PIER Phase 1 Report

MCIP15330

City of Surrey
March 31, 2018

CITY OF SURREY

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.

Therefore, this report consists of the following elements:

- **Chapter 1**: Mud Bay Shoreline Erosion Assessment Mapping Study
- **Chapter 2**: Mud Bay: Ecosystem Services Potential for Coastal Flood Protection (Literature review)
- **Chapter 3**: Mud Bay Coastal Geomorphology Study
- **Chapter 4**: Shoreline Assessment Mud Bay – Field Verification Report
- **Chapter 5**: Monitoring Phase 1 Memo
- **Chapter 6**: Regulators and Stewards Workshop Notes, Exit Surveys and Memo

Chapter 1

Mud Bay Shoreline Erosion Assessment Mapping Study

TECHNICAL MEMORANDUM

DATE 15 March 2018

Reference No. 1781834-001-TM-Rev0

TO Matt Osler, PEng, Project Engineer
City of Surrey

CC Morgan Tidd

FROM Claire Murray, PEng
Rowland Atkins, MSc, PGeo

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CITY OF SURREY SHORELINE ASSESSMENT MUD BAY

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by the City of Surrey (CoS) to complete a shoreline erosion assessment mapping study. The objective of the project is to classify areas of coastal dyke in Mud Bay. We understand that the CoS wishes to use the mapping to identify areas of potential future habitat or areas that may require invasive erosion protection under sea level rise (SLR).

1.1 Study Area

The study area includes approximately 27 km of dyking and shoreline from Annacis Hwy in Delta to Crescent Beach in the City of Surrey. The dykes of the Serpentine and Nicomekl Rivers, extending upstream to the sea dams at King George Highway, are also included. The shoreline in the study area is divided into eight reaches. The name and approximate length of each reach is listed in Table 1.

Table 1: Study Area

Shoreline Section	Length (km)
2 km section into Delta	2.0 km
Colebrook Dyke	5.2 km
Mud Bay North	3.9 km
Railway Dyke	2.4 km
Mud Bay South	4.9 km
Nico Wynd Dyke	2.0 km
Between Crescent Beach and Nico Wynd Dyke	3.8 km
Crescent Beach	2.5 km
Total	**26.7 km**

1.2 Project Scope

The project is divided into three main tasks:

- Data Review and Analysis – review of existing data relevant to the shoreline of the study area, including previous field and engineering studies.
- Mapping – Mapping of shoreline classification and indicators of instability identified from the data review and analysis.
- Reporting – preparation of short report documenting the mapping methodology and a summary of the results.

This technical memorandum represents one of the deliverables for the project. It summarizes the methods used and provides a short summary of the results in the following. The ArcMap 10.4 project file (.mxd) mapping file is included with this submission.

2.0 DATA REVIEW

Two previous Golder studies were reviewed as part of the present study.

In 2009, Golder prepared a dyke assessment and functional plan was prepared for the North and South Mud Bay and Colebrook dykes. This study included several site visits that were carried out in 2008, which allowed for the identification of areas of potential or observed instability and identification of areas of erosion and flood related damage. Photographs and descriptions of the shoreline from these site visits and provided in the 2009 report were used to aid in the classification of the shoreline in the present study; photographs in spot locations along the dykes collected for the 2009 report were used to validate the aerial photo interpretation.

In 2012, Golder prepared an Inventory of Dyke Infrastructure for the CoS. The study primarily documented the drainage and irrigation infrastructure along the dykes.

3.0 METHODS

The mapping was created in an ArcMap 10.4 project file using data provided by the CoS as a base. The data included 2013 LiDAR data and orthophotos from 2009, 2013, 2014 and 2015. The most recent orthophoto (2015) and LiDAR (2013) were primarily used for the shoreline classification. Where the appropriate shoreline classification was not obvious in the 2015 photo, the orthophotos from previous years were reviewed. The aerial photo interpretation was also spot validated against site photographs, where available, from the studies described in section 2.0.

For the shoreline classification, the dykes/shoreline are mapped with a single polyline. The line was taken near the centre of the dyke, railway, or walkway along the shoreline, as applicable. In the shoreline reach “Nico Wynd to Crescent Beach”, the actual position of the shoreline location was often not readily identifiable or obvious in the imagery due to overhanging vegetation. In the west part of the reach, the shoreline location was taken near the centre of the treed bench between the cliff toe and the shoreline. Where the area adjacent to the shoreline was relatively flat, the shoreline was mapped approximately 5 m landward of the crest along the shoreline.

Each polyline has two associated descriptors; DESCRIPTION and MUD_BENCH. A new polyline segment was started when either of the two descriptors changed. A description of each of the two descriptors is provided below.

3.1 Armouring Classification

The DESCRIPTION parameter classifies the type of armouring on the dyke or shoreline. There are three mutually exclusive categories for the armouring: unarmoured, cobble, and rock. A description of each category and how each was assigned is presented in Table 2. The classification for armouring concentrated primarily on the material at the toe of the structure. The toe is the location on the structure most frequently exposed to water and erosion. Toe erosion is a mechanism for destabilization that can lead to structure or bank failure. In addition, the upper slope is vegetated on most of the dykes observed and the material under the vegetation is unknown.

In locations where the shoreline was obscured in the orthophotos by trees, such as between Nico Wynd and Crescent Beach, the shoreline was assumed to be “unarmoured”.

Table 2: Description of mutually exclusive Values for DESCRIPTION (Armouring) Parameter

DESCRIPTION Value	Description	Example
UNARMOURED	Dyke toe is unprotected or vegetated. Determined by a green colour indicating vegetation or by no cobble or rock material visible.	
COBBLE	Cobble material at the toe of the dyke. Identified by colour and texture of the surface.	
ROCK	Stone material larger than cobble. Individual rock units able to be distinguished in the orthophoto.	

3.2 Mud Bench Classification

The MUD_BENCH parameter provides a description of the existing ground, or shoreline type, at the toe of the dyke. Four mutually exclusive categories were used for the classification; only one attribute was assigned for a given section of shoreline. If the waterline was located close to the toe of the dyke and there was no mud bench, the value of MUD_BENCH is "NO". If there was a mud-bench observed, the value of MUD_BENCH was set to "YES" for an unvegetated mud bench or "VEG" for a vegetated mud bench. A fourth category called "BEACH" was added for Crescent Beach, where the shoreline fronting the shoreline protection is beach material. A description of each of the four categories and how each was assigned is provided in Table 3.

Table 3: Description for mutually exclusive Values of MUD BENCH (Shoreline Type) parameter

MUD BENCH Value	Description	Example
YES	There is a mud bench is visible at the toe of the dyke/edge of shoreline. The mud bench extends out from the toe/edge of shoreline a minimum of 10 metres in the 2015 orthophoto.	
VEG	Vegetation visible on a mud bench at the toe of the dyke/edge of shoreline and extends no less than 10 m out onto the mud bench. Within the 10 m in front of the toe/edge of shoreline, the vegetation is not patchy and there are no un-vegetated drainage channels cut.	
NO	Very narrow or no mud bench; the waterline is located within approximately 10 metres of the toe of the dyke/edge of shoreline in the 2015 orthophoto. This category was only used on the banks of the Serpentine and Nicomekl Rivers.	

MUD BENCH Value	Description	Example
BEACH	Beach (sand) material at the toe of the dyke/edge of shoreline. The beach material extends a minimum of 10 m from the toe of the dyke/edge of shoreline. This category was only used in the Crescent Beach reach.	

4.0 RESULTS

Figures 1 through 8 show the shoreline classification produced in the present mapping study.

The armouring classification is shown as a single line along the shoreline. Rock armouring is coloured red, cobble armouring is coloured yellow, and unarmoured shorelines are coloured green. The colour scheme was selected to correspond to the expected potential wave energy that would have access to the dyke toe based on the assumption that the colour reflects the potential for wave-related erosion to be high. Rock has likely been placed on shoreline segments as a result of past erosion problems. At the other end of the spectrum, vegetation can be expected to establish primarily in areas of low wave energy.

The mud bench classification is shown as a polygon on the waterside of the armouring classification. Mud bench is coloured orange, vegetation is coloured yellow and beach is coloured green. There is no colour shown for the sections of shoreline with no mud bench. The colouring of the mud bench criteria was used to correspond to the expected susceptibility to SLR, where the beach (green) is expected to adapt the best to SLR, vegetation may be subject to coastal squeeze and the mud bench will allow greater access of waves to the dyke toe under raised sea levels. As noted in section 3.2, a vegetation buffer only exists where there is a mud bench present on the shoreline.

Table 4 presents the total length of shoreline with each classification in the study area. The shoreline lengths are also converted to a percentage of the total shoreline length (26,730 m) and provided in parenthesis in the table.

Table 4: Total Shoreline Lengths in each Classification, distances are provided in metres and converted to a percentage of the total shoreline length in the study area in brackets

DESCRIPTION (Armouring)	MUD_BENCH (Shoreline Type)				Total
	Yes (Bench present but not Vegetated)	Veg (Vegetated Bench)	No (No Bench)	Beach	
Unarmoured	5,751 (22%)	6,374 (24%)	1,163 (4%)	631 (2%)	**13,918 (52%)**
Cobble	1,525 (6%)	148 (1%)	5,852 (22%)	0 (0%)	**7,524 (28%)**
Rock	1,645 (6%)	828 (3%)	1,931 (7%)	883 (3%)	**5,288 (20%)**
Total	**8,921 (33%)**	**7,350 (27%)**	**8,946 (33%)**	**1,514 (6%)**	***26,730 (100%)***

Note: not all column sums will balance due to rounding to the nearest whole percent

Table 5 summarizes the proportion of each exclusive mud-bench criteria that is associated with each of the three armouring types. Table 6 summarizes the proportion of the armouring types that is associated with the each of the exclusive mud-bench criteria. The percentages in the two tables are derived from the shoreline lengths provided in Table 4 and summed by armouring type Table 5 and by mud bench type in Table 6.

Table 5: Percent of MUD-BENCH (Shoreline Type) by DESCRIPTION (Armouring)

MUD_BENCH (Shoreline Type)	DESCRIPTION (Armouring)		
	Unarmoured	Cobble	Rock
Yes (Bench present but not Vegetated)	41%	20%	31%
Veg (Vegetated Bench)	46%	2%	16%
No (No Bench)	8%	78%	37%
Beach	5%	0%	17%
Total by Armouring Type	**100%**	**100%**	**100%**

Table 6: Percent of DESCRIPTION (Armouring) by MUD-BENCH (Shoreline Type)

DESCRIPTION (Armouring)	MUD_BENCH (Shoreline Type)			
	Yes (Bench present but not Vegetated)	Veg (Vegetated Bench)	No (No Bench)	Beach
Unarmoured	64%	87%	13%	42%
Cobble	17%	2%	65%	0%
Rock	18%	11%	22%	58%
Total by Mud Bench Type	**100%**	**100%**	**100%**	**100%**

5.0 INTERPRETATION AND DISCUSSION

From Table 4, Table 5 and Table 6, the following interpretations can be made:

- Approximately 52% of the dyke/shoreline is unarmoured, 28% is cobble-armoured and 20% is rock-armoured.
- 60% of the dyke/shoreline in the study area is fronted by a mud bench, of which some is vegetated (27%) and some is un-vegetated (33%).
- 6% of the dyke/shoreline in the study area is fronted by a beach.
- 78% of the cobble-armoured dyke/shoreline has no mud bench and 13% of the unarmoured dyke/shoreline has no mud bench. Since the shorelines without a mud bench are only located on the river banks, we can infer that most of the cobble-armoured shoreline in the study area is located on the banks of the Serpentine and Nicomekl Rivers.
- 64% of the shoreline with an unvegetated mud bench is backed by an unarmoured dyke or shoreline.
- 87% of the shoreline with a vegetated mud bench is backed by an unarmoured dyke or shoreline.
- Most of the unarmoured dyke/shoreline is fronted by a mud-bench; 41% of the unarmoured dyke/shoreline is fronted by an unvegetated mud bench and 46% is fronted by a vegetated mud-bench. Sea level rise and the potential for loss of vegetation could adversely affect these sections of dyke/shoreline.
- 20% of the cobble armoured dyke or shoreline is fronted by a mud-bench and 2% of cobble armoured dyke or shoreline is fronted by a vegetated bench. These dyke/shoreline segments may require upgrading to maintain adequate levels of protection in the event of sea level rise as vegetated shorelines are reduced.
- 58% of the beach areas have armoured dyke/shorelines. Under sea level rise these dyke/shoreline areas the beaches may be squeezed by rising sea levels. These areas should be considered for replacement of the armouring with a constructed beach so that the shoreline is naturalized and better able to adapt to sea level rise.

The vulnerability of the dyke/shoreline segments in the study area to sea level rise is expected to be primarily a function of the toe elevation, exposure to wave action or current velocities in the rivers, and the existing level of protection. Portions of the shoreline with lower toe elevations will be more frequently exposed to water under rising sea levels. The mud-bench criteria can be used as an approximate indication of toe elevation. Shorelines without a mud-bench are expected to have a lower toe elevation and will be more frequently exposed to water under rising sea levels. The mud-bench classification can also be used as an indication of the likely exposure to wave action. The unvegetated mud benches may allow greater access of waves to the dyke under rising sea levels. Vegetated mud benches provide a slightly higher level of protection by removing some of the wave energy before the energy reaches the toe of the dyke/structure; however, vegetated mud bench areas are expected to be impacted by changing sea levels as the duration and depth of inundation and exposure to saltwater increases. Plants under these circumstances will likely die off and colonize higher ground if any is available. If no high ground is available, these shoreline segments may become progressively less protected by vegetation and convert to un-vegetated mud bench conditions. This shift to higher ground may be limited by the presence of a dyke or other structures and is commonly termed “coastal squeeze’. Beaches have some ability to dynamically adjust to water level changes and the shoreline with beaches are expected to see the least increase in wave action at the shoreline under sea level rise.

Due to rising sea levels, adaptation measures may be required to provide suitable slope protection for the dykes and shorelines in the study area, including:

- Armouring shoreline that is presently unarmoured.
- Extending protection further up the dyke/shoreline slope where existing protection is only at the structure toe.
- Increasing the size of the existing armouring cobble/rock where sea level rise will allow access of larger waves or river current velocities to the dyke/shoreline.
- Converting shorelines to constructed beaches where there is room and the wave, current, and water level conditions will permit.

6.0 CONCLUSIONS

The following conclusions are drawn from the present mapping study:

- A mapping analysis of existing dyke/shoreline areas mapped the dyke/shoreline relative to three mutually exclusive armour types (unarmoured, cobble, rock) and four mutually exclusive shoreline types (mud bench, vegetated mud bench, no mud bench, beach).
- From the mapping analysis, dyke shoreline segments with no mud bench were observed to be limited to the Serpentine and Nicomekl River channels.
- From the mapping analysis, approximately 27% of the shoreline in the study area has a vegetation buffer at the toe of the dyke. Coastal squeeze due to sea level rise is expected to reduce the vegetative buffer and result in increased wave access to the dyke/shoreline.
- Similarly, 87% of the dyke/shoreline that is currently partially protected by a vegetation buffer is not armoured. Rising sea levels may require some of these areas to be armoured in future as coastal squeeze impacts the vegetative buffer.

- Additionally, 52% of the shoreline is presently unarmoured and may over time need to be armoured due to sea level rise and increased wave action to the shoreline.

7.0 STUDY LIMITATIONS

The shoreline mapping is based on a desktop study only and is subject to field confirmation. Key limitations of the study include:

- Difficulty in interpreting the amount of armouring material, the thickness of armour material, and the interlocked characteristics of armour material from imagery. Additional limitations on distinguishing between scattered rock or cobble material and an engineered protection structure with sufficient material placement.
- Assumptions that the shoreline was unarmoured if it was not visible.

8.0 CLOSURE

We thank you for the opportunity to undertake this study. We trust that the information presented above meets your current requirements. Should you have any questions or comments regarding the above, please do not hesitate to contact the undersigned.

GOLDER ASSOCIATES LTD.

PROFESSIONAL PROVINCE OF C. A. MURRAY # 46291 BRITISH COLUMBIA ENGINEER
2018-03-15

PROFESSIONAL PROVINCE OF R. J. ATKINS BRITISH COLUMBIA GEOSCIENTIST
15 March 2018

Claire Murray, PEng
Coastal Engineer

Rowland Atkins, MSc, PGeo
Principal, Senior Geomorphologist

CM/RA/ap

This report has been provided in unsecured pdf format for the purposed of final reporting by City of Surrey. Only the hard copy may be relied upon as the final, approved document

Attachments: Figures 1 to 8 – Shoreline Assessment

https://golderassociates.sharepoint.com/sites/14289g/deliverables/issued to client - reserved for wp/project/1781834-001-tm-rev0/1781834-001-tm-rev0-shoreline assessment-15mar_18.docx

9.0 REFERENCES

Golder Associates Ltd. 2009. Dyke Assessment and Functional Plan: Mud Bay and Colebrook. 07-1450-0121. 28 August 2009.

Golder Associates Ltd. 2012. City of Surrey Inventory of Dyke Infrastructure. 1214470012-001-R-Rev0. 28 June 2012.

LEGEND

ARMOURING

- COBBLE
- ROCK
- UNARMOURED

MUD BENCH

- YES
- VEG
- BEACH
- NO

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SHORELINE ASSESSMENT
MUD BAY, SURREY, B.C.

TITLE

SHORELINE ASSESSMENT

CONSULTANT

Golder Associates

YYYY-MM-DD	2018-03-15
DESIGNED	CM
PREPARED	CDB
REVIEWED	RA
APPROVED	RA

PROJECT NO.	CONTROL	REV.	FIGURE
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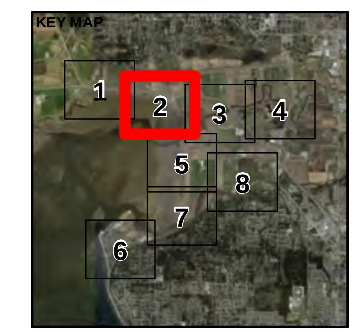
LEGEND

ARMOURING

- COBBLE
- ROCK
- UNARMOURED

MUD BENCH

- YES
- VEG
- BEACH
- NO



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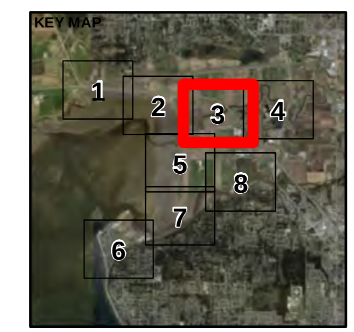
LEGEND

ARMOURING

- COBBLE
- ROCK
- UNARMOURED

MUD BENCH

- YES
- VEG
- BEACH
- NO



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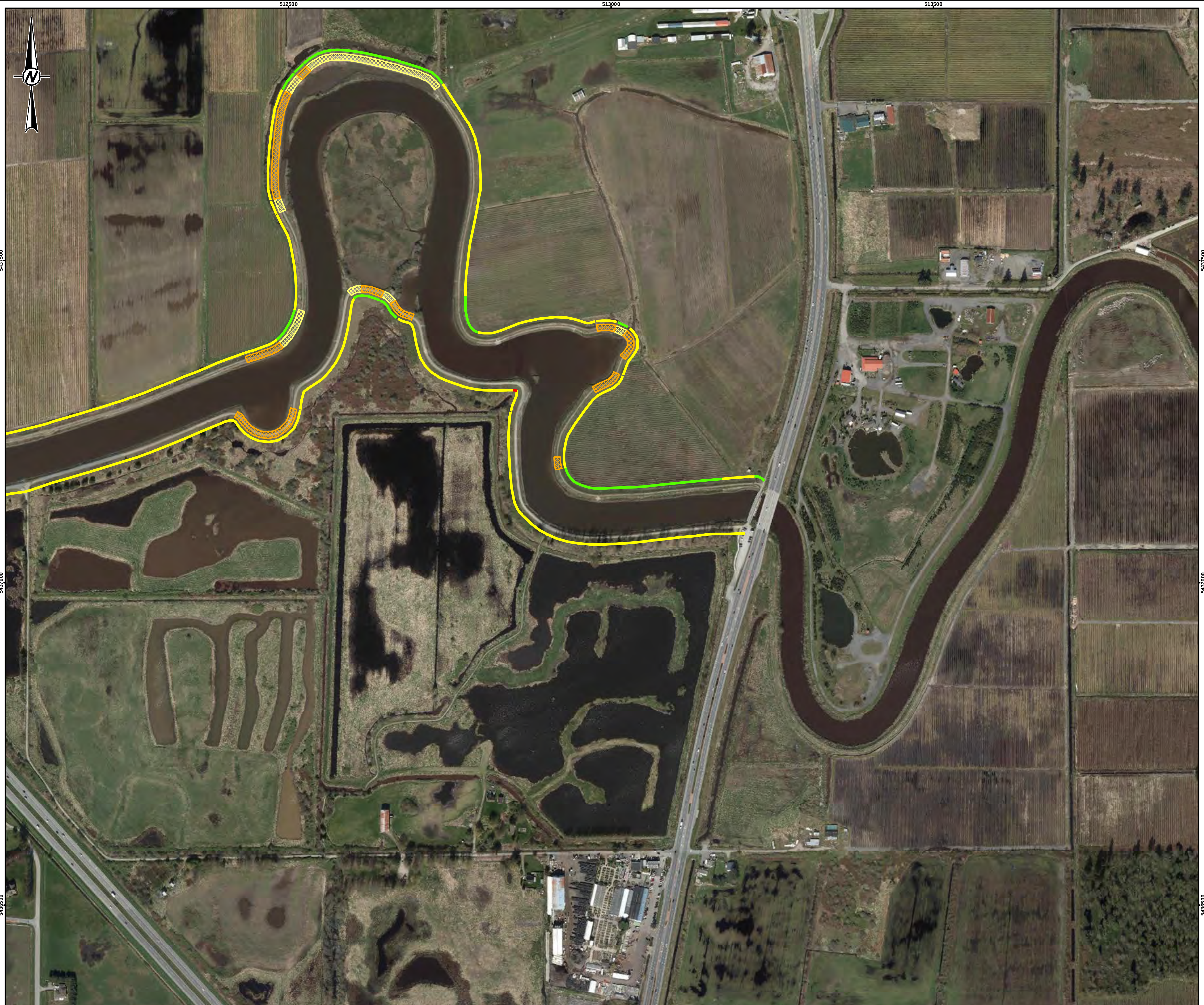

LEGEND

ARMOURING

- COBBLE
- ROCK
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MUD BENCH

- YES
- VEG
- BEACH
- NO

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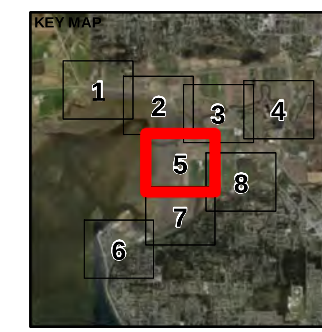
LEGEND

ARMOURING

- COBBLE
- ROCK
- UNARMOURED

MUD BENCH

- YES
- VEG
- BEACH
- NO



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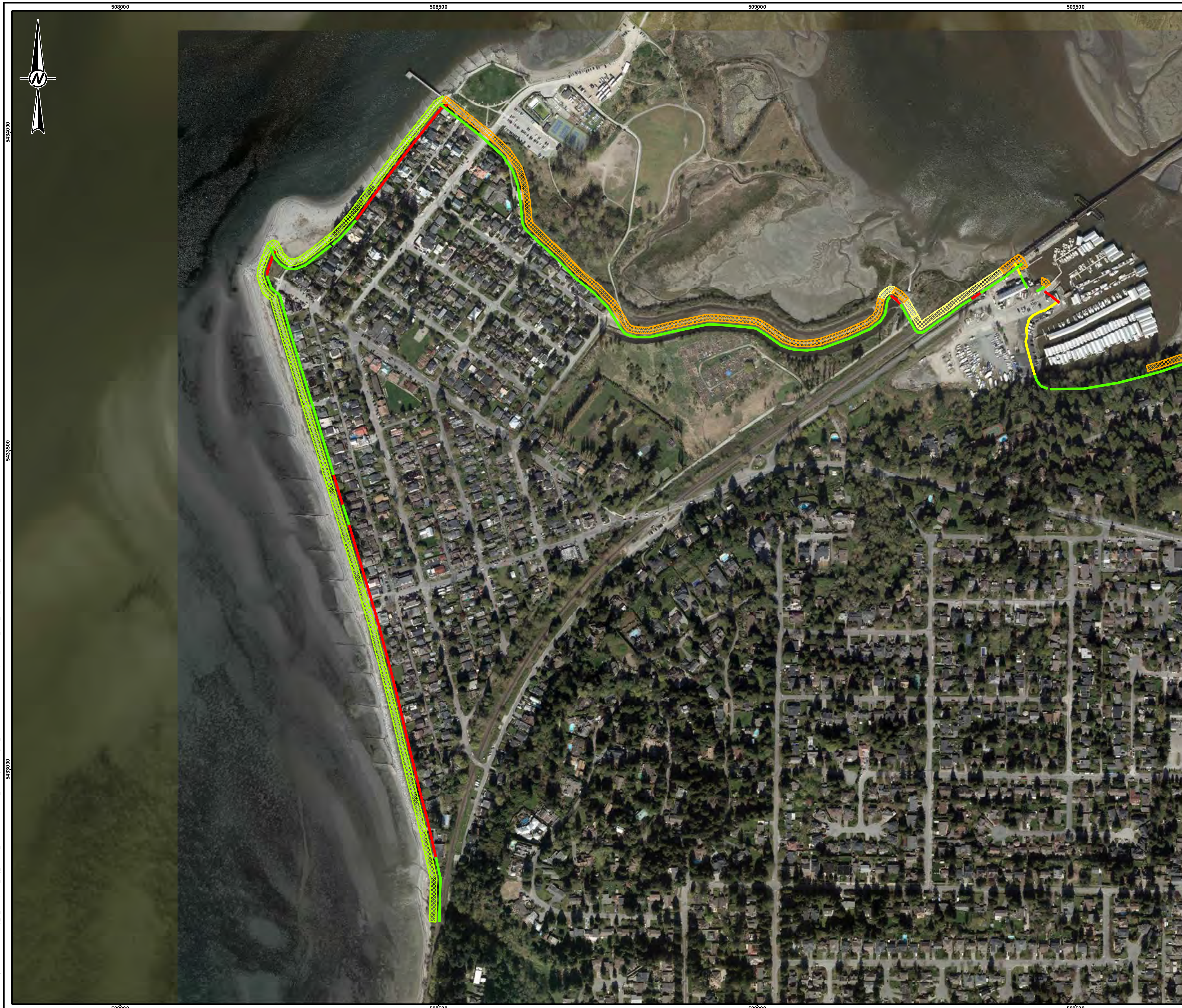

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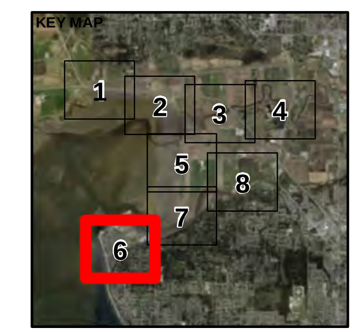
- BEACH
- NO



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COORDINATE SYSTEM: NAD 1983 UTM ZONE 10N

CLIENT
CITY OF SURREY

PROJECT
SHORELINE ASSESSMENT
MUD BAY, SURREY, B.C.

TITLE
SHORELINE ASSESSMENT

CONSULTANT
Golder Associates

YYYY-MM-DD	2018-03-15
DESIGNED	CM
PREPARED	CDB
REVIEWED	RA
APPROVED	RA

PROJECT NO.	CONTROL	REV.	FIGURE
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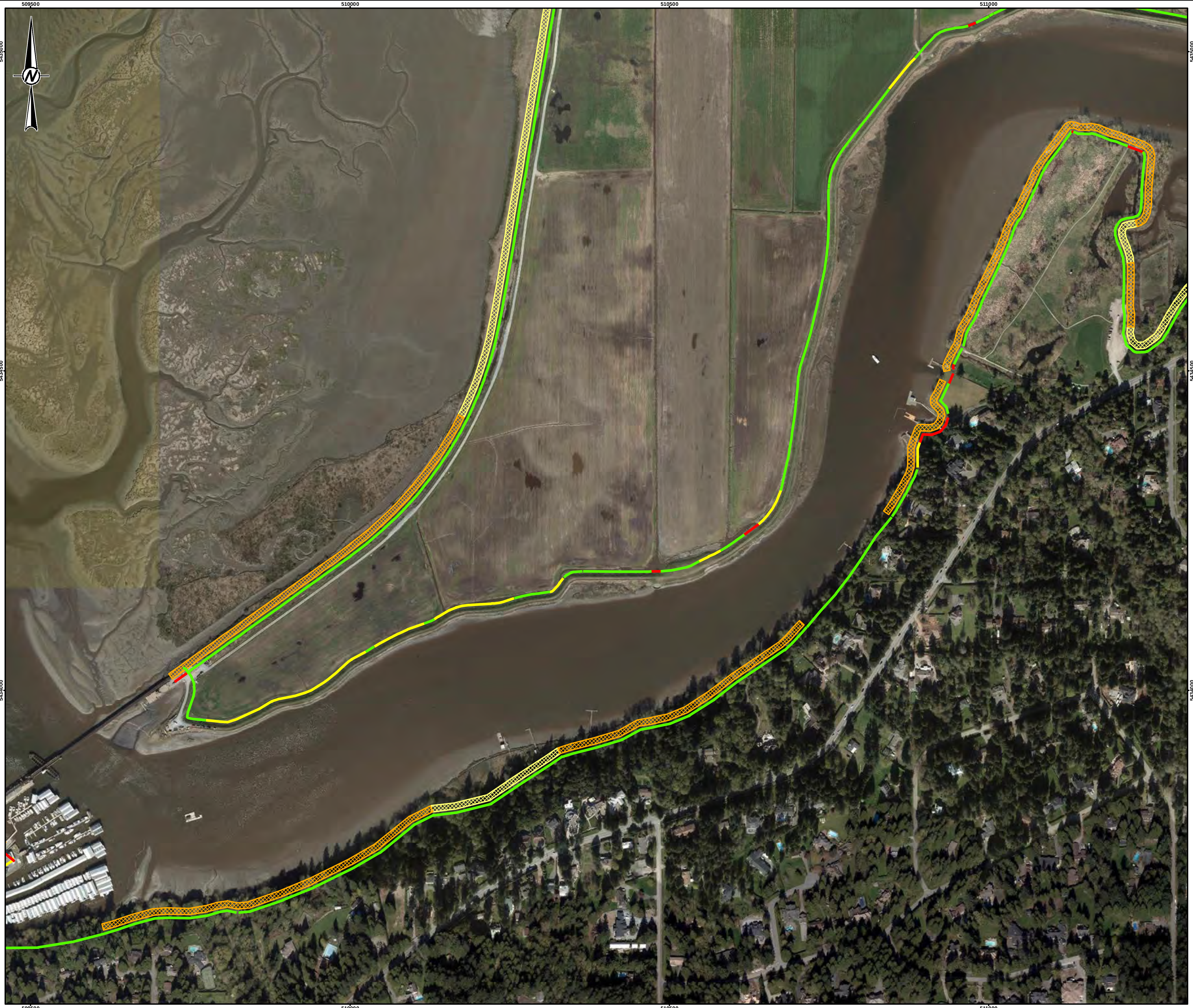

LEGEND

ARMOURING

- COBBLE
- ROCK
- UNARMOURED

MUD BENCH

- YES
- VEG
- BEACH
- NO

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REFERENCE(S)

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LEGEND

ARMOURING

- COBBLE
- ROCK
- UNARMOURED

MUD BENCH

- YES
- VEG
- BEACH
- NO

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REFERENCE(S)

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Chapter 2

Mud Bay: Ecosystem Services Potential for Coastal Flood Protection (Literature review)

Mud Bay: Ecosystem Services Potential for Coastal Flood Protection

Ducks Unlimited Canada

Report to: City of Surrey Coastal Flood Adaptation Strategy

February 12, 2018

Executive Summary

Located in the City of Surrey at the mouth of the Serpentine and Nicomekl Rivers, Mud Bay forms the eastern portion of continuous tidal habitat with Boundary Bay. Together, Mud and Boundary Bays contribute extremely valuable foraging habitat for waterbirds, and are recognized as a key component of the most significant Important Bird Area in Canada.

Relatively little published literature is available describing specific habitat conditions in Mud Bay. Available information describes extensive mud flats with eel grass beds in the lower and subtidal reaches and salt marsh habitat at the upper reaches, limited landward by dikes. These areas foster a rich food-web with readily available prey for the hundreds of thousands of waterbirds that depend on it daily during migration.

Like many coastal areas around the world, Mud Bay is vulnerable to the effects of climate change through sea level rise (SLR) and increased flood frequency and intensity. The City of Surrey is developing a Coastal Flood Adaptation Strategy (CFAS) and has expressed interest in the potential role of salt marsh ecosystems in the CFAS.

There is considerable literature available on the role of wetlands, and salt marshes specifically, in coastal protection. Marsh habitats contribute to coastal protection through wave attenuation, stabilizing coastlines, and flood water storage. There is evidence that salt marshes can accrete naturally to keep pace with sea level rise, making them more resilient in the long term than engineered infrastructure.

Many jurisdictions world-wide are incorporating wetland restoration in their coastal protection strategies. In addition to coastal protection, wetland restoration provides fish and wildlife habitat, water quality, and carbon sequestration benefits. Combining wetland restoration with engineered structures to accomplish coastal protection goals is gaining interest, especially in areas that are too heavily developed to rely on natural features alone. This approach may be appropriate for the City of Surrey.

Key information gaps should be addressed if the City of Surrey wishes to pursue wetland restoration as part of its CFAS. Prominent among these are assessing sediment supply and transport in Mud Bay; updating marsh vegetation surveys and marsh dynamics; and modelling future salinity gradient conditions. These factors would be critical for planning any successful marsh habitat restoration work.

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Introduction

Mud Bay is situated within the City of Surrey and forms continuous tidal habitat with Boundary Bay to the west. Mud Bay is influenced by the Serpentine River in the north and the Nicomekl River in the south and is bounded by dikes at the landward side (Figure 1). Immediately adjacent land uses include agriculture, parks, residential areas, Highway 99, and a marina. The Serpentine Wildlife Management Area is located upstream along the south bank of the Serpentine River, immediately east of Highway 99.

Figure 1: Mud Bay, 2017 Google Earth imagery

The City of Surrey has expressed interest in the potential role of Mud Bay's coastal wetland habitat in its Coastal Flood Adaptation Strategy (CFAS). This report provides a review of literature on the ecosystem components of Mud Bay, and their potential role in the City's CFAS. Subsequent sections of this report include a discussion of available information on the ecosystem components of Mud Bay, and on the role of coastal wetlands in flood protection, including a discussion of the resilience of coastal marshes to sea level rise. The report concludes with a discussion of the potential role of salt marsh restoration for flood protection in the context of Mud Bay, including key data gaps that should be addressed if the City of Surrey wishes to incorporate coastal marsh restoration in its CFAS.

Ecosystem Components

Hydrology

Mud Bay is characterized by mudflats, lined with fringing salt marsh habitat along diked agricultural land (Figure 1). Freshwater inputs come to Mud Bay from the Serpentine and Nicomekl Rivers, which drain a total area of 334 km^2 (KPA, 1994). The influence of the Serpentine and Nicomekl make Mud Bay less saline than neighbouring Boundary Bay, which is further from these rivers, and sheltered from the freshwater influence of the Fraser River by Point Roberts (BirdLife International 2018; Clague et al. 1998; Kellerhals and Murray 1969). Drainage through the salt marsh seaward of the dike is irregular and incomplete, occurring through a variety of small channels (Kellerhals and Murray 1969; visible in Figure 1). At lower elevations, tidal flats have well developed drainage networks with stable channels surrounded by eelgrass meadows in lower intertidal areas (Kellerhals and Murray 1969; visible in Figure 1).

The area draining into Mud Bay has limited water storage capacity because it lies on saturated soils close to the water table, particularly during winter when higher intensity storm events are most common (NHC 2015). Freshwater inputs to Mud Bay during storm events are already significant; for example, in a review of river discharge levels, NHC (2015) reports an instantaneous peak flow in the Nicomekl River of 96 m^3/s during a storm event in January 2005. Such high flow events are expected to become more frequent and intense in response to climate change (NHC 2015). Coupled with site-specific subsidence rates, relative sea level rise estimates for Mud Bay range from 10 - 12 mm/year (NHC 2015). These factors make the area very vulnerable to flooding: NHC (2015) provides detailed predictions of flood scenarios in Mud Bay in response to climate change including both flood events and SLR.

Sediment

Sediments in western Mud Bay are dominated by silty sand, supplied from cliffs at Roberts Bank, while eastern Mud Bay is predominantly fine mud consisting of clay from the Serpentine and Nicomekl Rivers, as well as silty-sand (Clague et al. 1998; Kellerhals and Murray 1969;

Northcote 1961). The wind-sheltered aspect of Mud Bay facilitates deposition of fine sediments (Clague et al. 1998; Kellerhals and Murray 1969).

Both the Nicomekl and Serpentine Rivers were historically dredged to ensure passage by shipping vessels as early as 1920 (City of Surrey 2008). Dredging of these rivers stopped in the 1980s and resulting sedimentation has been an impediment to vessel passage in more recent years (City of Surrey 2008). In addition to dredging, hardened shorelines and other infrastructure, such as seawalls, railway beds, piers and docks have also reduced sediment supply to the Boundary Bay area (de Graaf 2007).

Vegetation

An early report describes the salt marsh fringing Mud Bay as dense and up to 15 cm in height, with perpendicular extent from the dike as low as “a few tens of feet” (Kellerhals and Murray, 1969). This description appears consistent with the current extent of salt marsh in Mud Bay (Figure 1). Kellerhals and Murray 1969 described the leading edge of the salt marsh in Mud Bay as an eroding “active cliff” 0.5 m in height. This contrasts with their description of the leading edge of the marsh further west in Boundary Bay, which they believed to be accreting through a process in which organic matter was being trapped by the marsh edge in the fall, covered in sand in the winter, and then colonized by algal mats which facilitate the expansion of marsh vegetation in the spring and summer (Kellerhals and Murray 1969).

Eelgrass beds are present in the lower tidal and subtidal areas of Boundary and Mud Bay (Baldwin and Lovvorn, 1994; Bird and Cleugh 1979; BirdLife International 2018; City of Surrey 2008; Kellerhals and Murray 1969). 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 (Baldwin and Lovvorn 1992; Baldwin and Lovvorn 1994; Kellerhals and Murray 1969). Eelgrass beds in the bay include both native eelgrass species and introduced dwarf eelgrass (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).

North and Teversham (1983) mapped the distribution of vegetation in Boundary/Mud Bay using surveyor notebooks from 1859 – 1890. Notes from that time describe salt marsh, consisting of species such as glasswort (*Sarcocornia virginica*), sea arrowgrass (*Triglochin maritimum*) and seashore salt grass (*Distichlis spicata*). As of 1983, these vegetation types were still present in Boundary Bay, though to a much lesser extent that in the late 1800's as a result of diking (North and Teversham 1983). A number of subsequent vegetation surveys in Boundary Bay, including one at the eastern edge of Boundary Bay at Mud Bay in 1982, yielded a very similar plant list (Clague et al. 1998; Parsons, 1975; Porter 1982; Shepperd 1981). Prior to diking, the Serpentine and Nicomekl floodplains were most likely occupied by high-marsh species such as tufted hairgrass (*Deschampsia caespitosa*), transitioning gradually to shrubs, and then wet coniferous forest at higher elevations (North and Teversham 1983).

Biofilm

Biofilm is a mixture of organic matter, algae, microbes and meiofauna present as a thin layer on mud and sand-flats and represents a guild of important primary producers throughout the Fraser Estuary (Snyder et al. 2005; Jardine et al 2015; Otte and Levings 1975). Within the Fraser Estuary, Mud Bay has the highest concentration of biofilm per area (Jardine et al. 2015). Biofilm appears to be an important food source for migrating Western Sandpipers and managing habitat to maintain biofilm may be important for maintaining shorebird populations (Jardine et al. 2015). Biofilm can also be a valuable indicator of estuarine ecosystem health, since it represents a diverse suite of microorganisms which help to mediate many important biogeochemical processes (e.g. nutrient cycling; Snyder at al. 2005).

Invertebrates

Mud and Boundary Bays provide habitat for a wide variety of invertebrates which help support high numbers of migratory waterbirds foraging in the area (BirdLife International, 2018; Palm 2012; Pomeroy 2006). A diverse suite of invertebrates occupy the intertidal zone, including polychaete worms, annelid worms, nematodes, bivalves, small crustaceans and snails (Otte and Levings 1975; Schaefer 2004). These prey items are particularly important for sea ducks, such as white-winged scoter (Palm et al. 2012) and some dabbling ducks (e.g. northern pintail; Baldwin and Lovvorn 1994). In the higher tidal flats, where there tends to be fewer invertebrates because of increased exposure to air, polychaete worms and burrowing shrimp have been found in lower depressions (Kellerhals and Murray 1969).

Baldwin and Lovvorn (1992) took sediment cores in Boundary Bay to estimate the density of invertebrate prey available for dabbling ducks. The seven most common invertebrates included saltwater clams from the genuses Macoma and Mya; mudflat and sea snails from the genuses Batillaria, Maninoea, Nassarius, and Bittium; and bivalve molluscs from the genus Tellina.

These prey are particularly important in the diet of Northern Pintails (Baldwin and Lovvorn 1992).

McEwan and Gordon (1980) sampled benthic invertebrates in throughout Boundary Bay from as far east as the edge of Mud Bay and including Roberts Bank. These authors noted 77 invertebrate species, 48 of which were crustaceans, 23 marine worms, 13 snails, and 17 bivalves. Highest densities occurred near salt marsh habitat. On average, the density of invertebrates was three times higher in eastern Boundary Bay, near Mud Bay, than in western Boundary Bay (McEwan and Gordon 1980).

Fish

Surprisingly little published information regarding fish in Mud and Boundary Bay or in the Serpentine and Nicomekl Rivers is readily available. Serpentine and Nicomekl Rivers have coho salmon populations, which make use of associated estuary habitats in Mud Bay as they migrate out to marine habitats (Beacham et al. 2017). At high tides, the tidal flats in Boundary and Mud Bay attract Pacific staghorn sculpin, starry flounder, and Dungeness Crab (Schaefer 2004). Boundary Bay attracts spawning herring, an important forage fish for salmonids, marine mammals, and diving ducks (Levings 2004; Schaefer 2004). Beaches in this area provided spawning habitat for other forage fish in the past, including sandlance and surf smelt, though the hardened shorelines and other infrastructure around the Bays have reduced spawning habitat quality considerably (de Graaf 2007).

Birds

Together with Sturgeon Banks and Robert Banks, Boundary Bay and Mud Bay form a Site of Hemispheric Importance for migratory birds and is internationally recognized as an Important Bird Area (IBA) (Birdlife International 2018; de Graaf 2007). Since wintering and migrating waterbirds move around between Sturgeon Banks, Roberts Bank, and Boundary and Mud Bays, these areas have been amalgamated into a single IBA, which is considered the most significant IBA in Canada (Birdlife International 2018; de Graaf 2007). Together, Mud and Boundary Bays provide extensive mudflats and eelgrass beds, which supply abundant invertebrates, biofilm, and forage fish as prey for these birds (Baldwin and Lovvorn 1992; Baldwin and Lovvorn 1994; Elner et al. 2005; Harrison and Dunn 2004; de Graaf 2007; Schaefer 2004).

Boundary and Mud Bays are perhaps best known for supporting migratory shorebirds, which feed on the extensive un-vegetated mudflats (BirdLife International 2018; Schaefer 2004).

Throughout migration season, the Bays host most of the world's western sandpiper population: individuals number up to 500,000 birds daily (BirdLife International; Scheafer 2004). The Bays also provide key foraging areas for 10% of the global *pacifica* subspecies of dunlin, and 3% of the world's black-bellied plovers during migration (Birdlife International 2018). These abundant shorebirds provide an important prey source for raptors such as Peregrine falcons, Merlins, and Northern Harriers (Dekker and Ydenberg 2004; Pomeroy 2006).

Migrating waterfowl also forage in the Bays in large numbers. In fall and early winter, daily waterfowl counts often reach 100,000, including up to 2% of the global American Wigeon population and 1% of the North American Northern pintail population, as well as high numbers of mallard, green-winged teal, snow geese, and trumpeter swans (BirdLife International, 2018). Baldwin and Lovvorn (1992 and 1994) found that most dabbling ducks (i.e. mallard, wigeon, and brant) spent most of their time feeding on eelgrass beds below the mean water level. Other dabblers, including green winged teal and northern pintail, feed primarily on small crustaceans, snails, and bivalves (Baldwin and Lovvorn 1992; Baldwin and Lovvorn 1994).

Boundary Bay rookeries encompass 6% of the breeding population of the endangered *fannini* subspecies of great blue heron (BirdLife International 2018). Herons forage within eelgrass beds in Boundary and Mud Bays and may have benefitted from the expansion of these beds following the introduction of dwarf eelgrass (Harrison and Dunn 2004).

Role of Salt Marshes in Coastal Protection

In addition to its high biodiversity values, Mud Bay can provide coastal protection. Coastal communities have always born flooding risks associated with storms (Gedan et al. 2011; Koch et al. 2007), and these risks are being magnified by sea level rise (SLR; IPCC 2007; Temmerman et al. 2013). Hurricane Katrina brought renewed attention to the question of whether salt marshes might have a role in coastal protection (Bohannon and Enserink 2005; Day et al. 2007; Fischetti 2005). Katrina was followed by several extreme flooding events world-wide, including Cyclone Nargis (2008 in Myanmar), Hurricane Sandy (2012 in New York), and Typhoon Hyan (2013 in the Philippines), and the frequency of these event is expected to increase with climate change (Stark et al. 2015; Temmerman et al. 2013). In North America, the idea that coastal marshes can attenuate floods dates back to a 1963 US Army Corps of Engineers study which correlated storm surge elevation with inland marsh extent for storm events in Louisiana in the first half of the 1900s (U.S. Army COE 1963 *in* Shepard et al. 2011).

How Salt Marshes Protect Coastal Areas

Many authors refer to wave attenuation (e.g. Fonseca and Cahalan 1993; Koch et al. 1999; Massel et al. 1999), shoreline stabilization (e.g. Cahoon et al. 1999; Reed 1995; Rooth et al. 2003; Van Eerdt 1985; Waldron, 1977), and flood water storage (e.g. Bolduc and Afton 2004; Brody et al. 2007; Stark et al. 2016) as mechanisms explaining how salt marsh vegetation protects coastal areas from storm impacts. While some small-scale experiments conclude that marsh vegetation provides little to no coastal protection from waves and storm surge (e.g. Feagin et al. 2009), most of the academic literature does support the argument that marshes can protect coastlines through the mechanisms above (Gedan et al. 2011; Shepard et al. 2011).

Shepard (et al. 2011) conducted a review and meta-analysis of studies of these three mechanisms by which salt marshes contribute to coastal protection. To ensure a high level or rigour, these authors selected only field and laboratory studies that were controlled (i.e. comparing effects in vegetated versus non-vegetated areas), quantitative, and included explanatory variables (e.g. vegetation type, density, height). Following the selection process, the authors analysed ten studies on wave attenuation, and 18 studies (including 38 independent measurements) on shoreline stabilization. Shepard (et al. 2011) were surprised to find that, at the time of their review, very few studies rigorously examined the effects of coastal wetlands on floodwater storage; only four such studies were included in the review.

All ten studies on wave attenuation showed that salt marshes can provide significant wave attenuation, where the degree of attenuation was positively related to salt marsh transect length, vegetation density, and marsh elevation (Shepard et al. 2011). Many of these studies showed that 50% of wave attenuation occurs within the first 10 m of seaward marsh habitat, showing that despite smaller size, fringing marsh can contribute to flood resilience. Of the 38 independent measurements of the effects of marsh habitat on shoreline stabilization, 22 studies showed significant benefits. While no studies of flood water storage were rigorous enough to include in the meta-analysis, all four studies reviewed provide evidence suggesting that coastal marsh habitats drain water faster and more effectively than altered habitats and anthropogenic areas. Shepard (et al. 2011) concludes that salt marsh vegetation has a significant positive effect on wave attenuation and shoreline stabilization particularly for more frequent lower intensity storm events, and that these habitats also provide some benefits in terms of flood water storage. Gedan (et al. 2011) provide a similar review and meta-analysis and reach the same conclusion.

Wave Attenuation

Wave attenuation means a reduction in wave energy as waves pass through salt marsh (Fonseca and Cahalan 1992; Coops et al. 1996; Koch et al. 2007). This is usually the result of friction, caused by vegetation, disrupting waves (Massel et al. 1999), and is a function of vegetation biomass and coastal bathymetry; specifically, of the percent of the water column occupied by vegetation (Coops et al. 1996; Fonseca and Cahalan, 1992). While tall woody vegetation, such as mangroves, offer greater wave attenuation (Koch et al. 2009), salt marsh vegetation can be effective at attenuating smaller waves, which occur more frequently (Fonseca and Cahalan 1992). Because of this, coastal ecosystems will have greatest capacity to attenuate waves when vegetation is high and tides are low (Koch et al. 1999). While there is variability among study results, generally vegetation height, stiffness, and density as well as marsh elevation and width are all positively related to wave attenuation (Shepard et al. 2011). A more recent study found that continuous marshes with fewer, smaller channels provided greater wave attenuation than marshes with large, deep channels (Stark et al. 2016).

Shoreline Stabilization

Shoreline stabilization includes enhanced sediment deposition, increased marsh platform elevation through root production, and stabilization of marsh sediments (Shepard et al. 2011). Salt marsh vegetation promotes sedimentation and decreases erosion (Shepard et al. 2011; Thorne et al 2014). Vegetation driven marsh accretion may occur through a variety of mechanisms, including growth of fibrous root networks above-ground, stimulated by flooding (Nyman et al. 2006); plant litter from aboveground biomass (Craft et al. 1993); development of below-ground root biomass (Cahoon et al. 1999; Reed 1995; Wolaver et al. 1988); or increased capture of sediment from the water column by aboveground vegetation (Rooth et al. 2003; Van Eerdt 1985; Waldron, 1977). Organic matter content, proximity to freshwater channels, and tidal range are positive predictors of marsh accretion (Chmura and Hung 2004).

Where marsh vegetation is present, storm events can actually help drive sediment accretion: storm-mobilized sediments settle out in marsh vegetation after the storm has subsided, increasing sediment accretion within salt marshes (McKee and Cherry 2009). Kellerhals and Murray (1969) noted a similar process in Mud Bay, recording fresh fine clays trapped at the seaward edge of the salt marsh following very high tides.

Floodwater Storage

Floodwater attenuation means the capacity of salt marsh to reduce flood peaks by absorbing flood water (Shepard et al. 2011). One study suggests that larger wetlands can attenuate more water, though beyond a point, the benefits to increasing size drop off (Smolders et al. 2015). Wetlands positioned further in land in an estuary (though not necessarily at a higher elevation) appear to have greater per-area storage capacity (Smolders et al. 2015). Modelling of storm events in the Scheldt estuary under a variety of combined wetland areas and dike arrangements suggests that dike geometry can have a major influence on flood water storage (Stark et al. 2016). Dikes should be arranged in a way that minimizes pooling of water and disruption to wave attenuation (Stark et al. 2016).

Impacts of Sea Level Rise on Salt Marshes

While SLR will increase the need for coastal protection, it will also change the role of wetlands in providing it (Gedan et al. 2011). SLR will alter wetland coastal wetland accretion, and the capacity of these wetlands to provide storm and flood attenuation services (Gedan et al. 2011). Some predictions are for heavy wetland losses due to SLR (Craft et al. 2009; Nicholls et al. 1999). When marshes cannot migrate upland in response to sea level rise due to infrastructure such as dikes and sea walls, marsh survival depends on vertical accretion rate outpacing sea level rise (Thorne et al. 2014). Alarmingly, vegetation death in rising water levels could be irreversible: vegetation die-off can cause marsh platform collapse, lowering substrates to elevations too low for recolonization (Day et al. 2011; Goals Project 2015). Finally, channel dredging, which often occurs in diked areas, further exacerbates the problems of SLR by enhancing flood propagation (Temmerman et al. 2013).

Fortunately, some predictions of marsh loss fail to incorporate feedback mechanisms that may help coastal marshes keep pace with SLR (Gedan et al. 2011). These mechanisms include greater inundation of marsh vegetation with sediment-laden water (Temmerman et al. 2004), and enhanced vegetation growth rates in response to inundation (Morris et al. 2002; Nyman 2006). In an assessment of 78 coastal marshes in North America, Europe, and Australia, Cahoon (et al 2006) found that on average, marsh accretion rates exceeded the local relative sea level rise rates; a finding attributable to mechanisms discussed here. These mechanisms, by which estuarine wetlands keep pace with SLR, can makes them more sustainable in the long-term than engineered structures for coastal protection (Smolders et al. 2015).

Coastal Marsh Restoration for Coastal Protection

World-wide, conversion of coastal wetlands to agricultural, industrial, and residential land uses is thought to have increased flood intensity due to reductions in floodwater storage, wave attenuation, and shoreline stability (Brody et al. 2007; Shepard 2011; Temmerman 2013; Thorne 2014). Structures like dikes and levees can lead to erosion of marsh platform by cutting salt marshes off from riverine sources of sediment, and by compaction caused by pooling of water against the levees on the seaward side (Brody et al. 2007; Temmerman et al. 2013; Thorne et al. 2014). Because of access to tide water and low lying topography, estuaries are often heavily populated; and correspondingly developed. Taken together, these factors make estuaries extremely vulnerable to flooding (Koch et al. 2007) and researchers recommend salt marsh restoration programs to assist in coastal flood protection strategies (e.g. Gedan et al. 2011; Shepard et al. 2011). Some jurisdictions have begun pursuing coastal marsh restoration as a means of flood protection (Temmerman et al. 2013).

Compared to engineered infrastructure for the same purpose, salt marsh restoration has the added benefits of providing carbon sequestration, fish and wildlife habitat, water quality improvements, and recreational benefits (Goals Project 2015; Temmerman et al. 2013). Cost-benefit calculations suggest that in the long-term (20 - 25 years), salt marsh restoration is more economical for coastal protection than maintaining dikes in the Humber and Schelde estuaries (Temmerman et al. 2013). Despite these benefits, many coastal areas are simply too developed too close to tidal areas to rely solely on salt marsh restoration for protection (e.g. San Francisco Bay; Goals Project 2015). Increasingly, research is beginning to focus on combining natural coastal defenses provided by wetlands with engineered structures (Cheong et al. 2013; Stark et al. 2016; Sutton-Grier et al. 2015; Temmerman and Kirwan 2015). Some examples of where this is being implemented include San Francisco Bay, New Orleans, the Scheldt Estuary in Belguim and the Netherlands, and the Humber Estuary in the UK (Goals Project 2015; Stark et al. 2015; Stark et al. 2016; Temmerman et al. 2013).

In San Francisco Bay, for example, resource managers are undertaking large-scale restoration work to provide flood protection; in some areas, this will complement existing infrastructure (Goals Project 2015). Restoration in the San Francisco Bay is not only targeted at coastal protection; rather, protection is integrated with multiple objects, including maintaining fish and wildlife habitat, water and air quality, and recreation (Goals Project 2015). Broad strategies being implemented in San Francisco Bay are to restore ecological processes key in coastal ecosystem resilience. These include habitat connectivity, sediment supply and transport, and adjacent transition zone migration space so that vegetation species can migrate to higher ground in response to SLR (Goals Project 2015). Some specific actions include re-aligning infrastructure where possible and conducting modelling studies of sediment supply and transport to determine how to ensure sediment supply (Goals Project 2015).

Salt Marshes for Coastal Protection: Mud Bay Context

Modelling completed for the City of Surrey's CFAS finds that most of Surrey's coastal dikes provide inadequate flood protection for future floods, and that building some types of additional flood protection infrastructure, specifically off-shore break-waters may not be possible due to unstable sediments (NHC 2015). Coastal protection through a combination of marsh restoration and engineered structures may be a good option for the City of Surrey, given the level of development in the watershed, existing marsh ecosystem, and the high ecological value of Mud Bay. Restoring freshwater wetlands higher up in the watershed would also be beneficial as this would enhance watershed storage and reduce the volume of water being conveyed to Mud Bay during storm events.

Key drivers of salt marsh dynamics include: sediment supply and transport; salinity gradient; nutrients; sea level; and storm events (Goals Project 2015). City of Surrey has already begun examining sea level rise and storm events in detail (i.e. NHC 2015). Successfully incorporating salt marsh restoration into the CFAS would require some additional work to address the following information gaps:

- Sediment budget: is current sediment supply and transport in Mud Bay sufficient to allow marsh habitat to accrete naturally and keep pace with SLR?
- Salt marsh dynamics: vegetation surveys to provide an update on the current status of existing salt marsh habitat in Mud Bay is required. Some research on marsh processes, especially on if and how marsh cover is changing, would also be extremely useful.
- Salinity gradient: will existing vegetation species be able to adapt to future salinity gradients and fluctuations?

Finally, extent of open mudflats and eelgrass beds may change due to sea level rise. These habitat components are extremely valuable to migratory birds, for which Boundary and Mud Bays are of great renown. Any restoration work for the purpose of flood adaptation should consider the potential impacts on critical migratory bird habitat.

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Chapter 3

Mud Bay Coastal Geomorphology Study

MUD BAY COASTAL GEOMORPHOLOGY STUDY

DRAFT REPORT

Prepared for:

City of Surrey
Surrey, British Columbia

Prepared by:

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28 February 2018

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DISCLAIMER

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We would also like to acknowledge the cooperation of the City of Delta, who shared knowledge, information, and data with NHC through an agreement with City of Surrey. Provision of these materials efficiently advanced the understand the coastal processes at Mud Bay.

EXECUTIVE SUMMARY

The sedimentary condition of Mud Bay has implications for some of the potential coastal flood adaptation strategies being contemplated by the City of Surrey as a part of the Coastal Flood Adaptation Plan. The City of Surrey retained Northwest Hydraulic Consultants Ltd. (NHC) to conduct a high-level coastal geomorphology assessment to investigate the sedimentary condition of Mud Bay and understand the implications of this condition on sea level rise and coastal flood mitigation options. Background information and available data was reviewed, data was analysed to assess changes in historical to present conditions, and implications for sea level rise and mitigation were evaluated with respect to the sedimentological condition of Mud Bay.

Mud Bay is located on the northeastern side of Boundary Bay along the currently inactive southern edge of the Fraser River delta. Mud Bay is a shallow, tidally influenced bay with silty and sandy peat, salt marshes, sandy tidal flats, and dendritic drainage channels. Approximately 10,000 to 5,000 years ago, the Fraser River was a large source of sediment to Mud Bay; however, it no longer represents a contemporary sediment source. The three primary contemporary sediment sources to Mud Bay are the silt and clay delivered by the Serpentine and Nicomekl Rivers; sediment transported into the bay by longshore drift; and cliff erosion via wave action. The Serpentine and Nicomekl Rivers have a combined drainage of over 300 km^2 and discharge into the eastern side of Mud Bay. Sediments transported to Mud Bay via longshore drift and from cliff erosion are able to accumulate in Mud Bay because it is partially sheltered from southeasterly winds by Roberts Point and by Vancouver Island.

Historical to present elevation data and air photos were analysed to assess changes in Mud Bay. Historic (pre-1969) charts and maps were visually assessed at a macro level as they did not contain sufficient information to conduct detailed analyses. Recent (1969 to 2014) topographic and bathymetric data analyses were conducted to assess for potential sedimentation in Mud Bay over the last few decades. Air photos from 1949 to 2015 were analysed to assess for potential changes in the extent of the salt marsh, location and planform of tributaries within the mudflats, and location of the shoreline.

The results from the topographic and bathymetric analyses suggest 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. Quantifying historical sedimentation and subsidence rates in Mud Bay was not possible with the available data due to large data gaps, poor data resolution, and limited metadata. Additionally, in the context of the very slow rates of subsidence and sedimentation reported in the literature for areas surrounding Mud Bay, the recent period for which high quality data was available was not long enough for these slow changes to accumulate to a detectable level.

The results from the air photo analyses suggest relatively stable conditions in Mud Bay with respect to salt marsh extent, drainage channel planform, and shoreline location over the past 66 years. Observed changes in salt marsh extent and shoreline morphology during this time period were concentrated along the northern edge of Mud Bay and are largely attributed to the construction of Highway 99. The majority of drainage channels experienced minimal observable changes in location and planform over the past 66 years based on the air photo analysis.

Anticipated future climate changes are expected to impact the sedimentological condition of Mud Bay. Changes in relative sea level, changes to wave climate, and changes to freshwater and sediment inputs all have the potential to impact Mud Bay. Climate-induced sea level rise is expected to increase wave height at some locations within Mud Bay, which could lead to increased erosion in those areas. In addition, climate change has the potential to alter runoff patterns in the Serpentine and Nicomekl watersheds, which could impact freshwater and sediment inputs to Mud Bay. The relationships between land-use patterns, stormwater management, and rising sea levels is complex and there is uncertainty about how climate change might impact future conditions.

It is recommended that continued monitoring be conducted in Mud Bay to obtain a more detailed understanding of current conditions and better assess the impacts of climate change on Mud Bay. Sea level, wave height, and sedimentation monitoring in Mud Bay are recommended in the near- to medium-term future.

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1 INTRODUCTION

Northwest Hydraulic Consultants Ltd. (NHC) is pleased to present this report to the City of Surrey (CoS) describing the physical processes that have formed the physical environment of Mud Bay and our analysis concerning how future sea level rise will alter those processes and the physical system.

1.1 Study Objectives

The Coastal Flood Adaptation Strategy (CFAS) is a three-year initiative of the City of Surrey (CoS). CFAS takes a participatory, community-driven planning approach to exploring the impacts of climate change on the coastline while examining options for the long-term adaptation to sea level rise and increased runoff related to the changing climate. The Mud Bay Coastal Geomorphology Study was undertaken as part of CFAS to provide context for the various adaptation strategies that are to be contemplated.

Geomorphology is concerned with both the physical form of the environment and the physical processes that have resulted in the expressed form. Changes to one or more of the processes can result in changes to the physical system, which can be expressed over a range of time scales. The specific objectives of the present study are to:

1) Investigate the sedimentary condition of Mud Bay, in particular for indicators of whether it is in a state of erosion or accretion; and

2) Understand the implications of this condition with respect to sea level rise and coastal flood mitigation options.

1.2 Scope of Work

The work has been undertaken as a desktop study, relying on existing information that is available from previous studies, existing mapping, and historical aerial imagery. NHC outlined the expected scope of work in a scoping letter submitted to CoS, dated 17 January 2017, which identified three main tasks to be undertaken:

1) Review background reports and available data;

2) Data analysis of historical to present conditions;

3) Evaluate implications for sea level rise impacts and mitigation.

1.3 Study Area

The study is focused on Mud Bay, which occupies the eastern end of Boundary Bay fronting on to lands under the jurisdiction of CoS (see **Section 2.3**). Many of the processes that have formed and continue to modify Mud Bay are modified by adjacent geomorphic landforms, including Boundary Bay, Semiahmoo Bay, and Serpentine and Nicomekl Rivers. Although not the focus of the present study, information about these adjacent landforms is included for context.

1.4 Report Outline and Deliverables

This report is structured to provide background on existing conditions in **Section 2** that is based on existing information and data. **Section 3** describes the information that was collected from available sources and **Section 4** describes the methods that were used to analyse the data. **Section 5** describes the changes from historical conditions to present-day based on the analysed data, and **Section 6** discusses the anticipated future conditions that will be governed by ongoing processes as well as changes related to climate change.

2 PHYSICAL SETTING

The physical setting is described to provide context to the long-term changes that have been observed in the study area.

2.1 Study Area Boundaries and Principal Features

Mud Bay is located on the northeastern side of Boundary Bay along the currently inactive southern edge of the Fraser River delta (NHC, 2012). Boundary Bay and Mud Bay cover an area of 60 km^2 and face southeast on to the southern Strait of Georgia (NHC, 2012). **Figure 2.1** shows the Mud Bay study area. The western boundary of the study area is based on a somewhat arbitrary demarcation formed by a line extending from Sullivan Point (the point of land adjacent to Blackie Spit) and running north to the intersection of the shoreline boundary between the CoS and City of Delta (**Figure 2.1**). The northwest corner of the study area also corresponds to the western end of the Colebrook Dyke.

The shoreward boundary of the study area corresponds with the seaward side of the sea dykes along the CoS shoreline, except where it extends inland within the estuary portion of the Nicomekl and Serpentine Rivers.

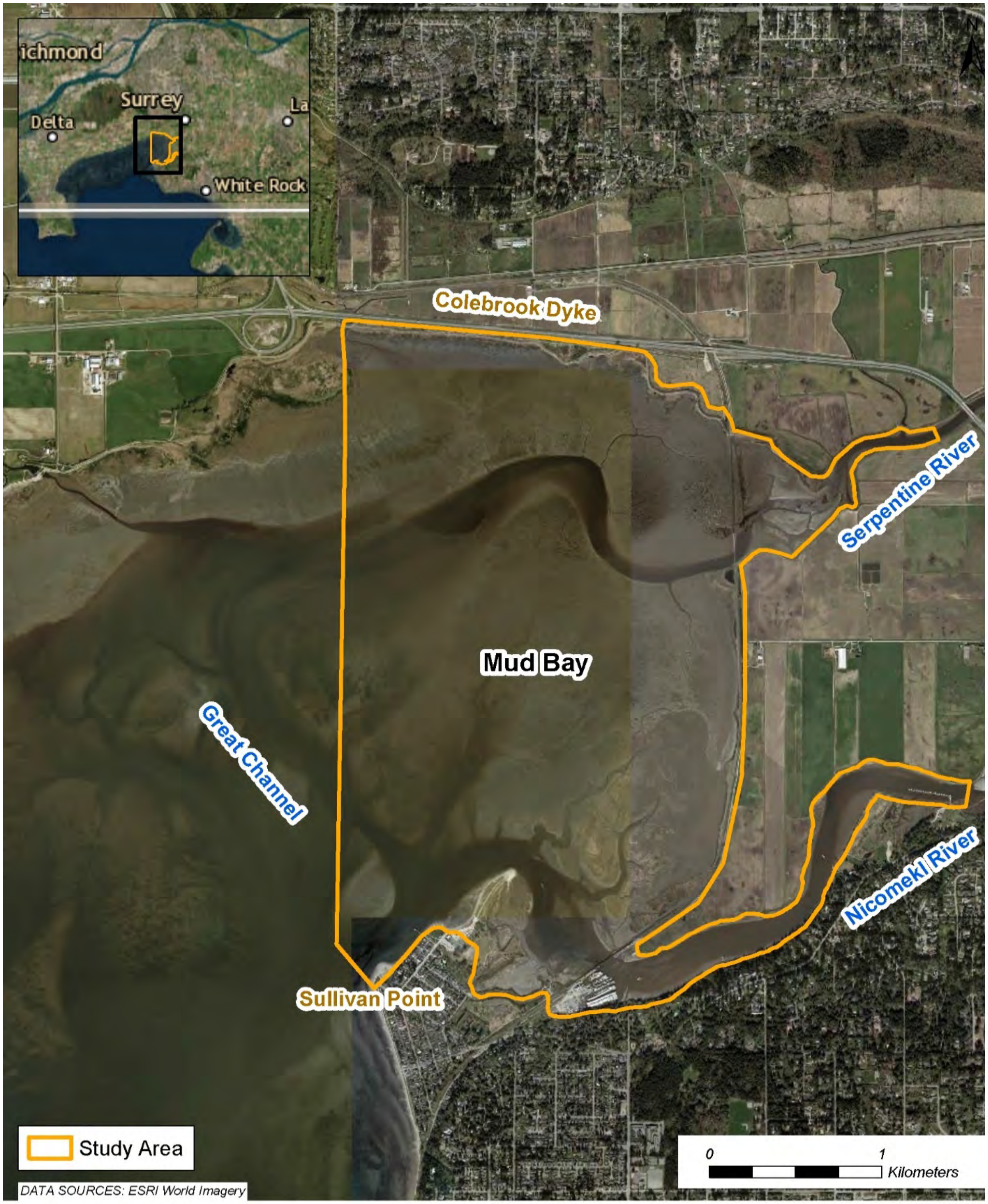


Figure 2.1 Mud Bay study area in British Columbia, Canada

2.2 Fraser River Delta

The contemporary Fraser River delta was formed since the most recent glaciation, beginning approximately 10,000 years ago. **Figure 2.2**, reproduced from NHC's (2014) *Proposed Roberts Bank Terminal 2 Technical Report Coastal Geomorphology Study* prepared for the Vancouver Fraser Port Authority, shows the development of the delta to the present day in simplified schematic form. The initially very rapid advance of the delta front and infilling of the Fraser Valley has slowed and present day sediment inputs to the delta, particularly those areas distal to the mouth of the Main Arm, are much reduced (NHC, 2014). In fact, nearly all of the present-day delta front at Boundary Bay had already developed as far back as 5,000 years ago, as evidenced by an absence of late Holocene Fraser River sediments at Burns Bog, directly between Boundary Bay and the Fraser River (Clague et al., 1983). The southern delta front is essentially inactive now, with the majority of its component sediments having been the result of historic deposition between 10,000 and 5,000 years ago.

The modern delta of the Fraser River commences near New Westminster and extends 15 to 23 km westwards in a broad delta plain encompassing Richmond, Ladner and Tsawwassen. The western margin of the delta extends into the Strait of Georgia approximately 27 km and includes Sturgeon Bank and Roberts Bank. Boundary Bay is located on the inactive southern side of the delta and extends 11.5 km.

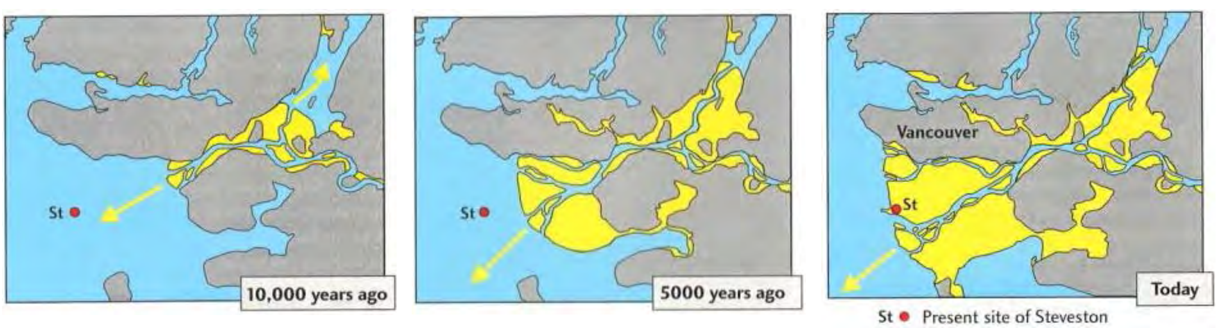


Figure 2.2 Growth of the Fraser delta and floodplain over the last 10,000 years (Clague and Turner, 2006)

2.3 Mud Bay

Mud Bay is a shallow, tidally influenced bay with sediments including silt, clay, and sand. Muddy clay-sized sediments are found along the shoreline of Mud Bay. The upper portion, which extends up to the sea dykes, contains silty and sandy peat and salt marshes. Hard substrate (e.g. gravel and cobble) generally exists only along the upper shoreline, corresponding to the presence of dykes and other shoreline armouring features. The upper portion is also characterized by having incomplete drainage, drainage channels oriented perpendicular to the shoreline, shallow depressions, hillocks, mounds, and vegetated areas. The intermediate and lower portions of Mud Bay contain sandy tidal flats and a well established network of dendritic drainage channels that both facilitate tidal exchange and sediment transport (Kellerhals and Murray, 1969). On the western edge of the study area, at the lower tidal flats, a large drainage channel called the 'Great Channel' cuts across the tidal flats and joins the Serpentine and Nicomekl Rivers. The Great Channel also connects with smaller drainage channels in the intermediate tidal flats. The tidal flats dip seaward at approximately 0.11 m/100 m within the study site before reaching a steeper slope east of the study site (Kellerhals and Murray, 1969).

The geology of Mud Bay and its surrounding areas is heavily influenced by the glacial history of the region. Substantial quantities of sediment in the area were deposited as a consequence of deglaciation processes and the many geologic features currently visible in Mud Bay were, in fact, formed thousands of years ago. For example, the majority of the sediment comprising the Fraser River delta at Mud Bay was deposited shortly after the last glaciation when meltwater streams from retreating glaciers were transporting large quantities of sediment. The growth of the Fraser River delta is discussed further in **Section 2.2**. Despite, it's historically large role in depositing sediment at Mud Bay, the Fraser River no longer represents an active source of sediment to 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 Serpentine and Nicomekl Rivers, discussed in **Section 2.4**, discharge into Mud Bay and deposit silt and clay into the bay. Sediment is also transported into Mud Bay via longshore drift. Sediment deposited by longshore drift is able to accumulate over time, rather than get eroded by wave action because of Mud Bay's unique physiography. As described further in **Section 2.6**, Mud Bay is partially sheltered from southeasterly winds by Point Roberts and by Vancouver Island. Additionally, the shallow waters of the Mud Bay tidal flats limit wave height. Both of these factors contribute to the accumulation of muddy sediments over time in Mud Bay (Kellerhals and Murray, 1969). Point Roberts also influences the sedimentology of Mud Bay in that some sediment eroded from the Pleistocene cliffs at Point Roberts via wave action is transported eastwards and deposited at Mud Bay (Kellerhals and Murray, 1969).

Mud Bay contains salt marsh environments believed to have formed under much different conditions than today, when a former Fraser River channel discharged into Boundary Bay (Government of Canada, 1998; Kellerhals and Murray, 1969). The present-day salt marsh areas occur along the coastline, with the greatest concentrations of salt marsh occurring in the southeastern and northeastern portions of Mud Bay. Over long term timescales, the salt marshes of Mud Bay have historically experienced erosion with pollen analysis providing evidence that 4350 years ago, the marsh used to occupy a much larger area (Kellerhals and Murray, 1969). This historical loss of salt marsh may be attributed to a combination of compaction and subsidence (Kellerhals and Murray, 1969).

2.4 Serpentine and Nicomekl Rivers

The Serpentine and Nicomekl Rivers have a combined drainage area of over 300 km^2 and discharge into Mud Bay (**Figure 2.1**). These rivers are tightly linked to Mud Bay and represent one of the three main contemporary sediment sources to the bay.

The Serpentine and Nicomekl Rivers are controlled by sea dams in their lower reaches that allow fresh water to flow into Mud Bay when the tides are low and prevent brackish water from migrating up river when tides are high. Construction of these sea dams and other structures used to prevent flooding and optimize agricultural development in the area are discussed further in **Section 2.5**.

The topography of the Serpentine and Nicomekl River floodplains are unique in that they have a bowl-like shape. The lowest elevations (below 0 m) of the floodplain are located in the eastern half of the lowlands; whereas the elevations of the western end of the floodplain, where the rivers discharge to Mud Bay, are typically 1 m higher. As would be expected, the floodplain elevations around the headwater tributaries are higher and the uplands reach to an elevation of 100 m (NHC, 2016).

The Serpentine and Nicomekl Rivers receive sediment from tributaries in their upper reaches and transport that sediment to the lower reaches. The tributaries that constitute major sources of sediment to the Serpentine River watershed include the upper Serpentine River, Mahood/Bear Creek, and Hyland Creek. The tributaries that constitute major sources of sediment to the Nicomekl River watershed include the upper Nicomekl River and Anderson Creek. In the upper reaches of the Serpentine River, where the channel transitions from the uplands to the flatter lowlands area, gravel and sand are deposited; whereas, in the lowlands area, the river banks contain substantial amounts of clay and silt (NHC, 2016).

In a study conducted by NHC (2016) for the City of Surrey, channel stability of the lowland reaches of the Serpentine and Nicomekl Rivers was assessed. NHC found that the main channels of these rivers had been relatively stable over the last few decades and that sediment transport increased in the downstream direction. These rivers, consequently, were found to have sufficient transport capacity in their lower reaches to flush sediment through the sea dams.

Consequently, as the Serpentine and Nicomekl Rivers discharge into Mud Bay, they deposit silt and clay into the bay (Kellerhals and Murray, 1969). After reaching Mud Bay, the Serpentine and Nicomekl Rivers both join a large drainage channel in the eastern tidal flats, known as the 'Great Channel' (**Figure 2.1**) (Kellerhals and Murray, 1969). The Great Channel incises through the tidal flats at an oblique angle and plays an important role in facilitating tidal exchange and transporting sediment within Mud Bay (Kellerhals and Murray, 1969).

2.5 Ocean Conditions

2.5.1 Tidal Range and Strength

Boundary Bay experiences mixed semi-diurnal tides, which means that there is an oscillation that occurs on a nearly daily basis that includes two high waters and two low waters (Luternauer et al., 1998; Shepperd, 1981). The two daily high waters and the two daily low waters are of different heights (Engels, 1999; Shepperd, 1981). **Table 2.1**, reproduced from the *Lowland River Morphology and Bank Stability Review* prepared by NHC for the City of Surrey (2016) presents astronomical tide statistics for Crescent Beach. As reported by NHC (2016), "Higher High Water Large Tide (HHWLT) represents the average of the highest high waters, one from each of 19 years of predictions. Higher High Water Mean Tide (HHWMT) represents the average of all the higher high waters from 19 years of predictions. Mean Water Level (MWL) is the average of all hourly water levels over the available period of record and usually corresponds close to Canadian Geodetic Datum (CGD) to a first approximation".

Table 2.1: Tide statistics at Crescent Beach from Canadian Hydrographic Service.

Tide Condition	Abbreviation	Elevation (m)	
		Chart Datum	Geodetic
Higher High Water Large Tide	HHW-LT	4.6	1.8
Higher High Water Mean Tide	HHW-MT	3.9	1.1
Mean Sea Level	MSL	2.8	0
Lower Low Water Mean Tide	LLW-MT	1.2	-1.6
Lower Low Water Large Tide	LLW-LT	0.27	-2.5

The mean tidal range for Boundary Bay – the difference between the higher high water and lower low water – is 2.7 m based on the Crescent Beach data presented in **Table 2.1**. This value of 2.7 m is also consistent with the mean tidal range reported by Kellerhals and Murray (1969), Shepperd (1981), and Dashtgard (2011). The mean tidal range falls within the 2 m to 4 m category, which classifies Boundary Bay as a mesotidal area. Tidal flats, marshes, and spits, all present in Boundary Bay, are characteristic features of mesotidal coastlines (Engels, 1999).

The strength of tidal currents varies temporally and spatially in Boundary Bay. Over Boundary Bay as a whole, the currents are stronger when the tide is flooding (rising tide); and, the currents are weaker and have a smaller duration when the tide is ebbing (dropping tide) (Luternauer et al., 1998). This asymmetry in the tidal currents is thought to impose a regional-scale control on the Fraser River delta, and is partially responsible for the steady northward shift of the main outlet from Boundary Bay to its present location over the last several thousand years.

The strength of the flood and ebb tides are not distributed evenly throughout the bay, where the flood tide is more concentrated on the eastern side of the bay and the ebb tide is more concentrated on the western side of the bay (Kellerhals and Murray, 1969). Spatially, there are active and inactive distributary channels throughout the bay that convey tidal water and sediment (Luternauer et al., 1998). Tidal currents are strongest within these tidal channels and along the margins of Boundary Bay (Dashtgard, 2011). It follows that within Mud Bay the tides are strongest and most concentrated during the flood tide , during which tidal waters are primarily conveyed by the active distributary channels and along the margins.

2.5.2 Wind Surge and Waves

Wave development in Mud Bay is limited by relatively low wind speeds and shallow water depths. In the *Serpentine, Nicomekl & Campbell Rivers – Climate Change Floodplain Review* prepared by NHC for the City of Surrey, NHC (2012) constructed a numerical model using the River and Coastal Ocean Modelling (RiCOM) software to assess the impact of local wind setup on the water levels in Boundary Bay.
The model grid extended from Point Atkinson in the north to Victoria in the south, containing 84,000 elements and 44,000 nodes. The resolution ranged from 10 m in areas of interest in Mud Bay to 1,000 m around the Western boundaries of the grid. The grid from pg. 49 of the *Serpentine, Nicomekl & Campbell Rivers – Climate Change Floodplain Review* is reproduced for this report in **Figure 2.2** and shows that the depths decrease from the open waters of the Strait of Georgia towards Boundary Bay,

and further decrease within the bay from the western and central portions of Boundary Bay towards Mud Bay. Shallow water depths can induce wave shoaling and breaking, so these low depths limit wave heights in some parts of Mud Bay under present-day sea levels (NHC, 2012).

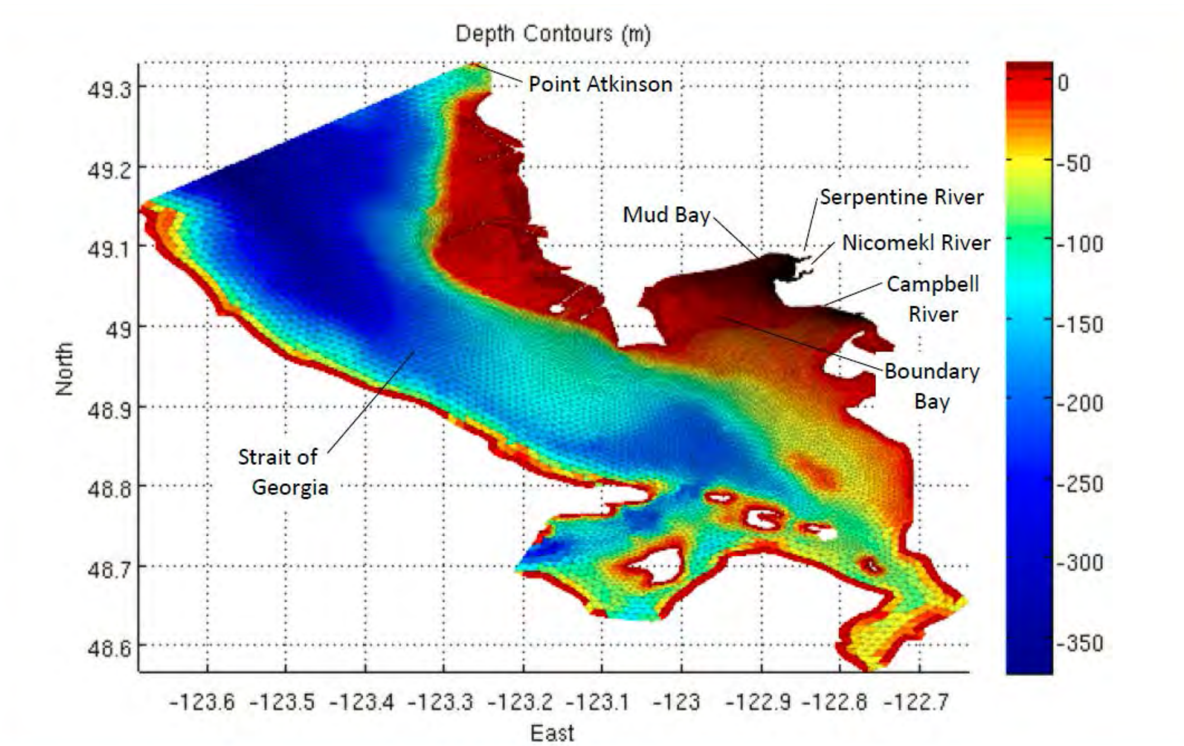


Figure 2.3 Wind-surge and wave computational grid reproduced from *Serpentine, Nicomekl & Campbell Rivers – Climate Change Floodplain Review* (NHC, 2012).

2.5.3 Current Direction and Longshore Drift

The dominant direction of the tidal currents in Boundary Bay is from the south, with the currents in Mud Bay in particular, flowing from southwest to northeast. **Figure 2.4**, modified from the CHS Atlas of Currents (Government of Canada, 2002) shows the direction and speed of tidal currents in the Strait of Georgia and Boundary Bay.

Mud Bay is partially sheltered from ocean waves originating in the Strait of Georgia because of its location along the coast and within Boundary Bay, as well as the presence of shallow water within the bay. Point Roberts Peninsula, on the western side of Boundary Bay, protects Mud Bay from some of the westerly and southwesterly winds in the area (Kellerhals and Murray, 1969). Furthermore, the fetch distance for wave development within the Strait of Georgia is limited by the presence of Vancouver Island, which blocks southeasterly winds originating in the Pacific Ocean from reaching Boundary Bay (Engels, 1999).

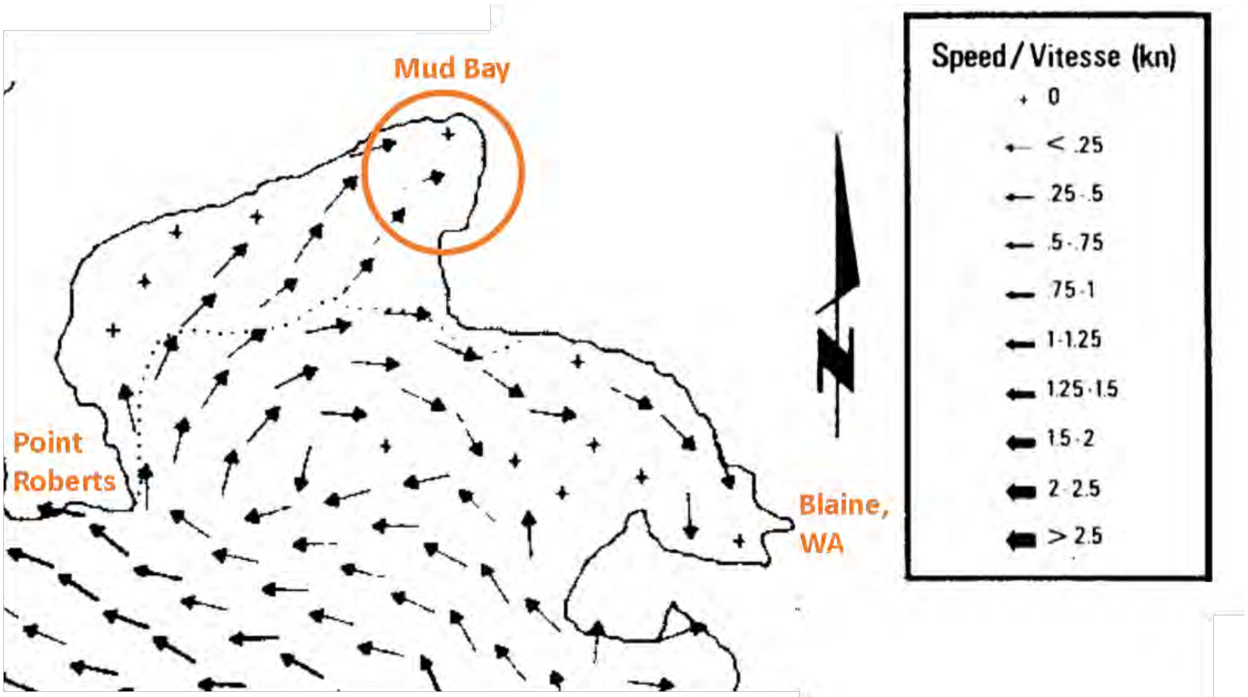


Figure 2.4 Tidal currents in Mud Bay. Figure modified from Tidal currents in the Strait of Georgia and Boundary Bay figure in CHS Atlas of Currents (Government of Canada, 2002).

The tidal and wave conditions of Mud Bay form an important context for assessing the sedimentary condition of Mud Bay. The wind protection afforded to Mud Bay and the pattern of the tidal currents allows muddy sediments to accumulate in Mud Bay, which would otherwise not occur (Kellerhals and Murray, 1969).

2.6 Human Interventions

The geomorphology of Mud Bay and its surrounding area has been altered by human interventions over the last 160 years. Beginning as early as the 1860s, people have built significant infrastructure around Mud Bay and the lower Serpentine and Nicomekl Rivers including dykes, sea dams, railways, and highways.

A series of dykes have been built along Mud Bay and the lower reaches of the Serpentine and Nicomekl Rivers to mitigate flooding and support agricultural development. Manual diking of the rivers began in the 1860s and the first machine-made dykes were built in 1898. Since the initial diking in the 1860s, a series of expansions and upgrades to the diking network have taken place (KPA Engineering Ltd., 1994). The Colebrook Dyke continues to extend along the northern shore of Mud Bay, just south of Highway 99, from Mud Bay Park to the Surrey-Delta border, where the Dyke Trail of Boundary Bay Regional Park is located. There is also a dyke along the southern bank of the Serpentine River, extending from the Serpentine sea dam to Mud Bay, and a dyke along the northern bank of the Nicomekl River, extending from the Nicomekl sea dam to Mud Bay. Both of these dykes are maintained by the Mud Bay Dyking

District. The City of Surrey maintains dykes along the southern bank of the Nicomekl River extending from the Nicomekl sea dam to Elgin Park (City of Surrey, 2018).

Sea dams were constructed on the Serpentine and Nicomekl Rivers in 1913 to support agricultural development (KPA Engineering Ltd., 1994). The Serpentine sea dam is located approximately 4.2 km upstream from the mouth of the Serpentine River at King George Blvd and the Nicomekl sea dam is located approximately 4.8 km upstream of the mouth of the Nicomekl River at Elgin Road. These sea dams have gates that are opened and closed to allow fresh water from the rivers to enter Mud Bay during low tide and prevent brackish water from travelling up river during high tide.

In addition to the dykes and sea dams, additional stormwater management infrastructure within the Serpentine and Nicomekl lowland area includes more than 100 km of ditches, 30 pump stations, 10 spillways, and 170 flood boxes (NHC, 2016).

The Great Northern Railway, which extends along the northern and eastern shorelines of Mud Bay, was constructed between 1909 and 1913 (Roberts, 2018). The railway has since undergone changes in ownership and is currently owned by the BNSF Railway Company. The BNSF Railway extends along the northern side of Mud Bay, offset from the contemporary shoreline by a strip of land approximately 150 m to 500 m wide. Along the eastern side of Mud Bay, the BNSF Railway aligns with the contemporary eastern shoreline, except where it crosses two small embayments formed at the mouths of the Nicomekl and Serpentine Rivers. The BNSF railway is built on a raised embankment along the eastern shoreline; however, it is not considered to be a dyke.

A stretch of Highway 99 was constructed along the northern edge of Mud Bay in the early 1960s. This stretch of highway lies immediately north of the Colebrook Dyke along the northern shoreline of Mud Bay. At the northwestern corner of Mud Bay, the highway continues westward, past the western-most extent of the Colebrook Dyke, and west of the Surrey-Delta border. At the northeastern corner of Mud Bay, the highway intersects the BNSF Railway by Mud Bay Park, just north of the Serpentine River embayment. Highway 99 continues to run in the eastward direction, past the BNSF Railway-Highway 99 intersection for approximately 1.2 km, after which it turns southeastward and crosses the Serpentine River. The construction of Highway 99 involved extensive dredging and some changes to the northern shoreline of Mud Bay.

In addition to the dredging associated with the construction of Highway 99, dredging has also taken place in southern Mud Bay. In 1963, 1970, and 1978, dredged material consisting of sand and fine silt was placed onto former marshes of Blackie Spit, north of Sullivan Point, resulting in substantial infilling of the area (Summers, 2001).

3 AVAILABLE INFORMATION

3.1 Bathymetry and LiDAR

Bathymetric and topographic maps covering Mud Bay from as early as 1846 to as recent as 2014 were collected from various sources, including the City of Surrey, the Corporation of Delta, Vancouver Archives, the University of Victoria digital collections, past reports and journal articles. These maps were of varying quality and utility for this project, where many of the historical maps offered minimal utility and the more recent data was very useful. Specifically, amongst the historical maps, it was a ubiquitous problem that the map extents included Mud Bay, but there were data voids over Mud Bay. In contrast, the more recent data, from 1969 onwards, had decent coverage of Mud Bay and was of sufficient quality to analyze. The analyses in this report will, therefore, focus on the recent data as described in **Section 4**; however, both recent and historical data sources that were assessed are listed in **Sections 3.1.1** and **3.1.2**.

3.1.1 Historical Data

Historic bathymetric charts and topographic maps with coverage of the Boundary Bay area were obtained in digital form or previewed online and visually assessed at a macro level. Many of these charts and maps were ultimately not ordered or analyzed in detail because they contained minimal to no elevation data within the study area.

The historic charts that were visually assessed at the macro level include the 1846 *Map showing the line of boundary between the United States and British possessions* published by Bowen & Co., the 1856 *Vancouver Island and the Gulf of Georgia* chart published by the Hydrographic Office of the Admiralty, the 1859-65 *Vancouver Island and Adjacent Shores of British Columbia* chart published by the Admiralty of London, the 1898 *Georgia Strait and Strait of Juan de Fuca* map published by the US Coast and Geodetic Survey, the 1899 *Juan de Fuca to Strait of Georgia* chart, and the 1949 *Georgia Strait and Strait of Juan de Fuca* published by the US Coast and Geodetic Survey.

The historic maps that were visually assessed include the 1876 *New Westminster District* map published by the Land and Works Department, the 1886 and 1892 *New Westminster District* maps published by Rand Bros. Real Estate Brokers, the 1887 *New Westminster District* map published by the Department of the Interior, and the 1923 *Fraser River Delta* map published by the Department of Mines.

3.1.2 Recent Data

In this report, recent data refers to Mud Bay data obtained over the last 50 years. Recent data was available for Mud Bay for the following years, listed in order of most recent to most historical: 2014, 2013, 2009, and 1969. The data types and quality vary as described below.

In addition to the recent data sources described below, many other sources were reviewed that did not cover Mud Bay. These sources include, but are not limited to, reports by Kerr Wood Leidal Associates (2004, 2007), Hay & Company (1995), Hay & Company and Associated Engineering (1987, 1991), and

Delcan (2010). These reports all address processes within Boundary Bay and/or within the areas surrounding Boundary Bay. However, where these reports discuss processes within Boundary Bay, they focus on the western side of Boundary Bay and where these reports discuss the areas surrounding Boundary Bay, they focus on areas that lie west of the City of Surrey border. As such, these reports do not include topographic or bathymetric data for Mud Bay.

2009 and 2013 DEMs

Digital elevation models (DEMs) for 2009 and 2013 and their source 2009 and 2013 LiDAR data were obtained from the City of Surrey.

The 2009 LiDAR data covered the eastern portion of Mud Bay, extending from the BNSF Railway along the eastern coastline of Mud Bay to approximately 2.3 km west of the railway. The data provided to NHC by the City of Surrey also covered additional area east of the railway; however, since that occurred outside of Mud Bay it will not be addressed in this report. The 2009 LiDAR data was acquired through multiple flight lines spaced approximately 523 m apart (Aero-Photo, 2012). The flight lines that covered Mud Bay were flown on February 19, 2009 and March 13, 2009. The vertical accuracy of the data at the 95% confidence interval was 20 cm.

The 2013 LiDAR data covered the eastern portion of Mud Bay, extending from the BNSF Railway along the eastern coastline of Mud Bay to varying western extents ranging from approximately 0.5 km to 1.3 km west of the railway. The data provided to us by the City of Surrey also covered additional area east of the railway; however, since that occurred outside of Mud Bay it will not be addressed in this report. The 2013 LiDAR data was acquired through multiple flight lines spaced approximately 344 m apart. The LiDAR data over the entire area was collected during flights on April 3, 2013 and April 11, 2013. The consolidated vertical accuracy was calculated and reported to be 13.0 cm using the 95th percentile statistical method (Airborne Imaging, 2013).

The 2009 and 2013 DEMs represent the highest resolution data that we were able to obtain for Mud Bay.

2014 Contours

Contour data for 2014 was obtained from the Corporation of Delta. The contours were created based on Corporation of Delta Spring 2014 LiDAR data; although the source LiDAR data was not provided to NHC. The contours have an interval of 0.5 m and are in the NAD83 reference system. The contours cover the western and central portions of Mud Bay.

1969 Contours

Contour data for Mud Bay was obtained from a paper map on pg. 71 of Kellerhals and Murray's (1969) paper. The Kellerhals and Murray (1969) paper does not specify the data source or collection date for the contour data. The paper was published in 1969, so 1969 is the most recent possible year that the contour data could represent. For simplicity, from this point forward, the contour data is referred to as the 1969 contours, although the contour data could have been collected in 1969 or prior to 1969. Kellerhals and Murray (1969) specify that: 'Elevations referred to Canadian Geodetic Datum' and identify a mean low low water of -8 ft.

3.2 Aerial Imagery

Air photos of Mud Bay were obtained for the 66-year period from 1949 to 2015 for which historical air photos and/or orthophotos were available. Air photos were obtained from the University of British Columbia Geographic Information Centre and orthophotos were obtained from the City of Surrey. **Table 3.1** details the specific years for which imagery was available and the corresponding photo scale and type of imagery.

Table 3.1 Historical imagery of Mud Bay between 1949 and 2015

Year	Scale	Type of Imagery
2015	n/a (10 cm resolution)	Orthophotos
2014	n/a (10 cm resolution)	Orthophotos
2013	n/a (10 cm resolution)	Orthophotos
2009	n/a (10 cm resolution)	Orthophotos
2004	1:20 000	Historical Air Photos
1999	1:30 000	Historical Air Photos
1994	1:25 000	Historical Air Photos
1990	1:30 000	Historical Air Photos
1984	1:20 000	Historical Air Photos
1979	1:20 000	Historical Air Photos
1969	1:12 000	Historical Air Photos
1963	1:12 000	Historical Air Photos
1954	1:10 000	Historical Air Photos
1949	1:10 000	Historical Air Photos

4 METHODS

4.1 Bathymetric and Topographic Analyses

Information describing the elevation of the seabed in the inter-tidal and sub-tidal portions of Mud Bay is available from a variety of sources, collected at various times in the past. Change detection through comparison of elevation changes to the seabed between surveys is potentially possible, but care must be taken to evaluate the magnitude of the detected change in the context of the error and precision inherent in the survey technique.

Topographic and bathymetric data of varying extent and resolution were analysed for Mud Bay from 1969, 2009, 2013, and 2014. Data from prior to 1969 was obtained but was not of high enough resolution in the area of interest to be used to detect elevation change in Mud Bay.

4.1.1 Historical Data

The historical (pre-1969) bathymetric charts and topographic maps were visually assessed at a macro level; however, these documents were not analyzed in detail because they contained minimal to no bathymetric and topographic data for the project site.

A brief overview of the findings from the macro level visual assessment are included in **Section 5.1.1**.

4.1.2 Recent Data

Analyses of recent (1969 to 2014) topographic and bathymetric data in Mud Bay were conducted, with different analyses applied to different time periods based on data type and quality. Detailed elevation change analyses were conducted using the high resolution 2009 and 2013 DEMs. In addition to the detailed DEM analyses, overview-level visual assessments were conducted comparing the 2009 DEM vs. 2014 contour data and 1969 contour data vs. 2009 DEM. There was limited spatial overlap in the extent of useable data from the following years, so comparisons across these years were not conducted: 2013 vs. 2014 and 1969 vs. 2013.

2009 DEM vs. 2013 DEM

Topographic data from 2009 and 2013 were compared to assess recent changes in the topography of the mud flats and salt marsh areas of Mud Bay. DEMs based on the 2009 and 2013 LiDAR data provided by the City of Surrey were displayed using identical symbologies and visually assessed to detect qualitative changes. Data voids, defined as “areas where there were no ground points for 256 m^2 or more”, were documented in the 2013 metadata, so these areas were masked out in the 2013 DEM (Airborne Imaging, 2013). Documentation of data voids was not included in the 2009 LiDAR metadata, so data voids were not masked out for the 2009 data.

An elevation difference map was generated using the 2009 and 2013 DEMs to quantify recent elevation changes in Mud Bay. A minimum level of detection threshold of 0.24 m was applied spatially-uniformly to the data, meaning that any elevation change smaller than +/- 0.24 m was not considered to represent detectable change when considering the precision and accuracy of the source data. The minimum level of detection threshold was determined by calculating the combined error of the 2009 and 2013 LiDAR data using the quadratic sum method described by Wheaton (2008). A minimum level of detection threshold was applied to the data to separate real change from systematic errors in the data.

2009 DEM vs. 2014 Contours

The 2014 contour data was overlaid on the 2009 DEM to visually assess changes in elevation and distributary morphology over this period.

1969 Contours vs. 2009 DEM

The 1969 contour map was extracted from the Kellerhals and Murray (1969) paper and georeferenced using stable reference locations. The georeferenced 1969 contour map was overlaid on the 2009 DEM to assess changes in elevation and distributary morphology. The 1969 data was in feet and was not digitized, so the 2009 DEM was converted into feet for ease of comparison.

4.2 Air Photo Interpretation

Air photos of Mud Bay were analyzed over the 66-year period from 1949 to 2015 for which historical air photos and/or orthophotos were available. The air photos were analyzed to assess for potential changes in the extent of the salt marsh; location and planform of tributaries within the mudflats; location of the shoreline; and other potential evidence of accretion or erosion within Mud Bay.

Changes in salt marsh extent were assessed by delineating the approximate salt marsh boundaries based on the 2013 imagery and comparing these delineated boundaries to the visible extent of salt marsh in photos from earlier years. Delineation of salt marsh extents from air photos without the benefit of ground truthing is known to be open to interpretation errors so it is important to consider the magnitude of the detected change in light of the probable error. The 2013 imagery was used because this represented the most recent available imagery with high visibility of salt marsh due to lower water levels compared to the 2014 and 2015 imagery. The 2013 salt marsh extent was delineated exclusively for comparison purposes with other air photos. There are limitations to the accuracy of using historical air photos to delineate salt marsh extent because the photos were taken at varying water levels resulting in variable visibility of the salt marsh environments; the photos were taken at different times of year resulting in seasonal variations in vegetation; the resolution and scale of the photos is variable; and the ability to distinguish between salt marsh and surrounding environments is limited in the absence of a site visit. If knowledge of salt marsh extents is required for purposes outside of the historical air photo analysis described in this memo, a more thorough salt marsh delineation program should be undertaken including on-site data collection and more in-depth analysis.

5 HISTORICAL TO PRESENT CHANGES

5.1 Bathymetric and Topographic Changes

Analysis of the historical and recent bathymetric and topographic data suggests that the majority of Mud Bay has remained relatively stable over the analysis periods, with the exception of areas that have undergone extensive anthropogenic development. Limitations in data availability and quality led to some conflicting observations of changes in Mud Bay and generally confounded the quantification of changes that may have occurred.

5.1.1 Historical Changes

Historical changes in the sedimentary condition of Mud Bay could not be quantified due to limitations in the available historical data; however, qualitative changes in the shoreline and morphology of Mud Bay were observed by comparing historical and recent information.

The historical charts that were examined were created primarily to indicate depths in the navigable portions of the study area so they contained minimal data for Mud Bay. The bathymetric data that was present on the old charts was typically restricted to a few measurements along the seaward extents of the Serpentine and Nicomekl Rivers, approximately 1.5 km east of the coastline. The sparseness of data points and low resolution of the charts made it difficult to discern the exact locations of these measurements, making data comparisons to later years challenging. The 2009, 2013, and 2014 data was obtained using LiDAR technology that is unable to detect depths below water surfaces. Consequently, the geographic areas where there was historical (pre-1969) nautical data available generally corresponded to geographic areas of data voids in the 2009 to 2014 data.

The pre-1969 topographic maps could also not be used to detect elevation changes over time because the topographic data shown on most of these maps did not include coverage of Mud Bay. An exception is the 1886 and 1892 New Westminster District maps (Anon, 1886, Anon, 1892) that included some contours and point measurements in the Mud Bay salt marsh and tidal flats. However, the reported values are inconsistent with the contour spacing calling into question the accuracy of the contours and making further analysis based on these contours suspect. It is possible that these contours were optimized for stylistic purposes, particularly given that the map is primarily a thematic land parcel map, rather than a bathymetric or topographic map.

Despite the lack of elevation data, the historical charts and maps did offer some useful information about the shoreline around Mud Bay. The historical maps suggest that the shoreline has undergone some changes over the past 168 years, with the majority of changes concentrated along the northern shoreline and around Crescent Beach. Smoothing and slight movement eastward of the eastern shoreline of Mud Bay between the historical and recent data is also evident. **Figure 5.1** shows a clip from the oldest (1846) map next to a clip of recent (2013) orthophotos to illustrate these changes.

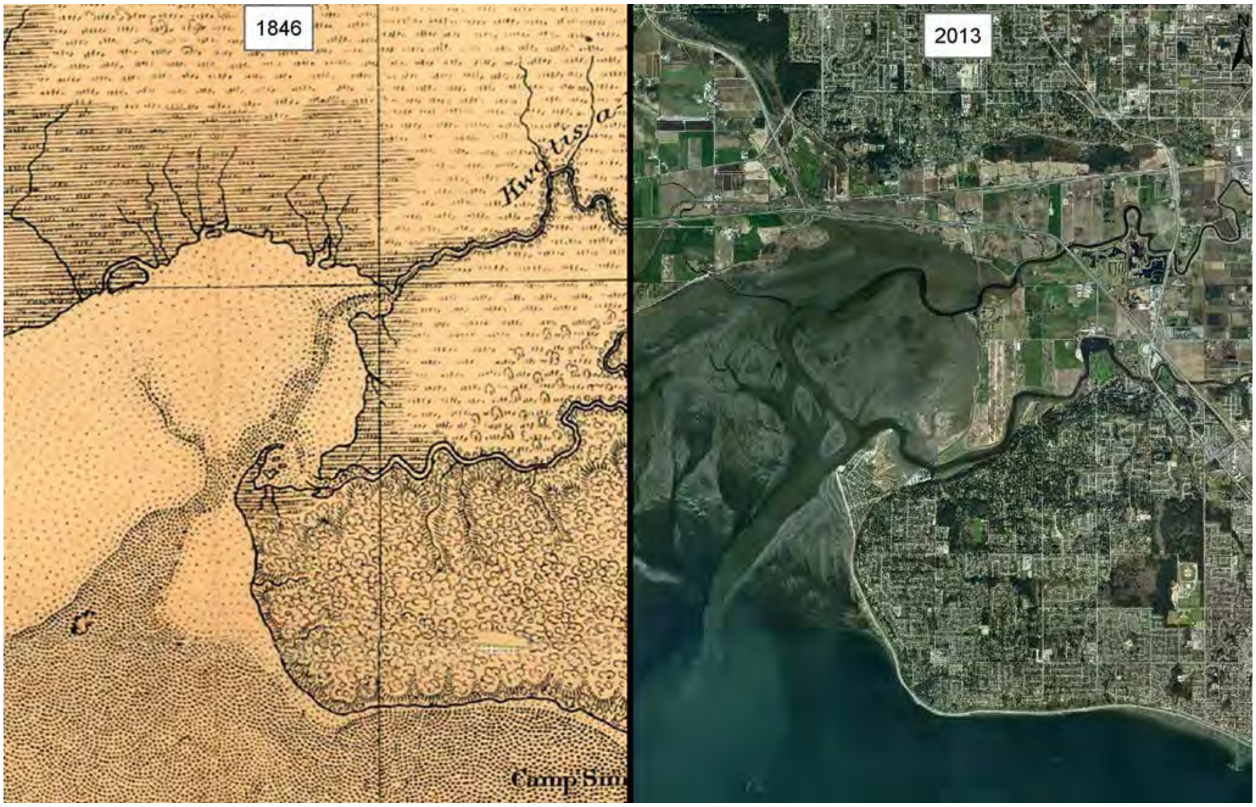


Figure 5.1 Historical (1846) map of Mud Bay compared to recent (2013) orthophotos of Mud Bay. Historical map (left) reproduced from *Map showing the line of boundary between the United States and British possessions* (Anon, 1846) and orthophotos provided by City of Surrey

Figure 5.1 reveals that the northern section of Mud Bay historically extended further northward than it currently does. The symbology on the 1846 map (Anon, 1846) also suggests that the area immediately north of Mud Bay was historically covered by a marshy area, although there is no legend visible on the map to confirm the meaning of this symbology. A historical vegetation map, *Vegetation of the Southwestern Fraser Lowland, 1858-1880,* created by North, Dunn, and Teversham (1979) based on surveys conducted between 1858 and 1877 shows a different salt marsh extent than what seems to be displayed in the 1846 map; however, both documents show that the salt marsh along the northern shoreline of Mud Bay extended further northward in the mid- to late-1800s than in the past decade. These changes in the northern extent of the Mud Bay salt marshes and shoreline can be attributed to a combination of human influences including agricultural development, dyking, and the construction of roads and railway north of Mud Bay.

Figure 5.1 also shows that the area around Crescent Beach used to be comprised of a few individual islands and has since been infilled to create a continuous land mass, at the present-day location of Blackie Spit. This infilling can be partially attributed to placing dredged material consisting of sand and fine silt from the Nicomekl River onto former marshes of Blackie Spit in 1963, 1970, and 1978 (Summers, 2001). The historical air photos provide further evidence of these changes as described in **Section 5.2.3**.

Finally, **Figure 5.1** shows that the eastern shoreline of Mud Bay has been smoothed out and moved slightly eastward since 1846. These changes occurred as a result of the construction of the Great Northern Railway along Mud Bay between 1909 and 1913 (Roberts, 2018), which is the present-day location of the BNSF Railway.

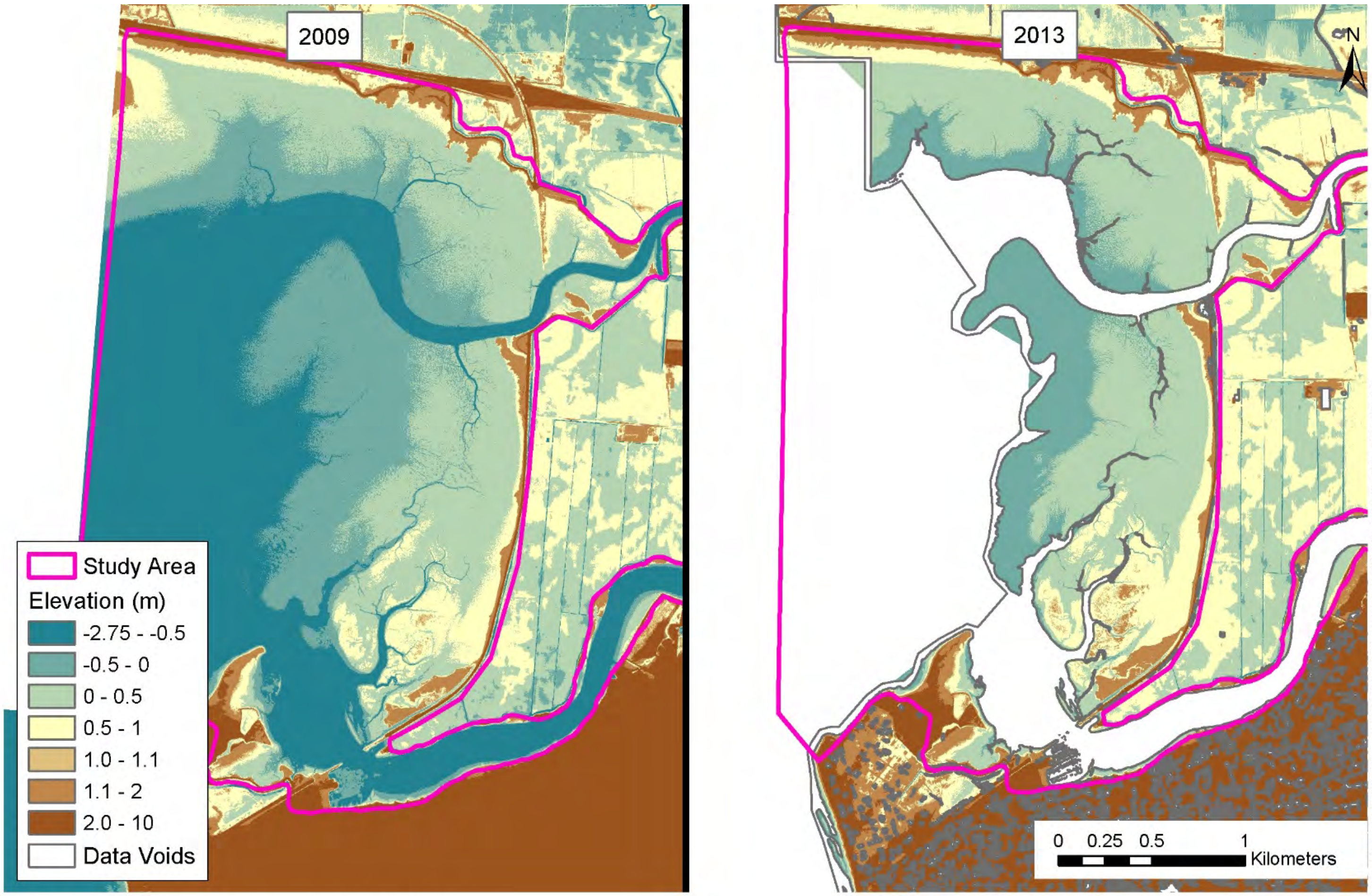
5.1.2 Recent Changes

Analysis of recent (1969 to 2014) topographic data in Mud Bay were conducted, with different analysis methods applied to different time periods as described in **Section 4.1.2**. Detailed analysis of the 2009 and 2013 DEMs were conducted to detect high resolution changes in the topography of Mud Bay. Overview-level visual assessments were conducted comparing the 2009 DEM vs. 2014 contour data and 1969 contour data vs. 2009 DEM to assess generalized elevation change patterns and distributary location changes over time.

2009 vs 2013 DEMs

Detailed analyses of the 2009 and 2013 LIDAR data allowed for the detection of higher resolution changes in the topography of Mud Bay as compared to the historical analysis.

Figure 5.2 displays the digital elevation models (DEMs) provided by the City of Surrey for 2009 and 2013 for visual comparison. The 2013 data shows data voids in white as documented in the 2013 LIDAR metadata (Airborne Imaging, 2013). Documentation of data voids was not included in the 2009 LiDAR metadata, so data voids are not illustrated; however, the 2009 elevations across areas submerged in water (ex. Serpentine and Nicomekl Rivers) shown in **Figure 5.2** are suspect given that the LiDAR technology used to obtain the data is unable to detect below-water elevations.



DATA SOURCES:City of Surrey 2009 and 2013 DEMs

Figure 5.2 Topography of Mud Bay in 2009 and 2013 based on City of Surrey LiDAR data. White areas represent areas for which there was no data available

Figure 5.3 shows an elevation difference map for Mud Bay based on the 2009 and 2013 DEMs. In **Figure 5.3**, elevation changes between -0.24 m and 0.24 m are reported as "undetectable" change because the minimum level of detection is +/- 0.24 m. This means that any changes smaller than +/- 0.24 m can not reliably be represented as detectable change. Data voids are shown in **Figure 5.3** as elevation changes could also not be detected in these areas. **Figure 5.3** suggests that between 2009 and 2013, the majority of Mud Bay experienced little to no elevation changes. Of the detectable elevation changes that do appear in **Figure 5.3**, many of these changes are suspect.

Figure 5.3 indicates that there was slight aggradation in the southern-most portion of Mud Bay between 2009 and 2013; however, this aggradation is highly suspect given the patterns in the data. In addition to the spatially uniformly applied minimum 0.24 m threshold of detection , the data collection method appears to have an additional, spatially variable, element of uncertainty. **Figure 5.3** shows a sharp change in elevation that extends over Mud Bay along a distinctive horizontal band approximately 520 m north of the Nicomekl River outlet, midway between Pass 13 and Pass 14 (**Figure 5.3**). It is physically unrealistic for such a sharp and uniform band of elevation change to occur in this area given the geomorphic processes active in Mud Bay. More likely, this band can be attributed to data collection and processing methods rather than to a real physical change. The LiDAR data was collected along multiple horizontal flight paths flown on different days in 2009. **Figure 5.3** shows the 2009 flight paths (labelled Pass 13 to Pass 19) flown to collect the 2009 data used to generate the underlying elevation change surface. Distinct horizontal bands in the elevation change map systematically occur roughly midway between each set of flight paths, suggesting that these bands might be related to data collection methods. Furthermore, the flight paths immediately south (Flight Pass 13) and north (Flight Pass 14) of the most pronounced horizontal band were flown before and after a high flow event in the Serpentine River, respectively. **Figure 5.4** displays stage data collected upstream of the Serpentine River sea dam by NHC as a part of past project work for the City of Surrey. The timing of Flight Pass 13 (February 19, 2009) and Flight Pass 14 (March 13, 2009) and the high stage event (February 25, 2009) are indicated in **Figure 5.4**. It is possible that there was a real physical change that occurred over Mud Bay related to this event since the Serpentine River delivers sediment to Mud Bay, but that change would have only been captured by the portion of 2009 data collected on or after the February 25, 2009 event.

Figure 5.3 also shows small elevation changes concentrated along the tidal distributaries of Mud Bay. Given that the LiDAR would not have been able to detect elevations below the water, these apparent changes are assumed to be relicts of the data.

Finally, the data does show some very small patches of slight aggradation distributed throughout Mud Bay, away from the distributaries and not correlated to the flight lines. Unlike the changes described earlier, the locations and patterns of these small patches do not make them suspect. These changes should still be considered with caution. The elevation change analysis depicts areas around Mud Bay that are known to be relatively stable as having undergone elevation changes of similar magnitude to those reported within the bay. For example, the data suggests that Highway 99 and the BNSF Railway have undergone elevation changes of similar magnitude to those shown within Mud Bay.

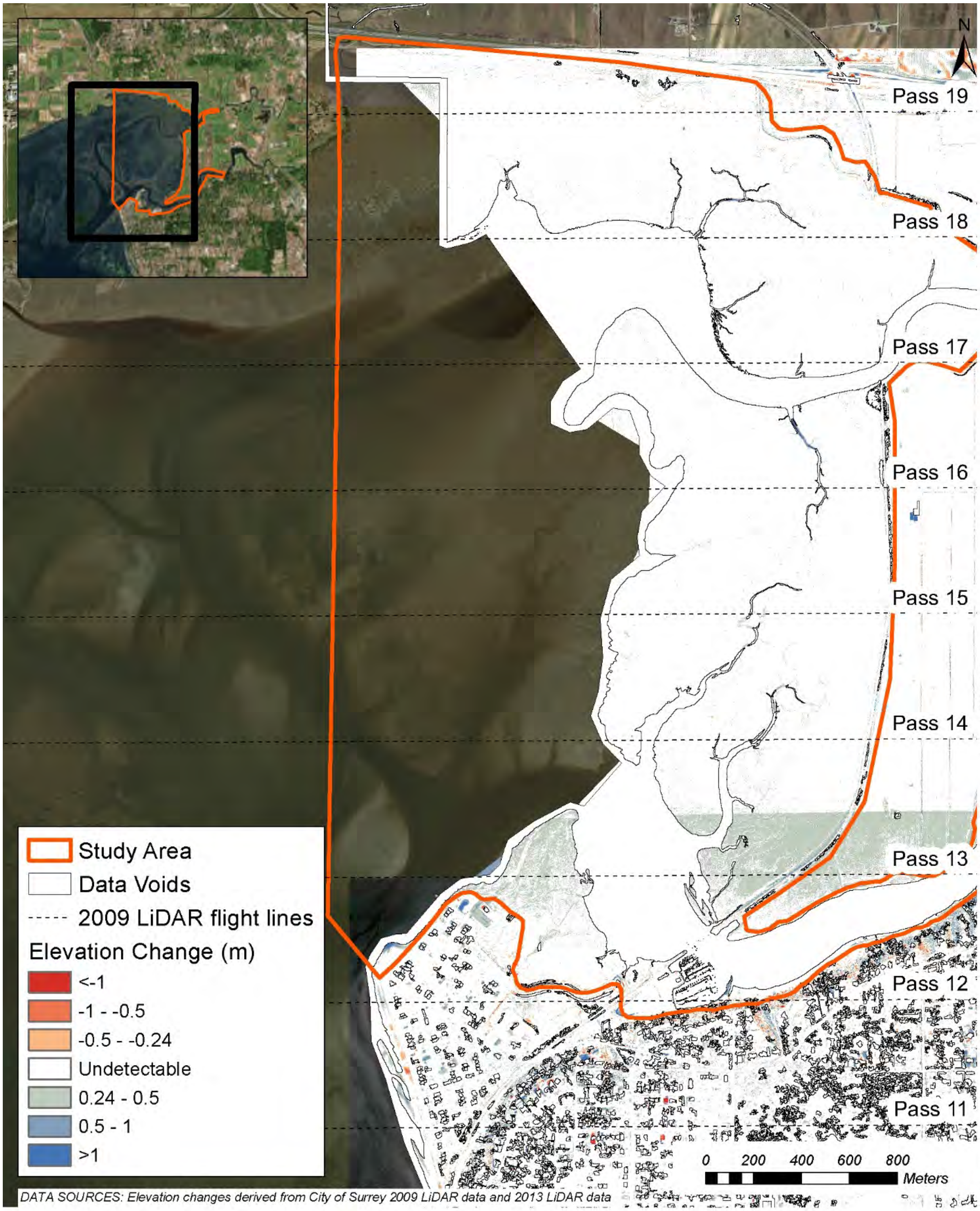


Figure 5.3 Elevation Change in Mud Bay between 2009 and 2013. LiDAR flight lines associated with 2009 data are shown by dashed lines

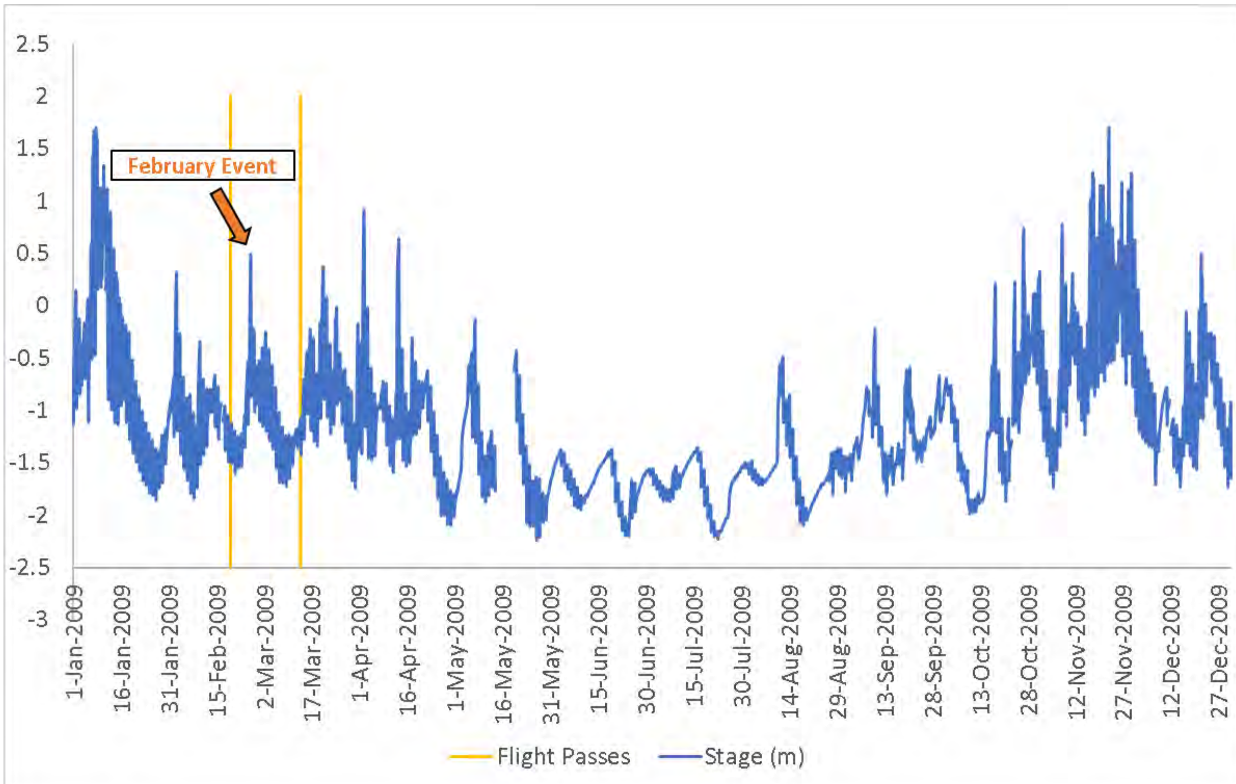


Figure 5.4 Stage of Serpentine River upstream of the sea dam for January 2009 to December 2009 with February high stage event, February flight pass, and March flight pass highlighted

This inconsistency may be attributed to horizontal accuracy limitations and calls the reliability of reported elevation changes in Mud Bay into question. The majority of the changes in Mud Bay are positive which may suggest a very slightly net positive sediment balance despite the inability to reliably identify precise magnitudes and locations of those changes, or it could simply be a systematic error in the data.

Overall, the topographic analysis suggests that the majority of Mud Bay has undergone no change, or very slight positive sedimentation between 2009 and 2013; however, the observed elevation differences were small enough that for the most part they could not be distinguished from the uncertainty associated with data collection and processing error. This result is not surprising given the expected slow rate of change and the short time span between surveys. Even if it is assumed that Mud Bay is experiencing the largest reported subsidence rate (3.5 mm/yr) in the area (See **Section 7.1.1**), which is likely an overestimate for Mud Bay given the more conservative subsidence estimates for western and central Boundary Bay, data spanning a 69-year period would be required to produce detectable change given a minimum level of detection threshold of 0.24 m. Data collected 69 years ago would likely have a higher minimum level of detection threshold than 0.24 m, given technological advances in data collection since then, making quantification of sedimentation within Mud Bay very challenging.

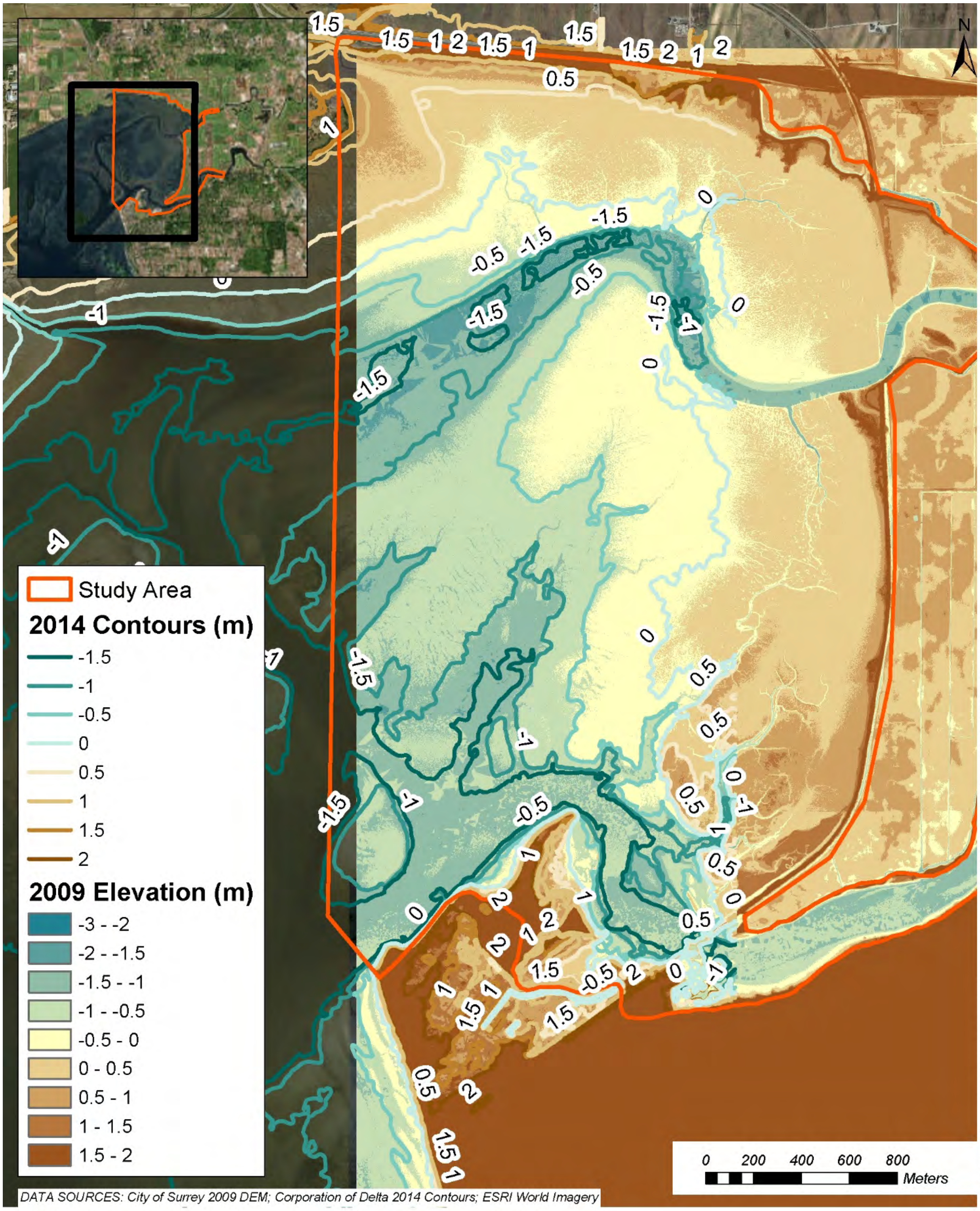


Figure 5.5 2014 Contours overlaid on 2009 DEM of Mud Bay.

2009 DEM vs 2014 Contours

Visual comparisons of the 2009 and 2014 data shows that the 2014 contours generally follow very similar patterns to the 2009 DEM throughout Mud Bay, which is consistent with the observation of relative stability from the 2009-2013 elevation change analysis. **Figure 5.5** shows the 2014 contours overlaid on the 2009 DEM for reference.

1969 Contours vs 2009 DEM

Comparing the 1969 survey data to more recently acquired data is attractive in that a much longer time period is measured. However, comparisons with older data introduce additional challenges with respect to the accuracy of the survey techniques and having access to information about the survey datum that was used.

Visual comparisons of the 1969 contours and the 2009 data were conducted; however, missing metadata for the 1969 data prevents definitive conclusions from being made. The reference vertical location for the 1969 data was unclear and therefore, there is more than one possible way to interpret the meaning of the reported values. The 2009 LiDAR data is in CGVD28. The Kellerhals and Murray (1969) paper from which the contour map was obtained (p. 71 – Fig. 2) does not specify the data source for the contour data. The paper does state: 'Elevations referred to Canadian Geodetic Datum'. It was standard practice to use CGVD28 between 1935 and 2013, which suggests that this contour data is likely in CGVD28 and does not require any vertical conversions. However, there is some additional information that conflicts with this conclusion. The 'Lower Low Water Mean Tide' for Crescent Beach in 2014 as published by the Canadian Hydrographic Service and reported by NHC (2016) as 1.2 m in chart datum and -1.6 m in Geodetic datum. This translates into 3.937 ft and -5.249 ft, respectively. Given that the Kellerhals and Murray contour map reports a mean low low water of -8 ft, this suggest that all values reported in the Kellerhals and Murray paper should be increased by about 2.75 ft (8 ft – 5.249 ft). Published comparisons of the chart and geodetic datum from 1969 for Boundary Bay were not found and a request for information from the Canadian Hydrographic Service did not lead to any new information being provided. Consequently, both approaches – leaving the 1969 data as is and adding 2.75 ft from the 1969 data were checked against 'stable' reference surfaces and background information about geomorphology processes. This analysis suggested that a 2.75 ft vertical adjustment should likely not be applied to the 1969 data.

With no vertical adjustment applied, the analysis suggests that between 1969 and 2009 the salt marsh fringe has remained relatively stable and the western tidal flats have undergone some degradation. **Figure 5.6** shows the 1969 contour data overlaid on the 2009 DEM. The 1969 data is expressed in feet, so the 2009 DEM is also shown in feet to allow for direct comparisons. **Figure 5.6** shows that the salt marsh fringe was at an elevation of over 4 ft during both time periods. The western tidal flats, symbolized by the green colour in **Figure 5.6**, appear to have lowered by about 0.61 m (2 ft) between 1969 and 2009, with elevations of -2 to 0 ft in 1969 compared to elevations of -4 to -2 ft in 2009. This observation should be considered with caution; however, because the LiDAR technology used to collect the data is not able to detect elevations below water, so this assumes that the measurements were taken when the area was not submerged. The central and eastern tidal flats, shown in orange appear to have lowered by approximately 2 ft as well; however, as noted in the legend, the +2 ft contour is an approximate contour and should, therefore, be regarded with caution. It should also be noted that **Figure 5.6** suggests that the Serpentine and Nicomekl River distributaries have also lowered substantially; however, this can not be concluded from the data because the LiDAR technology would not have been able to obtain reliable measurements in these submerged areas. It is useful to present the data along these distributaries, as it reveals that the planform location of the distributaries have remained relatively stable between 1969 and 2009.

Overall, the comparison of 1969 to 2009 data suggests that the morphology of large tidal distributaries has remained relatively stable; the salt marsh fringe elevations have likely remained relatively stable; and the outermost tidal flats have likely experienced some lowering over the 44-year period. These observations should be regarded with caution given the known limitations in the available data on which the comparison is made.

5.2 Air Photo Observations

The air photo analysis suggests that the extent of the salt marsh; and the location and planform of drainage tributaries within Mud Bay have remained very stable over the 66-year analysis period for which there were historical photos available (1949 to 2015). The air photo analysis shows changes in the shoreline of Mud Bay in two locations: on the northern edge of the Bay associated with the construction of Highway 99 and along the southeastern edge of the bay at Crescent Beach. The air photo analysis suggests that the shoreline of Mud Bay has remained relatively stable between the Colebrook Dyke and the mouth of the Nicomekl River over the analysis period.

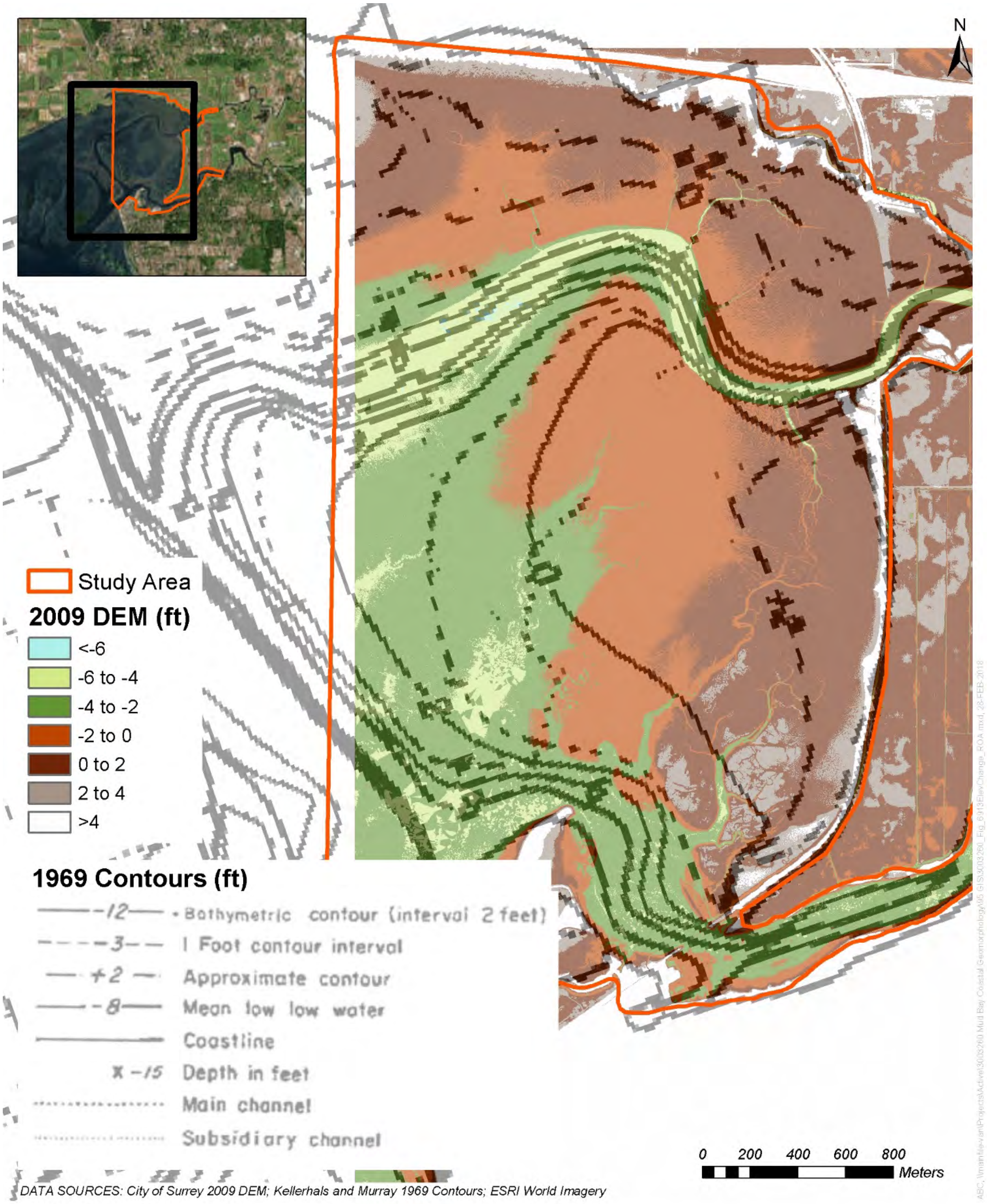


Figure 5.6 1969 Contours overlaid on 2009 DEM of Mud Bay.

5.2.1 Salt Marsh

The historical air photos show minimal changes in salt marsh extent in the southern and central portions of Mud Bay and show changes in salt marsh extent along the northern edge of the bay associated with the construction of Highway 99 (**Figure 5.7**). **Figure 5.8** and **Figure 5.9** show the approximate 2013 salt marsh boundaries overlain on imagery from 2013, 2004, 1979 and 1949 in the southeastern and central eastern portions of Mud Bay, respectively. Despite the higher water levels in 1949 and 2004 that make comparisons more challenging, these photos suggest that the extent of the salt marsh along the southern and central coastline of Mud Bay has remained relatively stable over the last couple of decades. In contrast, the salt marsh in the northern section of Mud Bay has undergone changes over the historical air photo analysis period. **Figure 5.10** shows the approximate salt marsh boundaries in the northeastern section of Mud Bay for 2013 overlain on imagery from 2013, 2004, 1979 and 1949. Substantial changes in salt marsh extent are evident between 1949 and 1979, associated with the construction of Highway 99 in the early 1960s. **Figure 5.11** highlights some of the changes along the northern edge of Mud Bay before (1954) and after (1963) the construction of the stretch of Highway 99 in that area. Salt marsh was lost during this process in areas that were dredged and has since re-established in other areas along the modified coastline.

Keeping in mind the limitations in the salt marsh delineation method detailed in **Section 164.2**, the air photo analysis suggests that the extent of the salt marsh within Mud Bay has remained relatively stable over the past few decades at the 1:20,000 scale level of analysis in areas that have not experienced substantial anthropogenic disturbance during the analysis period.

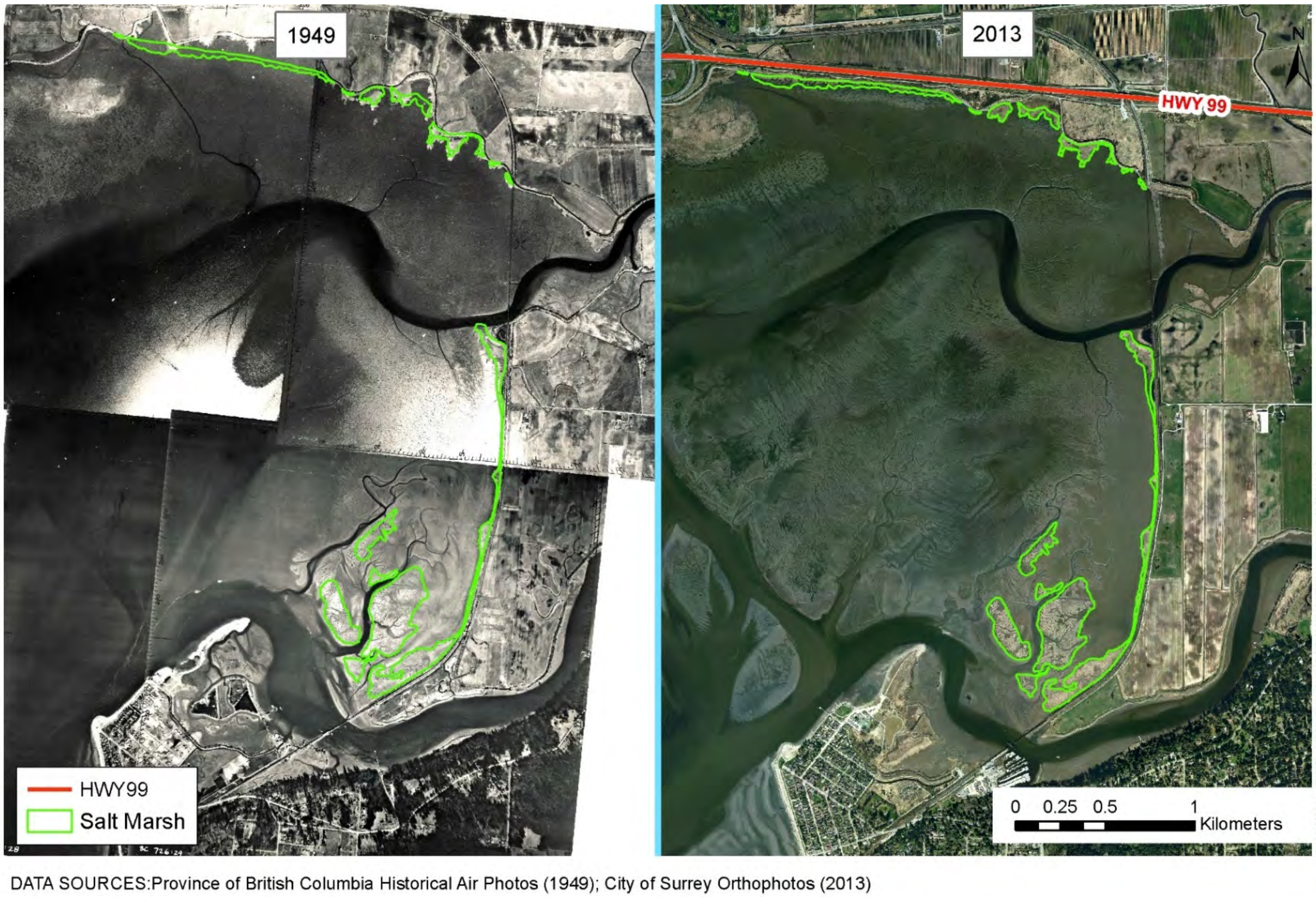


Figure 5.7 Approximate 2013 extent of salt marshes in Mud Bay overlaid on 1949 and 2013 imagery.

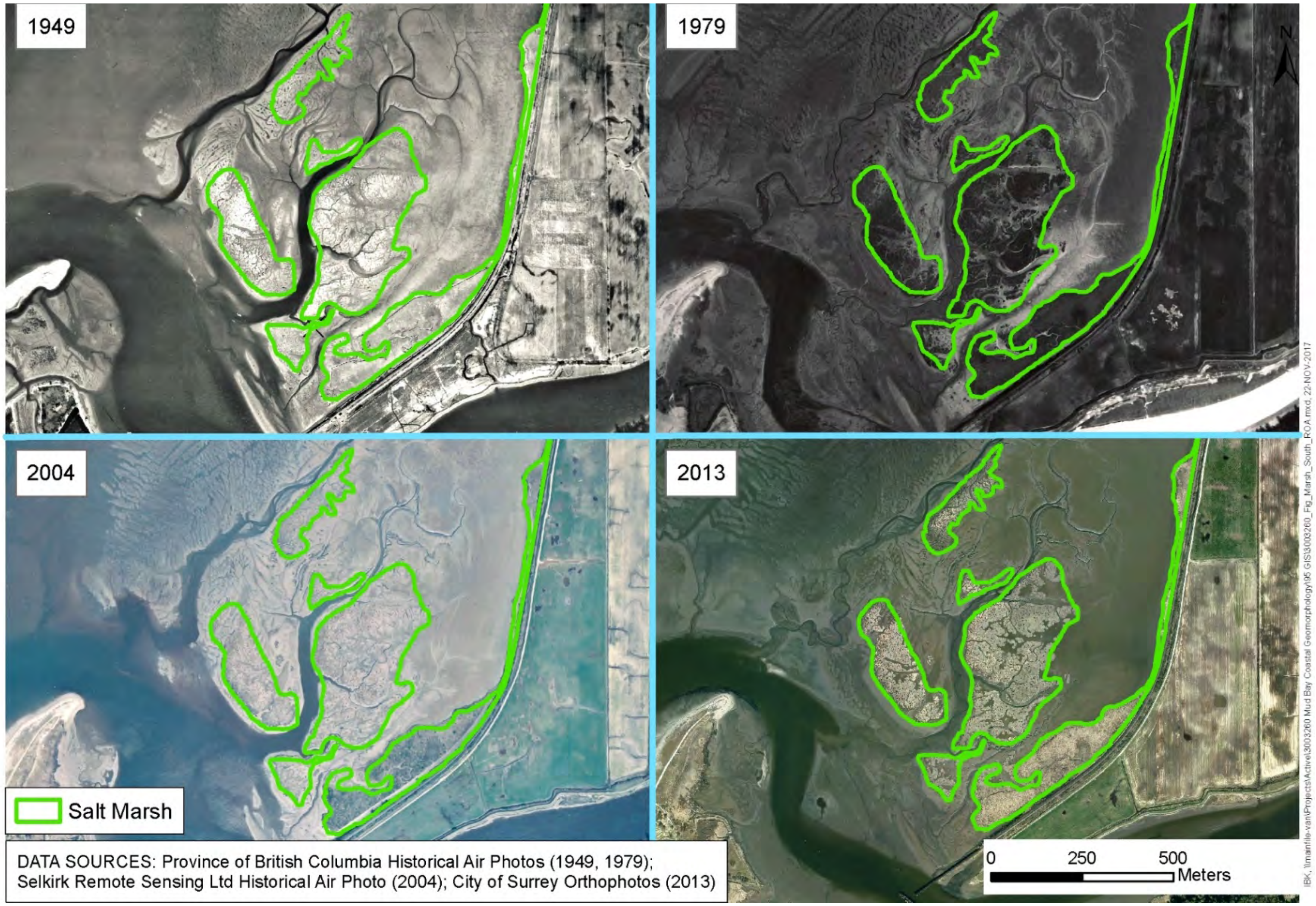


Figure 5.8 Approximate 2013 extent of salt marshes in southeastern portion of Mud Bay overlaid on 1949, 1979, 2004, and 2013 imagery

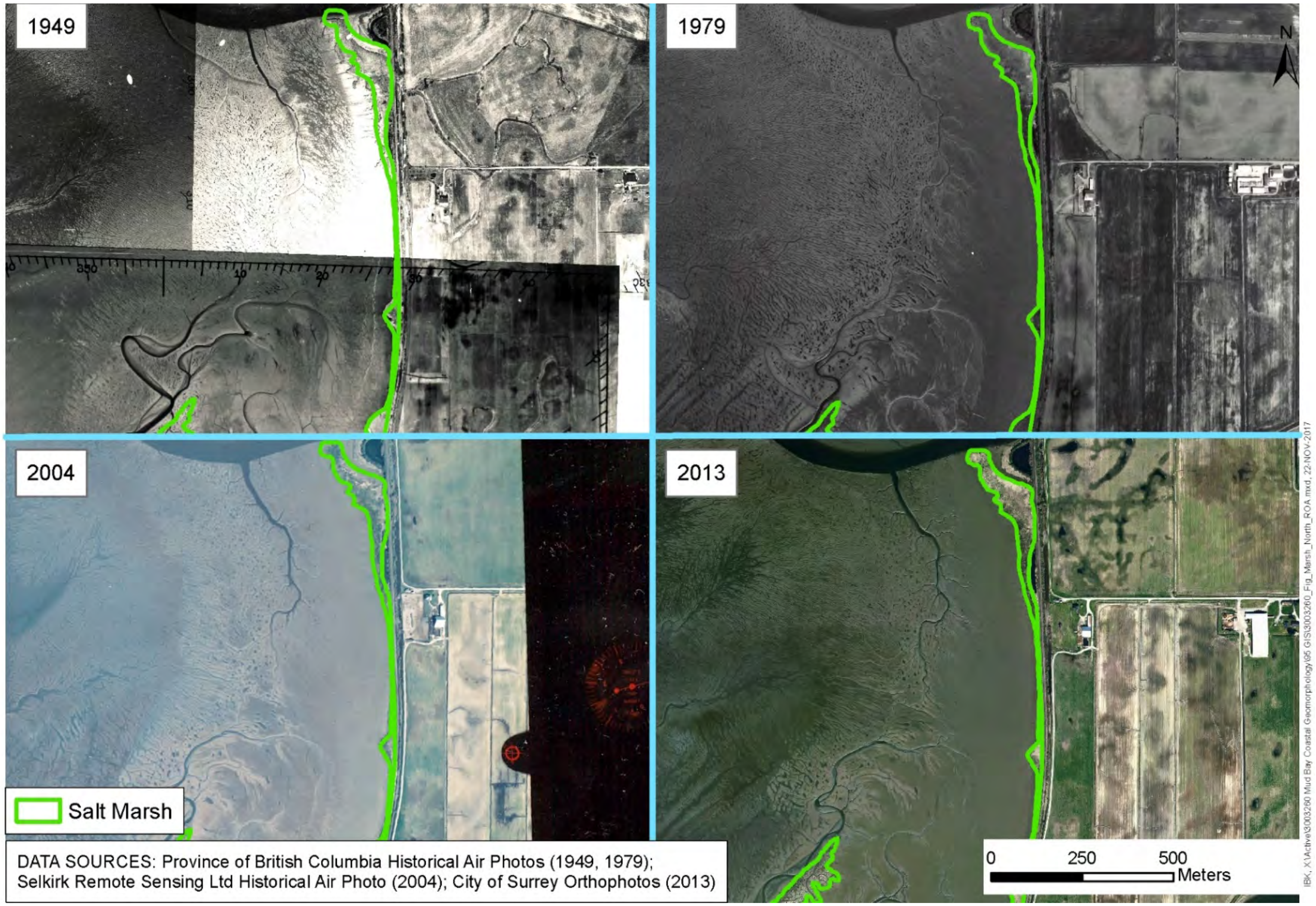


Figure 5.9 Approximate 2013 extent of salt marshes in central eastern portion of Mud Bay overlaid on 1949, 1979, 2004, and 2013 imagery

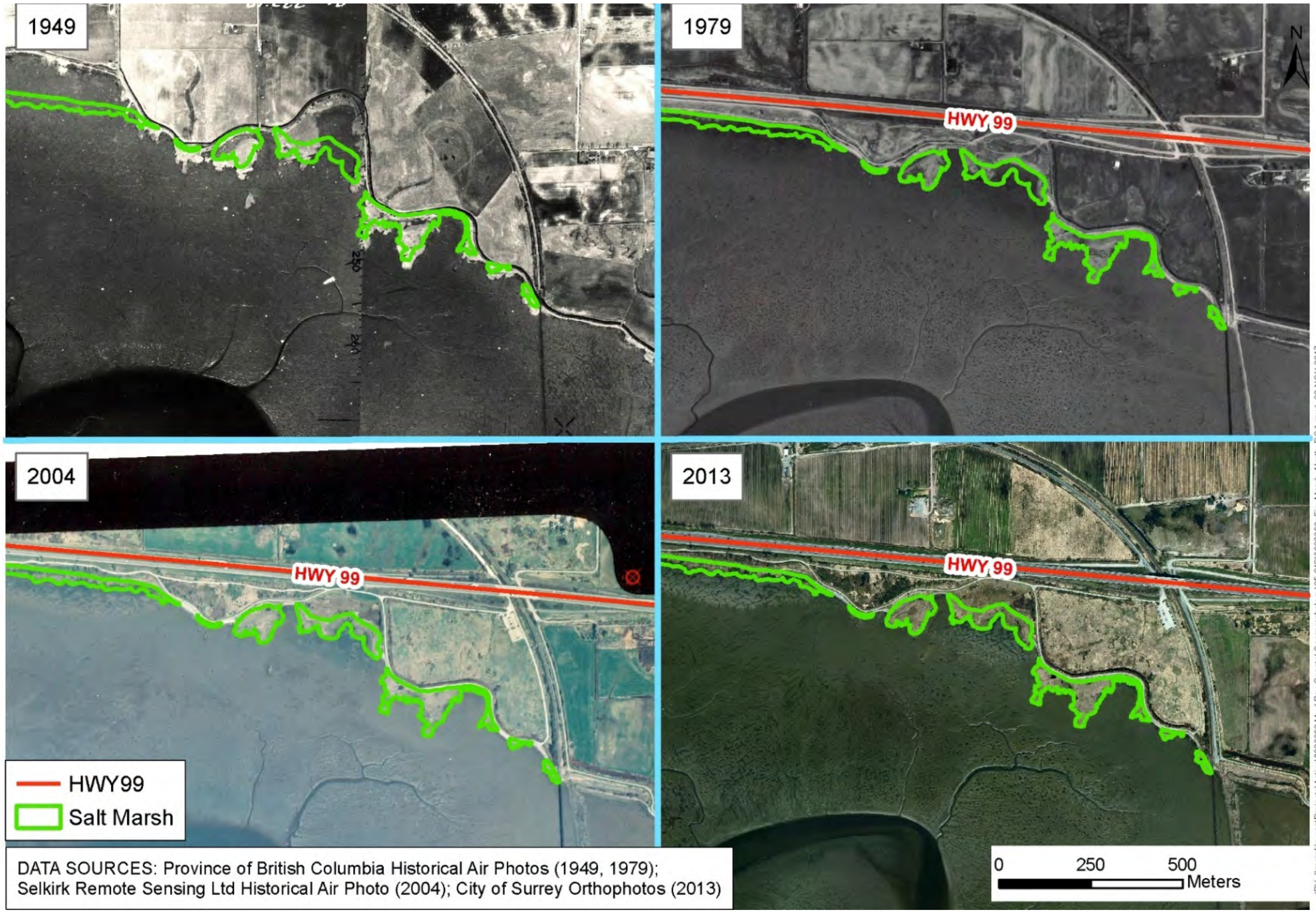


Figure 5.10 Approximate 2013 extent of salt marshes in northeastern portion of Mud Bay overlaid on 1949, 1979, 2004, and 2013 imagery.

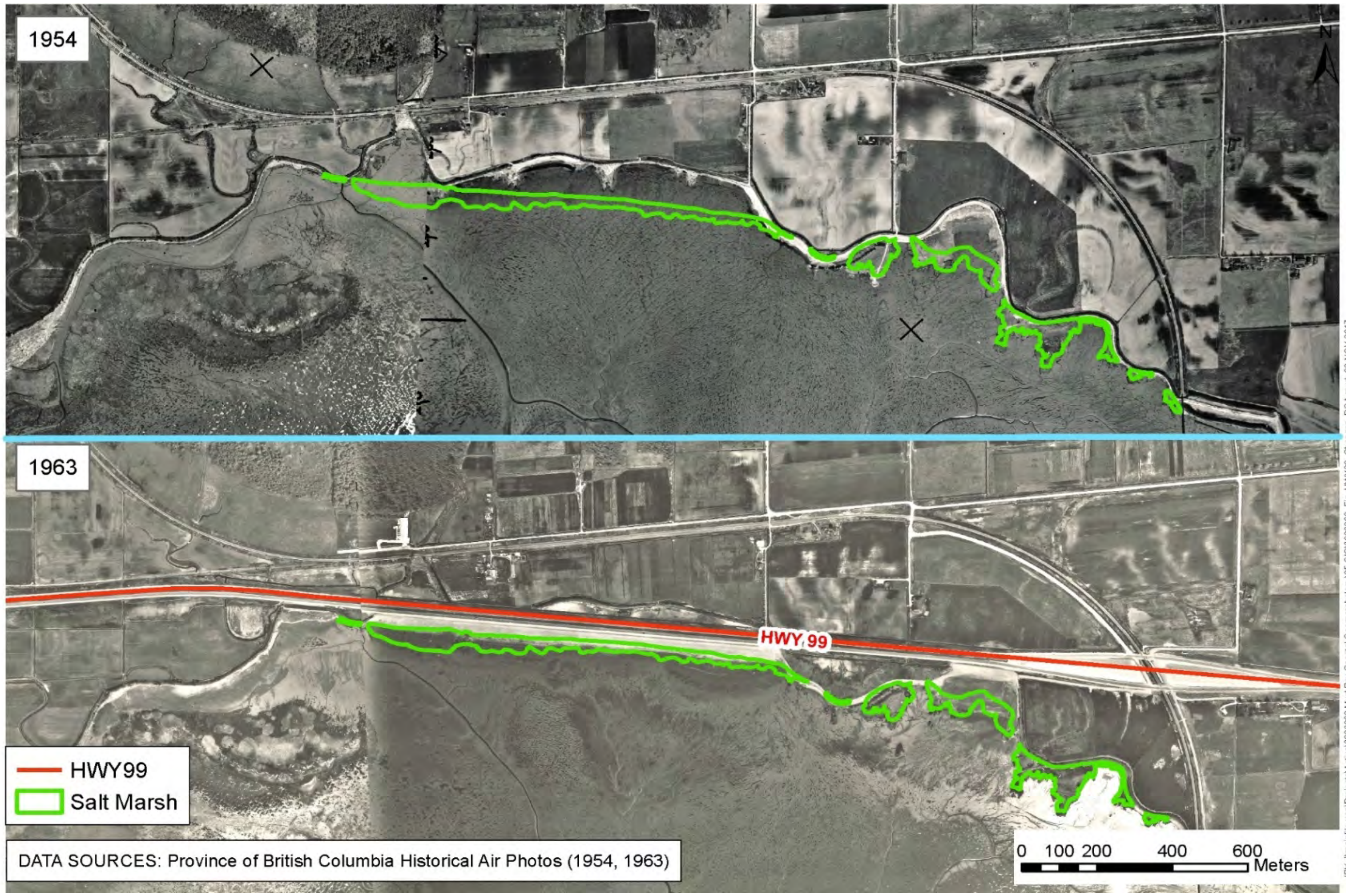


Figure 5.11 Approximate 2013 extent of salt marshes and shoreline changes along northern edge of Mud Bay overlaid on 1954 and 1963 imagery.

5.2.2 Drainage Channels

The location and planform of the drainage channels in Mud Bay were examined to provide an indication of the stability of sediment in the mud flats along the eastern side of Mud Bay. The air photo analysis suggests that the location and planform of the drainage channels over most of Mud Bay have remained very stable across the 66 year analysis period (1949 to 2015).

Figure 5.12 highlights some of the drainage channels and shows that their 2015 location is roughly the same as their 1949 locations with a few small exceptions. These exceptions include some of the drainage channels in the southeastern portion of Mud Bay circled in **Figure 5.13** where there have been slight changes to some of the smaller channels between 1949 and 1979. These channels appear to have been fairly stable between 1979 and 2013.

Overall, the majority of drainage channels have experienced minimal observable changes over the past 66 years. In addition to facilitating the exchange of tidal water, these channels transport sediment so their overall relative stability implies some balance between sedimentation and erosion processes in Mud Bay.

5.2.3 Shoreline

The air photo analysis shows some changes in the shoreline; however, these changes were concentrated along the northern edge of Mud Bay and were the result of extensive dredging in the 1960s associated with the construction of Highway 99. These changes can be seen in **Figure 5.11**.

The air photo analysis also shows substantial infilling within Blackie Spit, in the southeastern portion of Mud Bay, south of the mouth of the Nicomekl River. This infilling can be attributed to dredgate from the Nicomekl River, consisting of sand and fine silt, being dumped onto former marshes of Blackie Spit in 1963, 1970, and 1978 (Summers, 2001).

Aside from the shoreline changes caused by discrete anthropogenic disturbances along the northern edge of Mud Bay and at Blackie Spit, shoreline changes of note were not observed elsewhere within the study area during the analysis period.

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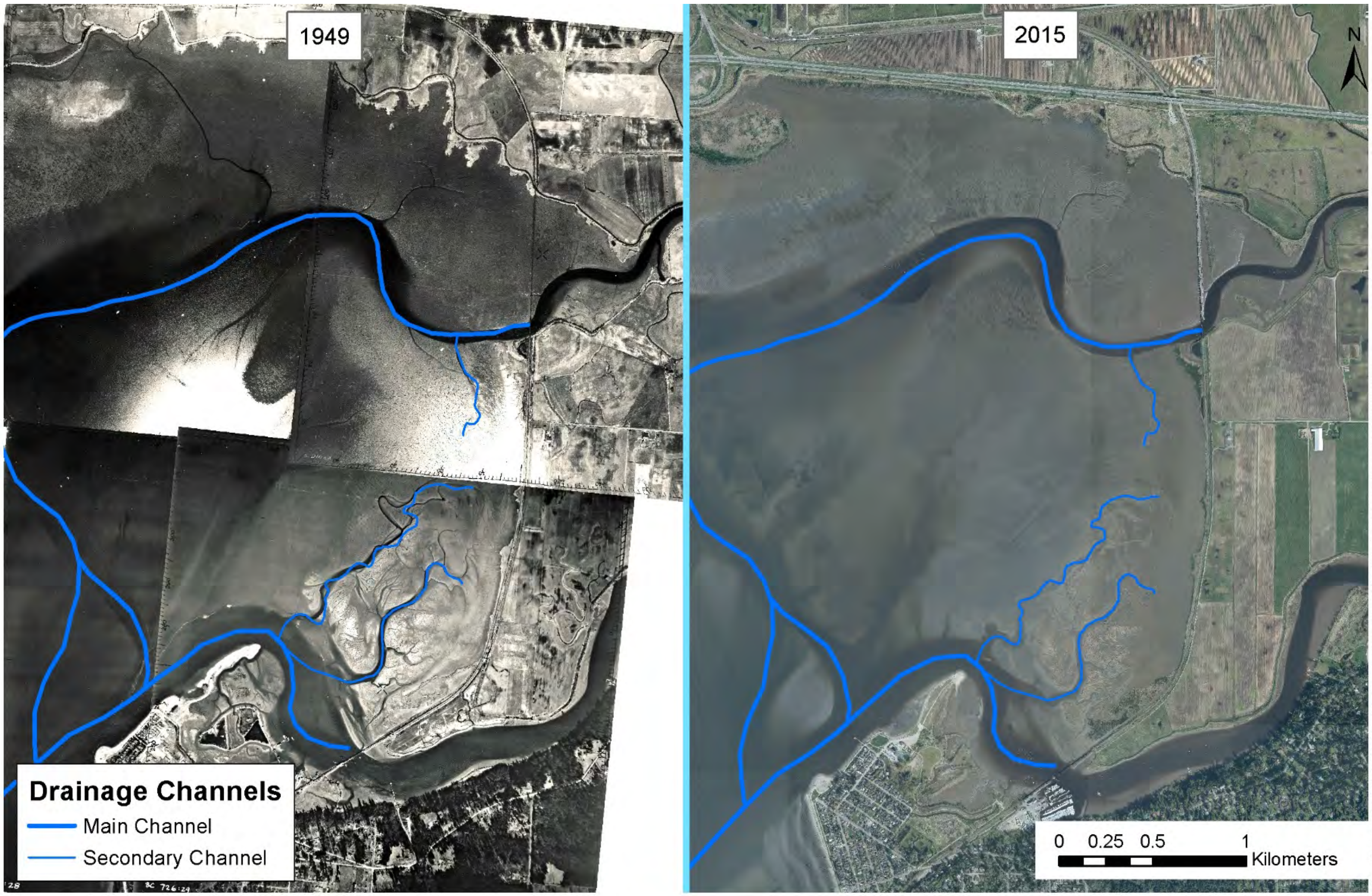

DATA SOURCES:Province of British Columbia Historical Air Photos (1949); City of Surrey Orthophotos (2015)

Figure 5.12 Approximate 2015 location of drainage channels (blue lines) in Mud Bay overlaid on 1949 and 2015 imagery.

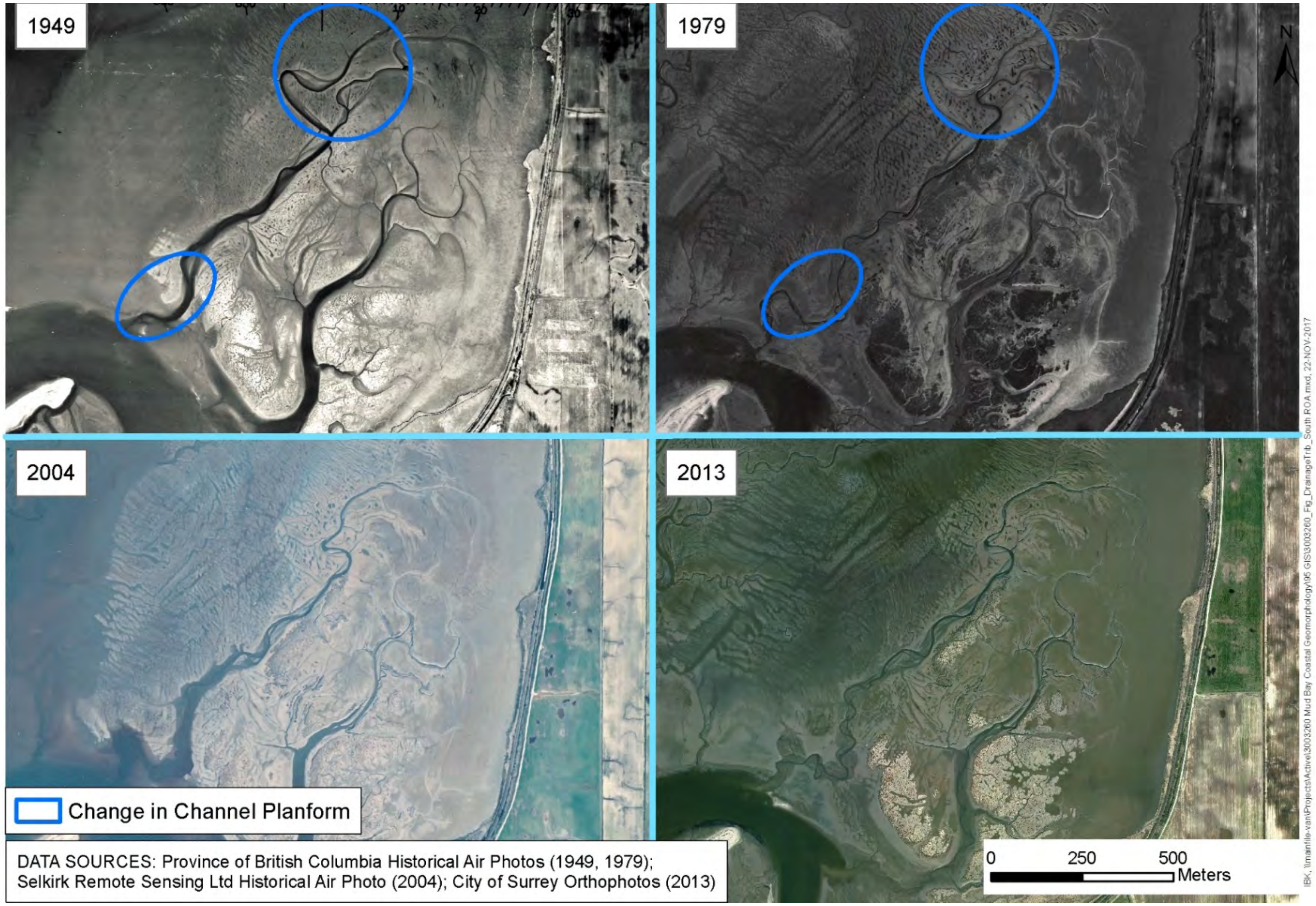

Figure 5.13 Air photos of drainage channels in Mud Bay in 1949, 1979, 2004, and 2013. Areas outlined in blue represent areas where the channels have experienced changes in location or channel pattern.

6 ANTICIPATED FUTURE CONDITIONS

It is generally accepted within the scientific community that anthropogenic changes to the earth's atmosphere will have a profound impact on future climatic conditions. Although estimates of the timing and magnitude of the anticipated changes vary, climate change is expected to result in changes to synoptic weather patterns, an increase in the frequency and intensity of storms, alter current trends in summer and winter temperature extremes, and increase the volume of water in the world's oceans (IPCC, 2013). Predictions of global trends do not necessarily downscale to local conditions, but it is possible to consider how these future changes will alter the interactions of physical processes and the physical environment in Mud Bay. The following factors have been considered as potential effects on the driving forces:

a) sea level rise, and

b) changes to the magnitude and frequency of storm events in the Strait of Georgia, and

c) changes to the flow regime and sediment inputs from Serpentine River and Nicomekl River.

6.1 Changes in Relative Sea Level

Relative sea level is a function of the height of the water in the ocean versus the absolute height of the adjacent land mass. Therefore, changes in relative sea level in the study area are a function of complex physical process relating to tectonics and subsidence in addition to processes relating to climate change.

6.1.1 Tectonics and Land Subsidence

The land surface of the Fraser River delta is subsiding due to settling and compaction of the relatively recently deposited sediments. Subsidence rates vary across the delta because of variations in the depositional history, thickness of sediments, and the thickness of the underlying Pleistocene unit (Hunter and Christian, 2001). At a regional scale, compression of the earth's surface due to the weight of ice during the last glaciation, and plate tectonics have generated complex crustal deformation throughout the Canadian Cordillera that also affect the relative elevation of the land surface (Clague et al., 1982).

The resultant land deformation has been quantified by Hill *et al*. (2013) at Roberts Bank using InSAR[1] technology to detect surface movement over several years, with the capability of resolving movements on the order of about 1 mm/year. Rates of uplift or subsidence were mapped across Metro Vancouver (**Figure 6.1**) and show that upland portions of the land behind Crescent Beach have experienced uplift in

[1] Interferometric Synthetic Aperture Radar

order of 2 mm/yr, while portions of the Holocene delta to the north of Mud Bay have experienced subsidence of greater than 3.5 mm/yr.

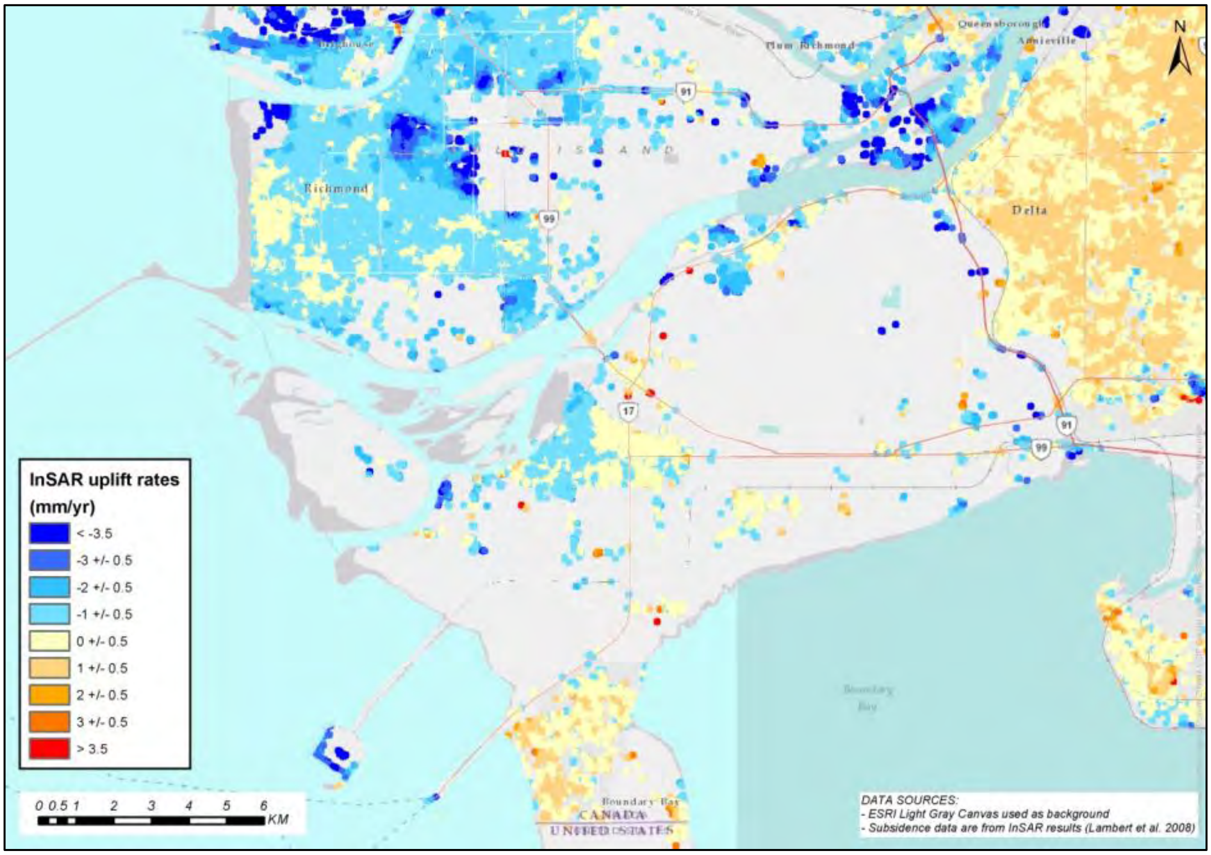

Figure 6.1 Uplift and subsidence rates across the western part of Metro Vancouver (various sources - from Hill et al. 2013).

Kellerhals and Murray (1969) also attempted to quantify subsidence rates in the area. Estimates of subsidence were not available for Mud Bay; however, Kellerhals and Murray (1969) reported subsidence estimates for western Boundary Bay at Beach Grove and for central Boundary Bay approximately 3.2 km west of the Great Channel. There are differences in the sedimentary condition of western Boundary Bay and Mud Bay. For example, the western half of Mud Bay experienced historical salt marsh transgression; whereas, Mud Bay has experienced historical salt marsh erosion (Kellerhals and Murray, 1969). Given their close proximity and shared sediment sources, it is expected that subsidence rates within western and central Boundary Bay would be similar to those of Mud Bay. Based on radiocarbon dating of peat and material within a midden, Kellerhals and Murray (1969) propose subsidence rates of 0.762 mm/year over the past 1,600 years in Boundary Bay at Beach Grove and 0.421 mm/year over the past 4,350 years in central Boundary Bay. These values fall within the range of uplift and subsidence rates quantified by Hill *et al*. (2013) for nearby areas within Metro Vancouver. Kellerhals and Murray (1969) also propose that near the centre of Boundary Bay, west of the Great Channel, the rate of subsidence should equal the rate of sedimentation for the past 4350 years.

6.1.2 Sea Level Rise

Climate induced sea level rise is expected to outstrip the magnitude of the changes already experienced in the century. Based on worldwide tide gauge records, global sea level has risen more than 0.2 m since the late 19th century (Thomson *et al*. 2008) but the rate of future sea level rise is expected to be considerably greater in the 21st century. Projections of the rate and overall magnitude of future sea level rise vary greatly depending on a suite of climate change scenarios that are considered, and seem to be trending higher in the more recent scientific studies as compared to earlier publications.

In 2008, Fisheries and Oceans Canada published forecasts of relative sea level rise for the year 2100 on the Fraser Delta for three scenarios (Thomson et al., 2008):

- Low estimate: 0.35 m
- Medium estimate: 0.50 m
- Extreme high estimate: 1.20 m

These relative sea level rise values are referenced to the year 2000 and incorporate the effects of both rising ocean levels and local land subsidence.

The Province of BC adopted a rate of sea level rise of 0.5 m by the year 2050 and 1.0 m by the year 2100 (10 mm/year) for the purpose of planning for coastal flooding throughout British Columbia (Ausenco-Sandwell, 2011b). The assumed sea level rise relation is shown in **Figure 6.2**, and the estimate for 2050 coincides with the medium scenario in Thomson *et al.* (2008) but on a much shorter time scale.

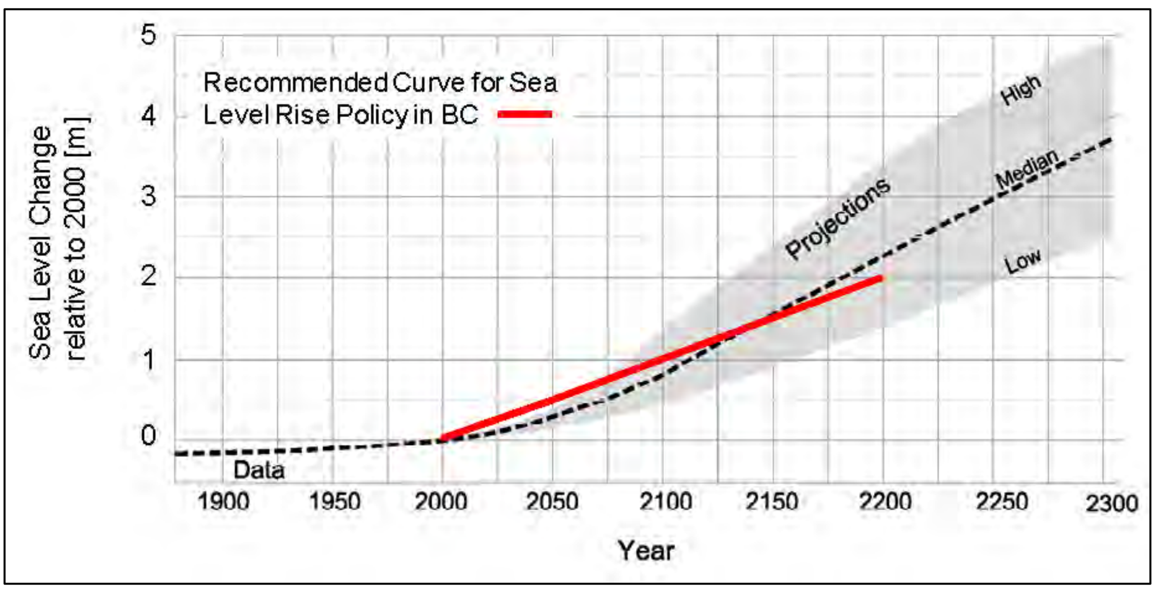

Figure 6.2 Projected sea level rise used in BC Ministry of Environment Climate Change Adaptation Guidelines (Ausenco-Sandwell, 2011b).

6.2 Changes to Wave Climate

The wave climate experienced in Mud Bay is a function of wind-generated waves and the relatively shallow depth of water, which has a strong influence on the degree of wave-bed interactions. Projected rises in sea level by 2100 are anticipated to reduce the effect of depth-induced wave breaking in Mud Bay. **Table 6.1**, modified from **Tables 5.8** and **5.9** in *Serpentine, Nicomekl & Campbell Rivers – Climate Change Floodplain Review* prepared for the City of Surrey (NHC, 2012), shows that the significant wave heights in some parts of Mud Bay are projected to increase between 2010 and 2100 as rising sea levels increase water depths. The wave heights presented in **Table 6.1** were produced using wave modelling software and input data from five large storms. Additional details about the wave modelling methodology are described in *Serpentine, Nicomekl & Campbell Rivers – Climate Change Floodplain Review* (NHC, 2012).

Table 6.1 Largest wave condition at several locations within Mud Bay for 2010 and 2100 water level scenarios modified from Tables 5.8 and 5.9 in *Serpentine, Nicomekl & Campbell Rivers – Climate Change Floodplain Review* (NHC, 2012).

	2010 Water Level Scenario			2100 Water Level Scenario			
LOCATION	Storm	Water Level (m)	Significant Wave Height (m)	Storm	Water Level (m)	Significant Wave Height (m)	Difference in Wave Height (m)
Colebrook – Serpentine	1994	2.94	0.28	1998	4.09	0.26	-0.02
Crescent Beach East	1982	2.70	0.48	1982	3.70	0.54	0.06
Mud Bay - Serpentine	1994	2.94	0.24	1982	4.09	0.21	-0.03
Mud Bay – Nicomekl	1982	2.70	0.23	1982	3.90	0.23	0
Colebrook (Hwy99)	1991	2.94	0.85	1994	4.09	1.19	0.34
Crescent Beach North	1982	2.70	0.69	1982	3.70	0.81	0.12
Crescent Beach South	2007	2.70	1.15	2007	3.70	1.50	0.35
BNSF Railway	1994	2.94	0.73	1982	4.09	0.86	0.13

There is considerable uncertainty about the changes that climate change will have on storm magnitude and frequency. There is a prevalent popular assumption, often reported in news media, that storms will become stronger and more frequent in the future.; however, definitive science-based analysis has not shown this to be the case in the Strait of Georgia. For instance, the draft policy discussion paper prepared by Ausenco-Sandwell (2011a) to inform policy on sea dykes and coastal flooding concluded that "Based on the available information it appears reasonable to conclude that no significant change is expected in coastal BC waters; however, further investigations are warranted to fully assess the regional implications and to further assess future trends." This conclusion is substantiated in Ausenco-Sandwell (2011a) with a discussion of the calibration of global and regional atmospheric-oceanographic model results against the last 40 years of available data for ocean weather and waves.

With increases in wave height in Mud Bay resulting from higher water levels, increased erosion of sediment in Mud Bay might occur, particularly in areas where the increase in wave height is more pronounced, such as around Crescent Beach, along the Colebrook-HWY99 section of the shoreline, and along the BNSF Railway. Other areas of Mud Bay, such as at the mouths of the Serpentine and Nicomekl Rivers, represent an exception to this trend, where wave height is not expected to increase. Here, wind speed and fetch, not depth, are the primary factors limiting wave height (NHC, 2012).

6.3 Changes to Freshwater and Sediment Inputs

The Nicomekl River and Serpentine River presently deliver fresh water and fine sediment to Mud Bay. Changes to runoff caused by climate change may result in changes to the delivery of fine sediment, but these will occur in the context of a very complex system that is modified by land-use patterns, stormwater management, and rising sea levels. With the existing state of knowledge of climate change-induced runoff patterns, it is not possible to make predictions of changes to the geomorphology of Mud Bay that may occur because of changes to changes in drainage basin behaviour.

6.4 Geomorphic Response to Climate Change

Regardless of the uncertainty around future conditions with respect to the frequency and magnitude of storms, the available evidence indicates that there will be an overall increase in wave heights at some key locations within Mud Bay (**Table 6.1**). Increased wave heights have the potential to drive geomorphic change at a faster rate than experienced in the recent past, particularly at upper shoreline locations where wave heights are typically quite small.

Acknowledging that making predictions of tidal flat response to sea level rise is highly complex due to the relationships between physical and biological factors, Hill *et al*. (2013) considered two techniques for visualising the effects of rising sea level at Roberts Bank. While Roberts Bank, which occupies a portion of the Fraser River delta, is a helpful comparison to the environment at Mud Bay, there are important differences, including the relative low wave exposure at Mud Bay and the dominance of muddy sediments as compared to the sandy sediments that comprise much of Roberts Bank.

The simplest of the techniques presented by Hill *et al*. (2013) is to simply assume that the landscape will be lower in relation to sea level in the future – a sort of 'drowning' of the feature (in this case Mud Bay). This approach serves as a useful visualisation tool but ignores the potential for the landscape to adjust as sea level rises over time. One approach that can be used to account for the evolution of the tidal flats during the period of rising water is the Bruun Rule (Bruun, 1988), which was used by Hill *et al*. (2013) to calculate the potential cross-profile changes that might occur as material is eroded from the upper or lower portions of the tidal flats and translated across the landscape. While this technique is useful for visualisation, it hasn't been proven and so is not appropriate for land management purposes. Given the relatively sheltered wave environment of Mud Bay, the drowning model is most plausible.

7 SUMMARY AND RECOMMENDATIONS

7.1 Summary

The underlying physical environment of Mud Bay is inherited from a landscape dominated by the most recent glacial period, and which has since been modified over thousands of years by ocean currents and wind-driven waves. Sediment inputs from upland sources as well as reworking of the materials in the bay and along the shoreline allow the landscape to accrete while subsidence and erosion losses to the deep ocean result in elevation loss. This review of background reports and data analyses of historical to present conditions in Mud Bay suggest that Mud Bay is in a state of relative stability. Of the changes that were observed in Mud Bay, the majority were localized and are apparently the result of discrete anthropogenic disturbances. This conclusion is based on multiple lines of evidence, none of which is definitive on its own, but which combine to form an overall picture.

The analysis of air photos and comparisons of topographic and bathymetric surveys suggest relatively stable conditions in Mud Bay with respect to sedimentation and salt marsh extent. Observed changes in salt marsh extent and shoreline morphology over the past 66 years are concentrated along the northern edge of Mud Bay and are largely attributed to the construction of Highway 99. Looking back further, to roughly 100 years ago, changes in the eastern shoreline of Mud Bay were observed and are attributed to the construction of the Great Northern Railway (presently the BNSF Railway). Air photos show that the planform morphology of distributaries within the tidal flats has remained fairly stable over the past 66 years, the period for which air photos were available. The earliest available bathymetric data of moderate resolution, 1969 contours, further support the observations from the air photos that the planform morphology of tidal flat distributary channels in Mud Bay have been relatively stable over the last few decades.

There was not sufficient data available to quantify historical sedimentation within Mud Bay. Historical sedimentation rates proposed by Kellerhals and Murray (1969) that are based on radiocarbon dating suggest that sedimentation in Mud Bay has occurred very slowly over the past 4,500 years. Minimal sedimentation was observed throughout the tidal flats in recent years (2009 to 2014); however, these changes could not be resolved from the uncertainty in the data. This result is not surprising, given the expected slow rate of change over this short time span. Apart from discrete anthropogenic disturbance events, the analysis suggests that despite historic evidence of long term salt marsh erosion and sediment reworking within Mud Bay (Kellerhals and Murray, 1969), over the last few decades Mud Bay has remained relatively stable.

The conclusion that the inter-tidal and shallow sub-tidal sediments have generally been stable is in apparent contradiction with the need for ongoing dredging of the Nicomekl River to maintain a navigation channel for boats. However, it is entirely plausible that infilling of the channels can occur while the surrounding inter-tidal features remain relatively stable. Sediment transport within the channel would be expected to be dominated by channelized currents, while sediment transport over the surrounding tidal flats would occur due to waves and tidal currents.

7.2 Recommendations

Based on the limitations in available historical data, the observed short- to medium-term relative stability of Mud Bay with respect to sedimentation, and the anticipated rise in sea level, it is recommended that wave and sedimentation monitoring be conducted in Mud Bay in the short- to medium-term future. Monitoring waves and sedimentation in Mud Bay using current technologies can provide information at a higher level of detail than was available historically. Given the slow rate of change in Mud Bay, higher resolution monitoring may reveal sedimentation patterns not observable with historical, coarser resolution data and may offer more insight into the effects of future rises in sea level on Mud Bay.

The findings of this study support the City of Surrey's initiative to conduct wave monitoring in Mud Bay. An increase in sea level rise has the potential to result in increased wave heights in some parts of Mud Bay, which could lead to increased erosion of sediment in the bay. It is recommended that water levels in Mud Bay be monitored to re-asses the relationship with water levels measured on the regional gauge network, which will help to understand how future rises in sea level compare to sea level rise estimates for 2050 and 2100. It is also recommended that wave heights in Mud Bay be monitored to further quantify the relationship between rising sea levels and wave heights, and to assess how this may impact erosion in Mud Bay.

The Serpentine and Nicomekl Rivers are an important source of sediment to Mud Bay, and changes in runoff patterns and sediment transport within these watersheds could impact sedimentation in Mud Bay. The relationships between land-use patterns, stormwater management, rising sea levels, and climate change-induced runoff patterns are very complex and difficult to predict with the available information. To better understand how changes in the Serpentine and Nicomekl Rivers could impact Mud Bay, it is recommended that climate change induced-runoff patterns in the Serpentine and Nicomekl Lowland areas be further studied.

Given the relatively stable sea levels and slow rate of sedimentation in Mud Bay over the past 4,500 years, conducting new sediment dating in Mud Bay may be of limited usefulness to predicting the impacts of sea level rise and coastal flood mitigation options on Mud Bay. There is a gap in available sediment dating information in Mud Bay and recent sedimentation rates are essentially not quantifiable because sedimentation and subsidence rates in Mud Bay are so slow that a longer monitoring time period would be required for changes to have accumulated to a large enough value to be detectable. However, the southern delta around Boundary Bay was already formed by 5,000 years ago. Prior to 5,000 years ago sedimentation conditions were very different than today with the Fraser having been a major source of sediment at the time. In contrast, the Fraser River is no longer an active source of sediment. Since the sedimentary conditions would have been so different more than 5,000 years ago compared to today, sedimentation and subsidence rates from more than 5,000 years ago might not be representative of how Mud Bay, in it's current sedimentological conditions, would respond to changing climatic conditions over the next hundred years. Additionally, over the past 4,500 years, during which Mud Bay was in a similar sedimentological condition to today, it is assumed that sea level was relatively stable. Consequently, it is expected that the historical record for the past 4,500 years would not contain an example of how sedimentation and subsidence rates in Mud Bay have historically responded to changes in sea level.

The findings of this study support the initiative by the City of Surrey to set up rSET platforms to monitor salt marsh sedimentation. There is evidence of historical salt marsh erosion in Mud Bay and it would be useful to better quantify contemporary rates of change in salt marshes. Recent loss and re-establishment of salt marshes in Mud Bay has been documented in response to human interventions along the Mud Bay shoreline (eg. dredging for road building). Additional human interventions along the shore would be required for some of the CFAS options, so it would be useful to gain more insight into rates of salt marsh transgression and regression in anthropogenically impacted areas. Given the limitations of quantifying sedimentation rates using the historical record, monitoring sedimentation using more current technologies, such as the rSET platforms, could provide data at a higher resolution than was available in the past. This might reveal smaller scale sedimentation patterns that were previously not detectable with coarser resolution data.

With respect to placement of the rSET platforms, as outlined in the *Coastal Geomorphology of Mud Bay Preliminary Assessment and Recommendations for RSET Platform Installations Memo* for the City of Surrey (NHC, 2017), it is recommended that the rSET platforms be spatially distributed along the coastline from the Colebrook Dyke to the mouth of the Nicomekl River such that several different environments within the bay are represented as much as possible given equipment limitations. To this effect, it is recommended that of the four rSET platforms to be installed, two be placed in salt marsh environments and two be placed in tidal flat environments characterised by unvegetated soft muddy sediments.

In placing the platforms in the salt marsh environments, it is recommended that they be placed in the northeast and southeast corners of Mud Bay where the salt marsh areas are most expansive to capture salt marsh processes (**Figure 5.8** and **Figure 5.10**). Since there have been observed changes in recent decades in the northern portion of Mud Bay, placing platforms in both corners could help represent these differential environments.

In placing the platforms in the tidal flat environments, it is recommended that the platforms not be placed directly on the tributaries as these tributaries facilitate the channelized exchange of tidal water and sediment that would not be representative of the processes in the tidal flats outside of these channels. It is also recommended that the rSET platforms not be installed in the locations outlined in blue in **Figure 5.13** as these indicate areas of recent drainage channel migration. Given the relative stability of drainage channels in the remaining areas, assuming the platforms are not installed in the areas indicated in **Figure 5.13** or directly on tributaries and assuming that there are not any extreme disturbances in the next few years, tributary migration is not expected to pose a problem for rSET monitoring in the near term.

In determining the placement of rSET platforms within the areas indicated above, practical limitations should be considered. Platforms should be placed at distances that are realistically walkable such that the people undertaking the monitoring program are able to walk to and from the sensors and take measurements within the window of time when the tide is low. It should also be considered that if monitoring is intended to take place during the winter months, measurements may need to be conducted at night to coincide with low tide and this may add extra time to conduct the monitoring in darkness.

It is important to consider that even having chosen representative monitoring locations, the rSET platforms will likely capture localized changes and it may be inappropriate to extrapolate the results obtained from one rSET platform to surrounding areas. Elevation changes can be very spatially variable, and it can be difficult to predict small scale changes using large scale data. Judgement must be used.

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Chapter 4

Shoreline Assessment Mud Bay – Field Verification Report

City of Surrey Shoreline Assessment Mud Bay – Field Verification Report

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27 February 2018

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Figures

1 Introduction

The City of Surrey (CoS) retained Golder Associates Ltd. (Golder) to complete a desktop shoreline mapping study to classify areas of coastal dyke in Mud Bay. CoS has also partnered with Friends of Semiahmoo Bay Society (FoSBS) to conduct a field review of Golder's desktop mapping assessment. This report provides a synthesis of field verification notes, photos and further detail about shoreline types and associated habitats observed.

2 Objectives and Scope

The primary objective of this project is to complete a field verification of a desktop shoreline mapping exercise conducted by Golder and to report on field observations. Field observations were supplemented with relevant background documents and data available for the study area.

The field review included the following tasks:

- Field visits of selected locations to ground truth shoreline classifications
- Photo documentation of ground truthed locations
- Reporting on findings and verification of Golder's classification

3 Study Area

The study area includes the tidally influenced foreshore with the City of Surrey bound by highway 91 to the northwest, Crescent Beach to the southwest and highway 99 to the east. The study area also includes both shores of the Nicomekl and Serpentine Rivers. As a part of Golder's desktop mapping assessment, the study area was divided into eight reaches as shown in Figure 1.

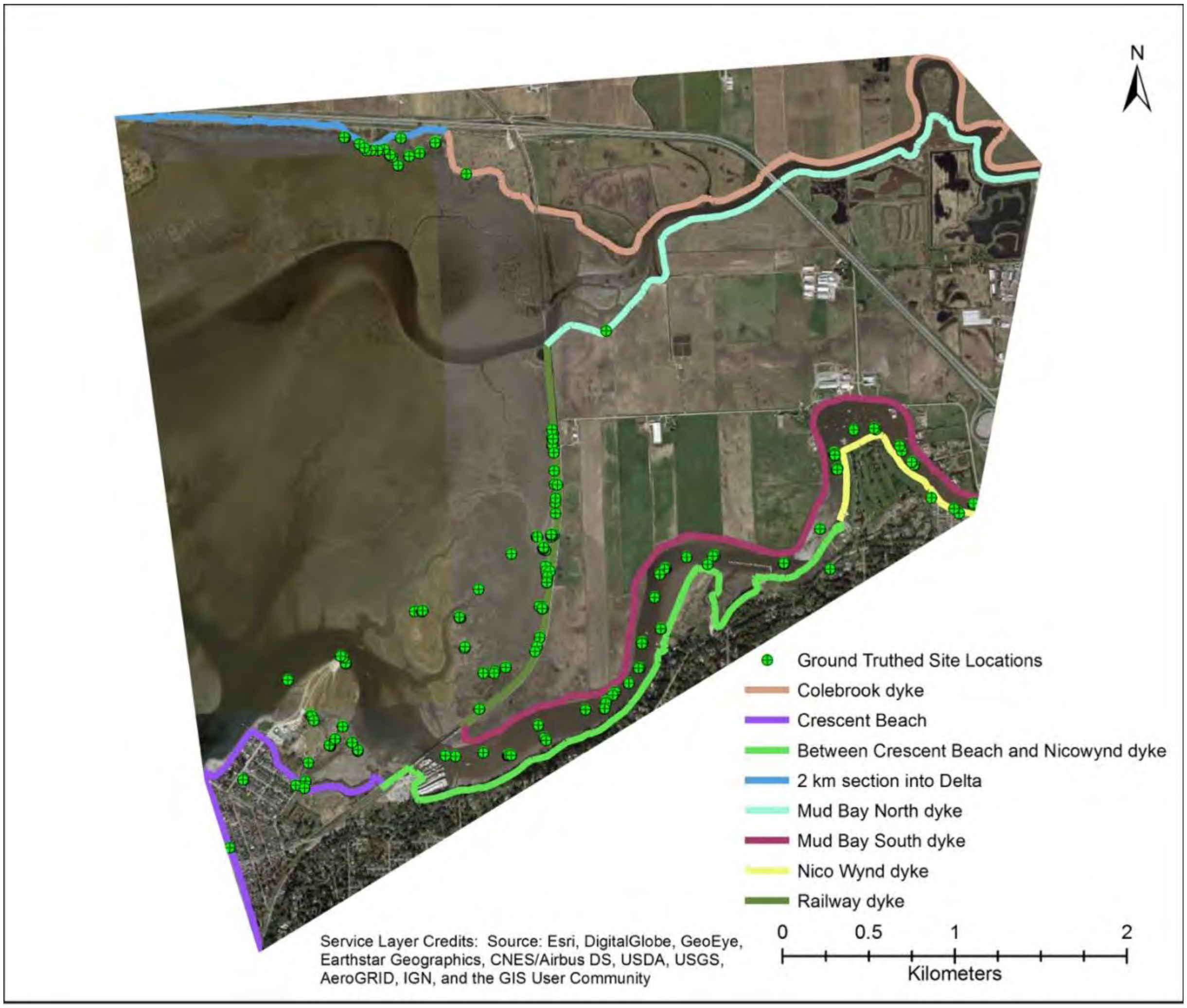

Figure 1 Map of study area and shoreline segment names and ground truthed site locations

4 Methods

4.1 Data Review

Several mapping projects have been completed in the area that have relevance to the shoreline mapping assessment project being led by the City of Surrey. The Province of BC has the Coastal Resource Information Management System (CRIMS) for viewing coastal and marine data including shoreline classification (ShoreZone).

Between July 2006 and October 2007 FoSBS lead an intertidal shoreline mapping and sampling project to determine the presence and health of forage fish spawning beaches in Boundary Bay and Mud Bay Areas. A review of the final report was completed, and relevant information has been included in this report.

In the summer of 2013 Ducks Unlimited Canada (DUC) completed a salt marsh mapping project to identify areas of Salicornia presence and approximate abundance. This data was reviewed to determine the locations of salt marsh within the study area and the approximate total extent.

In 2017 Golder conducted a desktop shoreline assessment study of Mud Bay that classified the shoreline by the type of armoring and the presence of a mud bench. There are three categories for the armouring: unarmoured, cobble, and rock. Mud benches were classified into four categories: the presence of a mud bench at the toe of the dyke un-vegetated, the presence of a mud bench at the toe of the dyke vegetated, no mud bench and beach. A description of each category and how each was assigned is provided in Appendix A.

4.2 Field Visits

Field visits were conducted on January 24-26 and February 5 and 15th. Access was either by foot, kayak and/or zodiac to specific locations shown in Figure 1.

5 Results

5.1 Salt Marshes

The study area has expanses of fringing salt marsh including both raised salt marsh benches (Figure 21) and sloping graduated salt marshes (Figure 9) with transitional vegetation. The surveys were completed in winter months, limiting the ability to detect vegetation species in detail. Generally, the high salt marshes had the following plant species present: *Distichilis spicata, Juncas gerrardi, Grindelia stricta*. Low salt marshes species were dominated by *Salicornia spp*. with some evidence of *Triglochin maritima and Carex lyngbei*. *Spartina anglica* was observed throughout the study area.

The approximate total extent of salt marsh in the study area is greater than 230 hectares as shown in Figure 2. This does not reflect the entire extent of salt marsh in the study area. The vegetated shoreline along the railway dyke is missing from this mapping project completed in 2013 by DUC.

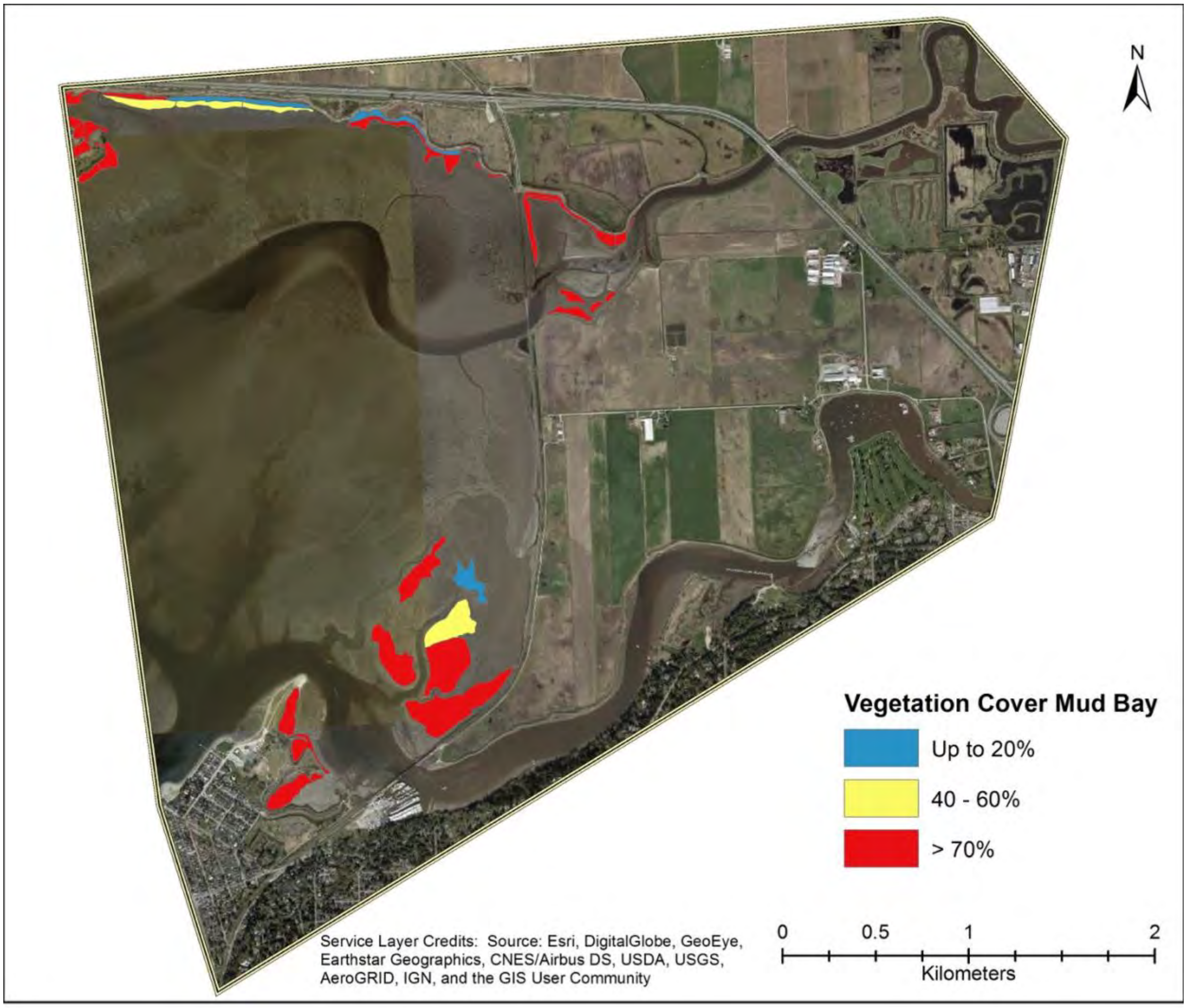

Figure 2 Mapped salt marsh vegetation in study area (2013)

5.2 Beaches

Beaches play an important role in the marine food chain. Gravel beaches with appropriately sized gravels and sand provide spawning habitat for forage fish species. Forage fish species are critical intermediary species feeding on plankton and then in turn feeding secondary species such as salmon and birds.

Surf smelt eggs typically anchor to pieces of gravel and fall into interstitial spaces within sediments layers (Penttila 2001). Gravel that is too coarse and/or shallow prevents successful egg development due to desiccation as a result of surface exposure (Penttila 2001). Seawalls and railway beds are physical barriers that block natural coastal processes (such as erosion) which supplies terrestrially-borne gravel sediments to beaches. Shoreline modification is the primary threat to surf smelt and sand lance spawning beaches (Penttila 2005).

The total extent of available and utilized spawning beaches in the study area is unknown. Field sampling conducted by FoSBS has confirmed the presence of spawning along the more exposed western shores of the Crescent Beach shoreline segment. This shoreline segment is approximately 1 kilometer long and has the potential for forage fish spawning habitat restoration to include placement of appropriately size gravel, removal of groins and planting of overhanging riparian vegetation. Currently, this shoreline is severely modified by backshore residential development, walking trails, removal of overhanging riparian vegetation and the installation of rock armoring and groins. As a result of these modifications this forage fish spawning location continues to degrade over time.

5.3 Shorezone

This shorezone data is subject to data sharing and copyright; it is worth noting and referencing for future potential assessment projects. The basic concept is the shore line can be split into alongshore segments and the segments can be systematically profiled by physical characteristics including but not limited to exposure, zones and substrate types (Figure 3).

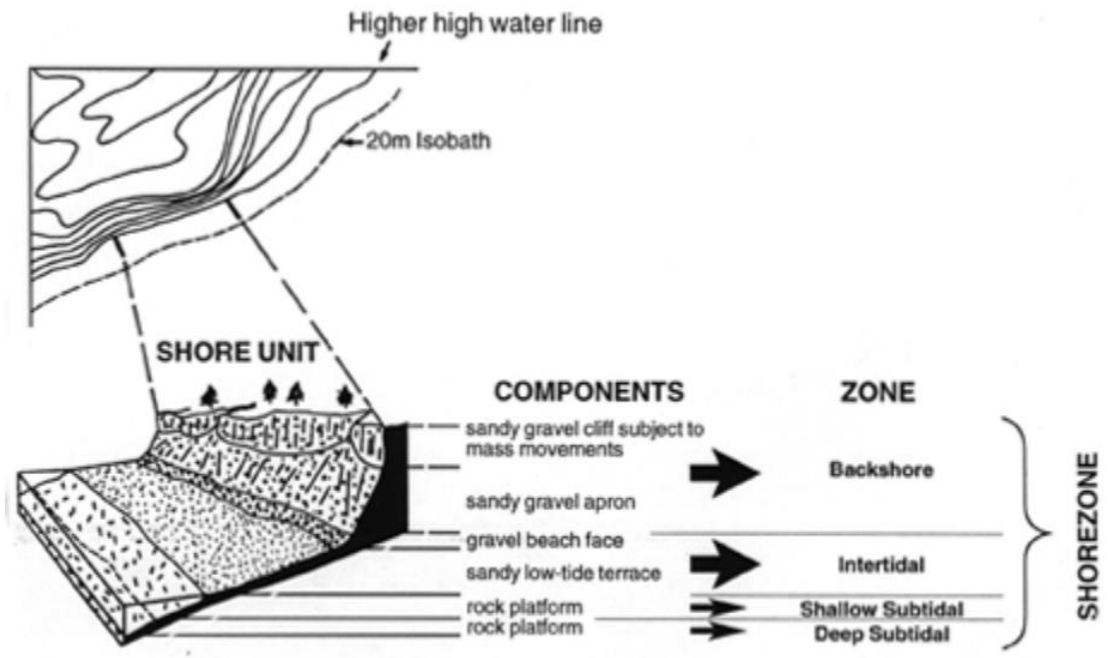

Figure 3 Schematic example of shorezone mapping (Howes, Harper & Owens 1984)

5.4 Golder Desktop Shoreline Mapping Review

The shoreline classifications of armouring and presence of a mud bench defined by Golder (Appendix A) were ground truthed at seven of the eight segments the shoreline was divided into. Ground truthing of the shoreline classification mapping completed by Golder found the classifications to be correct at all locations visited (Figure 1).

5.4.1 Crescent Beach

Western Side

The western side of the Crescent Beach shoreline segment is more exposed, consisting of gravel and sand beaches with some rock and cobble and expansive sand flats (Figure 4). The exposure to wave action allows for the presence of heavier substrates, creating these sandy rocky beaches. The backshore is heavily altered, and groins are present which appear to be impacting the processes of this drift cell. The groins reduce wave energy and shoreline erosion, protecting the dykes and residential community. This shoreline modification is likely impacting the shoreline substrate movement which is important in the development of beaches with appropriately sized gravel for successful forage fish spawning. Forage fish sampling in 2006 to 2007 found forage fish spawning presence at Crescent Beach but 95% of the eggs were dead. The coarse gravels at Crescent Beach (see Figure 5) results in eggs that are anchored on the surface of the beach, in direct sunlight resulting in egg desiccation. This is further exacerbated by a lack of overhanging vegetation to provide shade (De Graaf 2007, Penttila 2001, Rice 2006). A 2007 shoreline profile of a portion of Crescent Beach is shown in Figure 6 and the associated shore components and measurements are shown in Table 1.

Figure 4 Shoreline near Beecher St showing groins, impacted backshore and potential spawning habitat for forage fish

Figure 5 Coarse gravel on top of fine sand beach

Table 1 Crescent Beach Forage Fish Spawning Location Characteristics (De Graaf 2007)

Location: Crescent Beach, Beecher Place
Wave Exposure: exposed; south-west facing
Backshore: grass lawns, gravel sidewalk; residential housing
Shading: no shade; impacted shoreline

Zone/Component	Band (Form)	Substrate (material)	Other observed materials, plants, animals	*Slope	Height/Width	**Tide Height (m)	Horizontal Distance from HHW (m)
A1	Beach berm	Clastic: sand; rock (4)	Salt tolerant plants	6°	117.8 cm/ 11 m	5.8 m	11 m
B1 (+)	Beach face	Clastic: rock (4,3)	Rock; sand; logs; drift Zostera spp.	9.7°	50.2 cm/ 3 m	4.6 m	0 m
B2 (+)	Beach face	Clastic: rock (4,3,2)	rock	8.0°	80.9 cm /6 m	4.1 m	3 m
B3 top	Beach face	Clastic: rock (4)	Rock; barnacles; Ulva	5.0°	43 cm / 5 m	3.3 m	9 m
B3 bottom	Beach face	Clastic: cobble (5), rock (4)	Rock, sand			2.9 m	14 m
B4	Sand flat		sand				
B5	Sand flat		Sand; Zoster spp.				

Overall slope 6.7°
(+) Potential spawning habitat 0-6 m horizontal distance from B1

* measure from band height and width measurements
**measured against tide height of approximately 2.9 m at the beach face B3-bottom

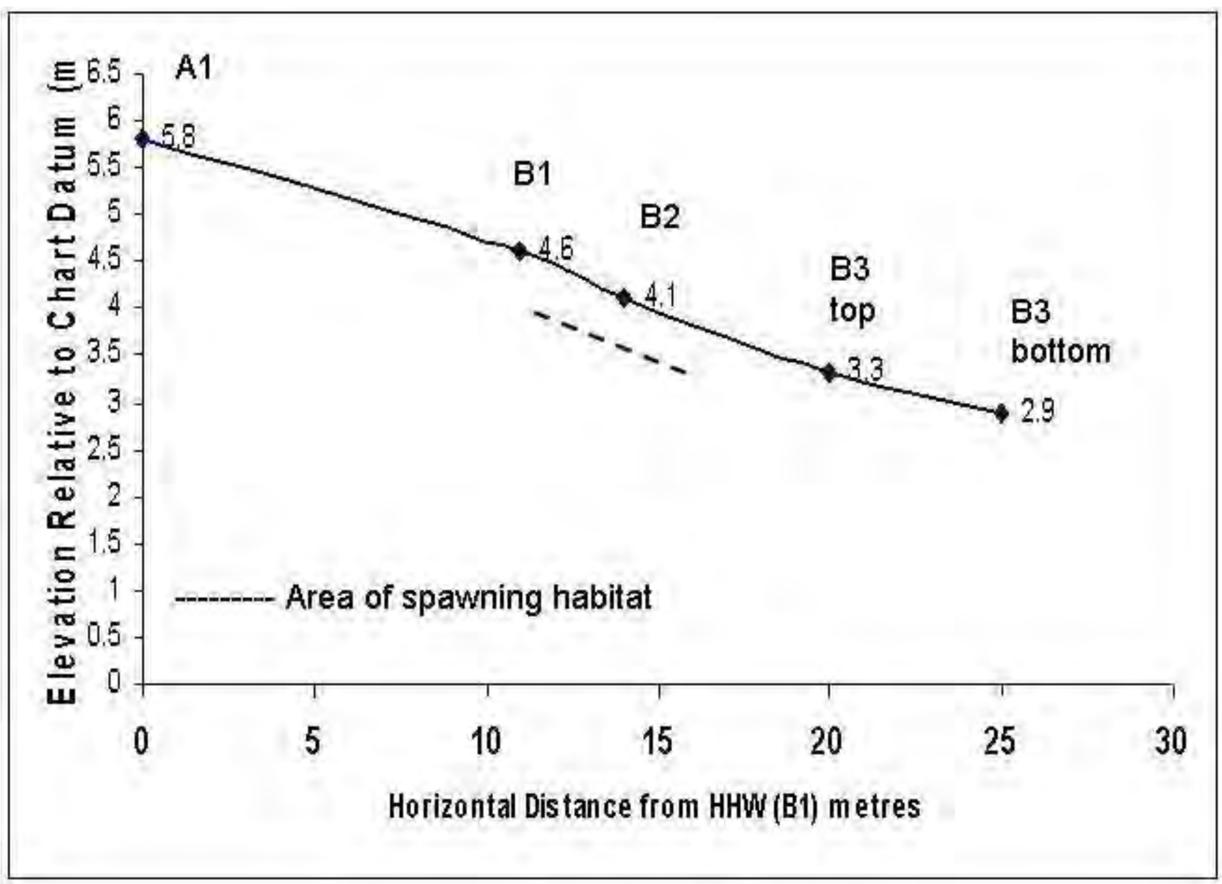

Figure 6 Crescent Beach Forage Fish Spawning Location Shoreline Profile (De Graaf 2007)

Eastern Side

The eastern side of the Crescent Beach shoreline segment consists of finer silty, clays and the establishment of salt marsh vegetation. There are no structures in the backshore or foreshore to impede the movement of gravels and sediments along the beach and there is no shading vegetation present on the spit.

Blackie spit

Figure 7 Gravel and shell hash substrate at Blackie Spit

On the north-west side the beach has shallow gravel with some pea gravel and shell hash on top of sand. On the south-east beach it is mainly coarse sand and shell hash.

Blackie Spit Park

Figure 8 Salt marsh at Blackie Spit Park

This area includes expansive salt marshes with tidal channels. The land ward edge of the salt marshes includes some trees and shrubs. Invasive *Spartina anglica* can also be found in some of these salt marsh areas.

5.4.2 Railway dyke


Figure 9 Sloping salt marsh

The southern extent of this shoreline segment includes a 58.70 hectare parcel of fee simple land owned by The Nature Trust of BC, The Nature Conservancy of Canada and the Province of BC (Wood et al 2017). The three agencies purchased this land in partnership in 1982 to protect the important salt marsh habitat at the mouths of the Serpentine and Nicomekl Rivers (Wood et al 2017). The shoreline includes a narrow salt marsh bands (< 10 m), larger ones and some gravel beaches. Raised benches and sloping salt marshes are found here with at least one gravel beach (Figure 11). The wrack line shows that high tides can reach with a few feet of the rail bed.


Figure 10 North facing shot alongshore


Figure 11 Narrow gravel beach in front of armored dike


Figure 12 Rock armoured with vegetated bench

5.4.3 Mud Bay North

Salt marshes are found along the toe of the dyke and as islands in the between the Mud Bay North shoreline segment and Colebrook shoreline segment. There are also tidal channels and pools throughout these salt marsh areas. Overhanging vegetation is not present likely as a result of regular mowing.

Figure 13 Salt marsh in the mouth of the Serpentine east of the trestle

5.4.4 Colebrook dyke

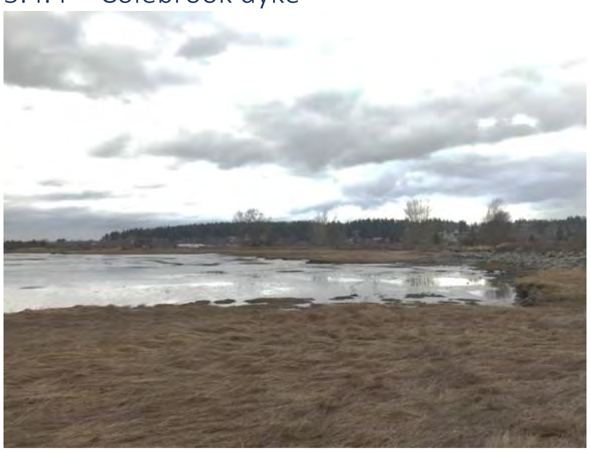

Figure 14 Sloping salt marsh at Colebrook shoreline segment west of the Serpentine River trestle.

5.4.5 Mud Bay South

Figure 15 Armored with no mud bench

Figure 16 Unarmored with vegetated mud bench

There are very limited amounts of trees, shrubs or any overhanging vegetation. Mostly raised salt marsh benches and steep sloping dykes, both armored and unarmored, make up this segment of shoreline.

5.4.6 Between Crescent Beach and Nico Wynd Dyke',

This section of shoreline includes a steep treed bluff (Figure 18), several private recreational docks, public and private marinas and a golf course.

Figure 17 Private docks along the shoreline

Figure 18 Steep treed bluff with residential housing

5.4.7 Nicowynd dyke

Figure 19 Constructed habitat bench

A constructed habitat bench is located near the Nicomekl river sea dam (Figure 19). It has not established as a functioning salt marsh.

5.4.8 2 km section into Delta

Figure 20 Salt marsh island on the mudflat

Figure 21 Elevated salt marsh bench

A mix of sloping salt marshes that gradual turn to mudflat (Figure 14) and raised salt marsh benches are found along this segment. The seaward edge of some of these eroding salt marshes have cobble beaches (Figure 21).

6 Recommendations and Concluding Remarks

- Spawning beaches are critical for forage fish populations that are critical to the trophic cascade of nearshore ecosystems. Installation of strategically placed feeder bluffs could provide flood protection and mimic natural coastal erosion processes to overcome gravel and sediment deficits along crescent beach
- Pursue licensing and use of Shorezone dataset to further inform CoS shoreline assessment studies

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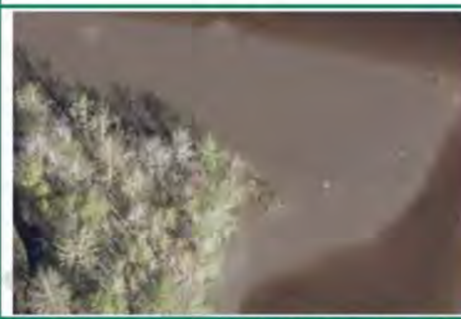
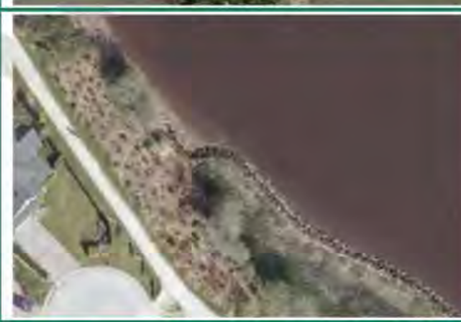
Appendix A

Table 2 Armoring Classifications (Golder 2017)

DESCRIPTION Value	Description	Example
UNARMOURED	Dike toe is unprotected or vegetated. Determined by a green colour indicating vegetation or by no cobble or rock material visible.	
COBBLE	Cobble material at the toe of the dike. Identified by colour and texture of the surface.	
ROCK	Stone material larger than cobble. Individual rock units able to be distinguished in the orthophoto.	

Table 3 Mud Bench Classifications (Golder 2017)

MUD BENCH Value	Description	Example
YES	There is a mud bench is visible at the toe of the dike. The mud bench extends out from the toe a minimum of 10 metres in the 2015 orthophoto.	
VEG	Vegetation visible at the toe of the dike and extends out onto the mud bench a minimum of 10 m. Within the 10 m in front of the toe, the vegetation is not patchy and there are no un-vegetated drainage channels cut.	
NO	Very narrow or no mud bench; the waterline is located within approximately 10 metres of the toe of the dike in the 2015 orthophoto. This category was only used on the banks of the Serpentine and Nicomekl Rivers.	
BEACH	Beach (sand) material at the toe of the dike. This category was only used in the Crescent Beach reach.	

Chapter 5

Monitoring Phase 1 Memo

MEMO

Date March 5, 2017

To Matt Osler
City of Surrey

From Matt Christensen

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 Near-shore Settlement and Water Quality Monitoring. This is an interim project update memo to report on the status of monitoring equipment installed and the next steps.

Installation of Equipment +6 month equipment rental payment

Figure 1 Map of installed equipment locations

rod Sediment Elevation Tables

Estuary accretion/erosion rates will be measured using rod Sediment Elevation Tables (rSET), consistent with methods implemented by the US Geological Survey (see www.pwrc.usgs.gov/set for details). Four rSET platforms were installed in Mud Bay at the locations shown in Figure 1. Their specific coordinates and recorded measurements are listed in Table 1.

Figure 2 Photo of installed rSET and measurements being taken

Measurements were taken on January 25th and February 15th, 2018. The next measurement recordings for the rSET platforms will be in June/July of 2018. The platforms need to be recorded with a real time kinetic gps to collect precise elevation and location coordinates. This will be done when the additional water quality data loggers are installed in March/April 2018. The marker horizons will also be placed during this time. The marker horizons will help differentiate between shallow subsidence and sediment accretion. Without them we are assuming any differences in surface elevation are due to sediment accretion.

Table 1 List of rSET platform locations and measurements

					Measurements (cm)								
Name	Lat	Long	Direction	Approximate Bearing (°)	1	2	3	4	5	6	7	8	9
MB1	49.0892982	-122.8669968	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	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	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	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

Water Quality

Water depth, temperature and salinity will be measured using dataloggers. Water depth and temperature are being collected at the current datalogger location (shown in Figure 1) with a Levelogger Edge 3001 (as shown in Figure 3). Two new locations will have one additional data logger (3001 LTC Levelogger Edge) installed at each in April. These new locations will collect temperature, depth and salinity information. The barologger (model: collects barometric pressure information from the site and is used to correct the water level from the level loggers by correcting 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

Label	Latitude	Longitude
Barologger	49.0599	-122.8649979
Levelogger 1	49.0631	-122.8659973

Figure 3 Photo of installed datalogger models

Chapter 6

Regulators and Stewards Workshop Notes, Exit Surveys and Memo

DIAMOND HEAD
3559 Commercial Street
Vancouver, BC 604.733.4886

March 15, 2018

Matt Osler
City of Surrey
13450 - 104 Avenue
Surrey, BC, Canada V3T 1V8

Re: Regulators Meeting with Department of Fisheries and Oceans

An informal meeting was held with science staff from the Department of Fisheries and Oceans (DFO) to discuss the Surrey Coastal Flood Adaptation strategy (CFAS). The meeting took place with three representatives from the DFO at the Pacific Science Enterprise Centre (4160 Marine Drive West Vancouver) on December 8th 2017. Attendees included:

- Theraesa Coyle, DFO
- Steve Macdonald, DFO
- Herb Herunter DFO
- Matt Osler, City of Surrey: and
- Mike Coulthard, Diamond Head Consulting

At this meeting the Surrey Coastal Flood Adaptation strategy (CFAS) was reviewed including the options being considered. Feedback during the meeting was general in nature as they are unable to provide support or recommendations until an official review process is initiated. Feedback was generally supportive of the process and level of consultation involved. Much of the discussion focussed on the options that might protect and/or enhance subtidal and intertidal ecosystems involved in the development

It has been recommended by the DFO that once an option has been chosen as the preferred approach that it be submitted as a “request for review” through the established submission process. This will ensure that the most appropriate representatives from the DFO are engaged.

Following this informal meeting, Theraesa Coyle attended the Advisors Group Meeting on March 9th when the options being considered were reviewed and discussed.

PIER Regulators Meeting - October 16, 2017

Additional Notes from final plenary discussion :
General:
SARA- are there lots of marine special at risk? Fresh water species is western painted turtle. Orcas will be effected
Migratory birds convention act (FED)- international piece of legislation.
Fisheries act (fed) BC land Act- concerns WMAs
Water sustainability act - Concerns irrigation water licenses
Environmental protection act- relate to contamination and clean up

Other:
-Sturgeon migrating to Boundary Bay
-No net loss is possible with various realignment/retreat options
-invasives are costly to manage if reclaimed land is returned WMA
-Under managed retreat floating greenhouses may be more realistic than aquaculture. Aquaculture may not be compatible with WMA

General:
Metro Vancouver is home to 53% of British Columbia's population, thus MV has a proportionately large voice in Provincial matters and can help shape policies.
Legislations: Contaminated sites: application of pesticides, phosphorous
Legislations: Contaminated sites: application of pesticides, phosphorous. DFO & Environment Canada. Migration Convention Act [Int'l]
-What about the unkown unkown's with majore landscape changes?

-If retreat is planned properly there may be opportunities to change agricultural production and not just eliminate. Ex. Changes to aquaculture --> but not just letting it "happen". Doing with more structure and purpose at the beginning of the process. Opportunuties to support new sectors through policies\incentives

-Externalized costs in managed retreat
-Final strategy policies need to consider fair compensation --> many not include business value in land assessment, especially for farms. Some aspects of agriculture transferrable but many not readily transferrable.
-Coastal Marshes, is topography of realignments able to increase marsh area to offset coastal squeeze or is it strictly Mud Flat Area that can be expected.
-Coordination across jurisdictions needed
-G/W is going to result in agricultural land loss. Regional G/W flow paths
A)More Detail needed on the environmental habitat assumptions and/or
B)Quality based discussion review --> keep honest with how accurate assessment is and whether it is likely to change final decision or shortlisting

Organization	Applicable Legislation	Concerns/Impacts	Significance of Concern	Comments
PRELIMINARY OPTION: MANAGED RETREAT				
Ministry of Agriculture	ALC	Loss of native soil for agriculture. Food prices will go up.	H	Greenhouse opportunities (floating) is not real agriculture (not practical) Higher O+M cost. Food prices will rise
Ministry of Agriculture	Fisheries Act	Fish can get spilled into flooded areas and not able to return to their habitat	H	
MFLNRO	Environmental Protection Act	Decommissioned infrastructure & potential contaminated sites		Phosphorous legacy in flooded agricultural soils.
MFLNRO/ DUC	ALC Act	Loss of ALR lands.	H	
MFLNRO/ DUC	Lands Act, Wildlife Act, MBCA, Fisheries act, SARA	Expensive to convert land. Pollution sources: nutrient spike from agriculture soil. New WMA- expensive to manage	L	
ALC	ALC Act	Elimination of agricultural land	H	Application to ALC for flooded land Is there potential to designate other land for Agriculture? Potential impacts to agriculture in Langley Potential impacts to agriculture land in Delta; option for potential dyking.
Project Biologist	Fisheries Act (DFO) SARA Water Sustainability Act Migrant Bird Act		L	Huge gain in habitat for salmonids Gain in habitat for SARA Net gain of stream area Net gain in wetland habitat Unsure on eelgrass habitat
City of Surrey	ALC Act, Fisheries (prov/fed)	Apply for exclusions (ALC) Better fish habitat/migration etc.	H	High impacts- loss almost total of agricultural land in Surrey. No application for rerouting infrastructure

City of Surrey	Water sustainable Act, Navigation Protection Act, SARA, Contaminated Sites, Weed Act -> Integrated Pest Management	Loss of water licenses Change in navigation Removal of Dykes Better habitat approval to remove old tanks/pesticides/ bldg. materials + wood chips from around blueberry plants invasive species and the management of them	H	** Ag. Opportunity --> “floating greenhouses” sources for soil will be challenging. More expensive for farming. Loss of Agricultural Land = $$ increase for food to Lower Mainland. Need to consider how livestock would be impacted.
ALC	ALCA regulations	Exclusion application required for exclusion of ALR- huge amount of ALR lost	H	Not sure what percent of ALR land would be left in Surrey.
City of Surrey	Environmental Management Act Environmental Protection Act			Managed retreat will highlight contamination concerns
Ministry of Agriculture		Would like to see fair compensation. Not only based on land value but on true impact of industry		
IoD	Dyke management act	Will the dikes be left in place or removed?	L	Some temporary works might needed as retreat goes on to protect land from flooding

City of Surrey	Right to Farm Milk Industry Act	Viability of Agriculture (non dairy), existing policies may not be sufficient to preserve continuity of business under relocation. Supply management and barriers to entry (dairy industry) may result in dairy industry consolidation under relocation, possibly outside of Surrey.	H	Big homes with leased lands to farmers: business needs to make minimum profit to earn a tax credit. Thus often an established farm leases lands from other parcels. Reverse leasers result in compensation to land owner not reaching the actual farmer of the land who will have a significant business disruption. In some cases a farm owned on one side of a river or highway is leased to another farmer who is dependent on the use of that land to have a viable business, thus potential for a cascading impact to the farm leasing the land facing retreat. Decouple the issue: Need to keep farmers not land. Land speculation driving values up and resulting in un used lands. need to apply pressure on non-farm use on ALR land.
Preliminary Option: RIVER REALIGNMENT				
Ministry of Agriculture:	Farm protection practices Act (Right to Farm) Environmental Management Act ALCA	Flooded areas reduce the number of crops that can be grown. forage land is also part of an environmental sustainable of nutrients + waste.	H	Compensation; many operations are part of a bigger operation making the whole operation not viable. forage land is also part of an environmental sustainable of nutrients + waste.
MFLNO WMA manager	Wildlife Act	impacts to serpentine WMA	H	Overall there appears to be a net increase of habitat but it isn't clear what habitat or their extent would be formed. There appears to be an overall trade off of salt marsh/marine habitat for fresh water habitat. It isn't clear whether the proposed freshwater lake would be freshwater or brackish

Metro Vancouver	Metro 2040	Impacts to Boundary Bay WMA including the Nicomekl river section	H	As per the coastal realignment needs to relocate the farms and enhance tools to protect existing agricultural land for farming.
City of Surrey	-Wildlife Act -Species at risk act, -Obligatory Bird convention Act; -Fisheries Act; -Environmental Management Act -Environmental Protection Act -Water sustainability Act		M M M M M M H	-Environmental impact is positive over the short term. -Depending on depth of water during high tide, needs to allow for estuary & eel grass depth/shallow. -lake could become an Environmental asset. Need to address the potential contamination of some sites. -Need to manage decommissioning of homes and businesses. -WSA: Irrigation uses of Lake--requires Water Licenses
IOD	Dyke Maintenance Act	Might run into ownership issues by having a highway on a dyke dyke would be significantly higher(sea dike) Rest of dike would be upgraded to higher standard and must meet seismic.	M	Could be mitigated with large structure --> section considered the clip out of highway corridor. could be mitigated with appropriate investment
City of Surrey	Dyke Management Act ARDSA agreement precedence, and future funding agreements may require irrigation upgrades as part of drainage improvements ALCA	What organization monitoring Hwy 99 if it starts to act as a dyke when not designed as one? Allows and encourages increasing resilience of remaining dyking to reflect the increase in flood hazard and consequences of urban areas of risk like Cloverdale by reducing the length of dyking currently maintained. Past Province and Fed requirements linked both drainage and irrigation in making investements in the late 80's through to mid '90's. Is that going to be the case in future agricultural investments? Also consider nutrient management	M	-Existing dykes non-standard and may warrant becoming standard to reflect increased hazard and new urban vulnerabilities Should the issues drainage and irrigation be linked? There is a risk future funding programs will. Regardless of programming, for agricultural viability they probably should be considered at the same time. -Significant dairy and livestock are impacted (Poultry operations)

City of Surrey	ALCA	Ensure restrictions are placed on newly created lands to permit appropriate crops and Not just "anything" - to permit relocation of a river		Must deal with endangered species protection requirements To ensure new environmental concerns were not created
MFLNRO-	Water sustainable act, DFO	Realignment of both rivers will have an impact on the waterways with significant opportunities for restoration and increase potential irrigation source through flow allocation	H	Doable with significant design/management details regarding lake design
Project Biologist	SARA, Migratory bid act, Water sustainability	Addition of high value habitat Changes to channel to Nicomekl and Serpentine Changes to habitat for commercial species	L	Changes to fish habitat and fish passage
Ministry of Agriculture:	WSA	Lost connectivity of streams. Will have to buy out dairy farms.		May give some ducks unlimited wetland to farmers loss of agricultural land Dyke stops at 184st. would need to build dykes eastern to supply ag. With irrigation water
City of Surrey	Navigation Fisheries (fed/prov) Water sustainability act ALC Inspection of Dykes Langley Approvals WMA	Loss of navigation channels loss of river. Tough for fish to find stream north of new channel -change to water paths loss of agricultural land new dyke/ loss of old ones transfer of lands	H	This option will be harder to win people over. *mud bay option will also impact sturgeon habitat which will be a huge loss.
MFLNRO/ DUC South Coast Coordinator	BC Lands Act SARA Fisheries Act Wildlife Act Water Sustainability Act	Removal of serpentine WMA this will affect salmon migration water flows will change due to new dam.	H	Will the serpentine and Nicomekl new flood plan be added to WMA? New habitat will be created which is good. Will animals be stranded behind sea dam?

ALC	ALCA Right to farm legislation vs. riparian areas. How that may impact property owners ability to farm near fresh water lake area.	Elimination of agricultural land Consider: water withdrawal allowance based on habitat vs. water requirements for farmers, and will it be satisfactory for water availability?	H	application to ALC for flooded land application to ALC for renewing if infrastructure do abandoned channels become private property?
NHC	WMA	Nicomekl lake- should be additional land to WMA. This lake could still be used as irrigation but needs to be in agreements		Concerned about Sturgeon habitat in Boundary Bay Skepticism that unless the land is cleaned up/restored (ditches/dyking) near Nicomekl lake area would not be optimal.
ALC	ALCA regulations	Exclusion and transportation/utility corridor applications to the ALC would be required. concern that loss of ALR is proposed and that the proposal may also negatively impact adjacent ALR lands belonging to neighbouring local governments	H	Will Surrey propose a 2 for 1 exchange of ALR land (2ha included for every 1 ha excluded?) this question applies to the 152nd option as well. Description says that a portion of the land would be retained for ag. Purposes but from previous workshops this option results in the same 16m^2 loss of ag. Land as the 152nd st proposal. Is this the case? The fresh water lake, even if available for irrigation is not an
Preliminary Option: COASTAL REALIGNMENT (152ND STREET)				
MFLNRO/WMA	wildlife Act WMA	Estimated habitat gains are too simplistic	H	More detailed work will be necessary to determine the amount and type of habitat to be formed and the time required for it to develop abandoned infrastructure & land elevations may have to be modified to ensure optimal development of salt marshes
Metro Vancouver	Metro Van 2040	Loss of agricultural land and equally important is the loss of farms and FARMERS. No farmers, no farmland need to change Metro 2040 (Board decision)	H	We need a farm relocation policy. Today we can start with stronger tools to protect existing agricultural land and reduce speculation to make relocation a more viable option. This is a good option as it builds resilience and adaptability

ALC	ALCA regulations	Exclusion and transportation/utility corridor applications to ALC are required	H	SERIOUS concerns with the loss of ALR
City of Surrey	EPA	Decommissioning of businesses and residents		Contamination concerns with decommissioning of infrastructure. Environmentally there are no issues of legislation
Ministry of Agriculture	Farm Practices, ALCA EMA	The land is also needed for nutrient management and environmental sustainable waste management		More pressure on remaining land
IoD	Dike Maintenance Act	Dike being used as a major transport corridor Depending on maybe other entitles to be viable	L	
City of Surrey	ALCA	Would have to be adjusted fairly significantly to be able to: a) Allow the municipality to reduce this land from ALR b) Eliminate the ALC land for environmental purposes first and ag. Second c) Permit easier development of the 152nd street super dyke		
City of Surrey	ALCA	This option could set a negative	M	
Ministry of Agriculture	WSA	Most water licenses will be lost food production/security will be reduced	H	Compensation san be discussed to provide additional water to agricultural lands in other parts of Surrey where there is insufficient or lack or water access.
MFLNRO	BC land act; BC water act		H	

NHC	WMA ALCA WSA	land gained to WMA would need to apply to exclude the land from ALC and additional approval for HWY re-routing etc.. Loss of water licenses		Land would need to be committed to be cleaned up and restored (planting, etc.) Is compensation needed? Not displacing land for development but for resilience. Going to lose that land eventually so is it an issue? The City does not have a duty to protect this land.
no name	fisheries, WSA, SARA Migrant bird act	Change to quality of habitat change to Nicomekl and Serpentine channels Additional habitat		
MFLNRO/DUC	BC land act; fisheries act	Will additional land be added to WMA. Serpentine WMA will have to be modified		Will this result in a new barrier to salmon migration? Both sea damn and former agriculture land has made it easier for fish
ALC	ALCA	Elimination of agricultural land Re-routing of infrastructure over agricultural land and consequently decreasing land for agriculture. agricultural land accounted for elsewhere in surrey?	H	Application to ALC to consider flooding agricultural land. Application to ALC to re rout infrastructure if it's on ALR land. There is potential to include other land to ALR and designated it as agricultural? ALC doesn't have a set policy of no net loss to agricultural land. Application to include land into ALR
City of Surrey	Water sus. Act Fisheries (Fed + Prov) Navigable waters ALCA Insp. Of Dyke approval SARA	Loss of irrigation water and water licenses Salmon & fish passages Change to navigation (good) New habitat	H	Need to look at where to give approval-special set up to deal with process need to apply to exclude land from ALC then rerouting infrastructure if moved to ALR land. Do this as a whole strategy. Are other lands improved?

Preliminary Option: MUD BAY BARRIER

NHC	SARA WMA/BC land act Migratory Bird Act Navigable Water Act Water Act Fisheries Act	Province is looking at introducing western painted turtle to serpentine doesn't allow pedestrian/recreation uses but WMA being revised so maybe could include resilience there could be lot lease issues water licences and irrigation issues	H	
MFLNRO	SARA BC Land Act Migratory Birds Navigable Water BC lands Act	Impact to residential orcas, habitat and food source. -Boundary bay wildlife management areas	H	Unprecedented situation with environmental impacts. Mostly federal legislation applies. Aquatic impacts. There are potential for compensation projects present but poor.
Ministry of Agriculture	WSA	Work in and about a stream change of water flow irrigation licences if the new area will be partially new agricultural land beneficial water use for agriculture	M	Water Sustainability Plan (WSP) supported by WSA can incorporate this option to manage water for all sectors including agriculture. Beneficial water use will need to be discussed under WSA to designate the specific use of the newly created area.
MFLNRO/DUO south Coast corridor	BC lands Act SARA Fisheries Act Navigable Water WSA	Fit into management plants of BB and Serpentine WMAs large impacts on pacific salmon w/ indirect impact on Orcas Water licenses		expropriation of WMA unprecedented? opportunity for collaboration in province large compensation required difficult to convert WMA land to agricultural SLR resilience
City of Surrey	Fisheries fed/prov SARA Migratory bird act BC land Act Navigable Water act WSA WMA	potential issues with Salmon habitat and migration change is species in area loss of habitat limit river movement need water licences- limited water for WMA area		Potential loss of WMA

ALC	ALCA	potential for increases of agriculture land minimal impact to agriculture;	L	Would agricultural land reserve be extended to include the new area? New investigation requirements for inland area If new land area continued to agricultural use, consider if ALR boundary extended to include then subject to ALCA
IoD	DMA	Potential impact to neighbouring community feasibility meeting seismic standard +cost	M	this project would have to be coordinated with other municipalities and jurisdiction which could be problematic Funding would have to be secured to ensure that all standards are met.
ALC	ALCA + regulation	minimal impact to ALR ALC would have few concerns no application to the ALC would be required	L	However.. in this case of catastrophic breach, impact to ALR would be significant. Would protocol be developed to help minimize the effects of a breach? -If additional agricultural land is made available as a result of this option, the ALC suggests Surrey consider an inclusion application to include the land within the ALR as part of a land swap
City of Surrey	Prov Wildlife act Migratory bird (fed) Convention act Fisheries Act	Boundary bay Wildlife management area could affect critical bid foraging area negatively affect forage fish and juvenile salmon habitat impacts to ell grass and species dependant on eel grass		WMA would be impacted. Major overwintering bird area. Habitat would be negatively affected Boundary Bay is important salmonid and forage fish habitat are of Nic and Serp. affect eel grass and dungeons crab nursery areas
Metro Vancouver	Regional growth Strategy Metro Van	The “perceived” protection of the barrier may encourage population growth and development outside the urban containment boundary	L	urban sprawl adds costs stronger tools to resist “development” of agriculture land for residential and non-farm use No ability for adaptation management

Project Biologist	Fisheries act Navigable waters act SARA Migratory birds act WSA	Reduction in habitat for commercial fish species ability for boars to travel direct impacts to species loss of migratory habitat change to Serp and Nic		
MFLNRO WMA manager	Wildlife Act (WMA)	Impact on habitat		unclear what impacts or benefits to habitat in the WMA are predicted to be behind the barrier or in front of the barrier infill of area behind barrier to allow agriculture would be most detrimental more information needed regarding water levels behind barrier and elevation predicted what type of habitat would persist there likely less damaging if door only closed during high surge events but less useful over time to address rising sea levels
Ministry of Agriculture	Farm practices protection EMA	Who would have owner ship of new land		
City of Surrey	LGA Any legislation involving the environment ALCA	Don't think here would be affected that much as these deal with land issues and municipal process. -would need to be adjusted to allow for these types of leasing/signing intrusions -if additional ag. Land is actually created it would be imperative that legislation was specific on weak is doable so that we don't get land owners planting inappropriate crops in any "newly" aerated ag. areas	H	Cannot leave crop types solely up to land owners - need to provide limits in these areas to reduce expectations of being "helped" to protect crops and investments leads Should Not be made. Municipality would need provincial support for that, Cannot be on going.

City of Surrey	-Delta/Surrey boundary jurisdiction complicated with MoTI -Fisheries Act -Navigable Waters Act	tie into coastal ground and dyking erosion in front of barrier from wave reflection dredging required.	M	Possible with land or right of way acquisition and engineering. complication crossing BNSF, HWY 99 & 91 Rip rap will mitigate but increase in footprint of works and trigger habitat compensation Dredging already scheduled

CFAS Coastal Regulators Workshop - Oct 17, 2017

Organization	Question 1			Question 2			Question 3		Question 4	Question 5	Question 6	Question 7
	To what extent is coastal flooding a concern to your organization in the area			Do you feel that your top concerns or ideas surrounding infrastructure adaptation were captured today?			Does your organization have any policies, plans, strategies or other documents that are relevant to the options presented?		Policies, plans, strategies or other documents	Are there any new regulation or opportunities you see in the future to help the are adapt to sea level rise?	What is the best way to keep your agency and organization involved? If not you, is there a person we should engage with?	Please provide any further comments on today's meeting
	Low	Medium	High	Yes	No	Comments	Yes	No				
ALC			1	1			1		ALCA + regulations	continued engagement with stake holders and land regulation and stewardship organization	Continued involvement with Kamelli and I but also need to engage with ALC	
Ministry of Agriculture			1	1			1		Agriculture water plan, climate action initiative, living water smart BCs water plan	WSP + WSA	I am the one.	
MFLNRO			1	1			1			WMA's and ecosystems	Keep me involved	Discussion for each of the 4 options felt a bit rushed. Bring the feds to the table.
ALC			1	1			1		ALCA + regulations	nothing specific	Email and workshops. Also a presentation to the ALC	This was a very useful workshop and the feedback forms / consultation docs were very clear. Much easier to fill out than those at the last engineering workshop

CFAS Coastal Regulators Workshop - Oct 17, 2017

Organization	Question 1			Question 2			Question 3		Question 4	Question 5	Question 6	Question 7
	To what extent is coastal flooding a concern to your organization in the area			Do you feel that your top concerns or ideas surrounding infrastructure adaptation were captured today?			Does your organization have any policies, plans, strategies or other documents that are relevant to the options presented?		Policies, plans, strategies or other documents	Are there any new regulation or opportunities you see in the future to help the are adapt to sea level rise?	What is the best way to keep your agency and organization involved? If not you, is there a person we should engage with?	Please provide any further comments on today's meeting
	Low	Medium	High	Yes	No	Comments	Yes	No				
MFLNRO			1	1		the level of detail was at a low level so the evaluation had already been conducted. A more complete response could have been provided	1					
anonymous			1	1			1		Metro 2040		Staff is already engaged	
Ministry of Agriculture			1	1					Don't Know		keep me involved	
MFLNRO			1	1		budget related	1		all of the standards and guidelines for flood protection	the Dike management act and associated guidelines may need to be updated to take account SLR	Keep us informed.	
City of Surrey			1	1		DFO and other federal gov't reps missing	1		Various Strategies	need integrated assessment process to assist in adaptations		

CFAS Coastal Regulators Workshop - Oct 17, 2017

Organization	Question 1			Question 2			Question 3		Question 4	Question 5	Question 6	Question 7
	To what extent is coastal flooding a concern to your organization in the area			Do you feel that your top concerns or ideas surrounding infrastructure adaptation were captured today?			Does your organization have any policies, plans, strategies or other documents that are relevant to the options presented?		Policies, plans, strategies or other documents	Are there any new regulation or opportunities you see in the future to help the are adapt to sea level rise?	What is the best way to keep your agency and organization involved? If not you, is there a person we should engage with?	Please provide any further comments on today's meeting
	Low	Medium	High	Yes	No	Comments	Yes	No				
MFLNRO			1	1		Unfortunately I have yet had the experience to know the details of prov. Legislation applicable. Should get further input from land and water.						
Total	0	0	10	10	0		8	0				
Percentage	0%	0%	100%	100%	0%		100%	0%				

Stewards November 17, 2017

Organization	Question 1			Question 2			Question 3		Question 4	Question 5	Question 7	Question 8
	To what extent is coastal flooding a concern to your agency and organization in the area			Do you feel that your top stewardship opportunities and challenges in Mud Bay were captured today?			Does your agency and organization have any policies, plans, strategies or other documents that are relevant to the co-benefits discussed today?		Policies, plans, strategies or other documents	Are there any new opportunities or partnerships you see in the future to help the area adapt to sea level rise?	What is the best way to keep your organization involved? If not you, is there a person that we should engage with?	Please provide any further comments on Today's meeting:
	Low	Medium	High	Yes	No	Comments	Yes	No				
DUC			1	1			1		More on the sort of implementation side. Our plan focus on ag. And wetland. It is more of a technical jurisdiction in support showing of partnership but it wont add to your work. Technical and out of	Potential use of rolling conversation covenants	Matt Christensen	Good work. Of all the municipalities I work with Surrey is most advanced and inclusive of DUC. Thanks, Dan
Nature Trust BC			1	1				1		South Coast conservation Land Management Program	Contact myself or Carl MacNaughton	
MFLNRO \ DUC			1	1				1		Updating the Boundary Bay WMA management Plan may be happening.	Contact me	
MetroVancouver			1	1			1		On my website	Land acquisition for park creation	myself and Laurie.bates-fymel@metrovancouver.org	Thanks! Good use of my time.
Ministry of Agriculture		1		1				1		Design of different agricultural system, drainage and irrigation, assessment of compensation needs.	through me = ok	
Bird Study Canada	1			1		We missed the pacific flyway. Part of what we are looking at is shift in artic breeding ground shifting flyways. This is linked to temp which is my concern.		1	Should connect with Canadian Wildlife service on what they are doing.	credible unions on information on ecogreen good and services	doing great- when you are ready it would be great to get a webinar for BSC members	
City of Delta			1	1		maintaining intertidal and salt marsh/ preventing loss of habitat due to coastal squeeze	1		Flood adaptation strategy (2016) currently doing a sediment transport study at boundary bay (report coming early 2018)			

Stewards November 17, 2017

Organization	Question 1			Question 2			Question 3		Question 4	Question 5	Question 7	Question 8
	To what extent is coastal flooding a concern to your agency and organization in the area			Do you feel that your top stewardship opportunities and challenges in Mud Bay were captured today?			Does your agency and organization have any policies, plans, strategies or other documents that are relevant to the co-benefits discussed today?		Policies, plans, strategies or other documents	Are there any new opportunities or partnerships you see in the future to help the area adapt to sea level rise?	What is the best way to keep your organization involved? If not you, is there a person that we should engage with?	Please provide any further comments on Today's meeting:
	Low	Medium	High	Yes	No	Comments	Yes	No				
Fraser Basin Council	1			1			1		Lower mainland flood management strategy, Salmon safe BC regional adaptation collaboration	LMFMS	Steve Litke, Charlene Menezes and myself.	
Delta Farmland	1				1	Ar. Delta Farm and Wildlife Trust top stewardship opportunities involved the preservation of farmland and no associated wildlife habitat. Most options involve a reduction in farmland and specifically high quality foraging habitat.		1			please keep me involved	
WCEL	1			1		Sub-regional area of Boundary bay not explored. I understand why, but not just to maintain this point	1		We are also preparing options on coastal mgmt options.	yes, investigation of dyke and larger scale option for BB, blue carbon opportunities?	through Matt O and Carrie B	

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A Rocha Canada		1		1				1		First Nations involvement- what does aboriginal law have to say about how we should manage these flood zones. Upland partnership- watershed approach- upland development and land use impact downstream flows.	Email me	thanks for the opportunity to participate. Were any transportation or railway people invited? How are they being engaged?
Total	4	1	5	9	1		5	5				
Percentage	40%	10%	50%	90%	10%		50%	50%				