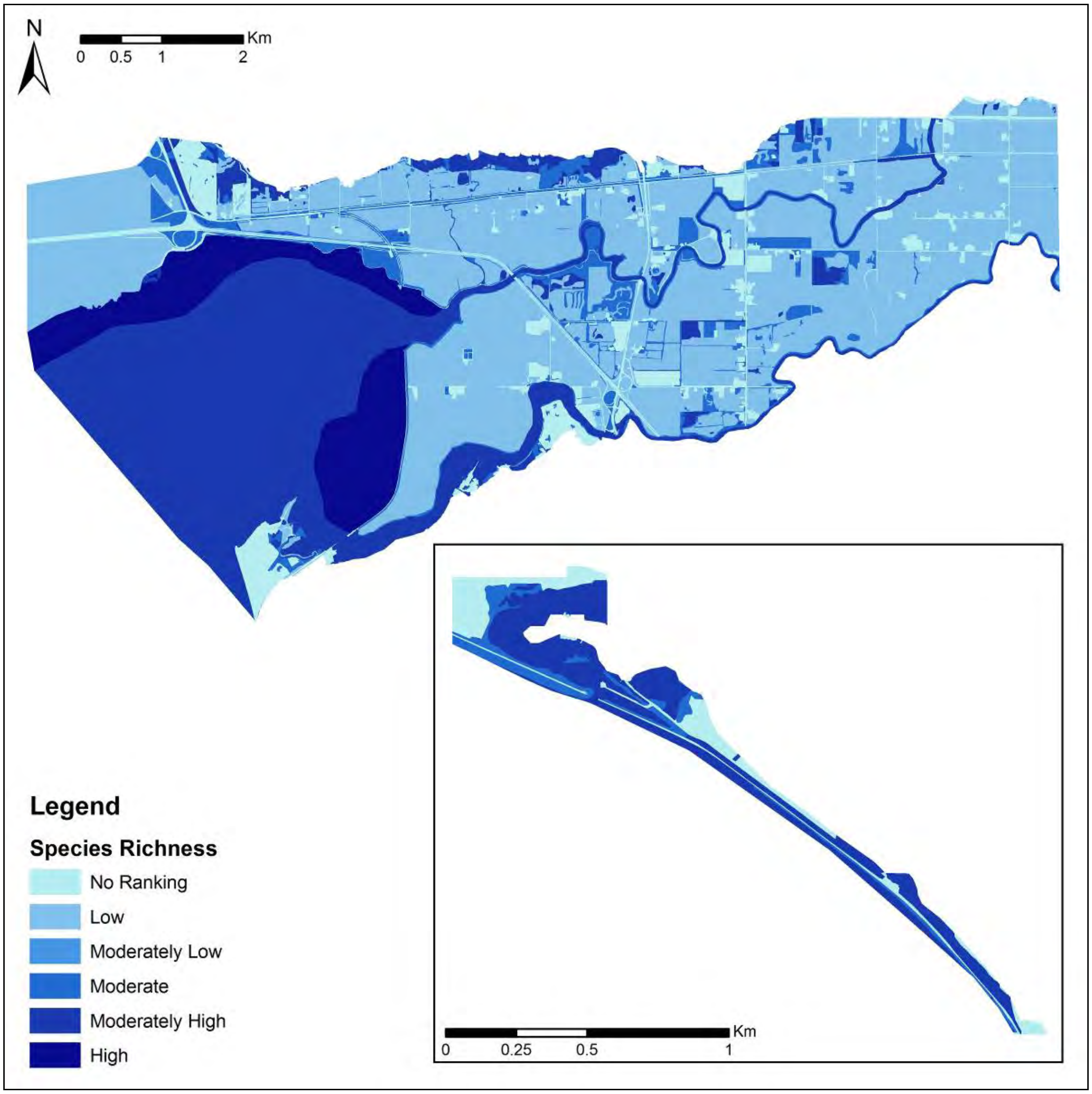

Figure 4: Habitat types by species richness. Darker areas represent areas of greater species richness capability.

2.5 Species at Risk (SAR) Ranking

Provincially Blue and Red Listed vertebrate Species at Risk (SAR) associated with each habitat type were selected based on data provided by the BC CDC. Relative SAR diversity by habitat type was assessed using a five point scale (Low, Moderately Low, Moderate, Moderately High, and High). Estuarine Marsh (32 species) and Freshwater River (30 species) have the highest SAR ranking, while Unmanaged Shrub is the lowest (8 species). Urban areas are unranked.

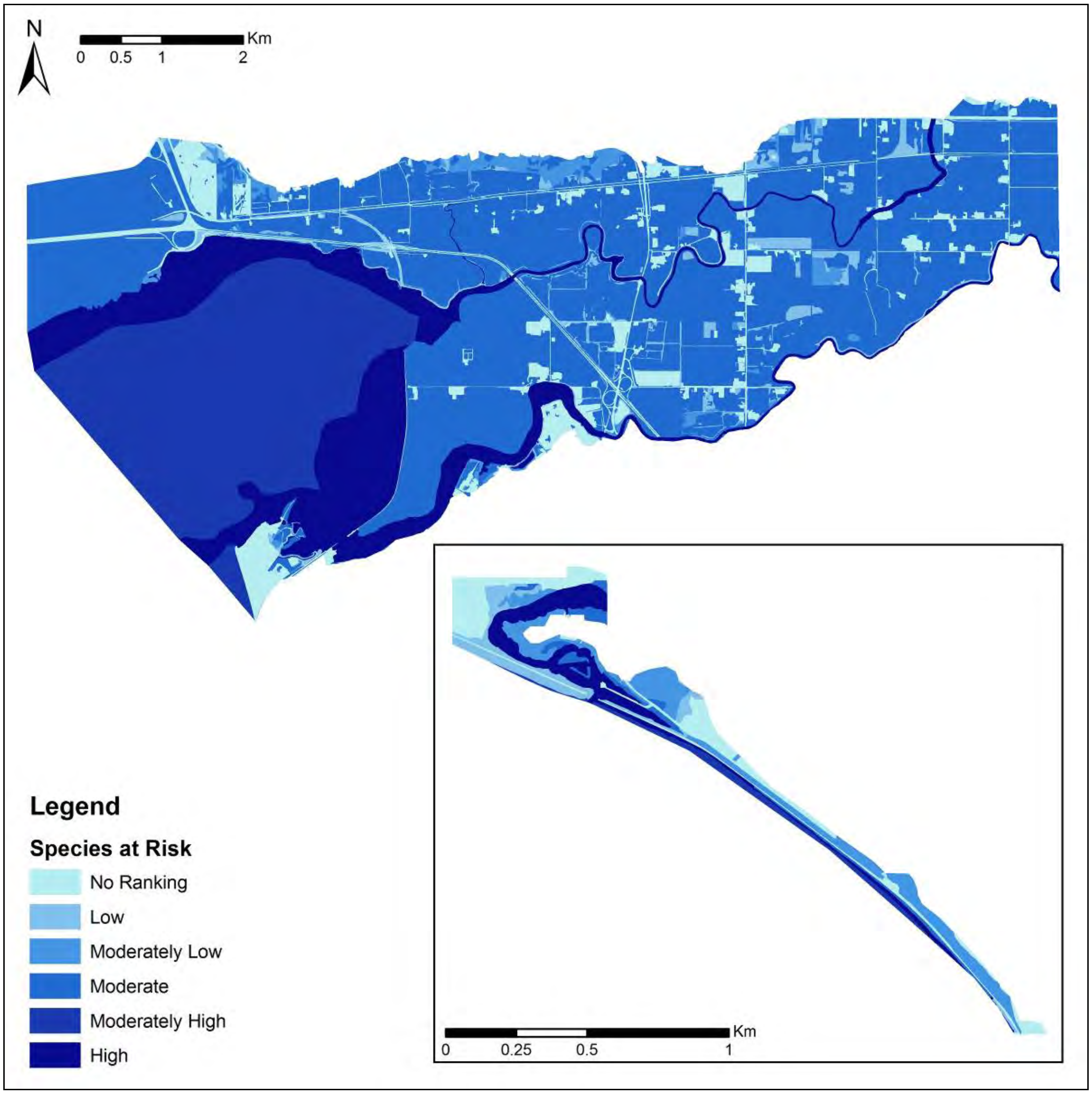

Figure 5: Habitat types by SAR. Darker areas represent areas of greater habitat value.

3.0 Existing ecological communities in the Mud Bay area

The habitat areas specific to Mud Bay are ecologically complex and support a high diversity of species. Seasonal migrations, impacts of rising sea level on the foundation elements of the food chain as well as interspecies influences contribute to the biological complexity.

A large area of Mud Bay is comprised of intertidal flats. These are generally sandy areas dominated by non-vascular plants (eelgrass being the predominant species). The eelgrass plant communities provide important food and shelter for a high diversity of both marine and terrestrial species.

The construction of dykes has condensed the area just above these flats that are considered estuarine salt marshes. In the absence of dyking, these areas extended well inland to land that has been converted to agricultural fields. The estuarine salt marshes along Mud Bay are generally constrained to a narrow band between the mud flats and the dykes. They exist between the mid to high tide level and are dominated by halophytic (salt-loving) plants. They are very productive as nutrients are continuously deposited and mixed by the action of tides and waves. Organic matter accumulates here and decomposes, attracting a diversity of insects, which in turn provides a rich food source.

The Serpentine and Nicomekl Rivers both drain into Mud Bay. These rivers are dyked, limiting the extent of the estuarine marsh and wetlands that once existed. There is tidal influence on the lower reaches of these rivers, below the seas dams on Highway 99. Despite the challenges associated with existing dykes, including flood control measures and poor instream habitat, there are extensive salmon migrations up these two river systems.

The intertidal areas are critical habitat for salmon, as well as spawning habitat for important foraging fish such as Pacific herring and surf smelts. These species are crucial components of the marine/intertidal food web. These intertidal areas are used extensively by adults and juvenile salmon for forage, cover from prey and to provide a zone for adaptation to the transition from salt to fresh water during migration.

There is a diverse community of micro-organisms and small animals (zooplankton) that exist in this intertidal zone. Larger organisms such as worms, shrimps, snails, crabs, jelly fish and shellfish also form an important part of the local food web. The changing conditions may alter the abundance and species composition of these species.

The Mud Bay intertidal zones form part of the pacific flyway which is a bird migration route along the west coast between wintering areas and nesting habitat. The mud flats of Boundary Bay are well known as important areas where large migrating flocks stop, rest and feed to ensure they have enough energy for the rest of their migration. These mudflats are also very important wintering areas for waterfowl, shorebirds, and other resident birds.

4.0 How will rising sea levels impact ecological communities in the Mud Bay area if current dyking infrastructure is maintained?

Predicting the impacts that rising sea levels will have on the habitat and diversity of species that live in this area is complex. Current terrain and elevations have been surveyed in detail and the expected changes to high tide levels can be modeled over time. We can predict how often dykes will be breached and how far flooding will occur. However, the changes that will occur to the ecosystems in these areas and how fast these changes will occur is very difficult to predict with certainty.

If dykes are kept in their current locations and upgraded to withstand the rising sea levels there will be a loss of exposure time of the intertidal mud flats. These areas will be covered with shallow water for longer. This will reduce the available foraging time for terrestrial species, but increase the exposure time for marine species. The extent of eelgrass communities is dependent on water depth and are expected to decrease with the rise in sea level. This will likely have a negative influence on the diverse community of species that rely on them.

The estuarine marshes that currently exist between the tidal flats and the dykes are expected to narrow even further. The water levels will rise up onto the existing dykes. This will reduce the amount of habitat for certain species that have found a niche on these dry rocky habitats.

Sea level rise is expected to dramatically change the habitat available for migrating birds. In particular, the ecological conditions of the mudflats may change and will be exposed for less time, reducing foraging capacity. The specific changes to the mudflats will be highly dependent on the transport of sediments and sedimentation from expected erosion.

As water depth increases, the availability of habitat to marine life will increase, however it is difficult to predict changes to habitat quality. With climate change it is expected that water temperatures may increase. This will also change the dynamics of species that inhabit these areas. There may be an increased likelihood that new invasive species will be able to establish where conditions had previously been too cold.

Examples of species that typically inhabit local intertidal ecosystems and the predicted impacts of rising sea levels on their populations is summarized in Table 2. These predictions are based on professional judgement considering numerous limitations and assumptions. Due to the complicated nature of tidal ecosystems, a comprehensive study would be required to more thoroughly predict these species impacts.

Table 2. Expected impacts of rising sea levels on species common to Mud Bay.

Species Common Name	Latin name	Seasonal use	Expected Impact of rising sea levels	Intertidal Flat	Estuarine Salt Marsh	Dykes
Shorebirds						
Western Sandpiper	*Calidris mauri*	Seasonal winter habitat	Negative			
Dunlin	*Calidris alpina*	Seasonal winter habitat	Negative			
Long-billed Dowitcher	*Limnodromus scolopacous*	Seasonal winter habitat	Negative			
Great Blue Heron ssp. fannini	*Ardea herodias fannini*	Year round	Negative			
Birds of Prey						
Northern Harrier	*Circus cyaneus*	Year round	Negative			
Red-tailed Hawk	*Buteo jamaicensis*	Year round	Negative			
Diving ducks						
Bufflehead	*Bucephala albeola*	Seasonal winter habitat	Uncertain			
Barrow's Goldeneye	*Bucephala islandica*	Seasonal winter habitat	Uncertain			
Dabbling ducks						
Northern Pintail	*Anas acuta*	Seasonal winter habitat	Negative			
Green-winged Teal	*Anas crecca*	Seasonal winter habitat	Negative			
Geese						
Brant	*Branta bernicla*	Seasonal winter habitat	Negative			
Loons						
Pacific Loon	*Gavia pacifica*	Seasonal winter habitat	Negative			
Gulls						
Glaucous-winged Gull	*Larus glaucescens*	Year round	Similar			
Marine species						
Salmon species	*salmonids*	Year round with seasonal migration	Negative			
Pacific Herring	*Clupea pallasii*	Migratory	Negative			
Common eel-grass	*Zostera marina*	Year round	Negative			
Starry flounder	*Platichthys stellatus*	Year round	Uncertain			
Dungeness crab	*Metacarcinus magister*	Year round	Negative			
Littleneck clam	*Mercenaria mercenaria*	Year round	Uncertain			
Reptiles						
Western terrestrial garter snake	Thamnophis elegans	Year round	Negative			

5.0 How can we help lowland ecosystems adapt to sea level rise under an approach of "managed retreat"?

Prior to European settlement, the study area was dominated by lowland plant communities of mostly shrubs and grasses with meandering watercourses, wetlands and bogs. This was a highly diverse and productive ecosystem. General vegetation types were mapped between 1858 and 1880 by Royal Engineers. Figure 2 illustrates the findings from these surveys. This map shows that there was a wide intertidal wetland marsh that existed north of the Serpentine and extending west. Between the Serpentine and Nicomekl Rivers, a grass dominated plant community existed. This area likely flooded regularly and may have been influenced by First Nations and early farming practices which were establishing in this area. To the east, upriver beyond what is currently 152nd Street, the plant community changed to a mix of grasses and shrubs typical of wetlands and bogs found on the pacific coast.

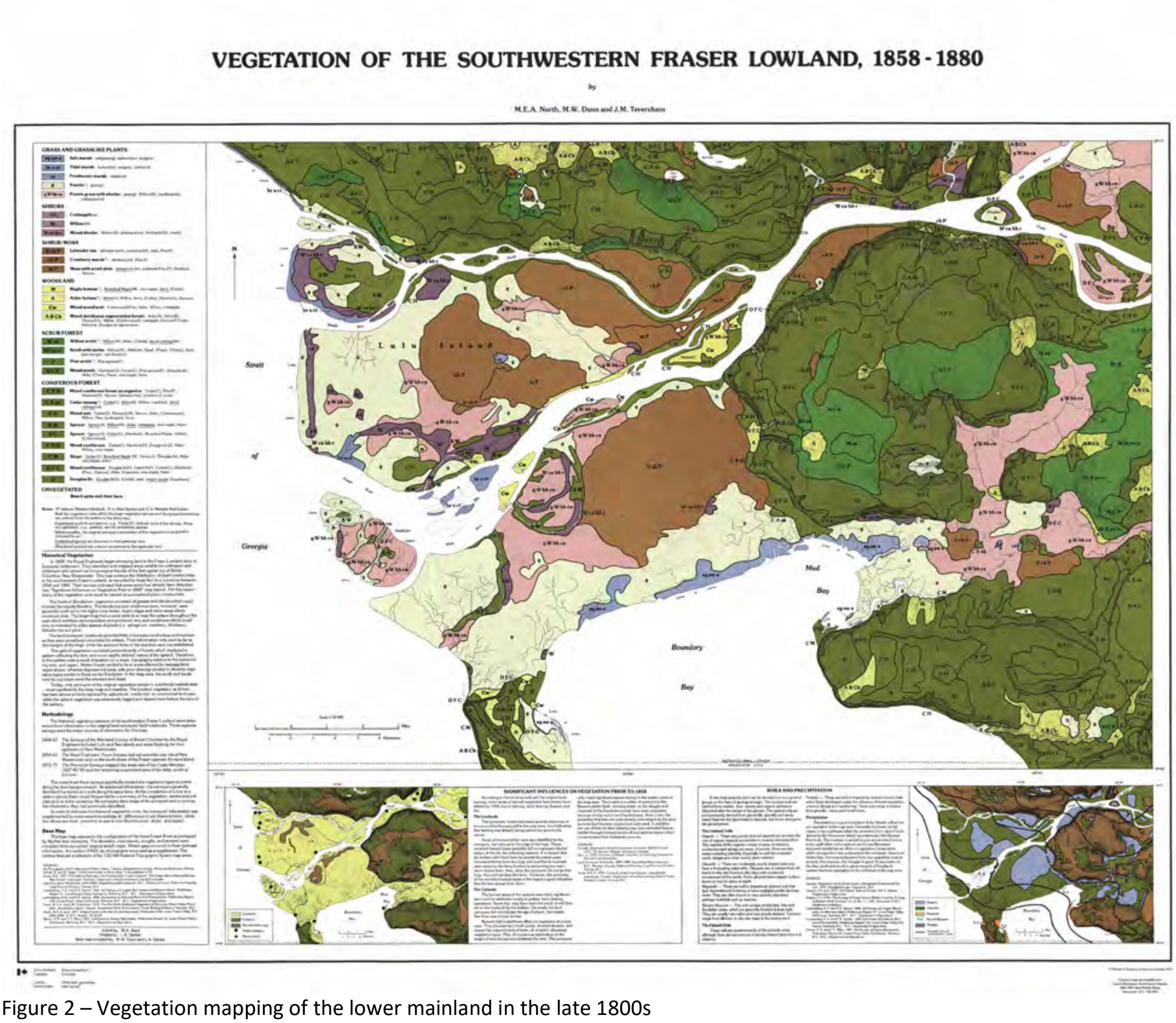

Figure 2 – Vegetation mapping of the lower mainland in the late 1800s

Mineral soils throughout the lowland area originated from marine and river deposits. These are generally fine textured, with a low component of coarse fragments. The marine deposits were composed of silt and clay, and were interspersed with layers of sand deposited during flooding of rivers. Many areas inland developed deep organic soils above these mineral soils.

These soils have been intensively farmed for over a century. However, the deep underlying soils remain similar with fine textures. It is expected that in the absence of shoreline protection, these soils would erode under the influence of high tides, waves and river flooding. Sea level rise will take place over a long period of time. If left unmanaged, the shoreline would slowly erode, carrying the soils into Mud bay.

The historic transition area between the terrestrial and marine environment included a brackish intertidal marsh that was regularly influenced by flooding and wave action. This ecosystem extended well inland (up to 1 km according to historic mapping) and provided an ecosystem that was adaptive to the influences of the ocean. Today, this zone is very narrow and compressed into a band between the mud flats and the dyking that protects the agricultural areas. If left to evolve naturally, it is expected that this intertidal marsh would expand inland with the influences of regular flooding.

The rate at which inland soils would erode and the succession of intertidal plant communities is highly dependent in intervention of the existing Dyke infrastructure. Complete removal of all Dykes would expose all lowland area to the full force of tidal and wave action. Soils would likely erode at the interface and be transported out. Partial removal of Dykes or creation of small opening in the Dykes would retain a barrier to mitigate wave energy. This would allow water to flood inland areas and transport sediment, but would reduce the rate of erosion.

Current modeling indicate that much of the lowland agricultural areas are at an elevation that is higher than that of an intertidal marsh, even with the expected rise in sea level. Therefore, erosion of these soils is a requirement for these marshes to encroach inland. The rate at which this would happen depends on what dyke infrastructure is left in place as well as proactive measures to encourage this process.

With careful planning and monitoring, measures can be taken that will speed up this process of succession and naturalization of these intertidal marshes. Completely removing dykes would allow wave action and flooding to act on what are currently agricultural areas. Further intervention could include the creation of lowland swales extending from the ocean into the fields to encourage flooding and erosion of the soils.

The historic flow of freshwater could also be encouraged. The dykes of the lower Serpentine and Nicomekl Rivers could be removed and small graded watercourses dug through adjacent fields. This would encourage the erosion of soils, encouraging sediment transport and the creation of wetlands.

If an option of partial or completed retreat is adopted, it is expected that a long-term restoration program could be developed that would encourage the reestablishment of the intertidal plant communities that existed prior to European settlement. These areas would provide diverse and high value habitat that would support a high level of biodiversity including resident and migratory species.

6.0 How would the Mud Flat and eel grass communities adapt to sea level rise?

The impacts of sea level rise on the mud flats and the eel grass plant communities is highly dependent on how eroding sediments are transported. Eel grass is known to survive best at depth ranges that are suited to each subspecies. An Environment Canada report published in 2002 suggests the depth at which eelgrass can grow is dependent on the depth that light can penetrate, as well as the ecotype of eelgrass (i.e. the deeper light can penetrate, the deeper eelgrass can survive)[1].

One study reviewed in the Environment Canada report found that eel grass's mean optimum depth range was up to -6.6 m below lowest low tide, depending on light attenuation[1]. Another study broke down optimum depth by ecotype, stating that the small ecotype (*typica*) is primarily intertidal, the medium (*phillipsi*) can survive up to 4 m below low tide, and the large (*latifolia*) can survive up to 10 m below low tide[1].

The change in the range of eelgrass with climate change was studied in Washington and elsewhere along the Pacific coast[2]. The model suggests that eelgrass ranges will be pushed further inland. This can be especially problematic in urban areas, where it will likely result in a decrease in the available eelgrass. The study modeled the potential effects of various sea level rise scenarios on eelgrass in specific estuaries, and showed little change on overall area in the estuary nearest to the lower mainland. Other estuaries in the mid-latitude range showed increases in area in undeveloped locations. Urban areas often had a negative effect on the ability of the eelgrass to migrate inland, as their range is often limited by hardscape features, including dykes.

The effects of sea level rise on the integrity of the existing eel grass communities in Mud Bay is difficult to predict. Also, intervention to promote process and succession is more difficult for these marine environments. A long-term restoration program for sea level rise in this area would include monitoring of sediments levels and eel grass communities in Mud bay.

7.0 How will Surrey look in 100 years if we adopt 152nd as a new barrier to retreat to?

The option to retreat to 152nd street has been chosen to illustrate how Surrey may look in 100 years. Predicting how this restoration area will evolve is difficult due to the complexity of variables involved and the many options for human intervention. For this prediction, it is assumed that sea level rise will be 1m in the next 100 years. It is also expected that there will be careful planning and regular intervention and monitoring to help accelerate and maximize the quality of habitat in the restoration area. This will likely include breaking of the existing dykes, the excavation of inlets, removal of dyke adjacent to the Serpentine and Nicomekl Rivers, and

[1] Environment Canada. 2002. Methods for mapping and monitoring eelgrass habitat in British Columbia.
[2] Shaughnessy, F.J., Gilkerson, W., Black, J.M., Ward, D.H., and M. Petrie. 2012. Predicted eelgrass response to sea level rise and its availability to foraging Black Brant in Pacific Coast Estuaries. Ecological Applications 22(6): 1743-1761.

creation of braided freshwater streams through current agricultural fields. It is also expected that there will be some planting to reintroduce desirable plants and efforts to remove invasive species that may compete with the establishment of native species.

It is also expected that Highway 99 would remain in place but be redesigned to allow water to flow below it. In intertidal marsh areas this would likely include a series of large culverts. Where the highway crosses low areas dominated by tidal flats, it would be suspended.

Based on elevation modeling developed by Northwest Hydraulics Consultants, we know that the current intertidal saltmarsh ecosystems exist at an elevation of around 0.5m. With 1m of sea level rise, areas now at 1.5m would then be the natural elevation of these marshes. The HHWLT in 100 years is expected to be just below 3 m. The existing terrain within the restoration area west of 152nd is currently mostly below 1m. Therefore, all of these areas are expected to be flooded regularly or lie below the high water level for prolonged periods of time. This should promote erosion and sediment transport throughout this area.

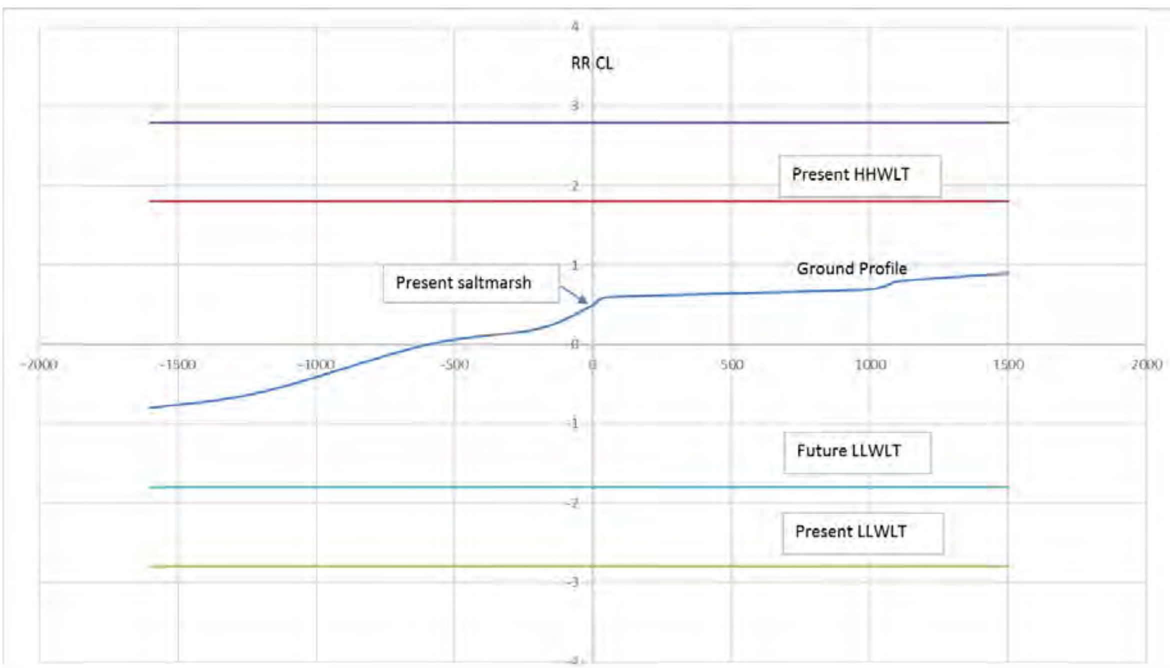

Figure 3 – Coastal profile illustrating the existing level of intertidal salt marshes as well as existing and predicted high and low tide levels (Northwest Hydraulic Consultants)

Currently the terrain model shows a mix of elevations in the restoration area. If dykes are broken, it is expected that areas that are lower than 0.5m (the current elevation of intertidal saltmarsh areas) will be inundated for long periods of time. These areas area likely to be too low for intertidal saltmarshes and would develop into tidal flats. These areas would be dry at low tide and consist of shore mud and organics with few plants.

As soils erode and with sediment transport it is expected that islands of intertidal saltmarshes will form in areas that currently are higher in elevation. The existing lower areas up against the 152 barrier may collect sediment and develop into saltmarshes as well. These intertidal marsh areas would consist of a complex of sub ecotypes. These would be influenced by elevation, how close they are to Mud Bay and wave action as well as the influences of fresh water mainly from the Serpentine and Nicomekl Rivers. These intertidal saltmarsh areas will all be below the high tide line and will flood frequently. It is not expected that any areas would be high enough that they could develop into tidal fresh marshes. Figure 4 illustrates the current elevation model for the study area. Figure 5 illustrates what this restoration area could look in 100 years.

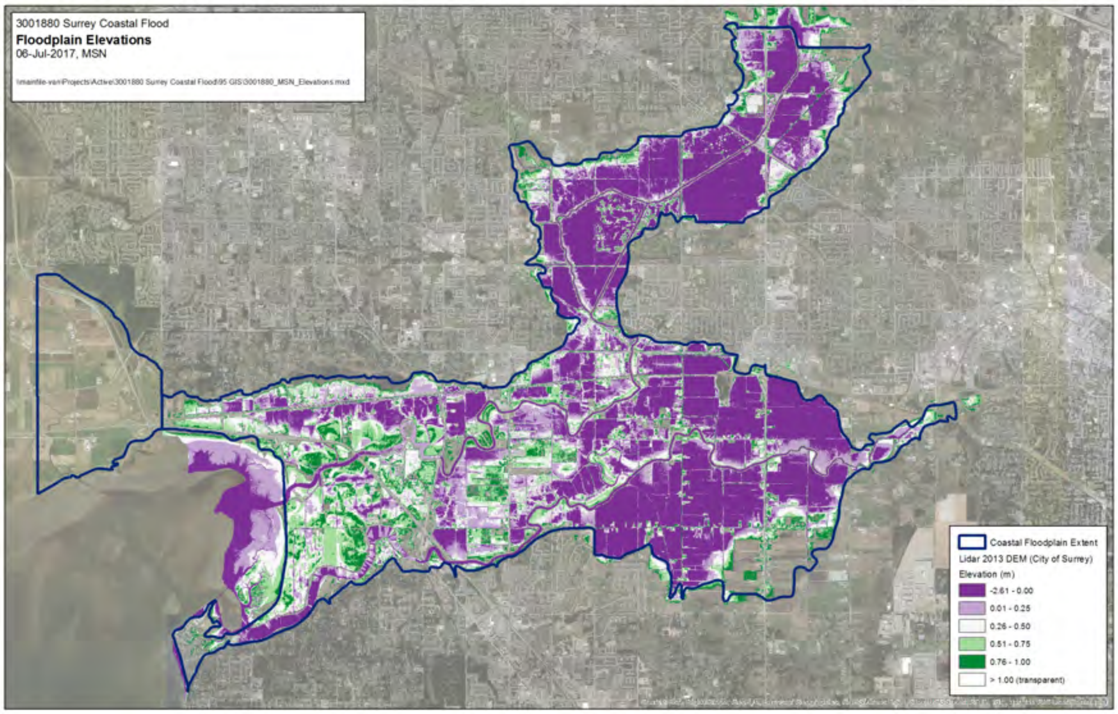

Figure 4 – Current elevation model (Norwest Hydraulic Consultants)

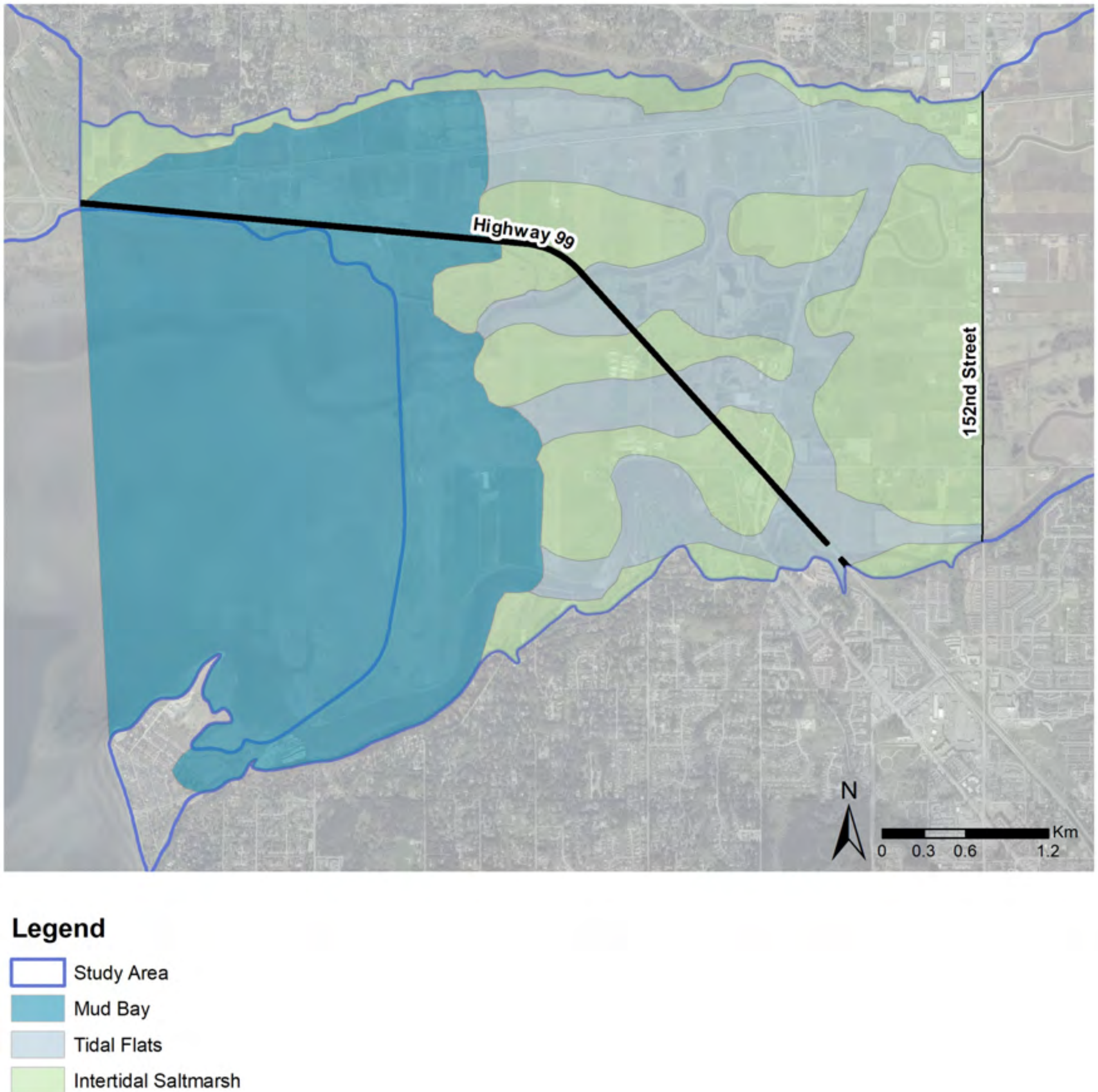

Figure 5 – Conceptual naturalization if a retreat to 152nd is adopted.

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Chapter 5

Ecosystem Vulnerability Workshop Summary and Notes

City of Surrey
March 28, 2019

PIER Ecosystem Vulnerability Workshop Summary

To identify greatest environmental vulnerabilities within the study area, ecosystem experts, environmental partners and agency representatives were convened in a workshop setting on November 27, 2018. The workshop was organized by Ducks Unlimited Canada, City of Surrey, and Diamond Head Consulting.

The workshop consisted of three components:

- **An overview of work completed** under the PIER project (for presentation slides please visit: https://www.surrey.ca/files/CFAS_PIERWorkshop27112018.pdf)
- **Review of preliminary risk assessment**—workshop participants self-sorted into two groups to evaluate risk scores of potential sea level rise impacts to either birds and mammals, or aquatic and terrestrial species, assuming Scenario #1 was adopted (see Chapter 4 for an overview of scenarios). The results of this exercise were used to inform changes to the Framework for Environmental Vulnerability (Chapter 4). An example of a worksheet used at the workshop is appended.
- **Brainstorming on key communications messaging**—participants considered what key messages should be communicated broadly about the ecosystem risks that they had identified as a priority in the previous step. Messaging input received using Message Box approach is summarized in the appendix.

The workshop brought together representatives from various levels of local, provincial, and federal government; experts from environmental NGOs; environmental consultants; and academia (e.g. City of Surrey, Metro Vancouver, Fisheries and Oceans Canada, Nature Canada, Birds Canada, University of British Columbia, etc.).

Appendices:

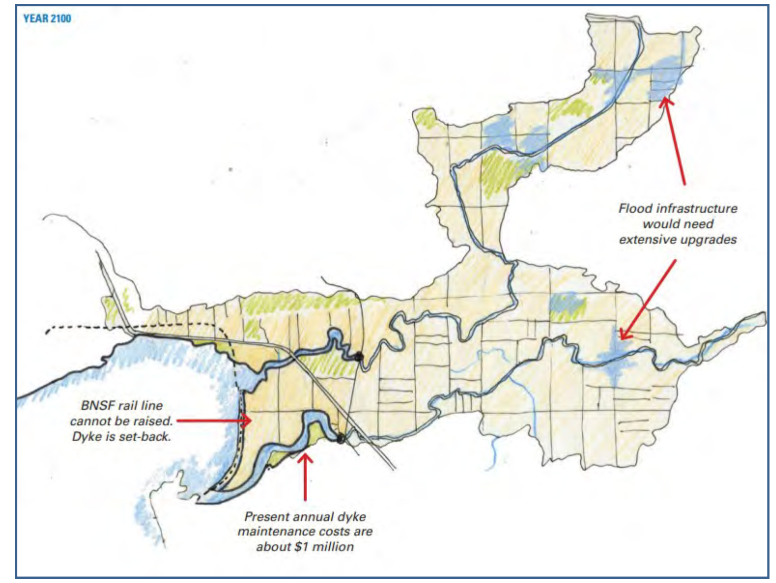
- Example workshop worksheet
- Message Box responses and summary

PRIORITIZING INFRASTRUCTURE AND ECOSYSTEM RISK
ECOSYSTEM VULNERABILITY WORKSHOP

Future Scenario: Current Conventions

There is currently a dyke at the interface of Mud Bay and the City of Surrey with a series of flood cells and pumping systems through the floodplains of the Serpentine and Nicomekl rivers. Occasional flooding occurs during King Tide events, as well as during severe storm events. Current management practices are reactive, with a focus on emergency response and recovery. This scenario assumes that these same methods for flood control will continue to be in upgraded and remain in place until 2100.

The responses to flooding will continue to be reactive and likely include emergency actions and recovery just prior to and after major storm events. Water damage will be mitigated as best as possible with sandbags and emergency pumping. Adapting to rising sea levels and storm events will include reinforcing and armoring these dikes to strengthen their position. Impacts of flooding to local residents and farmers will also be reactive. Infrastructure will be rebuilt as needed and soils will likely require amendment to mitigate the impacts of increased salinity.



Ecosystem Risk Framework

RISK = **PROBABILITY of Impact Occurring** × **Consequence of IMPACT on Species**

Risk Rating of Impacts on Species Groups		
Low	<10	Risks requiring minimal action
Medium	10-19	Risks that may require future action
High	20-25	Risks that require action

Probability of the Impact Occurring	
0	Not applicable
1	Very low
2	Low
3	Moderate
4	High
5	Very high

Consequence Rating of the impact on species groups		
0	No effect	Will have no impact on population levels
1	Very low	Insignificant or negligible effect on population levels
2	Low	May impact some individuals but will not have a significant impact on the local population levels
3	Moderate	Will have a noticeable impact on population levels. With habitat replacement/ restoration it will be possible for the populations to recover
4	High	Will have a significant and permanent impact on population levels in the study area. With habitat replacement/ restoration it may not be possible for populations to recover
5	Very high	Wil have impacts that could potentially result in the extrication of this group from the study area

PARTICIPANT AND/OR ORGANIZATION NAME AND CONTACT INFORMATION: ____________________

POSSIBLE DETRIMENTAL ENVIRONMENTAL EFFECTS	PROBABILITY OF IMPACT 1 - low, 5 - high	CONSEQUENCE OF IMPACTS ON SPECIES GROUPS AND RISK										COMMENTS
		Song Birds		Waterfowl		Shorebirds		Raptors		Mammals		
		Spotted Towee		Mallard		Western Sandpiper		Red-tailed Hawk		Townsend's Vole		
		Consequence	Risk	Consequence	Risk	Consequence	Risk	Consequence	Risk	Consequence	Risk	
LOSS OF INTERTIDAL HABITAT *The areas that are under the influence of changing tides provides critical habitat for both terrestrial and aquatic species. Rising sea levels will constrain this area up against diking.*	5	0	0	2	10	4	20	2	10	3	15	
LESS EXPOSURE TIME OF MUD FLATS *The mud flats of Boundary Bay are well known as important areas where large migrating flocks stop, rest and feed to ensure they have enough energy for the rest of their migration.*	5	0	0	2	10	5	25	2	10	0	0	
LOSS OF EELGRASS PLANT COMMUNITY *Eelgrass species are adapted to certain depths. Rising sea level is expected to push eel grass communities inland and reduce their abundance.*	4	0	0	5	20	3	12	2	8	0	0	
LOSS OF TERRESTRIAL HABITAT *Terrestrial habitat, including agricultural areas, shrub and old field habitat, is expected to decrease through flooding and erosion.*	2	1	2	1	2	2	4	4	8	4	8	
INCREASED SALINITY OF FRESHWATER HABITAT *The lower reaches of the Nicomekl and Serpentine will be lost and the extent of salinity will extend inland likely affecting wetlands.*	3	1	3	1	3	0	0	1	3	1	3	

ADDITIONAL RISK FRAMEWORK COMMENTS

Do you have any comments on the Ecosystem Risk Framework? Is there anything missing? How could it be improved?

ADDITIONAL FEEDBACK

Do you feel like there are other priority ecosystem issues in the study area, based on the risk assessment and other considerations, that weren't captured in today's group discussion? Are you aware of any additional risk reduction actions, opportunities, or approaches that were not discussed today?

MESSAGE BOX - Birds and Mammals (Song Birds, Waterfowl, Shorebirds, Raptors, Mammals)

Issue	Problems	So What?	Solutions	Benefits
Less exposure time of mud flats on shorebirds.	Reduced access to mudflats. Stressed shorebirds. Reduced populations.	Shorebirds foraging is tidally timed so they have less time to forage. Shorebirds will move away or have reduced populations.	Greenshores design to maintain mud flats. Import sediment to maintain depths to allow continued access to mudflats.	Shorebird populations maintained. Ecosystem resilience.
Mudflats + shorebirds	Loss of habitat. Loss of forage value.	Flyway-level consequences. Loss of ecosystem services.		Birdwatching.
Less exposure time of mud flats, impacting shorebirds.	Loss of food, land for migrating species.			Food. Rest area.
Loss of mudflats and impacts on shorebirds.	Biofilm critical food. Invertebrates critical food. Decrease/loss of those could have species/population-level effects.	Flyway (WESA) importance. Winter (Dunlin) importance.	Measure/monitor shorebird populations/species numbers, habitat interactions. Measure/monitor sedimentation patterns, geomorphology. Pilot projects, depositing dredge spoil. Full-scale deposition of sand (if pilots OK).	Birders. Economics. Species diversity. Connectivity - could impact other areas and systems.
Mudflats - effect of loss on shorebirds and diving ducks.	Loss of biofilm for shorebirds. Change in invertebrate communities and effect for foraging shorebirds and diving ducks. Effect of birds moving to other foraging areas (concentrations).			
Less exposure time mudflats impacting shorebirds.	Documented decline of shorebirds. A couple species highly dependant and risk SARA listing if loss this area.	Potential "critical habitat" listing seriously constrain actions impacting area but also enables flow of funds.	Understand and manage sediment movement on mudflats.	Shorebirds attract tourism. Mudflat support clams. Functional estuary maintained for other species.
Less exposure time of mudflats on shorebirds	Decrease in foraging habitat.	Impact on populations. Force populations to search for food in secondary/less opportune sources.	Monitor extent of impact on area/quality of mudflats. Implement measures that preserve current extent of mud flats.	Preserve shorebird habitat and populations. Birding (ecotourism).
Less exposure time of mudflats on shorebirds	Loss of food source.	Loss of recreation/education opportunities.	Grey solutions - berms?	Mitigates storm surges?

MESSAGE BOX - Birds and Mammals (Song Birds, Waterfowl, Shorebirds, Raptors, Mammals)

SUMMARY **Less exposure time of mudflats impacting shorebirds**	**Sea level rise results in reduced access to mudflats and loss of important foraging habitat for shorebirds. Loss of a critical source of food for shorebirds (in particular, biofilm and invertebrates) causes stress to these birds, leading to species or population-level effects, population declines and birds moving to other foraging areas.**	**Some species are highly dependant on this habitat and risk SARA listing if the habitat is lost. The consequences can reverberate throughout the flyway area, ecosystem services are lost, and so are opportunities for environmental education and recreation opportunities.**	**Need to monitor the quality of mudflats, sedimentation patterns and geomorphology, as well as shorebird populations and species numbers, to better understand the impacts. Implement pilot projects to implement measures of preserving the current extent of mud flats, such as Greenshores design, sediment deposits, or berms.**	**Ecosystem resilience, species diversity and habitat connectivity is enhanced. Shorebird and migratory bird habitat is preserved, bird populations are maintained; mudflats support clams and a functional estuary is maintained for other species. Birdwatching opportunities are an ecotourism attraction.**
Loss of eelgrass plant community affecting waterfowl populations and habitat.	Eelgrass loss reduces forage for waterfowl; reduces nursery for crab, fish; reduces detritus which provides substrate for invertebrates which feed fish and birds; increased erosion of marine environment; affects water quality; forces wildlife to alternate habitat such as farm fields.	Ecosystem may crash due to loss of prime element. Reduced fishery will affect jobs. Marine erosion will affect Crescent Beach and recreational opportunities.	Greenshores dyke design. Retreat and provide additional intertidal area. Maintain appropriate water depths through fill in bay. Provide alternate forage for water fowl where/when possible -- winter farm forage.	Birdwatching tourism. Resilient ecosystem. Commercial fishery including crab, salmon, molluscs. Carbon storage. Water quality for recreation standards. Reduced conflicts with agriculture.
Loss of eelgrass, impacts on waterfowl	Loss of grazing, loss of detritus, loss of invertebrates, loss of habitat forage value, loss of food. Waterfowl could move to secondary habitat including agricultural, which brings them into conflict with people more (e.g., widgeon, Brant geese).	Fewer waterfowl. Impacts on raptors who feed on waterfowl? Loss of ecosystem services. Loss of human activities (e.g. tourism, birdwatching). Most important area for waterfowl, loss of flyway consequences. Reduction in water quality. Impacts on recreational uses.	Monitor. Maintain conditions that eelgrass need using technical solutions, space to migrate. Reducing any other identified impacts on eelgrass. Need to understand capacity of eelgrass habitat to adapt.	Coastal protection through reduction of wave strength? Support for whole range of species. Birdwatching, tourism and locals. Carbon storage. Hunting. Reduce conflicts with agriculture.
Loss of eelgrass plant community, impacting waterfowl.	Loss of grazing land, loss of invertebrates, loss of detritus. Waterfowl conflict with agriculture. Loss of eelgrass affects water quality for recreational purposes. Widgeons only eat from farms.	This is most important wintering area in Canada. Waterfowl species declining. Affects food web. Lose support for conservation of the area.	Monitoring loss/change. Green shore solutions. Measure sediment. Increase sediment deposit, dredge soil.	Food. Stability. Birdwatching tourism. Water quality. Hunting. Educational benefit. Reduce conflict with agriculture.

Loss of eelgrass due to SLR, impacts on waterfowl.	Loss of food (direct foraging and from detrital food web). Reduction or loss of numbers and potentially species. Survival decline. Recruitment decline. -- Populations decline.	Waterfowl species/populations will decline or move to other areas. Ecosystem (food web) consequences. Flyway consequences.	Measure sediment movement patterns. Monitoring/mapping of eelgrass every X years. Increasing sediment supply somehow (dredge spoil, opening dams). Measure/monitor waterfowl numbers, habitat interactions.	Birders/tourists. Economy. Spices diversity. Connections of other systems (breeding/molting).
Effect of loss of eelgrass on waterfowl.	Forage opportunities for BRAN, AMWI. Loss of associated invertebrates for some sea ducks. Indirect effects on detritus/nutrient impacts to upper intertidal and marsh.	Conflict with agriculture if ducks move onto farmland. Ecological: waterfowl value in food chain (e.g. BAEA), flyway impacts. Social: hunting, wildlife viewing.		
	Globally eelgrass community shrinking and often in habitats being used shipping. The global decline in eelgrass is matched by an increase in waterfowl due to increasing breeding in north. This is leading to boom that being pushed into secondary habitats popular for recreation.	Farms and recreational parks are being overwhelmed by usage that is leading to anger at birds and loss of support for conservation.	Allow increase harvest. Allow FN to establish "natural foods market". Prohibit shipping development on low gradient habitat. Look at managed retreat as generally feeding habitat without parks.	New market for FN. Reduced conflicts with agriculture.
Loss of eelgrass community due to rising sea level.	Reduced grazing opportunity for waterfowl. Reduced detritus on mudflats and intertidal habitat - waterfowl and shorebirds.	Area is an important part of the migratory flyway. Eelgrass communities provide important source of food. Conflict with agriculture.	Sediment augmentation using Fraser dredge. Increasing sediment supply by removing effects of jetties. Assist with migration. Understand biophysical relationship of eelgrass to SLR - feedbacks -- model.	Educational. Ecotourism. Reduced conflict with agriculture.
Loss of eelgrass plant community on waterfowl	Loss of grazing habitat. Decline in waterfowl populations. Increasing grazing pressure on remaining area of eelgrass.	Increase in grazing of secondary sources (agricultural land). Downward cascading impact on eelgrass ecosystem. Impact fish populations (economic). Impact waterfowl populations.	Implement measures to ensure suitable water levels are maintained to preserve eelgrass plant communities.	Conserve waterfowl populations. Healthy population for hunting and birding (ecotourism). Maintain the ecological integrity of the eelgrass ecosystem. Reduce conflicts with agriculture.

MESSAGE BOX - Birds and Mammals (Song Birds, Waterfowl, Shorebirds, Raptors, Mammals)

Loss of eelgrass plant community on waterfowl	Loss of natural habitat - food source, nursery/protective function for waterfowl - decline in waterfowl numbers - decline in predators feeding on waterfowl.	Loss of revenues from recreational/hunting waterfowl. Loss of connection to nature/educational opportunity. Will affect migratory birds along Pacific Flyway.	City - grey and green solutions. Public - adopt a stretch of the beach. Environmental designation/zoning policies.	Reduce conflict with agriculture. Lessens storm surge?
Loss of eelgrass plant community impacting waterfowl	SLR will impact waterfowl by loss of eelgrass habitat/food. Widgeon/Brant.	Affects systems such as farms, flyway, impacts to other systems.	Implement adaptation. Research and plan needs of eelgrass.	Reduced agricultural conflict. Ecotourism.
Loss of eelgrass plant community waterfowl	Reduced eelgrass community area - reduced foraging area. Reduced foraging area - less energy replenishment for migratory waterfowl on the Pacific Flyway.	Decreased energy reserves for migrating waterfowl is detrimental to species populations. Impacts to fish stocks. Impacts to ecotourism and hunting opportunities. Waterfowl populations decline or movement to other areas where there may be impacts.	Model eelgrass response to SLR to determine possible solutions for eelgrass retention.	Maintain bird species benefits for ecotourism, hunting opportunities. Maintain fish stocks for economic values. Reduced agricultural conflict.
SUMMARY **Loss of eelgrass plant community affecting waterfowl**	**Increasing sea levels and coastal squeeze cause shrinkage of eelgrass communities, in turn resulting in loss of habitat forage value for waterfowl: reduced direct grazing opportunities, and loss of detritus which provides substrate for invertebrates which are a food source for fish and birds. This forces waterfowl to alternate habitats such as farmland or recreational lands, causes increased pressure on remaining eelgrass beds, less energy replenishment for migratory waterfowl, and a decline in population and species numbers.**	**Ecosystem may crash due to loss off prime element; waterfowl species are declining and the food web is affected--cascading effects on eelgrass ecosystem. As waterfowl seek alternative habitats they come in conflict with agricultural and recreational land uses, leading to a negative image of waterfowl and loss of support for conservation. Increased erosion, less ecosystem services and degraded environmental value affects nearby communities and recreational opportunities. Loss of revenues from recreational and waterfowl hunting activities, impact to ecotourism and environmental education opportunities, loss of connection to nature. Reduced fish populations, less economic activity from fisheries.**	**Monitor sediment movement patterns, change in eelgrass coverage. Research eelgrass conditions needs, its capacity to adapt and model its response to sea level rise to determine possible solutions. Maintain conditions chat eelgrass need and reduce any other identified impacts. Increase sediment supply (e.g. dredge spoil from Fraser River, opening dams, removing effects of jetties), assist with migration, green shore solutions. Monitor waterfowl numbers and habitat interactions. Implement "adopt a stretch of the beach" program and environmental/zoning policies.**	**Waterfowl populations are maintained and provide birdwatching, hunting and educational benefits to both locals and tourists. Conflicts with agriculture are reduced. Fisheries stocks, including crab, salmon and molluscs, are maintained for economic values. Other environmental benefits such as species diversity, maintained ecological integrity of the eelgrass ecosystem, carbon storage, water quality, reduced coastal erosion.**

MESSAGE BOX - Aquatic and Terrestrial (Marine Fish, Marine Crustaceans, Freshwater Fish, Amphibians, Invertebrates)

Issue	Problems	So What?	Solutions	Benefits
Loss of eelgrass community on marine fish (coastal squeeze)	Loss of habitat for fish. Loss of food for fish, decline in survival. Loss of coverage leads to overfishing/predation. Loss of spawning habitat for herring. Loss of sediment stabilization. Sediment transport - change in light/water depth.	Decrease in small fish and issues = decrease in salmon stocks = decrease in revenue. Impacts food webs. Decrease in blue heron feeding grounds. Decrease in waterbirds. Decrease in wave attenuation. FN food issues.	Green shore solutions. Herring spawning beds. Build benches. Don't lose it. Replace/restore it. Relocate it.	Maintain ecosystem. Maintain salmon stocks and crab fishery. Maintain birds = birdwatching. Less money spent on dyke upgrades. Decreased loss of land. Increased economic cobenefits of the Bay.
Loss of eelgrass community on marine fish	Eelgrass may decline due to rising sea levels.	Loss of critical habitat for many valued fish species and indirect effects (economic implications for fisheries).	Restore degraded habitats and mitigate SLR.	Support ecosystem functioning and retain valuable fish species.
Loss of eelgrass community on marine fish	Lack of cover, rearing, food supply as part of food web.	Loss can greatly impact salmons and the food web.	Protection and habitat creation/restoration projects. Continual monitoring and mapping. Wave suppression.	Key habitat feature. Supports important species (heron, salmon). Helps to protect valuable fishery/FNS.
Loss of eelgrass plant community for marine fish	Eelgrass expected to be lost with SLR. Significant loss of eelgrass has already occurred. Loss of rearing areas for juvenile fish. Loss habitat area for marine resident species. Loss of spawning for herring etc.	Decline of commercial, recreational, FN fisheries. Decline of key predators such as endangered SRKW. Decline of overall ecosystem productivity and health.	No easy solutions.	Nursery habitat for commercial and culturally important species such as herring and chinook salmon.
Loss of eelgrass plant community for marine fish	Eelgrass communities require certain depths to survive. As sea level rises, this can reduce the available habitat in which eelgrass can live. Marine fish rely on eelgrass so this can have a negative impact on marine fish. With coastal squeeze lose eelgrass communities which will have a negative impact on fish.	Impacts on larval herring. Loss of salmon. Rearing habitat loss. Economic impact to fisheries. Bad for predators such as birds and whales. Traditional reliance on salmon.	Monitoring. Habitat creation? Mapping. Wave environment?	

MESSAGE BOX - Aquatic and Terrestrial (Marine Fish, Marine Crustaceans, Freshwater Fish, Amphibians, Invertebrates)

Coastal squeeze - Loss of eelgrass plant community to marine environment.	Reduced biodiversity. Lack of ownership of problem. Coho salmon impacts, reduced fish population. Cover loss. Loss of fish, SRKW.	Economic value chain, salmon loss. Wave attenuation lost. Cover from predation. Improved water quality. Food web interconnectedness. Traditional value?	Provide higher elevation habitat for rearing. Don't lose habitat in 1st place (protect), preserve health. Work with offsetting habitat compensation (replace). Substitute critical aspects of food web. Offset coastal squeeze. Nature based solutions.	
Loss of eelgrass plant community and effects on marine fish	Eelgrass is a valued habitat for sheltering juveniles and their prey. Eelgrass may provide a significant role in stabilizing marine sediment and reducing sediment mobility (uncertainty). Eelgrass beds may reduce wave energy at shoreline through energy dissipation (uncertainty).			Eelgrass provides shelter.
Loss of eelgrass on marine fish	Loss of nursery value/habitat. Associated impacts on predators.	Fish stocks decline. Food web impacts (e.g. impacts to SRKW). Loss of carbon storage. Loss of wave attenuation services.	Monitoring. Green shores. Policy solutions. Restore and protect eelgrass habitat.	Economic, cultural and environmental benefits of protecting habitat of key fisheries and their predators. Carbon storage benefits. Wave attenuation benefits. Other ecosystem services.
Loss of eelgrass community for marine fish	SLR. Pushes them inland. Reduces abundance.	How the small aspects of an ecosystem affect the bigger things. Chain reaction of effects. What happens when we lose it?	Social media campaign - what is eelgrass? Break it down into digestible imagery and key messages. PR on what organizations are doing to solve it. How you're rebuilding it / artificial process.	Break it into how it affects food security. Mix of green and grey infrastructure to help it.
Loss of eelgrass on marine fish	With coastal squeeze, there will be a loss of eelgrass communities, which leads to a loss of fish habitat and decline in fish populations.	Loss of fish would impact marine predators and commercial/recreational/traditional fishing and tourism opportunities.	Protect existing habitats. Mitigate impacts and restore degraded habitats. Artificial structures, nature-based design, green shores, monitoring/mapping.	Important solutions to maintain ecosystem function and fish species habitat.

SUMMARY Loss of eelgrass plant community affecting marine fish	**are causing loss of eelgrass communities, leading to a reduction of important fish habitat. Eelgrass is a valued nursery habitat that shelters juvenile fish from predation and supplies a food source and prey for the fish. Loss of habitat area for marine resident species and loss of spawning habitat for herring. Results in declining populations of fish, for example salmon. Also impacts sediment stabilization and transport patterns.**	**Decline in fish stock impacts the food web (e.g. impacts to predators such as Southern Resident Killer Whales and birds), ecosystem services, commercial, recreational and First Nations fisheries, tourism opportunities, traditional value, and ecosystem resilience and productivity. Wave attenuation services are lost, carbon storage is compromised.**	**Protection of existing habitat. Habitat creation/relocation and restoration projects to mitigate impacts: artificial structures, nature-based design, Greenshores approach, provide higher elevation habitat, build benches, wave suppression. Continuous monitoring and mapping.**	**Ecosystem is maintained and through it salmon stocks, crab fishery, predator species. Ecosystem continues to provide valuable services; economic value of fisheries is maintained; recreational and traditional functions are preserved. Environmental, economic, social benefits of protecting habitat are realized.**
	Loss of habitat.	Loss of salmon - economic and social. Bad for predators. Commercial and recreational and social. First Nations.	Artificial habitat for eggs. Submerged breakwater. Stop climate change. Don't lose it, replace/restore, relocate it. Substitute artificially. Monitoring and mapping. Green shores. Artificial - build benches. Duplicate behaviour.	Egg deposit. Spawning. Food. Maintaining ecosystem function and fish habitat/species.
Loss of intertidal zones/habitat on marine crustaceans and others	Loss of FN food, fisheries. Loss of economics. Affects predator populations. Bivalves for birds to feed on. Loss of unconsolidated beach and loss of forage fish habitat.	Food web impacts. Negative up the chain to impact socio-economically important species and resources.	Relocate zone. Prevent SLR. Adapt to it.	Save money. Save ecosystems.
Loss of intertidal marine species and zone	Reduced invertebrates density. Habitat changes. Bivalve loss.			
Loss of intertidal on marine crustaceans	Coastal squeeze will lead to a loss of intertidal habitat for marine crustaceans.	Loss of marine invertebrates which are part of commercial and recreational harvest (crabs).	Retreat.	Maintain biodiversity.
Loss of intertidal habitat	As sea level rises this can result in a loss of intertidal habitat.	Negative impacts on organisms that rely on this habitat.		

Loss of intertidal habitat for marine crustaceans and fish	Changes to habitat through erosion/deposits. Rising sea levels through the dykes.	If you lose the small crustaceans then it affects the entire ecosystem. Chain reaction messaging.	Social media campaign - #SavetheBay - pictures of crabs, molluscs. Materials - facts sheets, infographics, publications. Engage younger enviros at schools, tying up with student clubs.	
Loss of intertidal habitat on marine crustaceans	SLR is causing loss of intertidal habitat (coastal squeeze). Loss of valued species - effects on fisheries (commercial, recreational, FN), ecosystem functioning, other indirect impacts.		Try to mitigate SLR. Restore degraded habitats - allow managed retreat.	Sustain fisheries resources and marine ecosystem functioning.
Impact of intertidal on marine crustaceans	Coastal squeeze from dykes. Intertidal just underwater. Some crustaceans need intertidal habitat which will disappear.	Clams - FNs. No more crabs.		
SUMMARY **Loss of intertidal habitat impacting marine crustaceans**	**Sea level rise is causing loss of intertidal habitat where such habitat cannot migrate landward: coastal squeeze. Habitat changes lead to reduced invertebrate density, marine crustaceans and molluscs loss.**	**Loss of intertidal habitat impacts valued species, effects on fisheries (commercial, recreational, First Nations) and loss of economic benefits, effects on ecosystem functioning, negative impacts on the food web, loss of salmon and predators.**	**Create artificial habitat for eggs, use submerged breakwaters and build benches, restore/relocate/substitute degraded habitats, allow managed retreat. [Social media campaign to share pictures of animals, #savethebay, engage youth, student clubs, infographics, publications.]**	**Ecosystem functions and biodiversity are maintained. Food webs and fisheries resources are sustained.**

Chapter 6

Wave and Wind Monitoring Plan

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northwest hydraulic consultants ltd

NHC Ref. No. 3004163

12 November 2018

CITY OF SURREY
Engineering Department
13450 104th Ave
Surrey, BC
V3T 1V8

Attention: **Arvinder Heer**
Engineering Assistant

Copy to: **Carrie Baron, PEng**
Matt Osler, PEng, MBA
Via email: AHeer@surrey.ca
CABaron@surrey.ca
MFOsler@surrey.ca

Re: **City of Surrey Drainage Project No. 4818-044**
Flow, Rain, OceanMet and Slope Monitoring & Maintenance
OceanMet Monitoring Options -DRAFT

Dear Mr. Heer:

Northwest Hydraulic Consultants Ltd. (NHC) is pleased to provide this summary of the OceanMet Monitoring reconnaissance on 26 September 2018 by NHC and the City of Surrey (CoS), review of sites and instrumentation, and presentation of options. Various instrument options have been evaluated in regard to the collection of wave and wind (velocity and direction) data, with consideration for the development of meaningful statistics and time series.

1 POTENTIAL SITES

The following sites were inspected on 26 September 2018 to examine their suitability for locating meteorological and wave measurement sensors (shown in Figure 1 below):

- Border Marker 'E'
- Border Marker 'F'
- Crescent Beach -Starboard Channel Marker
- Crescent Channel – Starboard Channel Marker
- White Rock – Breakwater
- Wickson Pier
- Sullivan Point
- Beecher Place
- Colebrook Road pump station

Figure 1 Locations inspected on 26 September 2018 for wind and/or wave monitoring (Google Earth Pro imagery, version 7.3.2.5491, 64-bit).

1.1 Border Marker 'E'

Border marker 'E' is used by the City of Delta (CoD), for water elevations monitoring, where an Endress + Hauser H3611i Microwave Radar Water Level sensor transmits the current water level via radio telemetry back to the CoD SCADA system. The site has heavy bird activity (significant bird droppings, and bird/fish carcasses). NHC visited this site only as a reference for how CoD has set up their monitoring station.

1.2 Border Marker 'F'

Border marker 'F' consists of an aluminum personnel platform (60" x 60" base) with hand rail surrounds, upon a dolphin consisting of 3-piles with an 18" outside diameter (OD) that extend out radially at an angle 25° from vertical. The platform supports a central solar powered navigation light and "F" sign. At 09:25 Pacific Daylight Time (PDT), 26 September 2018 a 13.9 m sounding measurement was made from the upper rail to the sea floor, while the water level was recorded at 9.14 m yielding a height delta of 4.76m. The resultant tide was 2.93 m above chart datum and correspondingly the Rail Elevation is 4.76 m + 2.93 m = 7.69 m above chart datum. Mean Tide Higher High Water (HHW) @ White Rock is 4.0 m; therefore, an anemometer must be installed at ~ 6 m (20') (based on: 4 m +10 m -7.69 m) above the rail to meet the 10 m height requirement. There was significant accumulation of bird droppings on the tower, and the area is heavily used for commercial crabbing. Extensive crabbing activity immediately adjacent to this location poses a significant risk of damage or loss to any seabed mounted instruments through entanglement in pot lines, and a sea bed mounted wave sensor or wave buoy is not suitable at this site. Only a radar sensor or pile mounted pressure sensor is suitable at this location.

1.3 Crescent Beach -Starboard Channel Marker

This Starboard Channel marker is made of a ~48” diameter single steel vertical pile. It supports a galvanized steel personnel platform measuring 120” x 96”, and carries a Starboard (Right) Day beacon, and Red Light with a total height of 152” above the personnel deck for channel marking. At 10:10 PDT, 26 September 2018, the rail to sea floor was measured at 11.39 m, while the water level was recorded at 5.05 m yielding a height delta of 6.34 m. The resultant tide level was 2.63 m above datum and correspondingly the rail is 8.97 m (based on 6.34 m + 2.63 m) above chart datum. Considering the HHW Mean Tide at White Rock of 4 m, an anemometer must be installed ~ 5m (16’6”) (based on: 4 m + 10 m - 8.97 m) above the rail. There was significant bird excrement, but no commercial crabbing activity, likely due to the shallower water. This location would be suitable for a bottom mount wave sensor, pile mount wave sensor, or radar sensor.

1.4 Crescent Channel – Starboard Channel Marker

This Starboard Channel marker is made of a vertical pile (13” OD) supported by two additional angled piles. The pile supports a personnel platform of irregular shape, generally measuring 70-1/4” x 40-1/2”. The platform hosts a channel marker light 80” above the decking, and starboard day beacons are affixed to the rails. The marker light is powered by a separate solar panel, and a battery box is mounted on the decking. At 11:00 PDT, 26 September 2018 the rail to sea floor was measured at 13 m, while the water level to sea floor was recorded as being 7 m. The height delta of 6 m added to the resultant tide level of 2.3 m results in a rail height of 8.3 m (based on: 6 m + 2.3 m) above chart datum. The method of measurement and the local current at this site made it difficult to accurately measure the depth, and tolerance should be given for any decisions based on these height measurements. An anemometer installed at this site would have to be 5.7 m (based on: 4 m + 10 m – 8.3 m) above the rail. Much like the other marine pile-based sites, this site also experiences a significant bird presence. There is a noticeable amount of vegetation on the sea bed in this location, as well as substantial current during ebb and flow, a bottom mount wave sensor would not be advised in this location, and any pile mounted pressure sensor would need a reasonable anti-fouling solution.

1.5 White Rock – Breakwater

This location is some distance away from the area of interest for wave growth, with waves that propagate into the Crescent Beach and Mud Bay area. There is also a large amount of pedestrian traffic and thus a higher risk of theft to the instruments or cabling. It was decided with CoS that the breakwater at the end of the White Rock Pier was not as suitable of a location as the other inspected sites.

1.6 Wickson Pier

Due to known issues with public interaction with the pier's structures (CoS Parks Division, *personal communication*), Wickson Pier is not a suitable location for wind monitoring. In addition, it is a nonsecure, nearshore structure, and it was decided with CoS that this site is not an ideal location for a wind monitoring station.

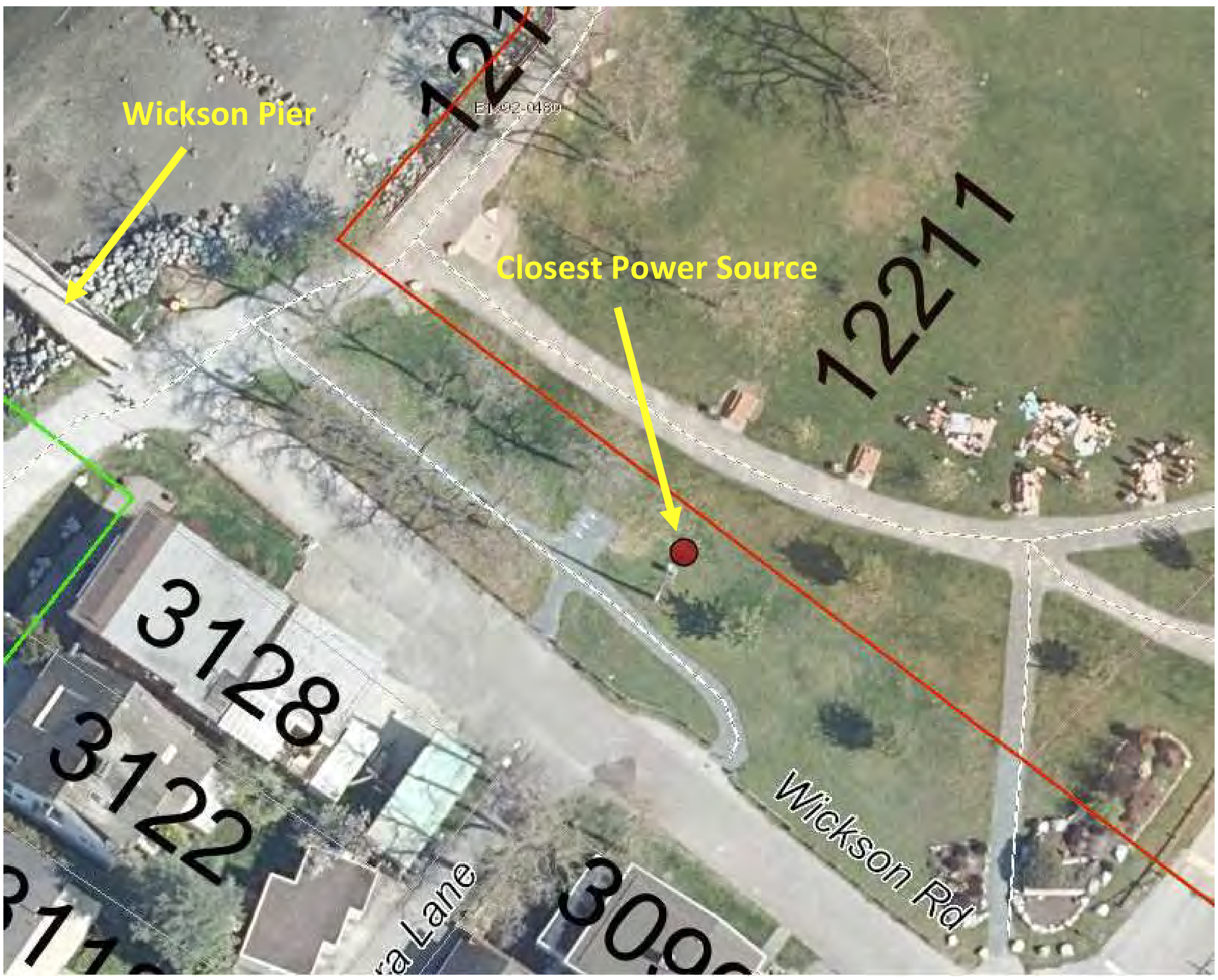

Image courtesy of CoS Parks Division

1.7 Sullivan Point

Sullivan Point park would require a tower to be installed in a park space. Special efforts would be required to make such a tower safe for public (i.e. prevent people from climbing it), such as a security fence around the tower, and CoS and NHC agreed there would be public backlash to the obstruction of view. The site was not investigated any further.

Image courtesy of CoS Parks Division

1.8 Beecher Place

NHC inspected the existing Beecher Place meteorological installation on the roof of the building to assess its condition. The station was identified as a Rainwise Inc. Mk III. It incorporates a mechanical combined propeller and vane, along with a temperature sensor, tipping bucket rain gauge, 418 MHz radio transmitter, and solar charging. There is no background information regarding on its installation, maintenance, or where the data is transmitted. The station was inspected, and it was found that the battery is dead (Eagle Picher Sealed Lead Acid, 6 Volt 4.5 AH). The tipping bucket collection cone was plugged with dirt and algae, this was subsequently cleaned. The reed switch on the tipping bucket was checked and appeared to be functioning. The airplane type anemometer spun freely, but the output was not checked as there was no clear pinout on the circuit board. No corresponding radio telemetry receiver was found anywhere on the premises. NHC has contacted Rainwise who suggested replacement of the system rather than refurbishing and replacing the telemetry unit. This location may be useful as a backup for nearshore readings, however, the station would need to be raised and would always be affected by mechanical turbulence from the surrounding trees and buildings.

1.9 Colebrook Road pump station

The Colebrook Road pump station was inspected following NHC's identification of the location as ideal for wind monitoring, falling inline with the potential Crescent Beach and Crescent Channel locations, with few trees or other sheltering influences nearby. The anemometer would need to be installed on an approximately 10 m high tower, on either the pump station structure, or on the dike. The tower could be a tilt-up, guyline or self-supporting, telecommunications triangular type tower. There is power to the control house, and existing data transmissions from the pump station are by radio telemetry.

CoS initiated a discussion with BC Hydro to evaluate the option of installing an anemometer on one of two hydro poles located near the Colebrook Pump Station. BC Hydro reviewed options and discussed with NHC, and installation of an anemometer on the hydro pole is not an option as it is a one-off type installation, and BC Hydro would need to invest significant effort to determine a configuration that would work (such as existing telecommunications attachments).

2 RECOMMENDED DATA COLLECTION PLATFORM (DCP) LOCATIONS

NHC recommends that the following three sites be considered for the offshore, nearshore, and onshore locations in support of the CoS OceanMet project as shown in Figure 2 below:

- Crescent Beach
- Crescent Channel, and
- Colebrook Pump Station

Figure 2 Recommended Data Collection Platform locations (Google Earth Pro imagery, version 7.3.2.5491, 64-bit)

The following subsections provide details on each preferred installation location, with the following section providing instrumentation options.

2.1 Offshore DCP – Crescent Beach

The "Crescent Beach" channel marker is the preferred location for an offshore data collection platform: It is entirely in Canadian waters, the water depth is less than 10m, which allows for a bottom mounted pressure transducer for wave measurement and is not a site frequented by commercial crabbers. Additionally, the support platform is large enough to accommodate any equipment enclosure required. The structure will require a 5m tower or pole on which to mount the anemometer. The tower or pole will possibly require a mount that will allow it to be extended and retracted for servicing of the anemometer.

It will be important to ensure that the anemometer tower installed on the marker does not impact the existing navigational lights. In consideration of this, NHC expects that the anemometer will need to be situated on the northwest corner to avoid any line-of-site interference from other approach directions by vessels.

The platform manufacturer will need to be contacted to confirm the support requirements of a tower or pole.

Equipment required:

- Enclosure
- Datalogger
- Cellular modem
- Cellular antenna
- 2 x 125 A-Hr Absorbent Glass Mat (AGM) batteries
- Solar charge controller
- 160 W Solar panel
- Anemometer
- 5 m tower for anemometer
- Wave sensor
- Cabling to wave sensor
- Miscellaneous cable and mount hardware

2.2 Nearshore DCP – Crescent Channel

The “Crescent Channel” channel marker is the preferred location for a nearshore data collection platform: it has a good-sized personnel platform and is ideally situated with no local obstructions. The anemometer would need to be installed on a 6 m high pole or tower to be 10 m above HHW mean tide, however, calculated adjustments can be made to the anemometer readings in order to allow a more reasonable 3 m high pole mount. This location could also accommodate a local pressure transducer as a wave sensor.

Equipment required:

- Enclosure
- Datalogger
- Cellular modem
- Cellular antenna
- 2 x 125 A-Hr AGM batteries
- Solar charge controller
- 160 W Solar panel
- Anemometer
- 6 m tower or pole for anemometer
- Miscellaneous cable and mount hardware

2.3 Onshore DCP – Colebrook Pump Station

The location of the Colebrook Pump Station is an ideal location for the onshore anemometer. A 10 m tower would need to be installed and could either be mounted on the dyke, on the pump station structure, or on the inlet structure. Tower options are shown in Figure 3 on the following page, including a self-supporting tower and guyline-supported tower. There is power at the pump station, but there is no local ethernet connection. There appears to be a radio telemetry system installed at the location, which presumably connects to the SCADA system.

Equipment required:

- Enclosure
- Datalogger
- If cellular communication preferred, then:
  - Cellular Modem
  - Cellular Antenna
- If AC power is not an option, then:
  - 2 x 125 A-Hr AGM Batteries
  - Solar Charge Controller
  - 160 W Solar Panel
- Anemometer
- 10 m Tower for Anemometer
- Miscellaneous cable and mount hardware.

Figure 3 Instrumentation tower examples: Universal Towers (left[1]) and Campbell Scientific (right[2]).

[1] https://www.universaltowers.com/towers

[2] https://www.campbellsci.ca/ut30

3 INSTRUMENTATION OPTIONS

The various options for instrumentation are discussed in the following subsections.

3.1 Repurposed CoS Telog R-3307A

CoS requested that NHC evaluate the possibility of applying data logging equipment recovered from the decommissioned 68th Avenue Ditch Water Level Monitoring Station. The logging equipment is a Telog R-3307A unit[3], with analog to digital conversion at 12-bit, and pulse counting; however, it appears to not support either SDI-12 or RS-485 sensor communication. This unit is not suitable for offshore or nearshore data collection, as most sensors NHC is considering utilize either SDI-12 or RS485 sensor communication. The unit's Siemens ultrasonic sensor[4] could be repurposed for a future install, such as the Bear Creek at King George Highway, once the construction of the LRT bridge is complete (a datalogger for this site already exists). The datalogger could either be repurposed for a future install or serve as a backup for the project.

3.2 Data Collection Platform (DCP)

It is recommended that data Logging, processing, and possible telemetry be handled by a Campbell Scientific logger, most likely a CR300[5] depending on preferred options for future expansion. NHC has extensive experience with these loggers, which are flexible to input parameters, efficient in data management, reprogrammable, adaptive to multiple communication options, and environmentally proven. The CR300 is required to poll sensors via SDI-12 or RS-232/485 and can acquire analog measurements.

3.3 Telemetry

Working alongside the CR300, a cellular modem will be available for data push/pull. This will interface with the logger via an ethernet connection.

3.4 Power

Most sites have no grid power supply and thus battery power with solar charging will be required in most cases. Non-spill AGM batteries would be installed with a solar charge controller, and a solar panel or array. An oversized solar panel would be specified and mounted vertically, rather than at ideal solar angles. The vertical arrangement of the solar panel minimizes snow accumulation in the winter and is expected to reduce the requirement for cleaning due to bird activity.

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[3] http://www.telog.com/Portals/31/documents/33xx_recorders.pdf

[4] https://w3.siemens.com/mcms/sensor-systems/en/process-instrumentation/level-measurement-with-level-measuring-instruments/continuous/ultrasonic/transmitters/Pages/sitrans-probe-lu.aspx

[5] https://www.campbellsci.ca/cr300

3.5 Wind (speed and direction)

There are several options for measuring wind, including mechanical and solid state. Some of the main options include Cup, Propeller, Vane, and Ultrasonic. Since the measurement sites have substantial bird activity, it would be advantageous to avoid any measurement instruments that require the installation of crossarms, which would encourage use as a perch.

3.6 Mechanical

Mechanical wind sensors have been in use for many years and are a proven technology with a reasonable service life. A combined propeller and vane style sensor is recommended over a cup anemometer. While this style of sensor does not have a quick response to gusts of changing wind direction, since the entire sensor must align itself with the wind to read appropriately, the unit is likely to outlast individual cup anemometer and direction sensor. NHC would consider the RM Young – Marine Wind Monitor (Model 05106) for wind velocity and direction. An SDI-12 interface is preferred over an analog version; FTS[6] is the only vender to offer an SDI-12 interface for this device, and at a reasonable price. These sensors are used on many offshore buoys.

3.7 Ultrasonic

Ultrasonic sensors with no moving parts are appealing from a maintenance point and have so far proven to be quite reliable. Theses sensors respond very quickly to gusts and changes in direction. The Gill WindSonic[7] is the sensor that NHC would consider for the current application: the sensor has a closed top, which is expected to prevent bird related debris (droppings, feathers, and fish) to accumulate on the surface of the sensors. The caveat is that this sensor is new technology. The sensor would require bird spikes, or other means of deterring birds from using it as a perch. The sensors do not require maintenance apart from cleaning; however, when these sensors fail, they tend to fail completely, requiring removal and servicing, or replacement by the manufacturer. Various bird deterring methods for ultrasonic sensors have been completed by the German Meteorological Service[8].

3.8 Waves

Wave measurements can be made by a multitude of methods. There are surface following accelerometer-based wave buoys, vertical resistance or capacitance-based spar buoys, bottom mounted pressure transducers, upward looking acoustic transducers, downward looking radar, and several others. The method of measurement selected is highly dependent on the goal, deployment conditions, and budget. A brief summary of the sensors NHC has evaluated for this project is provided in the following subsections. Figure 4 in the following section (Section 3.9) compiles a comparison of sensor types with

[6] https://ftsinc.com/

[7] http://gillinstruments.com/products/anemometer/windsonic.htm

[8] https://www.wmo.int/pages/prog/www/IMOP/publications/IOM-116_TECO-2014/Session%203/P3_21_Schubotz_Intercomp_birdrepellingtechniques_ultrasonic_anemometers.pdf

cost range (the price range provided for each sensor is based both options and various vendors), with cost values provided not including all necessary support hardware.

3.8.1 Radar

The Radac WG5 Height & Tide sensor[9] is radar based and intended to be mounted on a structure to measure waves immediately below the structure. There are two versions of this sensor, one with wave height (period and direction capability), and the other providing wave height only. The sensors communicate either through an ethernet connection, through webpage hosting, or via RS232.

This is by far the simplest sensor to install on a pile-based measurement location. It has no contact with the measured medium, is mounted on the personnel platform making it easily accessible, and requires very minimal maintenance. At $35k-67k (dependent on direction capability), however, it is one of the most expensive sensors.

3.8.2 Acoustic Doppler Current Profiler (ADCP)

The Teledyne Sentinel V20[10] with "Waves" firmware is an acoustic doppler current profiler (ADCP) with the capability of measuring waves. It is deployed bottom mounted, uses a pressure transducer to establish its depth, a central and four quadrant acoustic sensors to both trace the water surface and as measure particle velocity throughout the water column. The unit records data onboard for offboard processing through proprietary software. With the right options, the unit can be deployed independently or tethered. Deployment and recovery of this sensor is a serious affair, requiring multiple personnel and lifting equipment. When not tethered, pop-up buoys with an acoustic release must be installed on the mounting frame. As with all bottom mounted equipment, care must be taken to deploy this equipment in a location that will not suffer interference from local commercial or recreational crabbing. Bio-fouling must be considered, and the sensor unit would likely require cleaning on every service interval. Deployed on its own with a single external battery, the service period is 60 days, but more batteries could be added. The general price on this type of sensor is $43k to $66k.

3.8.3 Wave Buoy

The Marine Labs mWave[11] wave buoy is a wave following accelerometer buoy of small size (0.6 m diameter), which is relatively easy to deploy and would be anchored in the location of interest with a 3:1 rode scope. The raw data is recorded onboard and is either downloaded at the service interval or is transmitted via onboard telemetry equipment. The raw data must be processed to produce wave statistics, and this is done via an application program interface (API) using a cloud service. The data can be made available at user defined periods. A typical telemetry-based data cycle would be 20 minutes of data burst at the start of the hour, transmission to cloud storage, data processing through API, followed by data pull/push. The service interval for this device is less than 60 days, at which point the measurement cartridge must be removed and downloaded/recharged offsite. For near continuous service, the measurement cartridge can be exchanged for a previously charged unit. The price of $23k

[9] https://radac.nl/wave-height-tide/

[10] http://www.teledynemarine.com/sentinel-v-adcp?ProductLineID=12

[11] https://marinelabs.io/

includes a wave buoy and two measurement cartridges, such that continuous operation could be maintained. Bio-fouling must be considered: the unit will require an anti-fouling paint, and cleaning on every service interval.

3.8.4 Smart Pressure Transducer

Aanderaa[12] offers a pressure transducer-based real-time wave sensor with onboard calculation of wave statistics. This would be relatively straight forward to integrate into a data collection platform as it can be mounted to a pile, or near a pile on the sea floor. The pressure-based sensitivity to wave frequency is attenuated with depth, so care must be taken to keep the sensor above ~ 10 m depth. Bio-fouling would need to be considered, however the pressure bulb supplied with this sensor keeps the sensing element separate from the sensed medium and negates fouling of the element. Regardless, some regular cleaning would be required. The sensor is approximately $9k.

3.8.5 Standalone Logging Pressure Transducer

NHC has used standalone logging pressure sensor wave recorders on a number of projects. The unit, such as an RBR Concerto D|Wave[13], logs raw data onboard for processing through proprietary software off board. The units are small and easy to deploy and recover. The units can typically be downloaded onsite, batteries exchanged, and redeployed within an hour. If deployed independently, these sensors require pop-up buoys and float releases to facilitate recovery. As with other bottom mounted pressure sensors, care must be taken with respect to deployment depth due to frequency attenuation at depth. Additionally, care must be taken to avoid commercial/recreational crabbing areas. The sensors are approximately $4.6k. These units are not real-time, and bio-fouling must be considered.

3.8.6 Standard Submersible Pressure Transducer

As a final option, NHC has evaluated the possibility of using relatively low-cost submersible pressure transducers with the raw data logged by the CR300. NHC has routines for processing raw pressure data into wave statistics but has not yet attempted this with an onboard datalogger. It is believed that it is within the capabilities of the logger to process the statistics, and that this could provide a real-time option. The submersible pressure sensor is between $1k and $2k and would need a reasonable programming and testing effort for proof of concept.

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[12] https://www.aanderaa.com/productsdetail.php?Wave-and-Tide-Sensor-13

[13] https://rbr-global.com/products/standard-loggers/rbrduo-ct

3.9 Overview of Sensor Capability and Value

NHC has assembled a quick reference guide in Figure 4 on the following page with various advantages (pros) and disadvantages (cons) listed. The costs associated with each type are listed in Canadian funds, however, these sensors are not necessarily deployment ready, and most still require associated equipment such as mounts and cabling. Quotes provided by the various vendors have been appended at the end of this document, including quotes acquired by CoS prior to the start of this project year; final quotations will be requested when preferred measurement process is confirmed. Product brochures provided by vendors have been attached to this document, including a validation paper by mWave.

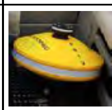
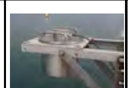
Sensor type - General Comparison							
Parameter	Method	Image	Make/Model	Output	PRO	CON	*Price Range
Wind Speed and Direction	Mechanical		FTS SDI RM Young *Wind Monitor (SDI-WS_RMY)*	SDI-12, or Analog	Sensor moves frequently so birds unlikely to interfere with it. Tried and tested for many years.	Requires servicing and calibration.	$1.5k to $2k
	Ultrasonic		Gill Instruments *WindSonic*	SDI-12	No moving parts. Does not require service or calibration. Responds quickly to gusts and direction change.	Requires bird spikes, these may interfere with readings. Requires closed top type. Requires heat if icing is likely. 'Newish' technology. **Demonstration to NHC of an online sensor failed.**	$1.6k to $2.7k
Waves	Pressure, Raw Output		Keller *Acculevel*	RS485, RAW pressure, logger processing required	Least expensive option. Real-time. Full control of processed output variables. Can be pile mounted, or sea floor block mounted.	Non-directional Processing must be completed by logger, with attenuation corrected. Depth limited due to attenuation (max depth ~ 10 m). Must be installed away from platform ~ 9 x pile radius.	$1k - $2k
	Pressure, On-board Recording		RBR *virtuoso* ^{3} *D|wave16*	On-board logging. Off-board processing. Local download	Can be pile, or sea floor mounted. Can be moved, but depth must be considered.	Not real-time. Depth limited. Must be downloaded and processed. Must change batteries. Must have recovery hardware (floats, releases, etc.)	$4.6k
	Pressure, On-board Processing		Aanderaa *5218*	Modbus RS485, on-board processing	No additional processing required. Real-time. Can be pile, or sea floor mounted.	Non-directional. Depth limited due to attenuation (max depth ~ 10 m). Must be installed away from platform ~ 9 x pile radius.	$9k
	Buoy		Marine Labs *mWave*	Local download/telemetry to cloud	Physically follows wave surface. Portable, can be deployed anywhere, but anchoring limits must be considered. Records wave direction. Raw and Processed Data can be pushed/pulled from cloud	Not local real-time. Max 60 day service interval. Surface visibility: potential for impact with local traffic or vandalism. Sensor package must be exchanged when batteries changed. Download and charging must be done offsite.	$23k
	Radar, Non-directional		Radac *WaveGuide 5 Height & Tide*	Ethernet or RS232/422/485	Mounted on DCP platform, non-contact. No calibration Required.	Fixed location.	$35k
	ADCP		Teledyne Marine *Sentinel V ADCP*	Local download or cable download.	Directional. Measures actual current. Can be tethered or not. If untethered, can be located anywhere.	Processing not done onboard. Not real-time. Big instrument package on sea floor.	$43k to $66k
	Radar, Directional		Radac *WaveGuide 5 Direction*	Ethernet or RS232/422/485	Mounted on DCP platform, non-contact. Real-time. Directional.	Fixed location.	$67k

Figure 4 Comparison of sensor types; *the price range provided for each sensor is based on both options and various vendors.

4 CLOSURE

DISCLAIMER

This document has been prepared by **Northwest Hydraulic Consultants Ltd.** for the benefit of **City of Surrey** for specific application to the **Drainage Project No. 4818-044 Flow, Rain, OceanMet and Slope Monitoring & Maintenance, City of Surrey (Boundary Bay and Serpentine River)**. The information and data contained herein represent **Northwest Hydraulic Consultants Ltd.** best professional judgment in light of the knowledge and information available to **Northwest Hydraulic Consultants Ltd.** at the time of preparation, and was prepared in accordance with generally accepted engineering practices.

Except as required by law, this report and the information and data contained herein are to be treated as confidential and may be used and relied upon only by **City of Surrey**, its officers and employees. **Northwest Hydraulic Consultants Ltd.** denies any liability whatsoever to other parties who may obtain access to this report for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this report or any of its contents.

Closing Statement

Thank you for the opportunity to review wind and wave monitoring options for the City of Surrey; we look forward to discussing these options further (please contact Piotr Kuraś pkuras@nhcweb.com).

Sincerely,

Northwest Hydraulic Consultants Ltd.

Prepared by:

Anthony Reynolds, Tech Dipl
Mechanical Engineering Technologist

Reviewed by:

Grant Lamont, MASc, PEng
Senior Coastal Engineer / Principal

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ENCLOSURES: Quote documentation

cc: Anthony Reynolds – NHC (treynolds@nhcweb.com)
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Chapter 7

Wave and Wind Monitoring RFQ

nhc
northwest hydraulic consultants ltd

NHC Ref. No. 3004163

19 March 2019

CITY OF SURREY
Engineering Department, Utilities Division - Drainage
13450 104th Avenue, Surrey, BC
V3T 1V8

Attention: **Arvinder Heer**
Engineering Assistant

Via email: aheer@surrey.ca

Re: **City of Surrey OceanMet Monitoring**
Proposed Enhancement to the Program Development

Dear Mr. Heer:

Northwest Hydraulic Consultants Ltd. (NHC) is pleased to provide the City of Surrey (the City) with a summary of proposed enhancements to the OceanMet Monitoring program configuration, including adjustments to the originally proposed scope and budget. Proposed enhancements are based on discussions with the City and their stated preferences, which will lead to an improved OceanMet monitoring program.

1 INTRODUCTION

NHC was retained by the City in September 2018 to install four OceanMet stations, including offshore, nearshore, and onshore wind monitoring stations, and a temporary wave monitoring station. Development of the OceanMet monitoring program was described in the Terms of Reference (ToR) for project No. 4818-044, and was included in NHC's *Flow, Rain, OceanMet and Slope Monitoring & Maintenance Proposal for Engineering Services*, submitted to the City on 7 August 2018. The originally proposed scope of work was awarded to NHC under contract 18-12280 and is covered by Purchase Order (PO) 408763.

Following award of this work, NHC met with the City on 29 August 2018 to define the goals for the City's OceanMet monitoring program and discuss development options that meet the City's monitoring objectives. Several additional teleconference discussions were then held to refine the goals for the program. Based on these discussions and the City's preferences, several enhancements to the original OceanMet monitoring program scope and budget are proposed.

This document compares the OceanMet monitoring program originally included in the ToR to the enhanced program underway, details recommended station configurations, and outlines the additional scope and associated cost for improvements to the original scope. The improvements only affect program development (i.e. configuration and installation), and the recommended maintenance program remains as presented in the original proposal (covered by the existing PO).

2 OVERVIEW

There have been improvements to the originally proposed OceanMet monitoring program, so that the program better suits the City's preferences. NHC understands the monitoring program is intended to support the calibration of a SWAN wave model, as well as monitor the development of storms in real-time (to facilitate response) and provide a long-term dataset to assess any changes in storm pattern, frequency, and intensity. The improvements to the original scope are related to station configuration, including station location and instrumentation, with the main adjustments being:

- Change of the Nearshore wind monitoring station from a land based to ocean pile mounted station.

- Addition of a second wind monitoring sensor at the Onshore wind monitoring station, allowing long term sensor comparison.

- Change from a single archiving wave monitoring station that would be relocated annually to two permanent real-time wave monitoring stations, installed in conjunction with the Offshore and Nearshore wind monitoring stations.

- Addition of a second wave monitoring sensor at the Offshore wave monitoring station, allowing long term sensor comparison.

This proposal details the station configurations that meet the City's preferences, and outlines the additional work required for the reconnaissance, permitting, sensor evaluation and testing, and installation related to these improvements. The station configurations that meet the City's preferences are:

- Colebrook Pump Station Onshore Wind Monitoring Station with comparison of ultrasonic and mechanical wind sensors.

- Crescent Channel Nearshore Wind and Wave Monitoring Station.

- Crescent Beach Offshore Wind and Wave Monitoring Station with comparison of wave sensors with onboard versus offboard data processing.

Table 2.1 compares the station configurations proposed in the ToR to enhanced configurations.

Table 2.1 Overview of original and enhanced configurations for OceanMet stations.

	Original	The City's Current Preference
1.1) Offshore Wind Monitoring Station		
Location:	Border Marker F	Crescent Beach Starboard Channel Marker
Sensors:	Ultrasonic anemometer Thermometer	Ultrasonic anemometer Thermometer
Datalogger:	Not specified	Yes
Telemetry:	Cellular	Radio connection to 3.0) Onshore Wind Station
Power:	Solar panel and battery bank	Solar panel and battery bank
1.2) Offshore Wave Monitoring Station		
Location:	Relocate annually to fixed piles	Crescent Beach Starboard Channel Marker
Sensors:	RBR Solo D	Pressure transducer with external datalogger
Datalogger:	None	Advanced for high-frequency wave monitoring
Telemetry:	None	Connected to 1.1) Offshore Wind Station
Power:	RBR internal power	Connected to 1.1) Offshore Wind Station
2.1) Nearshore Wind Monitoring Station		
Location:	Tip of Wickson Pier	Crescent Channel Starboard Channel Marker
Sensors:	Mechanical or ultrasonic anemometer	Ultrasonic anemometer Thermometer
Datalogger:	Not specified	Yes
Telemetry:	Cellular	Radio connection to 3.0) Onshore Wind Station
Power:	Assume power from Street Light	Solar panel and battery bank
2.2) Nearshore Wave Monitoring Station		
Location:	N/A	Crescent Channel Starboard Channel Marker
Sensors:	N/A	Pressure transducer with onboard processing Pressure transducer with external datalogger
Datalogger:	N/A	Advanced for high-frequency wave monitoring
Telemetry:	N/A	Connected to 2.1) Nearshore Wind Station
Power:	N/A	Connected to 2.1) Nearshore Wind Station
3.0) Onshore Wind Monitoring Station		
Location:	Beacher Place	Colebrook Pump Station
Sensors	Existing weather station	Ultrasonic anemometer Mechanical anemometer Thermometer
Datalogger	Not specified	Yes
Telemetry:	Cellular	Cellular Radio connection to 1.1. & 1.2) Offshore and 2.1 & 2.2) Nearshore
Power:	120V power assumed from building	Solar panel and battery bank

3 RECOMMENDED IMPROVEMENTS TO STATION CONFIGURATION

NHC has reviewed various station locations and instrumentation options for the City's OceanMet monitoring program. The recommended instrumentation and station configurations are presented in the subsections below. Most of the information is drawn from the OceanMet Options memo submitted on 12 November 2018.

3.1 Anemometer Selection

There are several options for measuring wind, including mechanical and solid-state sensors.

Ultrasonic solid-state sensors have no moving parts, which is appealing from a maintenance perspective, and these sensors respond very quickly to gusts and changes in wind direction. Following on discussions with the City, **NHC recommends installing ultrasonic Gill WindSonic sensors at all wind monitoring stations**. The caveat is that this sensor is relatively new technology. These sensors have a closed top, which is expected to prevent bird related debris (droppings, feathers, and fish) from accumulating on the surface of the sensors. It would still require bird spikes, or other means of deterring birds from using it as a perch. The Gill WindSonic does not require maintenance apart from cleaning; however, when these sensors fail, they tend to fail completely, requiring removal and servicing, or replacement by the manufacturer.

Mechanical anemometers have been in use for many years and are a proven technology with a reasonable service life. Following review and discussion with the City, **NHC recommends installing a mechanical anemometer along with an ultrasonic sensor at one station for long term comparison purposes.** A combined propeller and vane style sensor is recommended over a cup anemometer. While this style of sensor does not have a quick response to gusts of changing wind direction given the entire sensor must align itself with the wind to read appropriately, the unit is likely to outlast individual cup anemometers and wind direction sensors. Following on discussions with the City, **NHC recommends installing the propeller and vane RM Young – Marine Wind Monitor (Model 05106) at the Onshore wind monitoring station** in addition to the GILL WindSonic sensor for comparison purposes.

3.2 Wave Sensor Selection

Wave measurements can be made by a multitude of methods depending on the monitoring goals, deployment conditions, and budget for the program.

Aanderaa offers a pressure transducer-based real-time wave sensor with onboard calculation of wave statistics. This sensor would be relatively straight forward to integrate into a data collection platform and it can be mounted to a pile, or near a pile on the sea floor. The pressure-based sensitivity to wave frequency is attenuated with depth, so care must be taken to keep the sensor above ~ 10 m depth but deep enough that it remains submerged even at very low tides. Bio-fouling (buildup of marine growth) would need to be considered, however the pressure bulb supplied with this sensor keeps the sensing element separate from the sensed medium and negates fouling of the element. Regardless, some regular cleaning would be required. Following review with the City, **NHC recommends installing an Aanderaa pressure transducer at the Offshore monitoring station.**

NHC has evaluated the possibility of using relatively low-cost submersible pressure transducers with the raw data processed and wave statistics calculated by a separate datalogger. NHC has routines for processing raw pressure data into wave statistics but has not yet attempted this in real time on a separate datalogger and a reasonable programming and testing effort for proof of concept is needed. It is believed that it is within the capabilities of the logger to process the statistics, and that this could provide a relatively low-cost real-time wave monitoring option. Following discussions with the City on these options, **NHC recommends installing relatively low-cost pressure transducers with separate dataloggers at both the Nearshore and Offshore monitoring stations.**

NHC has considered both bottom mounted and pile mounted options for wave monitoring sensors.

A bottom mounted configuration can be advantageous because it allows the sensors to be placed a distance away from the pile, limiting pile interference with wave patterns. Servicing the sensors is also simplified, as bio-fouling would not prevent retrieval of the mounting platform (in comparison to mounting within a perforated well, for example). Care must be taken, however, to deploy this equipment in a location free from interference from local commercial or recreational crabbing, or where currents move large debris that may entangle and damage the sensor cables. This option is also vulnerable to bed aggradation and degradation, and there is no way of ensuring the elevation, location, and orientation of the sensor will remain the same following redeployment after maintenance. NHC has thoroughly investigated the bed elevations and range of tides at the recommended locations, and does not recommend a bottom mounted configuration due mainly to excess depth. While the bed is sufficiently deep to ensure the sensors would remain submerged at very low tides, these would be deeper than the recommended 10 m, creating attenuation of higher frequency waves that would be undetected.

NHC recommends wave sensors be mounted on piles. Pile mounts ensure the sensors are at appropriate depths, locations, and orientations following all deployments. It also offers some protection for both the sensor and cables from crabbing and debris. Pile mounted systems are vulnerable to bio-fouling of the sensors, possible impact from debris like logs, and buildup of marine growth along deployment tracks, all of which can impair sensor retrieval if maintenance is infrequent or intermittent. There are pros and cons to both bottom and pile mounted options, but the pile mounted option allows for collection of data across all wave periods of interest (approximately 4 second to 20 second) due to sensor depth.

3.3 Colebrook Pump Station Onshore Wind Monitoring Station Configuration

The Colebrook Road pump station was inspected following NHC's identification of the location as ideal for wind monitoring, falling inline with the potential Crescent Beach and Crescent Channel locations, with few trees or other sheltering influences nearby. The anemometer would need to be installed on an approximately 10 m high tower. The City initiated a discussion with BC Hydro to evaluate the option of installing an anemometer on one of two hydro poles located near the Colebrook Pump Station. BC Hydro reviewed options and discussed with NHC, and installation of an anemometer on the hydro pole is not an option. There is power at the pump station, but there is no local ethernet connection.

The pump station is scheduled for upgrades in the next few years. NHC reviewed proposed plans for the upgrade to ensure recommended configuration for the Onshore wind monitoring station are compatible with both the current and upgraded pump station.

NHC recommends the installation of a 10 m high tilt-up lattice tower on the flood box structure adjacent the existing pump station; it is understood that the flood box structure will remain throughout the replacement works of the pump station. The tower base will be anchor bolted into the concrete deck of the flood box, and supported by 3 guy wires anchored to the flood box and to the abutting dyke. The tower will support both an ultrasonic and a mechanical anemometer for comparison, a radio antenna, a cellular antenna, and solar panel. A small kiosk enclosure will be fastened to the flood box deck near the tower and will house the datalogger with cellular and radio modems, solar charge controller, and battery bank.

3.4 Crescent Channel Nearshore Wind and Wave Monitoring Station Configuration

The Crescent Channel Starboard Channel Marker is made of a vertical pile (0.33 m outside diameter) supported by two additional angled piles. The pile supports a personnel platform of irregular shape, which hosts a channel marker light 2.0 m above the decking, and starboard day beacons affixed to the rails. The marker light is powered by a separate solar panel, and a battery box is mounted on the decking.

The Crescent Channel Starboard Channel Marker is the recommended location for a nearshore data collection platform: it has a good-sized personnel platform and is ideally situated with no local obstructions. The anemometer would need to be installed on a 6 m high pole or tower. This location could also accommodate a local pressure transducer as a wave sensor. An anemometer installed at this site would have to be 5.7 m above the rail. Much like the other marine pile-based sites, this site also experiences a significant bird presence.

NHC recommends that a pole constructed of 3.5 inch pipe be mounted to and extended above the platform railing and may be supported by backstays at its mid-length. The pole will be reduced to 1 inch pipe size at its apex to provide a mounting point for the mechanical anemometer at 5.7 m above the platform railing. An additional enclosure will be secured to the personnel platform to house radio telemetry equipment, data logger, solar charge controller, and battery bank. A solar panel will be affixed to the platform railing facing south.

There is a noticeable amount of vegetation on the sea bed in this location, as well as substantial current during ebb and flood. A bottom mount wave sensor would not be advised in this location, and any pile mounted pressure sensor would need a reasonable anti-fouling solution.

NHC will design and construct a combined cable conduit and slotted support track (see Figure 1) which can be installed from the surface to deploy a submersible pressure transducer for wave monitoring. The conduit track will be affixed to the vertical 0.33 m diameter pile by saddles & u-bolts above water (see Figure 2), and saddles & cinch chains where inaccessible underwater (see Figure 3). A carriage will be free to slide along the inside of the slotted support track with a tab to support the transducer external to the track (i.e. exposed to the water column out of the bottom of the track). The cable will be retained within the slotted support track and will exit through a slot in the track along with the transducer tab, maintaining the correct bend radius for the cable. The transducer carriage will be held in elevation by a fixed length flat bar, which will allow for surveying in the sensor, and repeatable deployment elevation post maintenance. The slotted support track will require anodes for galvanic corrosion control, and some marine anti-fouling paint to minimize bio-fouling. Quarterly maintenance is recommended for the wave sensor system to assess corrosion and fouling conditions. Maintenance intervals may be able to be adjusted after a few inspections.

Figure 1 **Example of a combined cable conduit and slotted support mounted to a pile. A similar configuration will be used at the Crescent Channel Nearshore Wind and Wave Monitoring Station; however the slotted support will be larger diameter.**

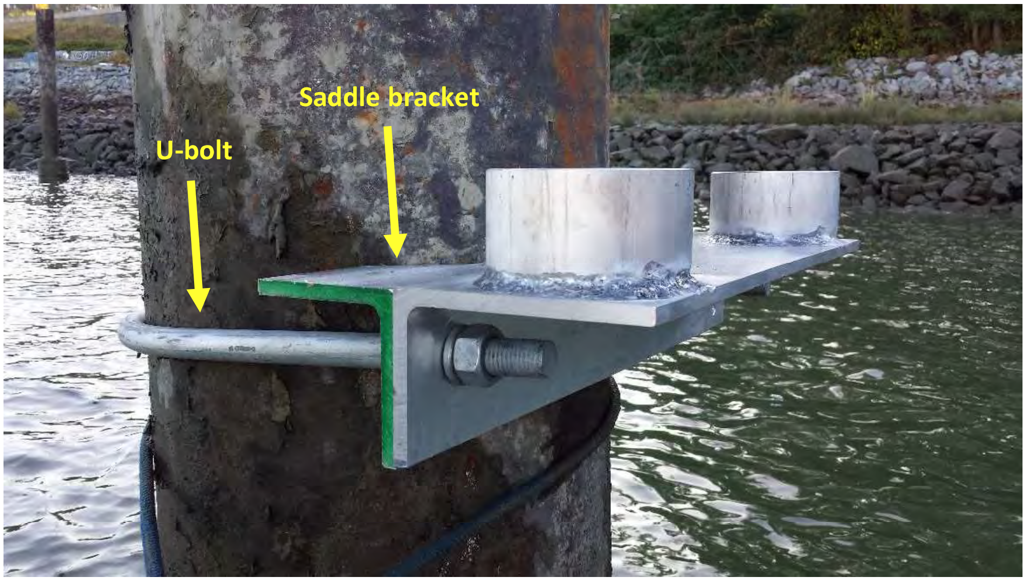

Figure 2 Example of a U-bolt and saddle bracket around a pile. A similar configuration will be used to affix the slotted support track at the Crescent Channel Nearshore Wind and Wave Monitoring Station above the installation water level.

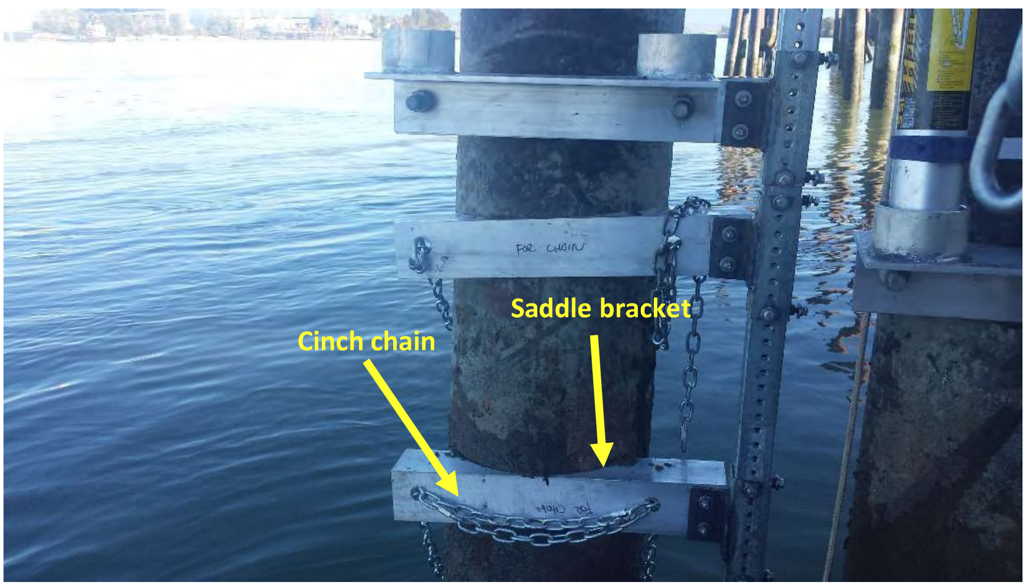

Figure 3 Example of a saddle bracket and cinch chain around a pile. A similar configuration will be used to affix the slotted support track at the Crescent Channel Nearshore Wind and Wave Monitoring Station below the installation water level.

3.5 Crescent Beach Offshore Wind and Wave Monitoring Station Configuration

The Crescent Beach starboard channel marker is made of a 1.2 m diameter single steel vertical pile. It supports a galvanized steel personnel platform and carries a Starboard (Right) Day beacon, and Red Light with a total height of 3.9 m above the personnel deck for channel marking.

The Crescent Beach starboard channel marker is the recommended location for an offshore data collection platform: It is entirely in Canadian waters and is not a site frequented by commercial crabbers. Additionally, the support platform is large enough to accommodate the required equipment enclosure. The structure will require a 5 m tower or pole on which to mount the anemometer. It will be important to ensure that the anemometer tower installed on the marker does not impact the existing navigational lights. In consideration of this, NHC expects that the anemometer will need to be situated on the northwest corner to avoid any line-of-site interference from other approach directions by vessels. Much like the other marine pile-based sites, this site also experiences a significant bird presence.

Like the Crescent Channel station, NHC recommends that a pole constructed of 3.5” pipe be mounted to and extended above the platform railing and may be supported by backstays at its mid-length. The pole will be reduced to 1” pipe size at its apex to provide a mounting point for the mechanical anemometer at 5.7 m above the platform railing. An additional enclosure will be secured to the personnel platform to house radio telemetry equipment, data logger, solar charge controller, and battery bank. A solar panel will be affixed to the platform railing facing south.

There is no commercial crabbing activity at this location, likely due to the shallower water.

Again, similar to the Crescent Channel station, NHC recommends a combined cable conduit and slotted support track which can be installed from the surface to deploy a submersible pressure transducer for wave monitoring. The conduit track will be affixed to the vertical pile by saddles & strapping above water, and saddles & cinch chains where inaccessible underwater (see Figure 1 to Figure 3). A carriage will be free to slide along the inside of the slotted support track with a tab to support the transducer external to the track (i.e. exposed to the water column out of the bottom of the track). The cable will be retained within the slotted support track and will exit through a slot in the track along with the transducer tab, maintaining the correct bend radius for the cable. The transducer carriage will be held in elevation by a fixed length flat bar, which will allow for surveying in the sensor, and repeatable deployment elevation post maintenance. The slotted support track will require anodes for galvanic corrosion control, and some marine anti-fouling paint to minimize bio-fouling. Quarterly maintenance is recommended for the wave sensor system to assess corrosion and fouling conditions. Maintenance intervals may be able to be adjusted after a few inspections.

4 COMPARISON OF ORIGINAL AND RECOMMENDED SCOPE OF WORK

The following subsections compare the originally proposed scope of work to the enhanced scope of work.

4.1 Desktop Reconnaissance

The originally proposed scope of work included a desktop assessment to identify suitable monitoring locations with respect to the City's objectives and coastal assets, taking into consideration that the wave station would be relocated annually.

Following initial discussions on the City's preferences, NHC provided recommendations on a more in-depth desktop reconnaissance to ensure the originally proposed locations would best serve the monitoring program. Discussions with the City and NHC OceanMet specialists identified ideal data collection locations different from those originally included in the ToR, with the adjusted locations providing more valuable information for SWAN wave model calibration and better data for assessing the development of storms in real-time.

The in-depth desktop reconnaissance also included discussing different monitoring instrumentation options with the City, leading to the development of an adjusted monitoring strategy including: two fixed wave monitoring locations, and a long-term sensor comparison program for both wind and wave monitoring. The fixed wave monitoring locations significantly increase the value of wave data, providing the ability for real-time and long-term analysis. The sensor comparison benefits the City by providing redundant sensors in the event of station malfunction, as well as establishing the long-term value of more robust or less expensive sensors when sensor replacement is required, or new stations are commissioned.

The in-depth desktop reconnaissance was completed in September 2018, with some additional effort required in November and December 2018 as additional monitoring strategies were proposed and considered.

4.2 Field Reconnaissance

The originally proposed scope of work included field reconnaissance to assess station installation options at the following locations:

- Border Marker 'F'
- Wickson Pier
- Beecher Place

Based on the in-depth desktop reconnaissance, several other locations were included in the field reconnaissance. The City benefits from this additional scope as it ensures the best monitoring locations are selected. Additional locations included in the field reconnaissance are:

- Colebrook Road Pump Station
- Border Marker 'E'
- Crescent Beach – Starboard Channel Marker
- Crescent Channel – Starboard Channel Marker
- White Rock – Breakwater
- Sullivan Point

Field reconnaissance was completed in September 2018.

4.3 Permitting

The originally proposed scope of work involved NHC providing technical support and advice on station installation, with the City leading the role for the approvals and communications related to permitting.

The City has lead approvals and permitting efforts, however the level of support required from NHC has been greater than originally expected. NHC has invested effort liaising with agencies, including:

- Surrey Parks
- Surrey Facilities
- International Boundary Commission
- Canadian Coast Guard
- NAV Canada
- Transport Canada
- DFO
- BC Hydro
- Boundary Bay Airport

NHC has provided summaries, sketches, and detailed plans of proposed installations, as well as required documents and specifications, such as aviation height restrictions, to support the City with their initial contact with stakeholders, as well as the application and permitting process.

NHC has spent additional effort reviewing the proposed Colebrook Pump House design to ensure station configuration is compatible with both the existing and proposed Pump House.

Permitting support is ongoing.

4.4 Sensor Evaluation

The originally proposed scope of work included preparation of a memo outlining the recommended equipment for each OceanMet monitoring station.

Following discussions with the City, the scope of the memo was expanded to include a summary of all monitoring stations identified in the in-depth desktop reconnaissance and inspected during field reconnaissance, as well as a review of all instrumentation options, allowing the City to make the most informed decisions on the monitoring program. NHC invested additional effort into:

- Detailing the benefits and drawbacks of all monitoring stations identified in the in-depth desktop reconnaissance.
- Investigating both bottom mounted and pile mounted options for wave monitoring stations.
- Developing an organic growth management plan for wave monitoring stations to ensure long term viability of the station; limiting dampening of wave signals by organic growth while still maintaining a protective structure around the sensor.
- Researching available wind and wave sensor options.
- Inquiring with vendors on detailed instrumentation specifications to ensure appropriateness for the intended use.
- Reviewing all sensor limitations, including consideration for wave attenuation at depth; initial quotes and recommendations by sensor vendors did not account for these considerations, with NHC's thorough review identifying and resolving these issues (described in the following paragraph). The process has been very iterative.
- Requesting additional quotes and following up with vendors to ensure the lowest possible price, resulting in savings of $4,500 to date.

Due to NHC's diligence in reviewing available wave monitoring sensor options, several sensor limitations have been identified. NHC has thoroughly reviewed available sensor specifications, confirming sampling frequency capabilities with vendors. The originally proposed scope of work does not include testing instrumentation prior to installation, however **NHC now recommends all wave sensors be tested prior to installation** to ensure they meet vendor specifications as sampling limitations provided by vendors have not been clear. Currently NHC has acquired a Steven's and OTT sensor to ensure sub-second sampling required for proper wave monitoring is possible.

A memo outlining location and sensor options was submitted on 12 November 2018.

4.5 Sensor Installation

The originally proposed scope of work includes installation of one pile mounted and two land-based wind monitoring stations, as well as one pier mounted archiving wave monitoring station.

Following discussions with the City and clarification on the City's preferences, NHC recommends installation of one land based and two pile-based wind monitoring stations, as well as two pile mounted real time wave monitoring stations. Stations will include:

- Colebrook Pump Station Onshore Wind Monitoring Station.
- Crescent Channel Nearshore Wind and Wave Monitoring Station.
- Crescent Beach Offshore Wind and Wave Monitoring Station.

Additional time and effort are required for the recommended installations for:

- Installing an additional pile mounted station.
- Installing an additional wind monitoring sensor for comparison purposes.
- Installing an additional wave monitoring station.
- Installing permanent structures for wave monitoring stations (versus temporary movable structures), including time required for manufacturing wave sensor mounting hardware.
- Installing an additional wave monitoring sensor for comparison purposes.

NHC has already sourced and purchased the tower and ultrasonic anemometer recommended for installation at the Colebrook Pump Station. The datalogger and telemetry device require one month purchase and delivery time. Installation of this station can occur within a month of approval of the relevant portion of this proposal. Permitting for the pile mounted wind and wave monitoring stations remains pending, and equipment has not yet been purchased. There is six to eight week delivery time required for wind and wave monitoring sensors once these are ordered. If permitting for pile mounted stations is granted in March 2019, installation is proposed for May 2019.

5 COST COMPARISON OF ORIGINAL AND ENHANCED PROGRAM

Table 5.1 presents the level of effort, fees, and expenses for the enhanced monitoring program currently proposed based on the City's preferences, along with the cost for the originally proposed program, and the difference between these programs. Table 5.2 presents the cost for instrumentation and mounting equipment for the enhanced program. Details of the recommended instrumentation are provided in Table 5.3.

Table 5.1 Comparison of fees and expenses by task for the originally proposed and enhanced program.

Task	Sub-Total Hours	Sub-Total Fees	Sub-Total Expenses	Total	Included in Existing PO	Requested
Desktop reconnaissance	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Field reconnaissance	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Permitting support	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Sensor evaluation and memo	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Colebrook Pump Stn	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Crescent Beach Installation	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Crescent Channel Installation	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 5.2 Comparison of instrumentation by task for the originally proposed and enhanced program.

Task	Sub-Total Instrumentation	Included in Existing PO	Requested
Desktop reconnaissance	[redacted]	[redacted]	[redacted]
Field reconnaissance	[redacted]	[redacted]	[redacted]
Permitting support	[redacted]	[redacted]	[redacted]
Sensor evaluation and memo	[redacted]	[redacted]	[redacted]
Colebrook Pump Stn Installation	[redacted]	[redacted]	[redacted]
Crescent Beach Installation	[redacted]	[redacted]	[redacted]
Crescent Channel Installation	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]

Table 5.3 Detailed costs for recommended instrumentation by station.

Task	Instrument	Total
Colebrook Pump Station Installation	Universal Towers 9-30 (10m) tower	[redacted]
	RFM18-SS	[redacted]
	Guy wire and hardware	[redacted]
	Cross brace for tower	[redacted]
	Verticals for cross brace	[redacted]
	RM Young SDI-12 Wind Monitor	[redacted]
	Gill WindSonic SDI-12	[redacted]
	Enclosure with pedestal	[redacted]
	CR300-RF407 datalogger	[redacted]
	Cell modem microhard bullet	[redacted]
	Lightning protection	[redacted]
	Sunsaver solar regulator	[redacted]
	Batteries	[redacted]
	Solar panel 160 Watt	[redacted]
	Panel mount	[redacted]
	Feed through terminals, cabling	[redacted]
	Shipping	[redacted]
Crescent Beach Installation	Anderaa level sensor	[redacted]
	Steven's level sensor	[redacted]
	RM Young SDI-12 Wind Monitor	[redacted]
	RS485-RS232 converter	[redacted]
	Enclosure with pedestal	[redacted]
	CR1000X	[redacted]
	Spread spectrum radio	[redacted]
	Lightning protection	[redacted]
	Sunsaver solar regulator	[redacted]
	Batteries	[redacted]
	Solar panel 160 Watt	[redacted]
	Panel mount	[redacted]
	Feed through terminals, cabling	[redacted]
	Schedule 80 pipe 2"	[redacted]
	Schedule 80 pipe 1.5"	[redacted]
	Schedule 40 pipe 1"	[redacted]
	Materials for mount construction	[redacted]
	Shipping	[redacted]
Crescent Channel Installation	Same as Crescent Beach Without the Anderaa level sensor	[redacted]
	Total	[redacted]

6 CLOSURE

Feel free to call or email to discuss this summary of recommended development scope and budget adjustments. Elizabeth or Piotr can be reached by phone (604.980.6011) or email (ebaird@nhcweb.com | pkuras@nhcweb.com) to discuss.

Sincerely,

Northwest Hydraulic Consultants Ltd.

Unsigned document prepared by…

Elizabeth Baird, MSc, GIT Hydrologist	Anthony (Tony) Reynolds Engineering Technologist

Unsigned document reviewed by…

Piotr Kuraś, PEng, PE, RFP
Hydrologist/Associate

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