Lake St. Martin Outlet Channel Baseline Shoreline Assessment

Prepared for:

The KGS Group

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Zuzek inc.
ONE WORLD

Location of Proposed Lake St. Martin Outlet Channel, June 11, 2019
(image courtesy L.Wazney, KGS Group)

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1.0 INTRODUCTION

Zuzek Inc. was retained by the KGS Group to support the design of the Lake St. Martin outlet channel. Refer to the spatial extent of the project in Figure 1.1. Combined with a second channel connecting Lake Manitoba to the southern reaches of Lake St. Martin, the project will be designed to convey additional water from Lake Manitoba to Lake Winnipeg during flood conditions. Refer to the KGS Group (2016) conceptual design report for additional background information on the project.

Figure 1.1 Lake St. Martin Proposed Outlet Channel

The scope of the Zuzek Inc. investigation includes the review of background documents, background on the site visit and field data collection, long-term shoreline change calculations, estimates of longshore sediment transport, and a conceptual sediment budget for the existing shoreline conditions. Support for the preliminary and detailed design of the inlet and outlet works will be provided by evaluating sedimentation potential and estimated near-field/far-field shoreline impacts.

Subsequent reporting will evaluate the potential influence of the proposed inlet and outlet works on the shoreline considering the baseline established in this report, sediment transport modeling, and potential erosion and depositional patterns.

2.0 BACKGROUND DATA AND FIELD WORK

Section 2.0 of the report summarizes historical lake level data and the 2018/2019 field work completed for the study.

2.1 Historical Lake Levels

Monthly mean water levels for the Hilbre gauge on Lake St. Martin are presented in Figure 2.1, and date back to 1966. The location of the gauge relative to the channel is noted in Figure 2.3. The lake levels are not regulated but they are influenced by the rate of water released from the Fairford Dam. Water levels during the survey were approximately 243.4 m, which is near the lower range of historical conditions, but still rough 0.8 m higher than the recent lows in 2003.

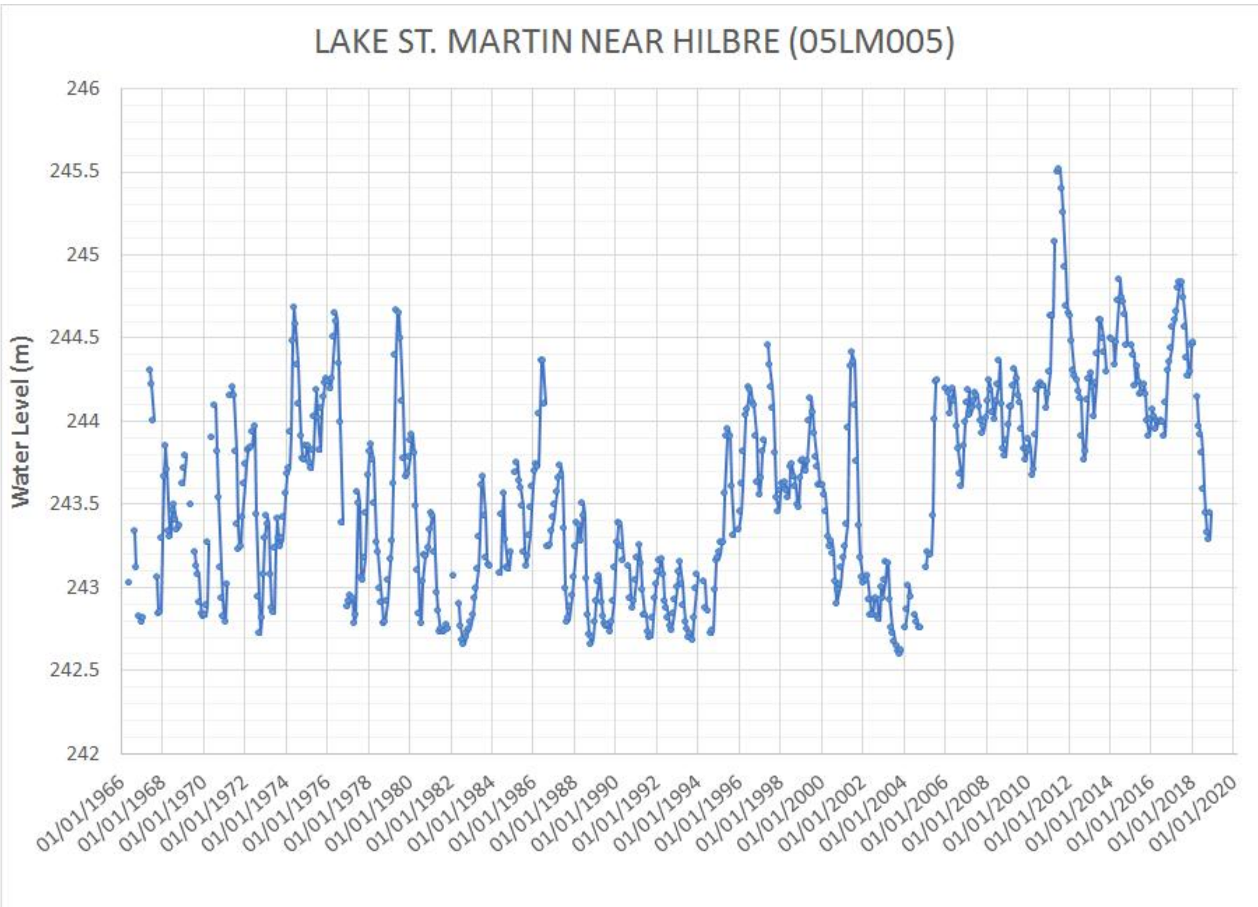


Figure 2.1 Measured Water Levels at the Hilbre Gauge, Lake St. Martin (data from ECCC)

The Berens River gauge is in the northern basin of Lake Winnipeg, east of Sturgeon Bay and the proposed outlet. Monthly mean water levels are presented dating back to 1914 in Figure 2.2. The location of the gauge is noted on Figure 2.5. It is important to note that Lake Winnipeg Regulation began in 1976 with the construction and operation of the Jenpeg Generating Station. The upper and lower operating range for the lake (217.9 m and 216.7 m respectively) is noted on the water level plot. During the survey, water levels were approximately 217.5 m.

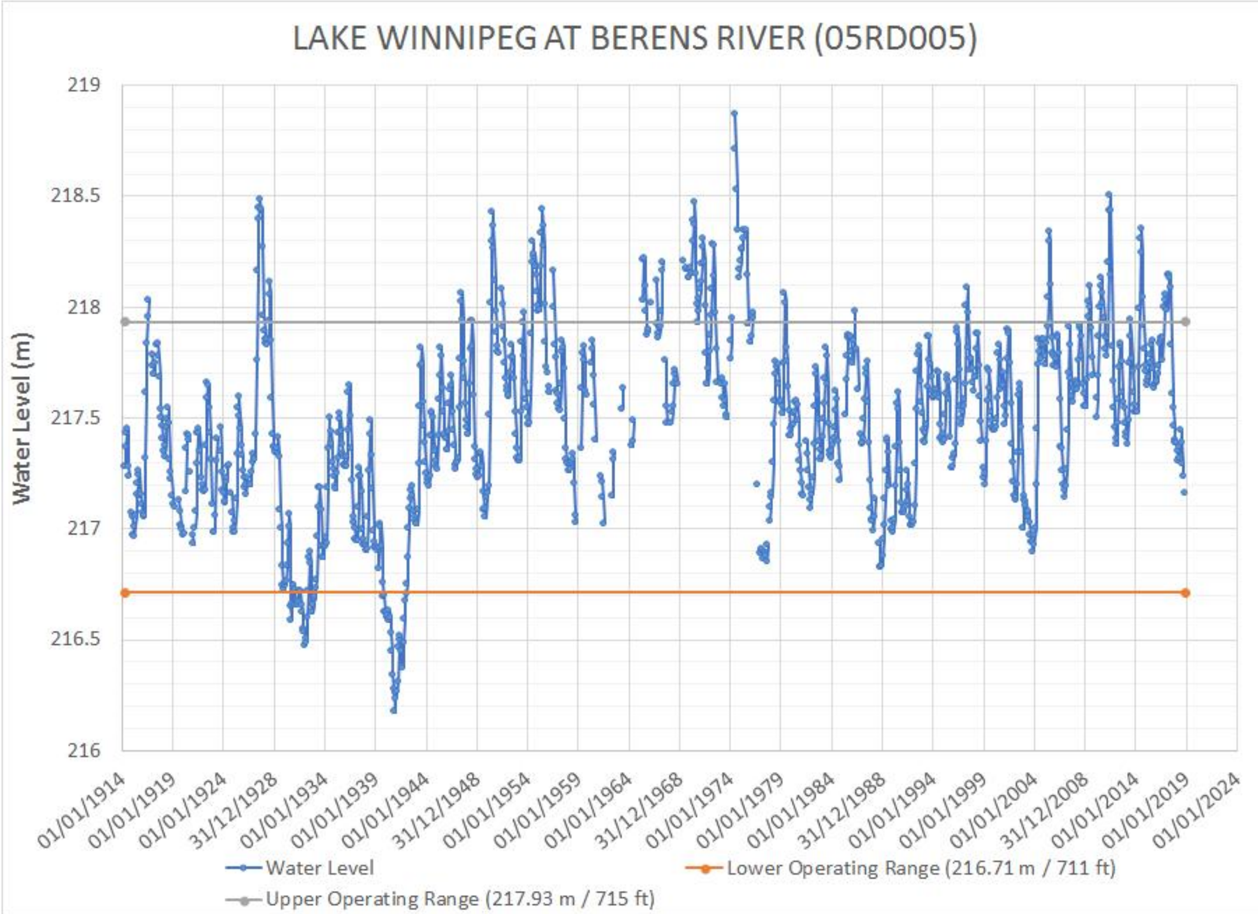


Figure 2.2 Lake Winnipeg Water Levels from the Berens River Gauge (data from ECCC)

2.2 November 2018 Shoreline Observations

The proposed channel is in an area of relatively flat land known as the Manitoba lowland. The underlying bedrock dips to the southwest and consists of dolomites and limestones. The bedrock is covered by shallow deposits of glacial till and proglacial lacustrine sediment (KGS Group, 2016). For example, during our field work we observed several limestone bedrock outcrops along the banks of the Dauphin River, 3 km inland from the Lake Winnipeg shoreline. Post-glacial organic deposits, such as peat, have formed in low-lying areas and are often bordered by higher glacial moraines.

A reconnaissance-level field investigation was completed in November 2018 to collect initial site observations and support our investigation throughout the winter months. Due to the frozen lake conditions, the sites were accessed by helicopter.

2.2.1 Channel Inlet on Lake St. Martin

The proposed inlet location was observed on the afternoon of November 20th, 2018. Figure 2.3 summarizes the photograph locations, including Waypoints 18-24 to 18-28, along the north shore of the shallow embayment at the proposed inlet location. With lower water levels and frozen conditions, the rocky lake bottom substrate in the embayment was exposed. The gravel, cobbles, and boulders were angular, suggesting a low energy regime. The rocky headlands (e.g., WP 18-27 and WP 18-28) featured a higher concentration of cobbles and boulders.

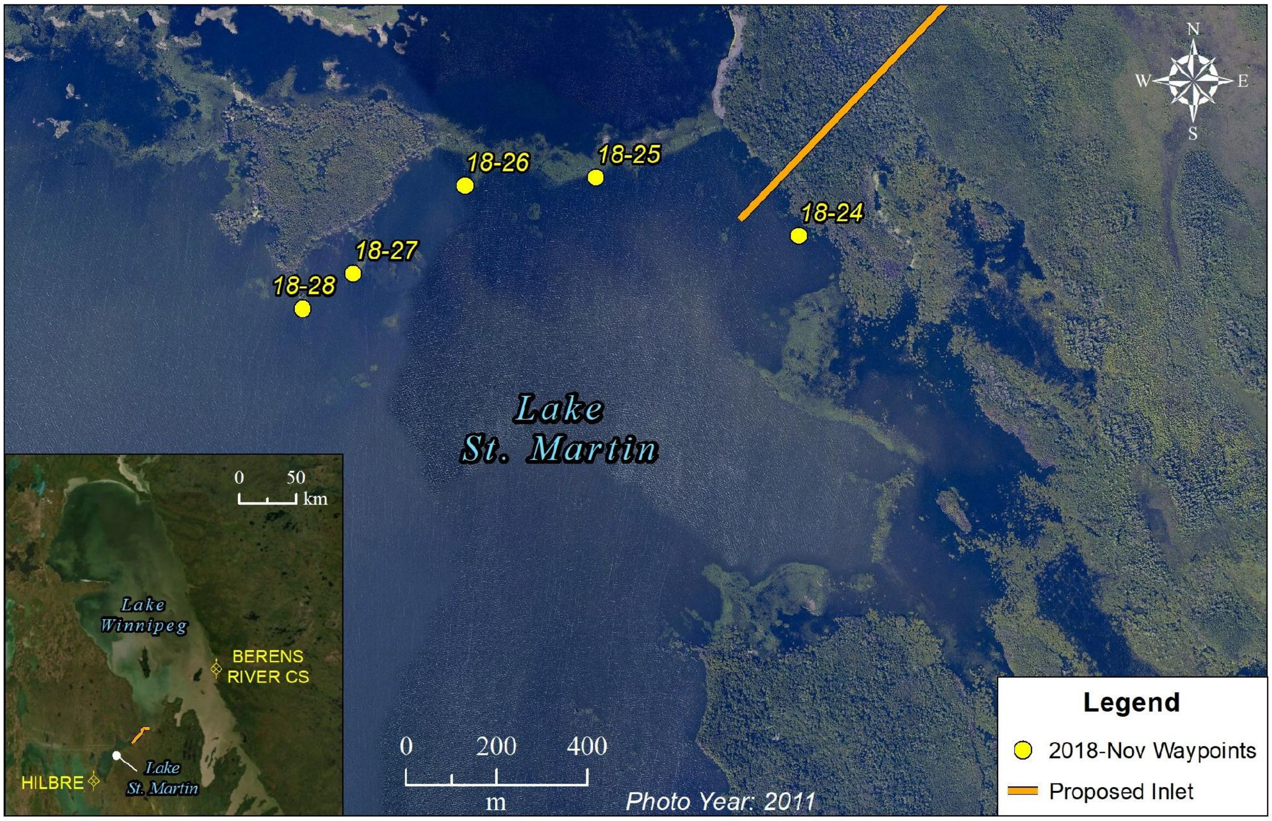


Figure 2.3 Waypoints 18-24 to 18-28 on Lake St. Martin (visited Nov. 20, 2018)

Key Observations:

- Exposed Lake Bottom: the exposed lake bottom in the embayment featured angular pebbles and cobbles, with larger rounded (fluvial or glacially weathered) boulders. Refer to Photos A and B in Figure 2.4. These initial field observations suggest that the wave climate on Lake St. Martin can erode the glacial sediment (tills and lacustrine clays) but is not energetic enough to transport the larger material (cobbles and boulders) along the shoreline. Where the glacial sediment features high concentrations of cobbles and bounders, a self-armouring process leads to the formation of the rocky headlands prevalent on Lake St. Martin. Refer to Photos C and D in Figure 2.4. Also, when the in-situ rock reaches a sufficient volume, the underlying glacial sediment is protected from further erosion and stabilizes at low to average lake levels.

- Marsh Shoreline: Between the headlands and sheltered from direct wave attack, dense stands of emergent vegetation have developed on Lake St. Martin (Photo C in Figure 2.4).

- Longshore Drift: Due to the small fetches on Lake St. Martin, its irregular shoreline, and shallow gently sloping nearshore, the wave heights that reach the inlet shoreline will be small, especially during low to average lake levels. Minimal sand deposits were observed, and no major sandy depositional features are evident in the northern reaches of the lake in the orthophotography. Initial field observations suggest longshore drift of sand and pebbles is not a significant physical process controlling shoreline evolution on Lake St. Martin in the vicinity of the inlet.

- Proposed Inlet: The proposed inlet is in a very shallow gently sloping embayment. Excavation of the channel below the lakebed will be required to generate the necessary conveyance for the inlet (P.Leclercq pers com., 2019). The need for structures to prevent channel sedimentation in the executed channel will be evaluated in future reporting.

A: Angular Lake Bottom Material (WP 18-24)

B: Boulders and Cobbles on the Exposed Lakebed (WP 18-24)

C: Boulder Headland Protecting Emergent Marsh Vegetation (WP 18-26)

D: Helicopter at Tip of Boulder Headland (WP 18-28)

Figure 2.4 Pictures from Nov. 20, 2018 Site Visit

2.2.2 Channel Outlet into Lake Winnipeg

Approximately 7 km of shoreline north and south-east of the proposed outlet were observed by traversing the frozen shoreline on November 20, 2018. Figures 2.3 presents the Waypoints, with 18-13 representing the proposed outlet location.

Figure 2.5 Waypoints 1 to 23 on Lake Winnipeg (visited Nov. 20, 2018)

Our key observations are summarized:

- WP1 to WP6 - Beach and Ridge System: Sandy shoreline with signs of small long-term erosion rate, especially between WP1 to WP 2. Refer to Photo A in Figure 2.6. The vegetated ridge increases in elevation towards the tip of Willow Point (to the east). Shoreline erosion generates new sediment that is transported to the east.

- WP6 to WP8 - Headland for Willow Point: The headland features a higher concentration of cobbles and boulders than the adjacent shoreline, possibly due to a glacial ridge or ground moraine. Another explanation is ice-push processes, during breakup, when ice-entrained boulders are pushed onshore in ice-sheets and concentrated in a ridge at the waterline (Barnes, 1982; Philip, 1990). A picture of the western boulder headland is provided in Photo B of Figure 2.6. Between the hardpoints of the headland, signs of shoreline erosion were observed (i.e., exposed tree roots).

- WP8 to WP13 – Southeast Shore of Willow Point: Limited wave exposure (small fetch to the east and sheltered from waves from the north Lake Winnipeg basin) but the shoreline appears to have a long-term erosion rate based on the exposed and eroding peat at the shoreline. See Photo C in Figure 2.6. The orientation of the shoreline is not conducive to sand accumulation and there are no significant beach deposits.

- WP13 to WP23 – Beach and Ridge System: The beach – ridge system starts at the proposed outlet location and extends to the estuary in Sturgeon Bay Park Reserve. A sandy beach and vegetated ridge separate the lake from the marsh/bog, and appear to be related to wave overtopping processes and aeolian transport of sand onshore. Exposed tree roots suggest there is a low long-term erosion rate, as seen in Photo D of Figure 2.6. Sections of shoreline that feature ground moraine with a higher concentration of cobbles and boulders erode slower than the adjacent shores and form small headlands. These ground moraine areas also have higher elevations (e.g., WP17 to WP21). Eroded peat debris on the beach suggests the outlet could become a sediment trap and zone of accumulation when not in operation.

A: Exposed Tree Roots on Dune Ridge Suggest Slow Erosion Rate (WP 18-1)

B: Boulder Headland at Willow Point (WP 18-8)

C: Eroding Peat Shoreline SE of Willow Point (WP 18-10)

D: Eroding Shoreline East of Outlet (WP 18-16)

Figure 2.6 Photographs from the Nov. 20, 2018 Site Visit

2.3 June 2019 Lake Survey

A comprehensive field survey was completed between June 10th to 13th, 2019 by staff from Zuzek Inc., the KGS Group, and North-South Consulting. Data was collected at the inlet on Lake St. Martin, the outlet into Sturgeon Bay on Lake Winnipeg, plus the Fairford River and Dauphin River. The river observations have been archived for future use and are not extensively discussed in this report.

The data collection, including shoreline observations, digital photographs, bathymetric data, sonar imaging of the lake bottom, and surficial sediment samples are described in the following report sections.

2.3.1 Bathymetry and Sonar Data Collection

The SOLIX is a single-beam bathymetric and sonar system with built-in recording and navigation tools. The transducer was mounted at the back of the boat with a dedicated GPS antenna located directly above the unit. Refer to Figure 2.7. The unit auto-corrects for the depth of the transducer below the lake surface and the depths were recorded every second.

The depth readings were corrected using real-time hydrometric data acquired from the Government of Canada water level website. This real-time data features water level readings taken at 5-minute intervals. The following gauges were considered: Lake Winnipeg at Berens River, Lake St. Martin near Hilbre, and Fairford River near Fairford. For each gauge, the average water level was determined for each survey day. To calculate the corrected elevation, the average water level elevation was added to the SOLIX depth for the corresponding day and location. For example, SOLIX depths were collected for Sturgeon Bay on June 12, 2019. The average real-time water level for June 12 was 217.54m CGVD, taken from the Lake Winnipeg at Berens River gauge. A SOLIX depth of -2.5m would translate to a corrected elevation of 215.04m (217.54 + (-2.5)).

The real-time hydrometric data can be found here:
https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html

Transducer Mount

Control Monitor for Navigation

Figure 2.7 SOLIX Transducer Mount on Survey Boat and Control Head

The SOLIX also collects 2D sonar imaging in cross-section and bottom image formats. The sonar imaging provides continuous data to characterize the lake bottom and when used in combination with the ponar grab samples discussed in Section 2.3.7, it can help verify the lake bottom substrate. Refer to the sample output in Figure 2.8 for Line 4, west of Willow Point. Close to shore, the cobble-boulder pavement transitions to a sand bar, back to cobble-boulder lag, then back to sand bar. In the cross-sectional view (middle), these transitions are clearly seen based on the bottom roughness and the texture of the sonar signal. In the downward imaging, the sonar captures a swath 30 m wide to the left of the boat. The transitions from lag deposit to sand are clearly seen in the 2D image. To the right of the boat track, the sonar signal is compromised by the engine turbulence and can not be interpreted.

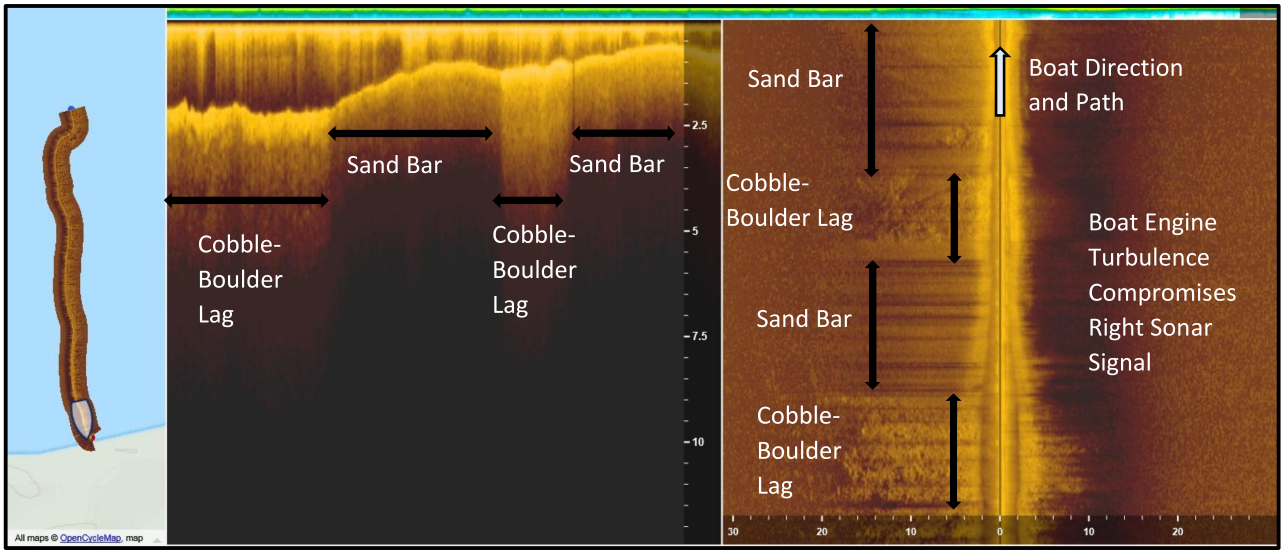


Figure 2.8 SOLIX Line 4 Track (left), Cross-section (middle), and Down Imaging (right) Captures Transitions from Cobble-Boulder Lag to Sand Bars. Depths and Distances in Metres

The Line 9 SOLIX image data is presented in Figure 2.9 and features a lake bottom with an irregular honeycomb pattern. Given the rapid long-term erosion rate of this shoreline, as discussed in Section 3.1, it is possible that the substrate features exposures of eroded peat. The holes or depressions may represent former open water areas in the marsh, while the higher surrounding surface area represents former locations with dense, peat forming emergent vegetation.

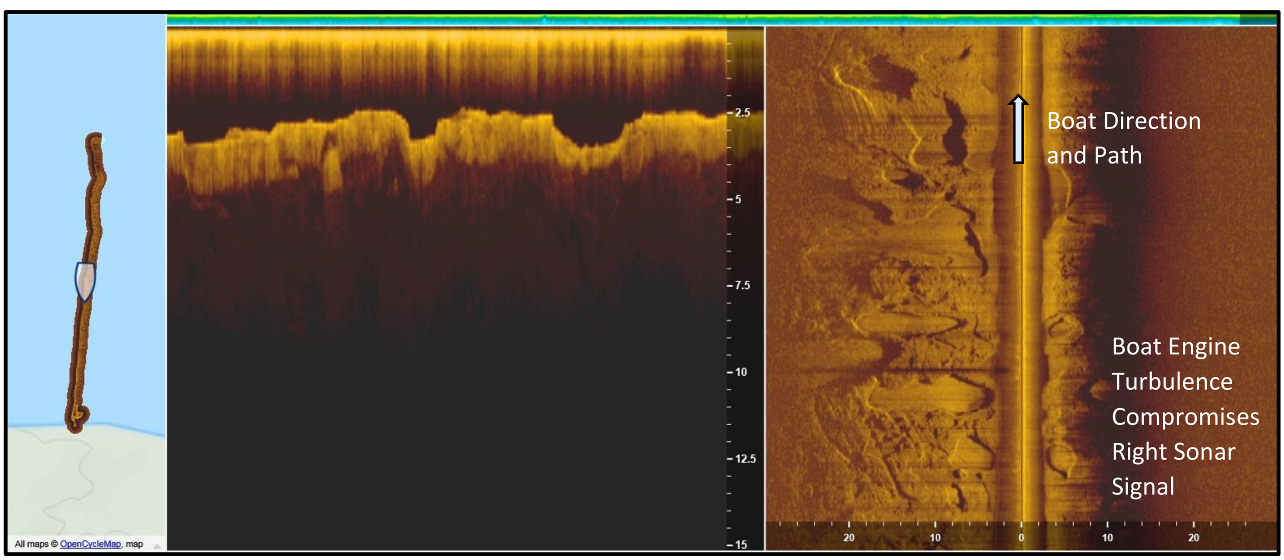


Figure 2.9 SOLIX Data for Line 9 (potential peat lake bottom)

The total length of the SOLIX data collected on the Fairford and Dauphin Rivers, plus Sturgeon Bay and Lake St. Martin is presented on page 11 in Figure 2.10. The depths are colour coded. Approximately 70 km of trackline data was collected in four days.

During the processing of the SOLIX depth data, differences in the elevations were identified when compared to the MIKE21 model Digital Elevation Model (DEM), which was assembled with the 2017 North-South survey of Sturgeon Bay and other sources further offshore. The 2019 profiles and the areas of overlap with the 2017 North South tracklines are presented in Figure 2.11. For reference, Profiles 4 to 10 are used for our sediment transport analysis described in Section 3.4 of the report.

Figure 2.12 plots the SOLIX data for Line 8, located east of the proposed outlet. The 2019 profile captures multiple sand bars in the shallow nearshore bathymetry. In contrast, the profile extracted from the MIKE21 DEM is also plotted on Figure 2.12, and it is deeper than the SOLIX depths and features a very smooth lake bottom.

The primary cause of this difference is mainly attributed to the level of detail captured during the surveys. The SOLIX survey was generally more detailed than the 2017 North South survey allowing for better representation of nearshore bathymetric characteristics such as sand bars. The 2017 North South survey was also completed for a different purpose than to assess shoreline morphology and was therefore based on an approximately 500m spaced tracklines offset from shore. For example, along Line 6 north of the proposed outlet, there simply is very little bathymetric data available from the 2017 survey to characterize the nearshore (refer to Figure 2.11). This is not uncommon with lake surveys, as the shallow depths along the shoreline are typically the most difficult to capture in a traditional boat-based bathymetric collection. To develop the DEM, a linear interpolation was applied between survey points and the shoreline. This can introduce error when compared to the actual bathymetry within the interpolated zone, such as the depths collected with the SOLIX survey.

Another source of error includes the variability in water levels that may have occurred during one or both surveys due to wind and wave conditions on Lake Winnipeg. This could have resulted in the assumed water level used to develop the DEM to be higher or lower than the actual water level for each survey points.

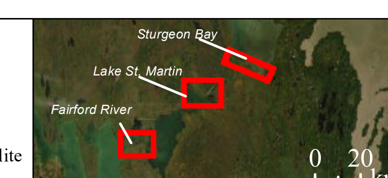
In general, these differences in elevations do not impact the conclusions described in this report regarding erosion and sedimentation trends in vicinity of the proposed Outlet. However, accurate shallow nearshore depths are needed for the sediment transport calculations, as discussed in Section 3.4.

JUNE 2019
FIELD WORK

Figure 2.10 Bathymetric and Sidescan Data Collection
June 10 to 13, 2019

Collection Dates:
June 10 - Lake St. Martin
June 11 - Lake St. Martin, Fairford River
June 12 - Sturgeon Bay
June 13 - Dauphin River

Background Image: ESA Sentinel 2A Satellite dated June 18, 2019



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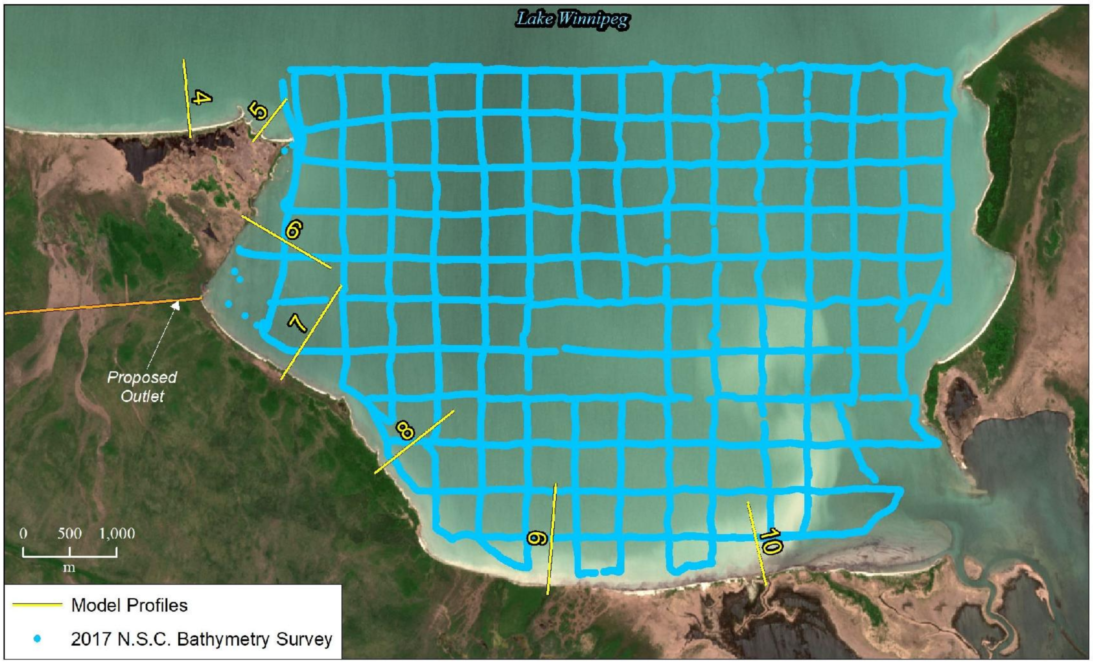


Figure 2.11 Tracklines from 2017 Bathymetry Survey used for the Model Bathymetry

Figure 2.12 Comparison of SOLIX Bathymetry at Line 8 (east of outlet) and MIKE21 Model Bathymetry

2.3.2 Summer 2019 Inlet Observations on Lake St. Martin

Lake St. Martin was revisited on June 10th and 11th, 2019 to collect additional shoreline observations and bathymetric data. The Waypoints and bathymetry profiles collected are presented on Figure 2.13. Lower lake levels and shallow conditions made navigation in the lake very challenging in early June 2019.

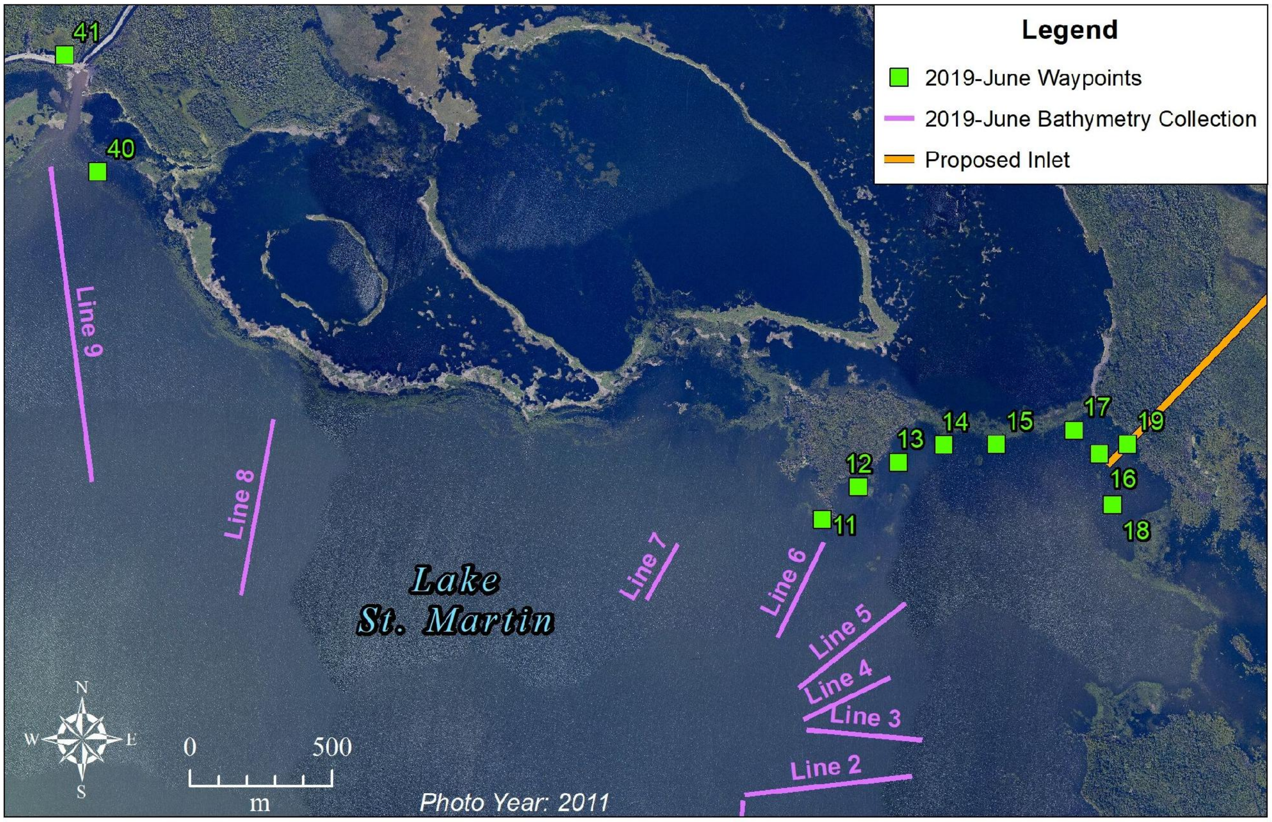


Figure 2.13 LSM Waypoints and Survey Lines, June 10-11, 2019

The location of Profile LSM-6 is presented above in Figure 2.13. The lake bottom was relatively flat and then featured a cobble-boulder ridge close to shore. Refer to Figure 2.14.

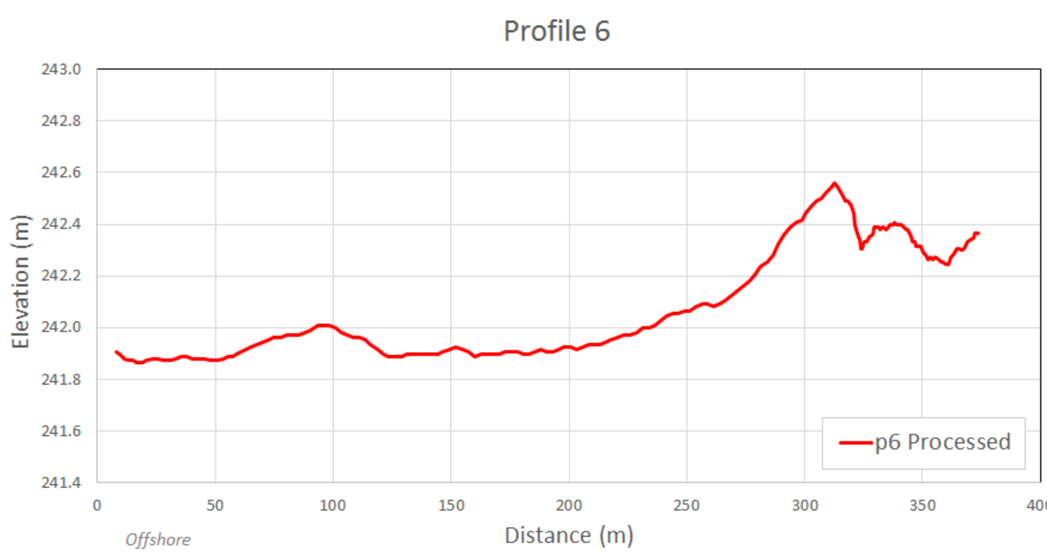


Figure 2.14 Profile LSM-6

In Figure 2.15 a series of photographs for a typical cobble-boulder headland found in the lake (taken from WP 11 in Figure 2.13) are presented. Well sorted gravel, cobble, and boulders are present at different shore elevations, with the larger material (i.e., boulders) found higher up the beach slope, possibly attributed to ice-push. The nearshore features scatter pieces of rock fragments, gravel, and sand. From a shallow hole, glacial till or lacustrine sediment was encountered below the surface layer of sand and gravel, softened by exposure on the lake bottom.

Typical Shoreline with Sorted Material

Typical Headland Anchored by Boulders

Mixed Angular Substrate at the Waterline

Till/Lacustrine Sediment from the Waterline

Figure 2.15 Headland Beach Systems on Lake St. Martin, June 10, 2019

The shoreline west of the proposed inlet was traversed on June 10, 2019, after gaining access to the shoreline at WP11. The path followed is captured by WP11 to 19, as seen in Figure 2.13. Due to the low lake levels, large areas of exposed lakebed were observed, as seen in Figure 2.16. Like the November 2018 observations, the lake bottom material was very angular, indicating a low energy environment.

Fracturing of the limestone cobbles and boulders was observed, and this process creates newer small angular beach material over time. Below the beach sediment, glacial sediment was again observed, as seen in Figure 2.16.

The water elevation during the bathymetric survey was 243.4 m CGVD, making it impossible to navigate into the inlet embayment. Figure 2.17 presents the survey line (5) that terminates on the edge of the embayment. The water depth was less than 1 m at the terminus of the line. Since the embayment features scattered boulder piles, navigation further onshore was not possible.

Headlands Backed by Marsh

Freeze-thaw Processes

Angular Beach Sediment

Clay/Mud below the Hard Beach Sediment

Figure 2.16 Shoreline Conditions North on the Inlet, June 10, 2019

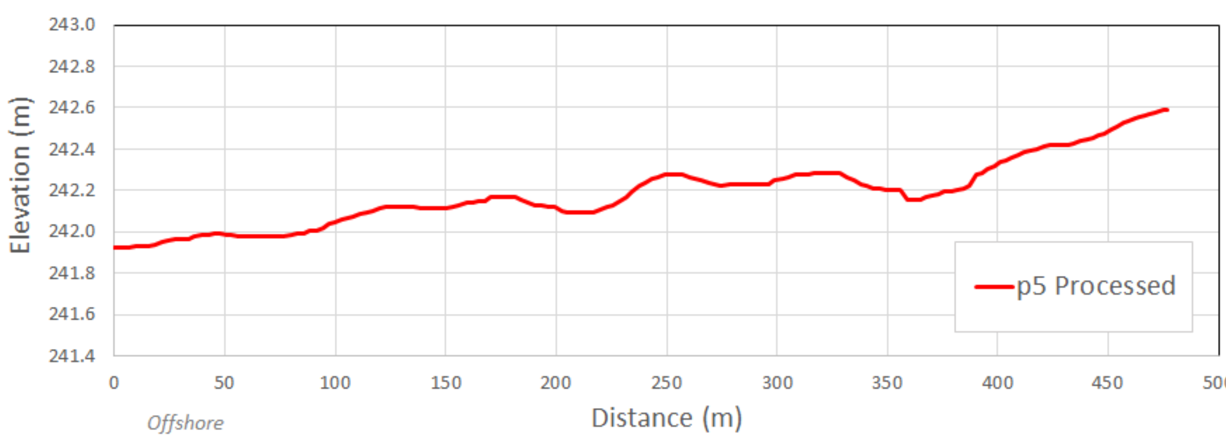


Figure 2.17 LSM Profile 5

Photographs of the shoreline at the proposed inlet are presented in Figure 2.18, including the cutline, exposed lake bottom, and shallow nearshore conditions with boulder piles. At the waters edge glacial sediment was also encountered below the sand and gravel on the beach, as seen in Figure 2.18a. The shallow conditions at the proposed inlet, the exposed lake bottom, and boulder piles are best seen in the oblique photograph in Figure 2.18b.

Cutline for Proposed Inlet Alignment

Gently Sloping Nearshore

Shallow Nearshore with Boulder Piles

Sand-Gravel at Waterline with Clay

Figure 2.18a Shoreline Conditions at the Inlet, June 10, 2019

Figure 2.18b Proposed Outlet Location (*image courtesy L. Wazney, KGS Group*)

On June 11, 2019 the Reach 1 emergency relief channel was also visited by boat, providing a valuable opportunity to observe the form and function of the original channel, along with the shoreline response. The bathymetry data collected during our approach to Reach 1 is presented in Line 9 below (Figure 2.19) and features a very gentle slope (e.g., 1:1,000).

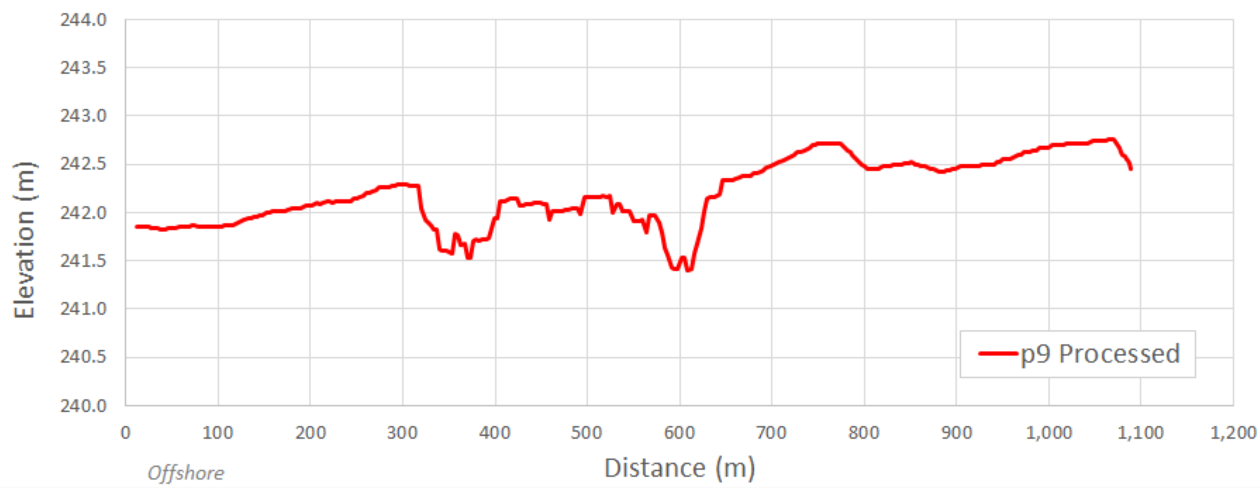


Figure 2.19 Line 9 at Reach 1 Inlet

Photographs of the site conditions are presented in Figure 2.20 and briefly summarized:

- Photo A: Shallow condition lakeward of the cut-off berm. This area was excavated during construction and operation of Reach 1 (P.Leclercq pers com. July 22, 2019). Although not seen in Photo A, there were no visible signs of shoreline erosion observed on our approach,

- Photo B: The shoreline immediately east of the cut-off berm is presented in Photo B. Sorted sand-sized beach material has accumulated at the waterline. This is one of the few locations were a sand-sized beach deposit was observed on the northern reaches of the lake. Presumably the sand was transported to this area by currents during the operation of Reach 1,

- Photo C: Lake side of cut-off berm. Small sand-sized beach deposit at the waterline,

- Photo D: On the back side of the cut-off channel, a large depositional deposit was observed. This feature is attributed to the material (unsorted) used to construct the berm, not natural deposition during the operation of the channel. The large rock debris remained in the berm, while the finer sands and gravels were transported into the channel during decommissioning,

- Photo E: Reach 1 looking inland. Small delta-like deposits were observed at the base of the unvegetated side slopes.

- Photo F: Gully formation attributed to overland drainage, with sedimentation in a small delta.

In summary, our observations suggest there were no major shoreline alterations on the approach to Reach 1, with only one minor accumulation of sand-sized material along the east bank of the cut-off berm. The sedimentation inside of Reach 1 is attributed to the material used to close the channel, not sedimentation from the flows in the channel.

A: Shallow Nearshore Conditions Lakeward of the Cut-off Berm (area of excavation)

B: Minor Sand Accumulation East of the Cut-off Berm

C: Lake Side of Cut-off Berm and Small Sand Deposit at the Waterline

D: Sedimentation on the Channel Side of the Cut-off Berm

E: Reach 1 Channel with Exposed Side-slopes

F: Gully in Channel Side-Slope and Sediment Accumulation (mini-delta)

Figure 2.20 Reach 1 Conditions on June 11, 2019

2.3.4 Summer 2019 Outlet Observations in Sturgeon Bay

The summer 2019 field work in Sturgeon Bay extended from the mouth of the Dauphin River to Sturgeon Bay Park Reserve. The location of Profiles 1 to 11 for the bathymetric data collection, along with WPs of sediment samples and shoreline photographs are noted on Figure 2.21 below.

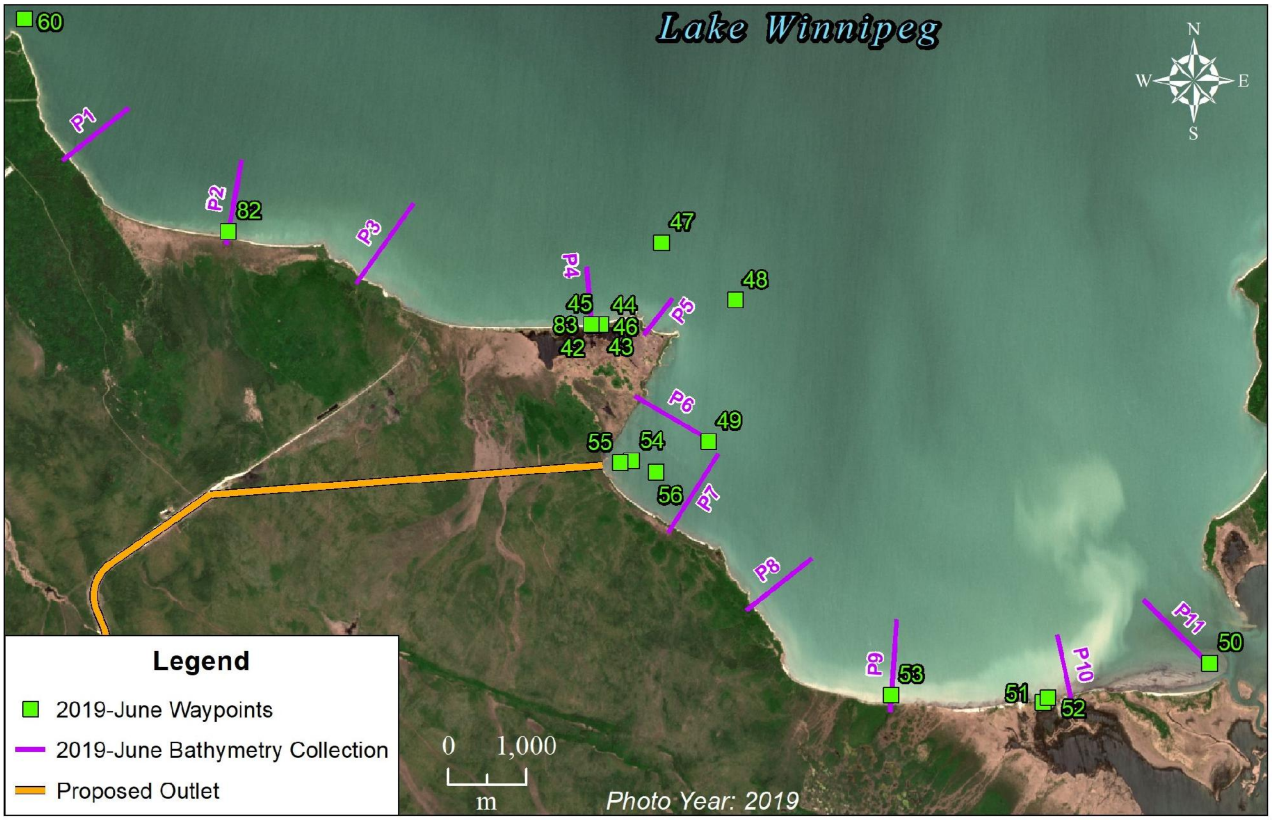


Figure 2.21 Location of Bathymetric Profiles and Waypoints (WPs) in Sturgeon Bay

Key observations are summarized geographically and with a focus on shoreline change trends and sediment conditions.

Dauphin River Mouth

The Dauphin River was traversed by boat on June 12th, 2019. The spatial extent of the survey is noted on Figure 2.10. Approximately 3 km upstream of the rivermouth, large pebble-cobble bar features were observed in the river. Refer to Figure 2.22 for a sample image, with Pelicans resting on the crest. With the lower river stage, these features were large and easy to identify (e.g. >50m long). At the mouth of the river, a ponar grab sample retrieved a large sample of pebbles and cobbles (Figure 2.22) from the riverbed. Investigating the sediment transport potential of the Dauphin River is not part of this investigation. However, these field observations suggest the river may be a small sediment source for the shoreline of Sturgeon Bay.

Shallow Nearshore with Boulder Piles

Sand-Gravel at Waterline with Clay

Figure 2.22 Cobble-Pebble Bar in the Dauphin River and a Bed Sample from the Rivermouth

Dauphin Rivermouth to Willow Point

The shoreline from the mouth of the Dauphin River to Willow Point features a sandy beach and ridge system of varying height. The nearshore typically features scattered cobbles and boulders, and a sandy substrate close to the shoreline. Refer to Figure 2.23 for a picture of the Line 2 shoreline and sandy substrate captured with a ponar grab sample.

Line 2 Sandy Shoreline

Fine Sand from Nearshore Bay, Line 2

Figure 2.23 Line 2 Shoreline and Lakebed Sample from Sandbar

The Profile 2 bathymetric data is plotted in Figure 2.24. The profile is roughly 1 km in length and features a very gentle ~1:300 slope. The sonar data indicates most of the profile consists of a cobble-boulder lag deposit over glacial sediment.

A sample of the sonar ~300 m from shore is presented in the top panel of Figure 2.25. The left image is a cross-sectional view of the lake bottom and the right image is the bottom imaging. The lakebed consists of a cobble-boulder lag deposit over glacial till.

Closer to shore, a zone of submerged aquatic vegetation (SAV) was detected with the sonar and is presented in Figure 2.25 (bottom panel). The SAV transitions to a sand substrate, which was validated with the lakebed sample extracted and presented in Figure 2.23.

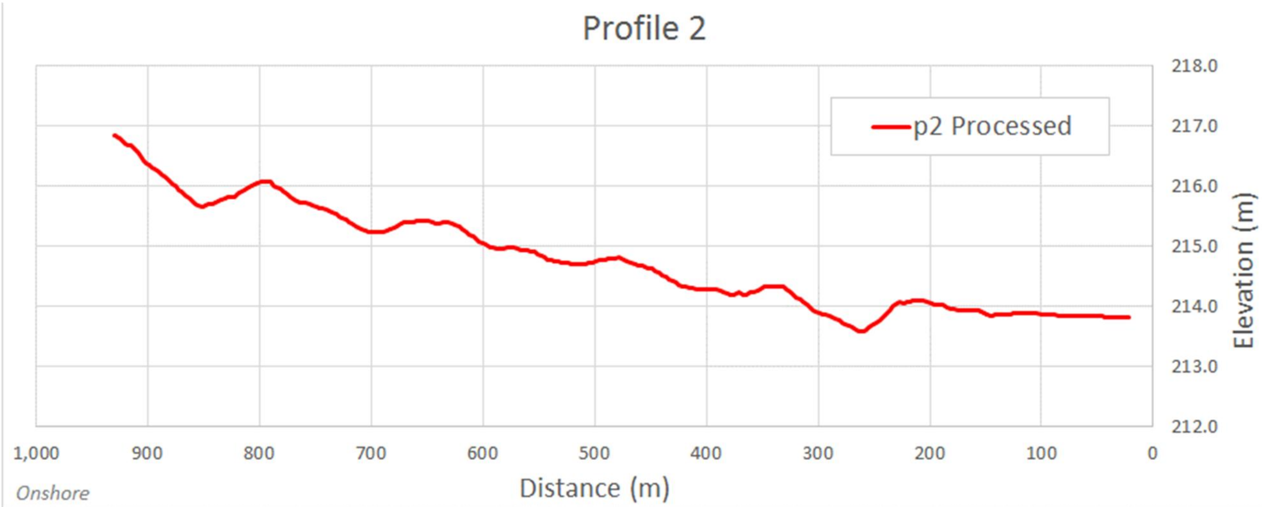


Figure 2.24 Line 2 Profile

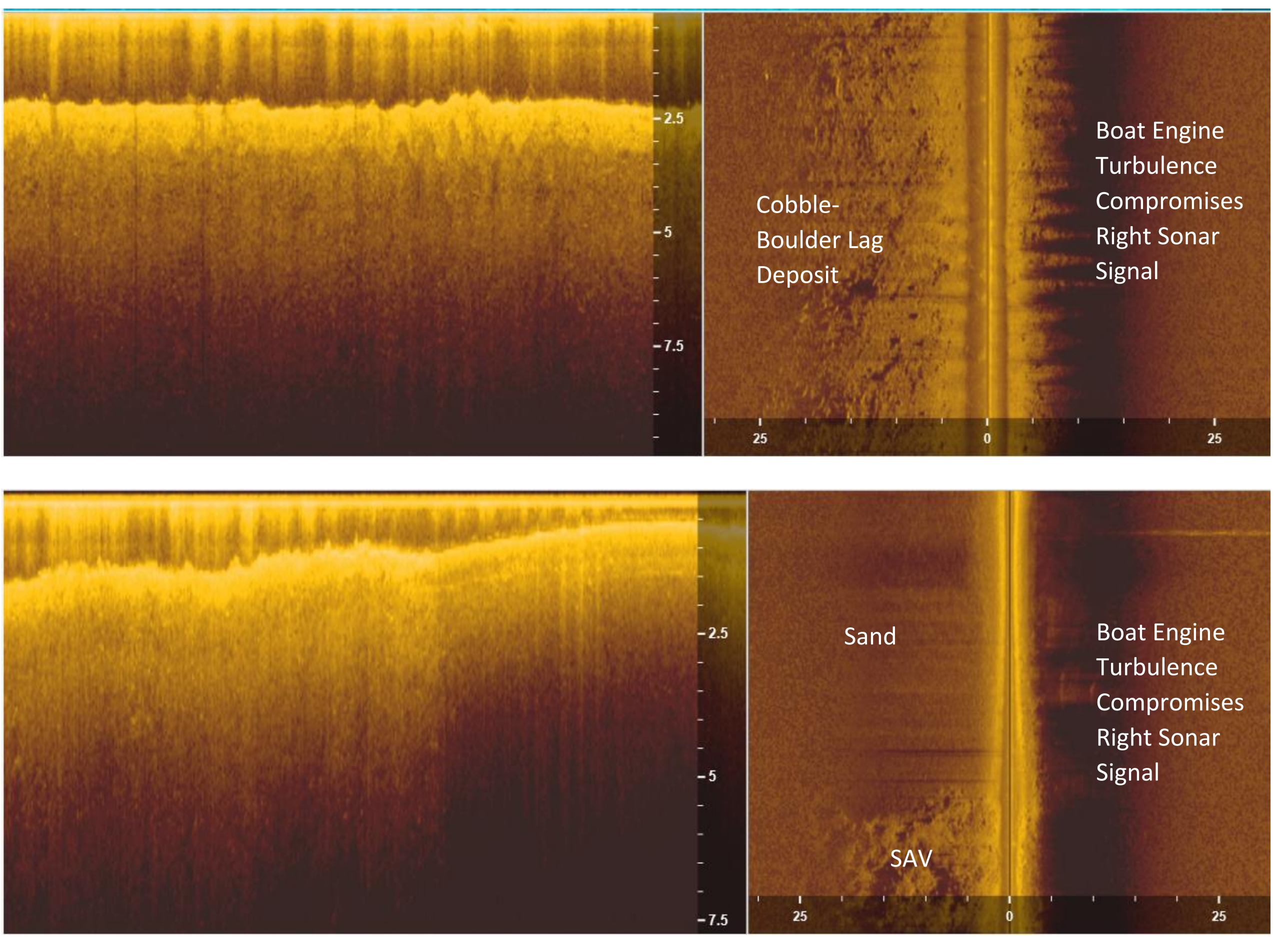


Figure 2.25 Line 2 Sonar ~300 m from Shore with Cobble and Boulders over Glacial Sediment (top) and ~100 m from Shore Submerged Aquatic Vegetation (SAV) Transitions to a Sand Lake Bottom (bottom)

Willow Point West

The Willow Point headland functions as a sediment trap for sand transported from west to east in Sturgeon Bay. The shoreline adjacent to the point features a wide sand beach and vegetated ridge system, as seen in Figure 2.26. The area also features active aeolian transport, with evidence of beach sediment transported inland by wind.

Cutline for Proposed Inlet Alignment

Gently Sloping Nearshore

Figure 2.26 Wide Sand Beach and Ridge System at Line 4 (west side of Willow Point)

Channel Outlet

An oblique aerial photograph of the proposed outlet channel looking south is presented in the top photograph of Figure 2.27. The eroding peat shoreline on the east side of Willow Point, along with peat accumulation at the shore is seen on the right side of the image. The shoreline conditions, looking west towards the proposed outlet are presented in the bottom image of Figure 2.27. A wide sand beach is present, along with a vegetated sand ridge. The shallow and gently sloping nearshore features scattered boulders.

Profile 6 is located along the back side of Willow Point. Refer to the Figure 2.21 map for the location. The bathymetry data for Profile 6 is plotted in Figure 2.28 and highlights the shallow and gently sloping conditions north of the proposed outlet. The nearshore slope adjacent to the shoreline is ~1:500.

The material retrieved from two ponar grab samples close to the proposed outlet are presented in Figure 2.29. At WP49, approximately 1 km offshore, the lake bottom was hard and only a small sample of cobbles and pebbles were retrieved. Closer to shore at WP55, a fine homogeneous sand sample was retrieved.

Outlet Shoreline Looking South (*image courtesy L.Wazney, KGS Group*)

Outlet Shoreline Looking West (*image courtesy L.Wazney, KGS Group*)

Figure 2.27 Cut Line and Proposed Channel Outlet looking south (top) and looking northwest (bottom)

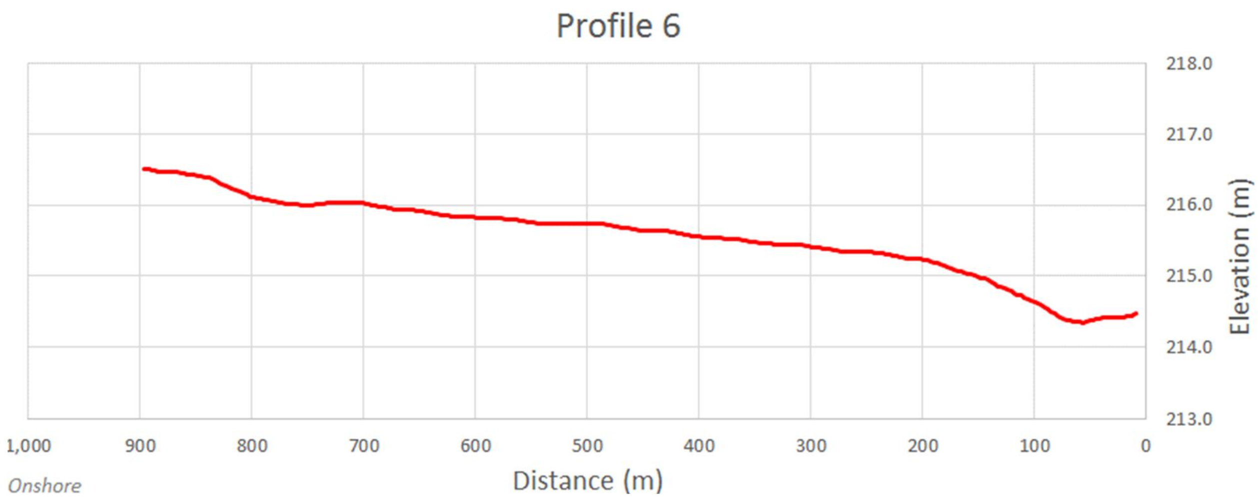


Figure 2.28 Profile 6

WP49 Cobble-Gravel Lakebed Sample

WP55 Sand Lakebed Sample

Figure 2.29 Lakebed Samples near Proposed Outlet

Sturgeon Bay Park Reserve

The Sturgeon Bay Park Reserve shoreline features a long sandy barrier beach system, that is eroding and migrating inland into the marsh. As the shoreline migrates inland, former peat sediments that formed in the sheltered marsh are exposed in the nearshore, and at the waterline. Refer to Figure 2.29 for a typical picture of this eroding shoreline. Evidence of sand transport inland by wave overtopping during storms and aeolian transport was also observed, suggesting this region of the shoreline is a sediment sink.

A ponar grab sample from WP50, which corresponds to the terminus of Line 11, featured a homogeneous dark sand deposit, as seen in the right image of Figure 2.29.

Eroding Peat Shoreline

Sandy Nearshore Lakebed (WP50)

Figure 2.29 Eroding Peat Shoreline and Sandy Lake Bottom Sample at WP50

2.3.5 Lakebed Samples to Verify Substrate Mapping

The lake bottom substrate mapping collected for Lake St. Martin by North-South Consulting, is presented in Figure 2.30, with the location of the proposed inlet noted. Due to rough lake conditions on June 10th and 11th, 2019 no lakebed samples were retrieved from Lake St. Martin. Several observations were collected from the beach by digging shallow pits, as noted in Figures 2.15, 2.16, and 2.18. These samples correspond to the area of unclassified substrate (red shading) in Figure 2.30.

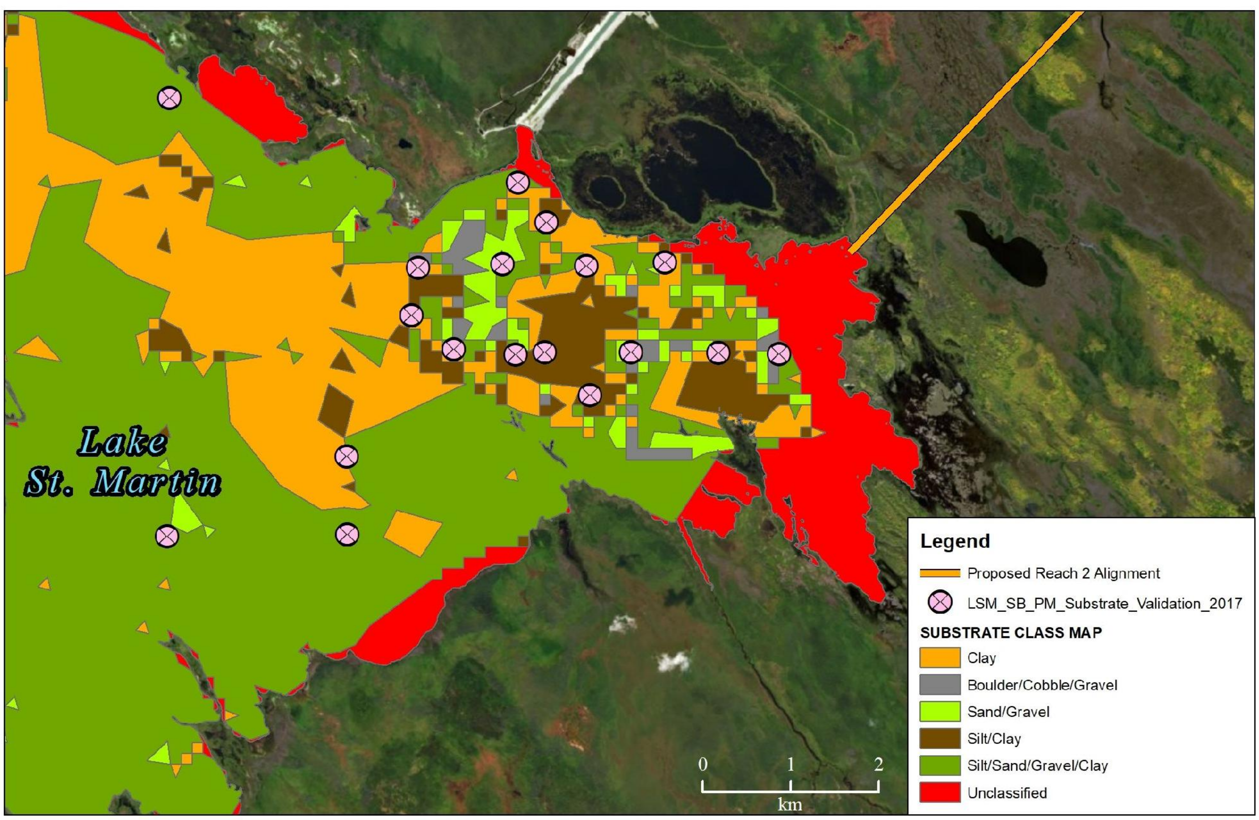


Figure 2.30 Lake St. Martin Substrate Mapping for NS (2017)

The substrate classification map for Sturgeon Bay, also generated by North-South Consultants, is presented in Figure 2.31. A total of eight samples were retrieved on June 12, 2019 to verify the substrate classification and ensure the substrate zones had not migrated. The results are summarized in Table 2.1 and presented visually in Figure 2.32. Our samples are generally in agreement with the North-South substrate mapping. Our interpretation of the Sand/Silt/Clay classification, based on our observations, is: 1) close to shore, the lake bottom can feature exposures of glacial till and patches of sand (e.g., WP53), and 2) further offshore in deeper water, this classification represents a mobile sand sheet formed by longshore currents.

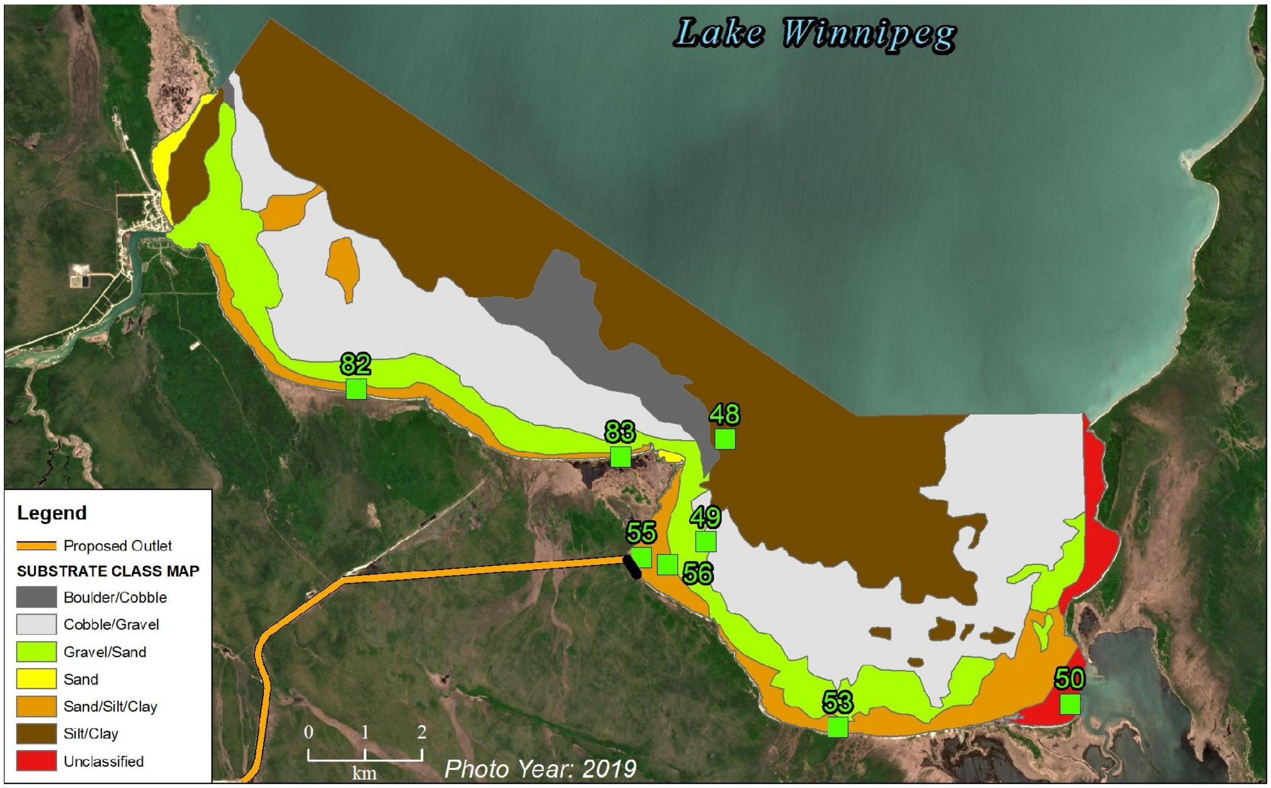


Figure 2.31 Sturgeon Bay Lakebed Substrate by North-South Consultants

Table 2.1 Zuzek Inc. Observations versus North-South Classification

Location/Waypoint	June 12, 2019 Sample	N-S Substrate Classification
Line 2 / WP82	Sand	Sand/Silt/Clay
Line 4 / WP83	Sand	Sand/Silt/Clay
WP48	Mud	Silt/Clay
WP49	Pebbles and Cobbles	Cobble/Gravel
WP55	Sand	Sand/Silt/Clay
WP56	Sand	Sand/Silt/Clay
WP53	Sandy and Clay	Sand/Silt/Clay
WP50	Sand	Unclassified

Line 2 WP82 - Sand

Line 4 WP83 - Sand

WP48 - Mud

WP49 – Sand and Pebbles

WP55 – Sand (proposed outlet excavation)

WP56 – Sand (offshore of outlet)

WP53 – Sand and Clay (Line 9)

WP50 – Sand (Channel to Sturgeon Bay Reserve)

Figure 2.32 Ponar Grab Samples of Surficial Lake Bottom Conditions

3.0 ANALYSIS

The shoreline change analysis is described in Section 3.0, including a shoreline change assessment with historical aerial photographs, storm characterization, numerical modeling of hydrodynamics and waves, sediment transport predictions, and preparation of a regional sediment budget.

3.1 Shoreline Change Assessment

Historical aerial photographs from four temporal periods, including 1948, 1949, 1963, and 1992 were received from GeoManitoba. Shorelines derived from the historical aerial photographs were compared with recent orthophotography (2011 and 2017). When interpreting features from registered aerial photographs there is some level of uncertainty due to factors such as photo resolution and scale, photo quality, and positional accuracy of a geo-referenced photograph.

The historical images were geo-referenced with ArcGIS software using recent orthophotographs as the base. Root Mean Square (RMS) errors, which is reported during the geo-referencing of aerial photos with GIS software, were used to estimate maximum horizontal positional error in the geo-referenced photos. It is also important to note that technical studies (Crowell et al, 1991) have shown the actual horizontal error in registered aerial photographs is generally much less than the report RMS error. The average RMS errors are reported in Table 3.1 for the various photo series on Lake St. Martin and Sturgeon Bay.

Table 3.1 Maximum Potential RMS Error for Aerial Photo Registration

Lake St. Martin			
Photo	**No. Photos**	**Approximate RMS Error (m)**	**Lake Level (m)**
1948	3	1.5	243.50
1963	3	4.8	242.83
1992	4	3.0	242.82
2011	n/a		245.50
2017	n/a		244.74
Lake Winnipeg			
Photo	**No. Photos**	**Approximate RMS Error (m)**	**Lake Level (m)**
1948	4	3.8	217.60
1949	4	5.5	217.34
1963	3	5.0	217.64
1992	10	2.4	217.77
2011	n/a		218.47
2017	n/a		217.83

Methods used to minimize errors in georeferenced imagery included using well distributed tie points, selecting appropriate transformation methods, and routine visual checks against base imagery. When the rate of change between two georeferenced aerials is greater than the combined RMS error, which is generally the case with this study, a high degree of confidence can be placed on the results (Zuzek et al, 2003).

Delineation of shoreline change reference features, such as the vegetation line or waterline, can introduce uncertainty during the digitizing of the feature in GIS. This may be due to poor photo resolution and quality, feature misidentification, lack of vertices to adequately represent a feature, or obscurity of the feature due to vegetation, shadows, sun glint, and in some cases, physical markings on the photo prints. Uncertainty during delineation was minimized by using large map scales (e.g., 1:2,500 or better) to view photos that allowed for enough vertices to be drawn, and frequent comparisons with other photo years to help identify feature position and extent.

Lake levels will also influence the location of the waterline and in some cases, the edge of vegetation (if the vegetation can adapt quickly to the new lake level regime). The maximum difference in water levels in the historical imagery (1948 to 1992) was 0.68 m on Lake St. Martin and 0.43 m on Lake Winnipeg. When the high water levels in 2011 are considered, the maximum difference is 2.68 m on Lake St. Martin and 1.13 m on Lake Winnipeg.

3.1.1 Lake St. Martin Near Inlet

Historical aerial images were georeferenced for 1948, 1963, and 1992 for the north-east corner of Lake St. Martin, in the vicinity of the proposed inlet. Given the lack of beach features on the lake, changes in the vegetation line were compared between the photographs. Except for extreme high lake level conditions (e.g., 2011), the vegetation line is not influenced by lake level fluctuations, making it a useful shoreline change reference feature. The results for four geographic areas are described below.

Area A – Proposed Inlet

Vegetation lines were digitized for 1948, 1963, 1992, 2011, and 2017 from the aerial photography at the proposed inlet site and presented on the 1992 aerial photo (Figure 3.1). While there have been some minor changes in the vegetation line, the fluctuations are likely attributed to water level changes and vegetation migration upslope/downslope in response to changing lake levels, not shoreline erosion.

Several prominent rock piles in the nearshore region of the embayment were identified on the historical aerials and digitized. Based on the results in Figure 3.1, these boulder piles have been very stable over the last 70 years, suggesting the lake bottom has also been very stable close to the proposed inlet.

Area B and C – Headlands South of Proposed Inlet

Two large headlands south of the proposed inlet were evaluated for long-term changes in the vegetation line using imagery from 1948, 1963, 1992, and 2011. In general, there has been some lakeward migration of the vegetation line since 1948. This is most prominent in the north-west corner of the headlands, as noted on Figure 3.2 and 3.3. This change in shoreline position appears to be linked to migration of the vegetation in a lakeward direction, not the accumulation of beach material in a depositional environment.

Area D – Reach 1 Emergency Channel

Changes to the shoreline vegetation east and west of the Reach 1 emergency channel were digitized and compared in Figures 3.4 and 3.5 from 1948 to 2011. The comparison highlighted a mixture of advancing and retreating vegetation at Reach 1. No consistent trend was calculated. As with Areas A, B, and C, the migration of the vegetation communities observed in the aerial photographs appears to be related to water level trends, not erosion or sedimentation.

In summary, given the relatively small wave climate on the north basin of Lake St. Martin, the gentle lake-bottom slope, and erosion-resistant cobble-bedrock headlands, no discernable erosion or accretion trends were observed from the aerial photograph analysis. Fluctuating lake levels appear to be the most significant influence on the advance and retreat of the waterline and emergent/shrubby vegetation at the shoreline.

3.1.2 Sturgeon Bay Near Outlet

Historical aerial images were geo-referenced for 1948, 1949, 1963, 1992, and 2011. The spatial coverage for these years varies from the Dauphin River to Sturgeon Bay Park Reserve. The shoreline change trends are discussed for main regional areas.

Area E – Profile 2 Shoreline (East of Dauphin River Mouth)

Between 1948 and 2011, the shoreline in the vicinity of Profile 2 has eroded approximately 11 to 19 m, which translates into an annualized erosion rate of approximately 0.18 m/yr to 0.3 m/yr. At the eastern margin of Area E there has been very little change in the shoreline position, possibly benefiting from the stability of the cobble-boulder headland to the east. Refer to Figure 3.6 for the results. This is a low-lying shoreline which is very susceptible to erosion and shoreline recession during periods of high lake levels.

As the shoreline and lake bottom erode, new sand and gravel is added to the system for transport along the shore. Therefore, this region is classified as a sediment supply area.

Area F – Willow Point West from 1948 to 2011

Changes in shoreline position for the west side of Willow Point from 1948 to 2011 are presented in Figure 3.7. The barrier ridge that shelters the marsh from the lake has retreated approximately 42 m in 62 years, for a long-term recession rate of 0.68 m/yr. The field observations suggest this recession is due to a combination of wave overtopping that pushes the barrier ridge further into the marsh and aeolian transport of sand over the crest of the ridge. Three prominent lobes of sand that were migrating into the marsh in 1948 are identified with yellow arrows in Figure 3.7, which uses a combination of the 1948 and 1949 image as the background. Therefore, this process of shoreline erosion and inland migration of the sand ridge has been occurring for more than 60 years.

Area G – Shoreline at the Proposed Outlet

The south side of Willow Point is an eroding peat shoreline. The shore has retreated 17 to 43 m over the last 67 years, for an annualized erosion rate of 0.27 m/yr to 0.69 m/yr. Refer for Figure 3.8. While the retreating shoreline only contributes dislodged pieces of peat, the associated lake bottom erosion is likely a minor source of new sand and gravel for the littoral drift system in Sturgeon Bay.

The shoreline south-east of the proposed outlet has receded 14 m to 19 m from 1949 to 2017, for an annualized recession rate of 0.21 m/yr to 0.28 m/yr. These measurements are consistent with the field observations, that identified uprooted trees at the back of the beach. The eroded shoreline and lake bottom contribute new sand and gravel to the nearshore.

Area H – Sturgeon Bay Park Reserve

The most dramatic changes in shoreline position were calculated for the Sturgeon Bay Park Reserve, south-east of the proposed outlet. Between 1949 and 1992, the barrier beach sheltering the marsh and estuary from Lake Winnipeg wave action has retreated approximately 170 m to 300 m. This translates to an annualized recession rate of 4 m/yr to 7 m/yr.

The barrier beach separating the lake from the marsh is very low-lying and susceptible to wave overtopping during storms at high lake levels. As the waves wash over the barrier, they transport sediment into the marsh, creating depositional lobes of sand. Two prominent locations with wash-over deposits are noted on Figure 3.9 with yellow arrows on the 1949 and 1992 imagery.

These high rates of shoreline erosion explain the large exposures of peat observed on the beach at Line 10 (refer to Figure 2.29). As the barrier beach migrates inland into the marsh, lenses of peat that formed in the marsh are now exposed on the lake bottom and at the waterline.

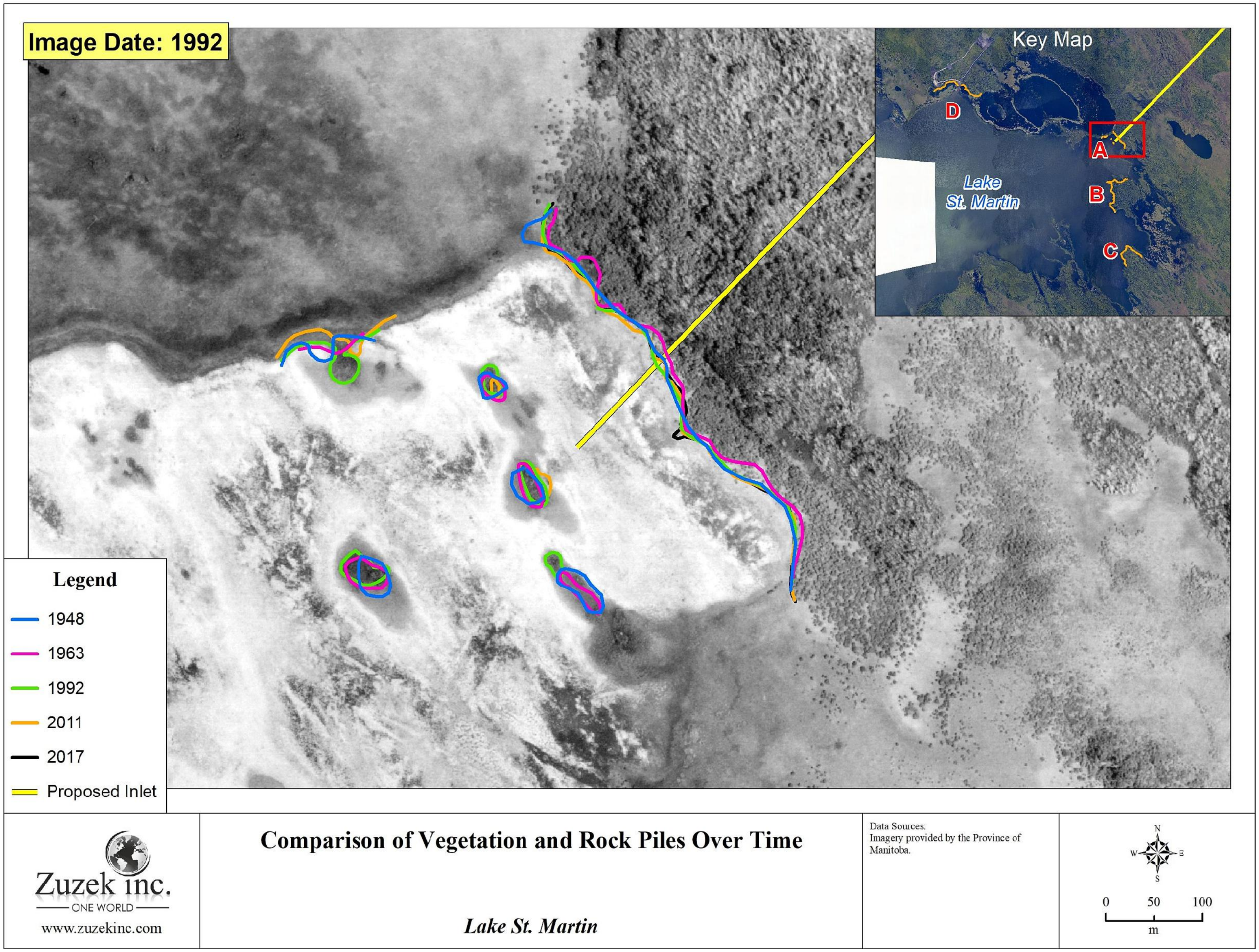


Figure 3.1 Historical Vegetation Lines at Proposed Inlet

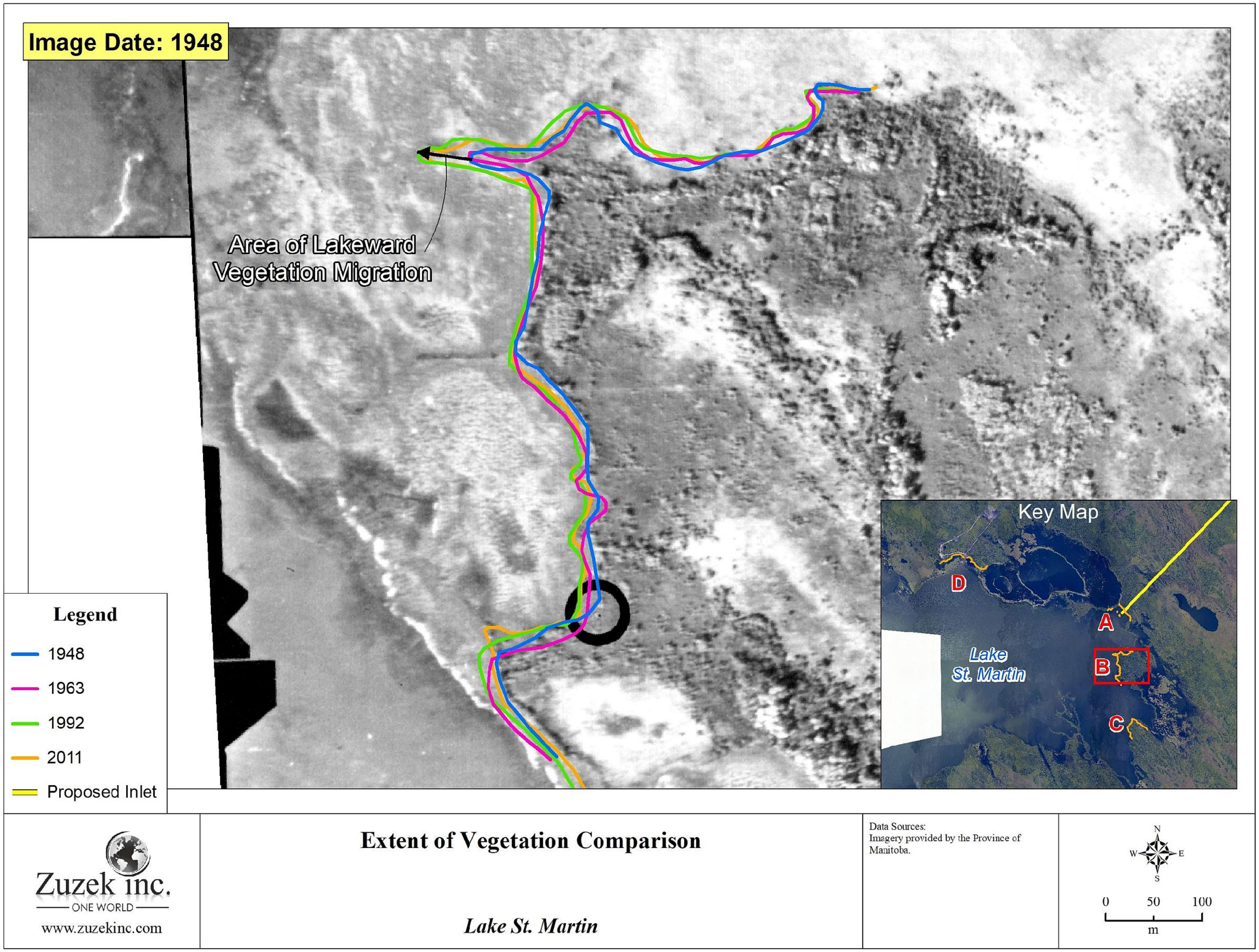


Figure 3.2 Headland B South of Inlet, 1948 Imagery Background

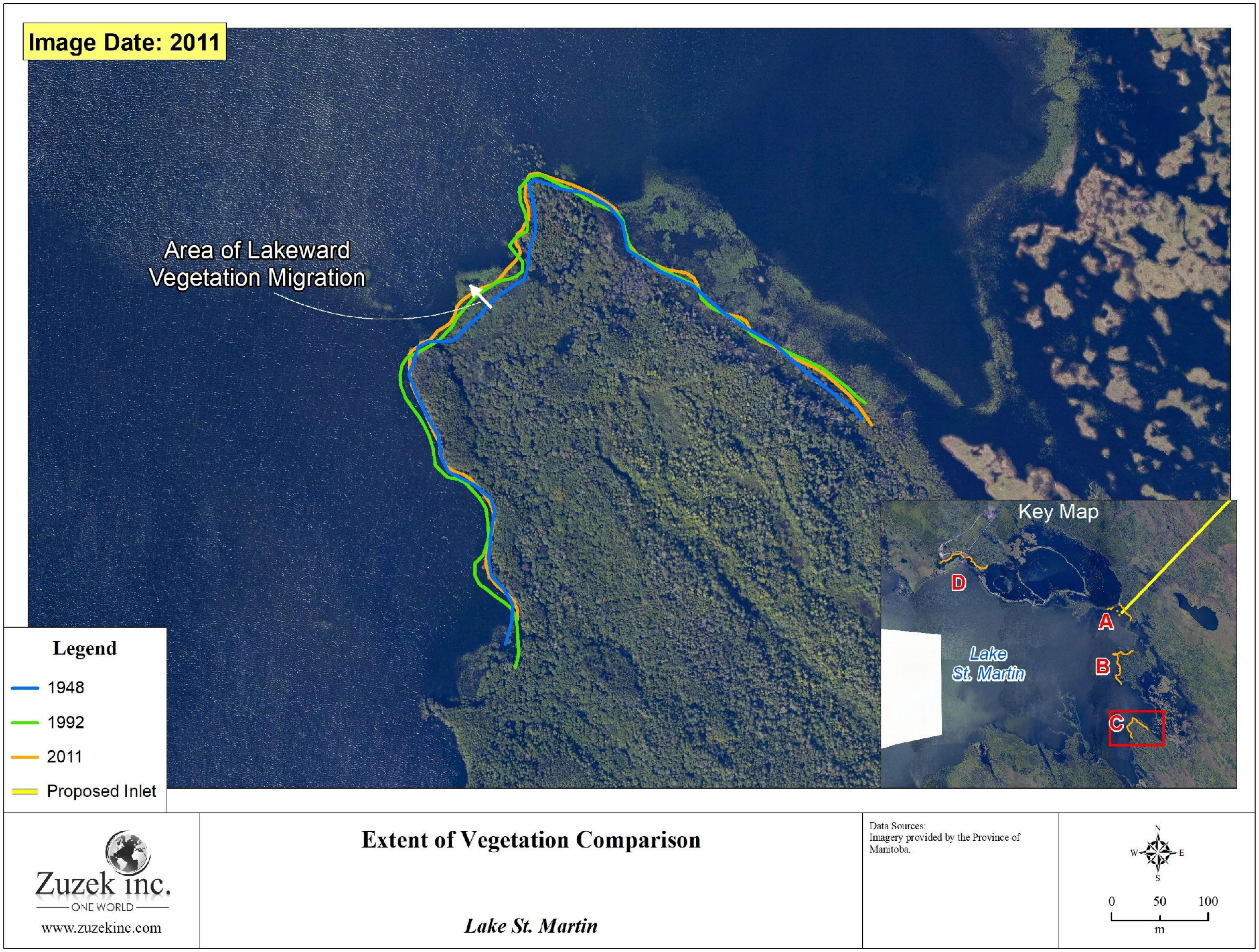


Figure 3.3 Headland C South of Inlet, 2011 Imagery Background

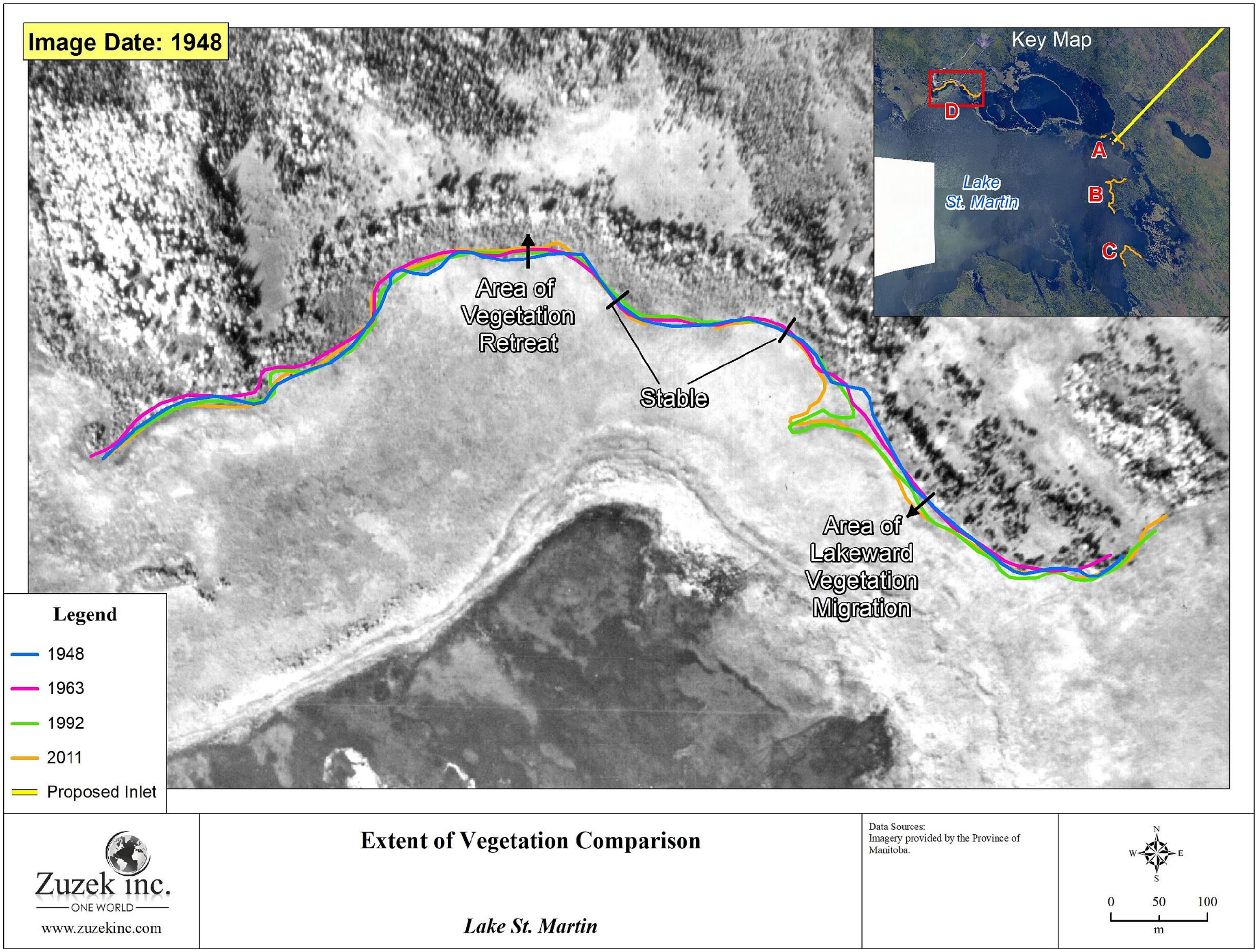


Figure 3.4 Reach 1 Emergency Channel, 1948 Imagery Background

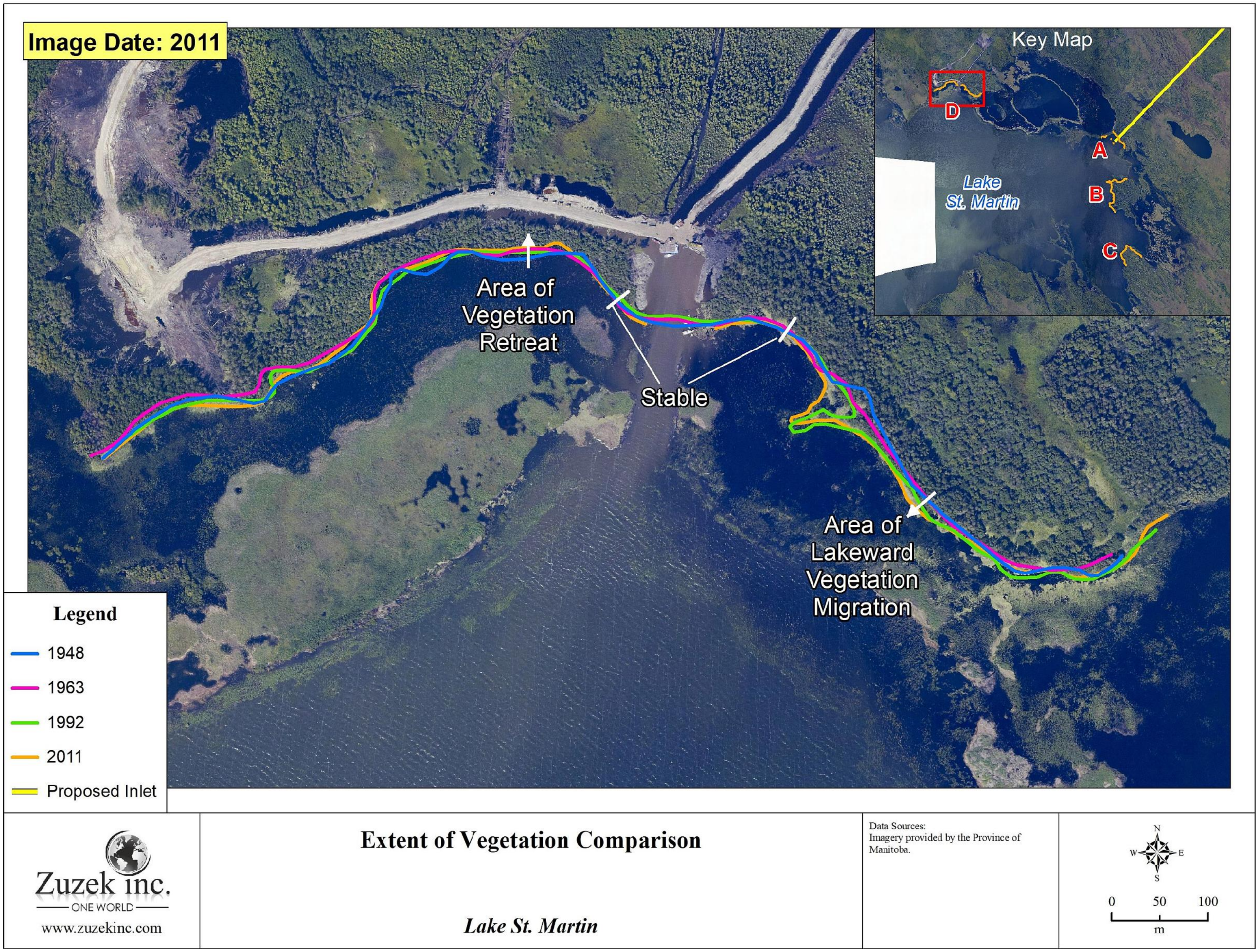


Figure 3.5 Reach 1 Emergency Channel, 1948 Imagery Background

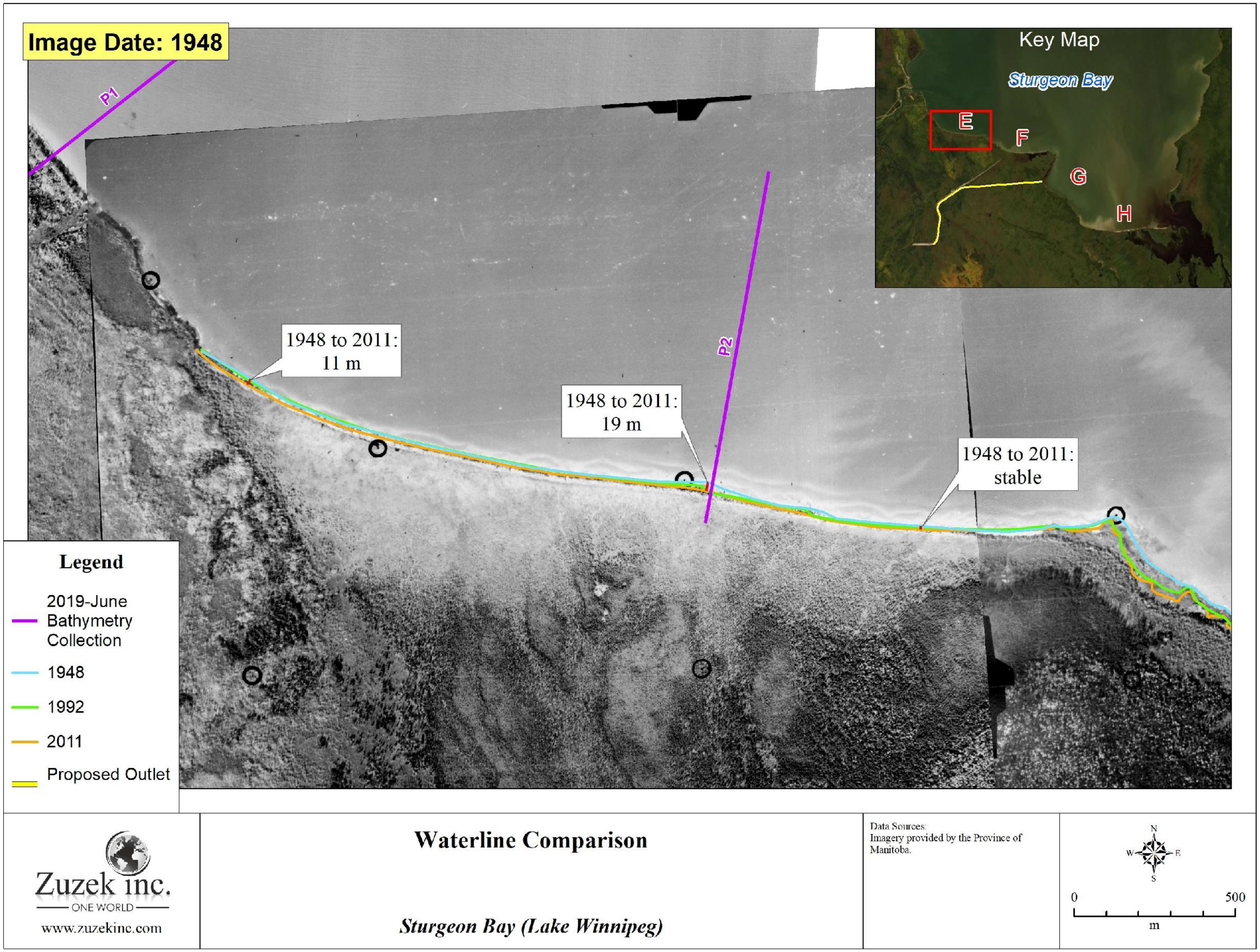


Figure 3.6 Line 2 Shoreline between Dauphin River Mouth and Willow Point (Area E)

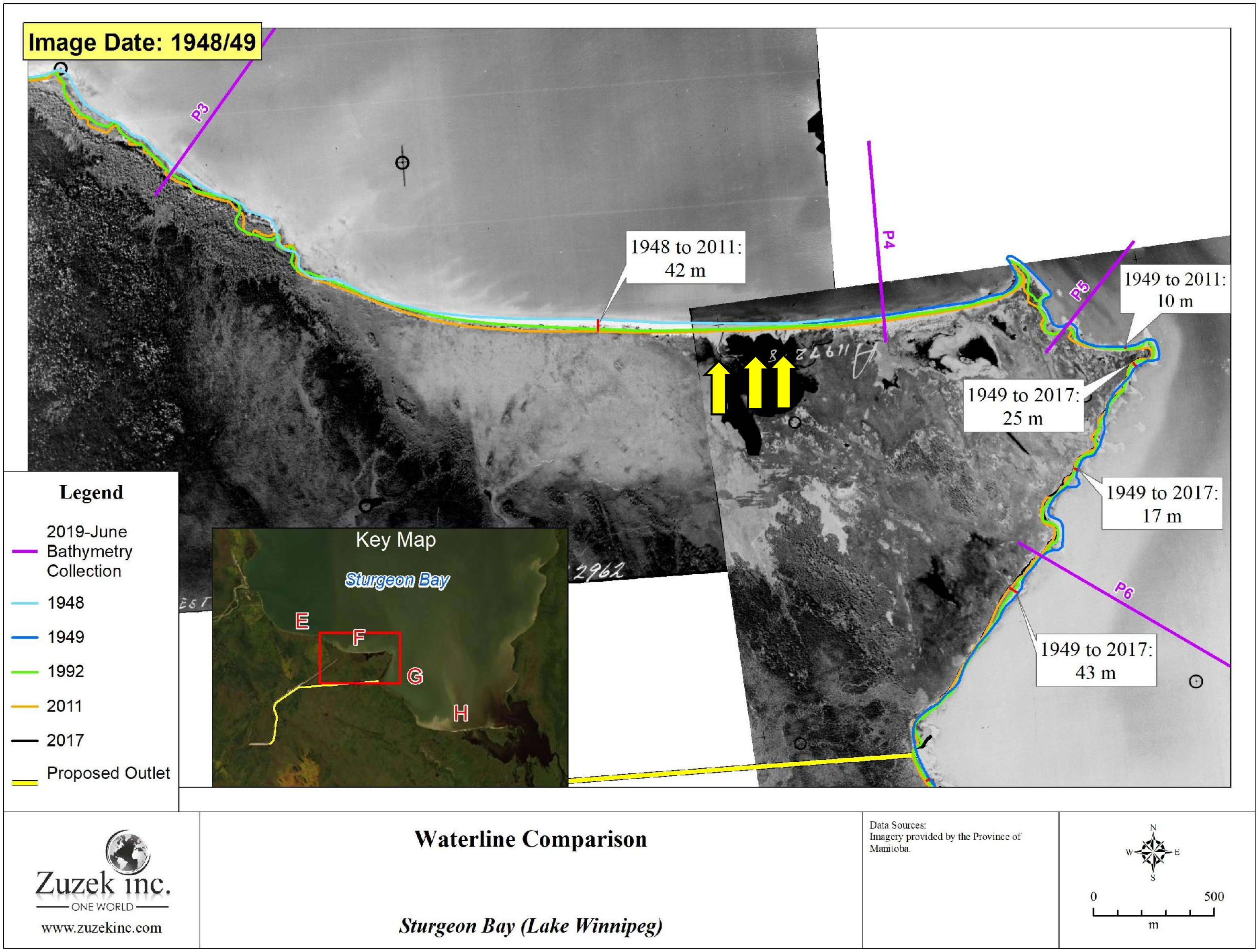


Figure 3.7 Historical Shoreline Change for the West Side of Willow Point (Area F)

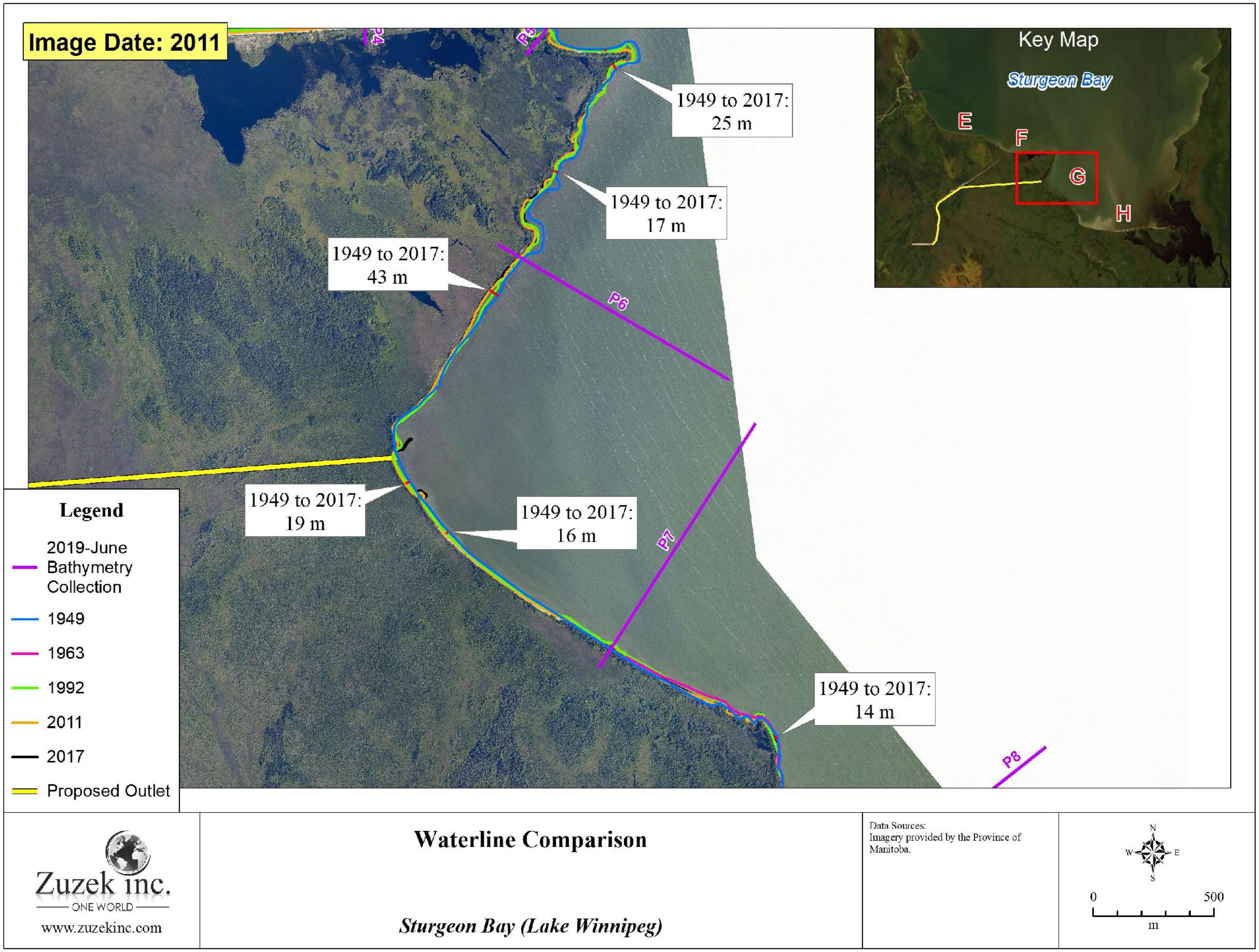


Figure 3.8 Shoreline Change Measurements in the Vicinity of the Proposed Outlet (Area G)

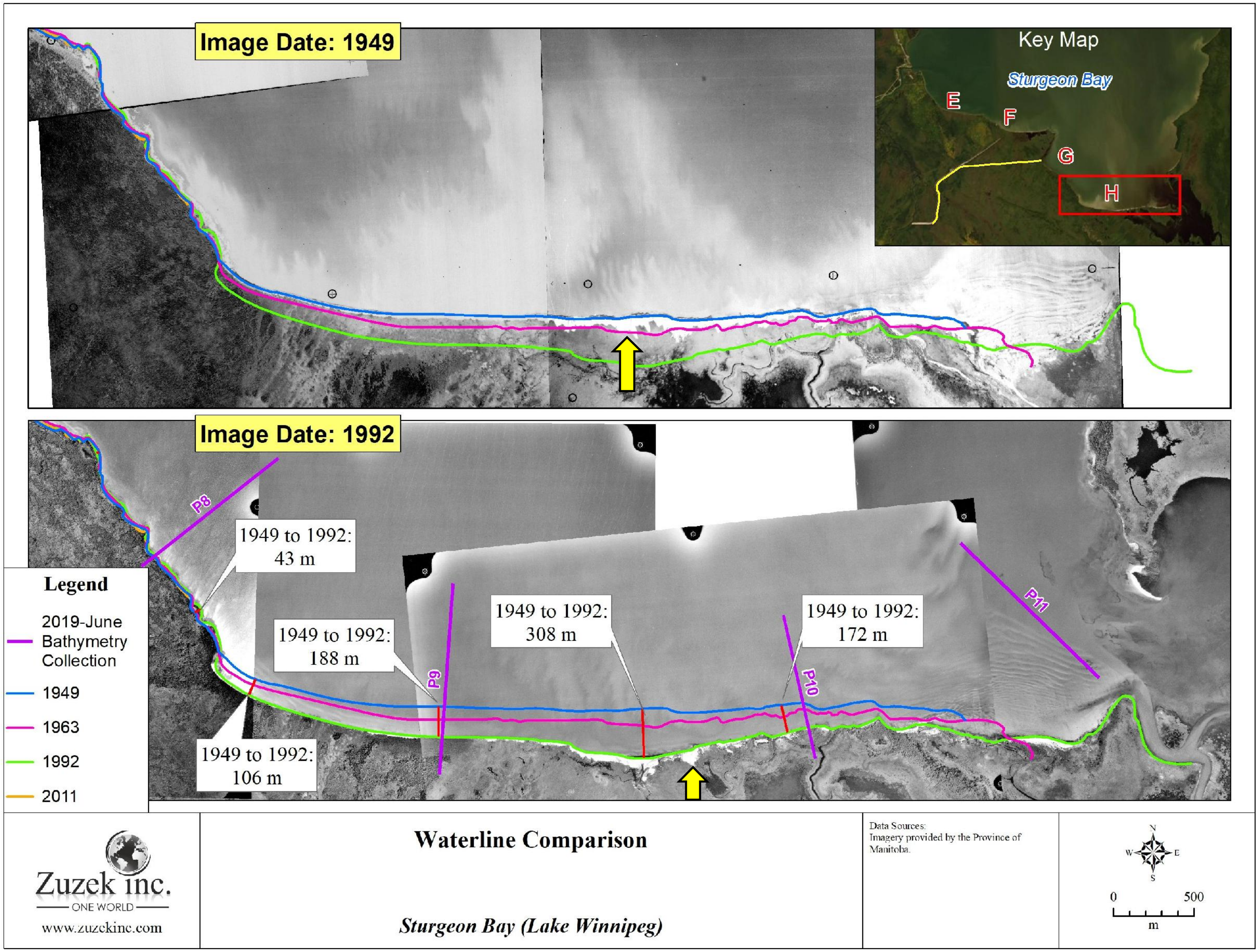


Figure 3.9 Shoreline Recession from 1949 to 1992 at the Sturgeon Bay Park Reserve (Area H)

3.2 Storm Analysis with Measured Wind Data

Historical data on storms and corresponding wave conditions at the proposed inlet and outlet are required for the regional sediment transport analysis and assessment of channel sedimentation potential. Figure 3.10 identifies three wind stations maintained by Environment Canada near the proposed inlet and outlet. Table 3.2 summarizes the start, end, and duration of the historical wind records at the three stations.

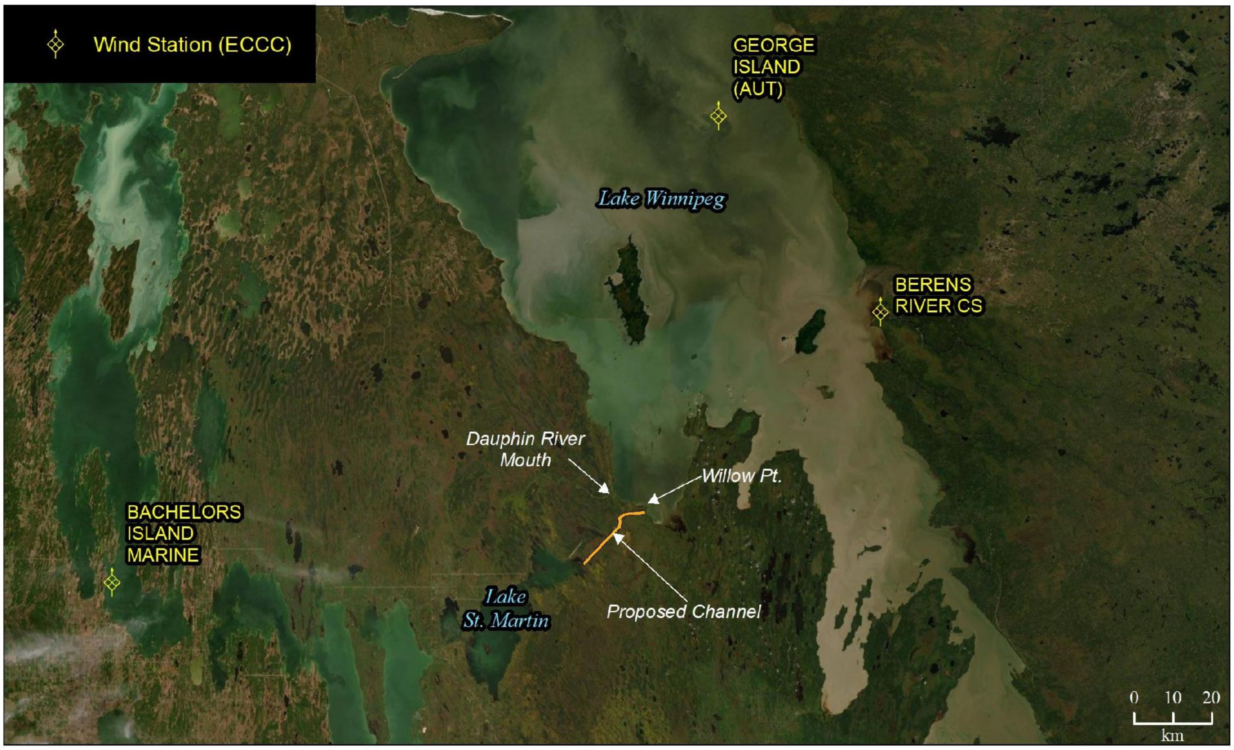


Figure 3.10 Wind Stations Close to the Proposed Channel

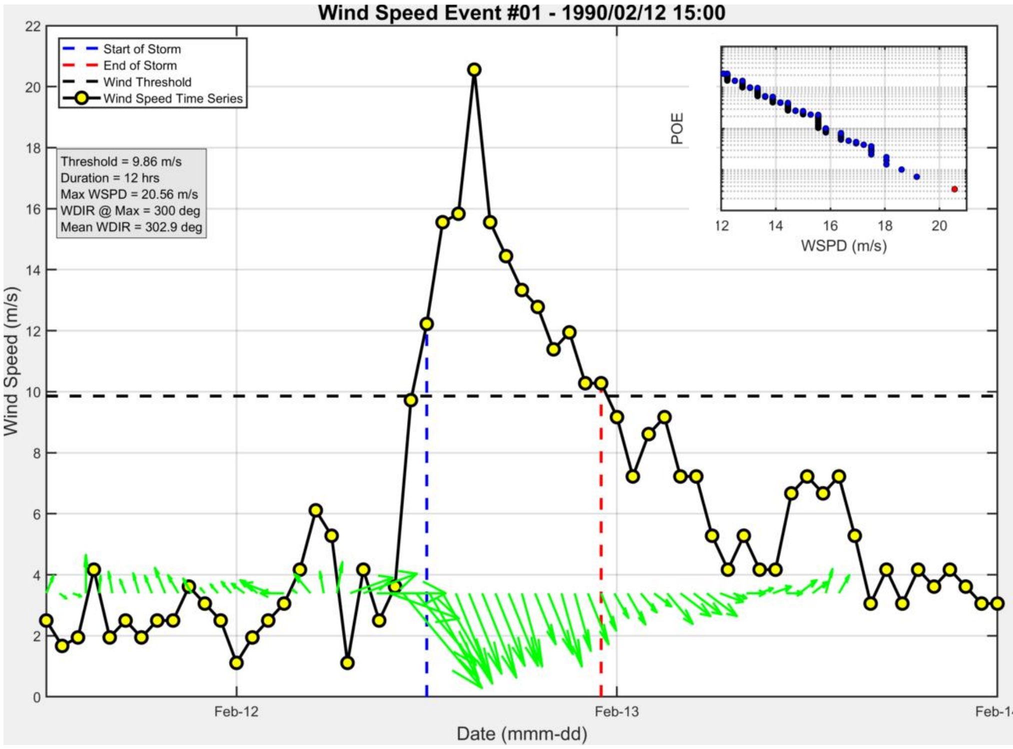
Table 3.2 Duration of Measured Wind Data at Stations

Wind Station	Start	End	Duration (years)
Bachelors Island	July 1994	Oct. 2010	16
Berens River	May 1985	Feb. 2019	34
George Island	March 2004	Jan. 2019	15

3.2.1 Storm Selection Methodology

Existing Matlab tools were used to identify historical windstorm events from the measured data. The user specifies a wind speed threshold, such as 10 m/s, that must be exceeded for an event to be considered a storm, a minimum duration, and a time lag (if winds drop below the threshold but then exceeds it again within the specified threshold, it is still considered one event).

A sample of the windstorms from Berens Island is presented below in Figure 3.11. Event #1 features the largest speed (20.6 m/s) with winds from the north-west. A similar storm, Event #31, also features waves from the north-west but the peak speed was only 14.4 m/s.



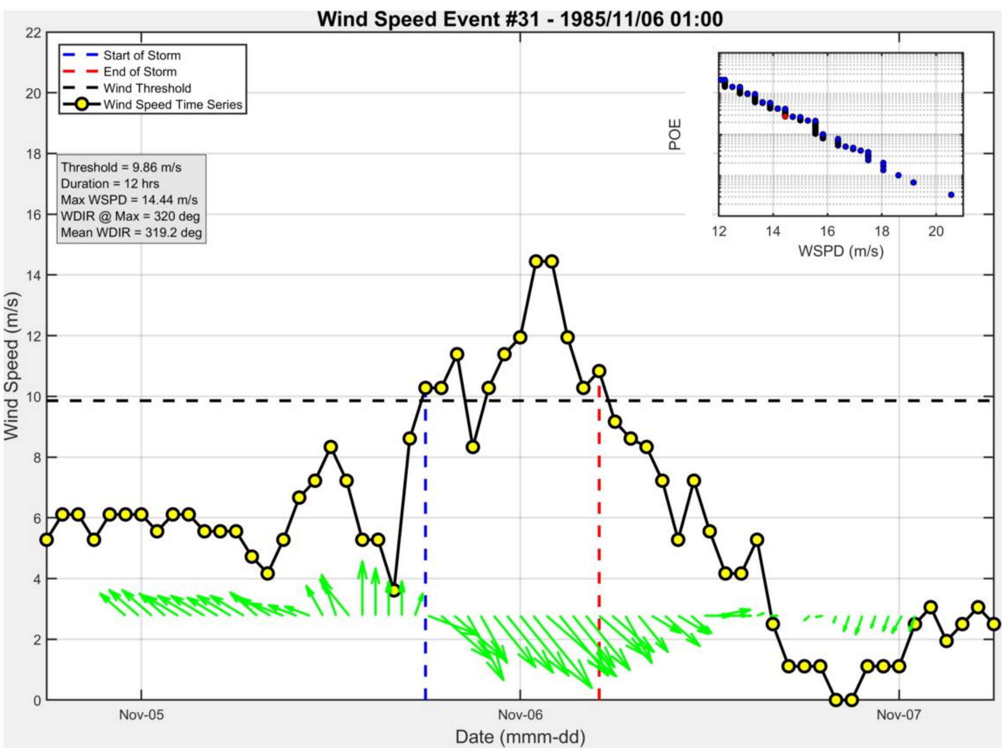
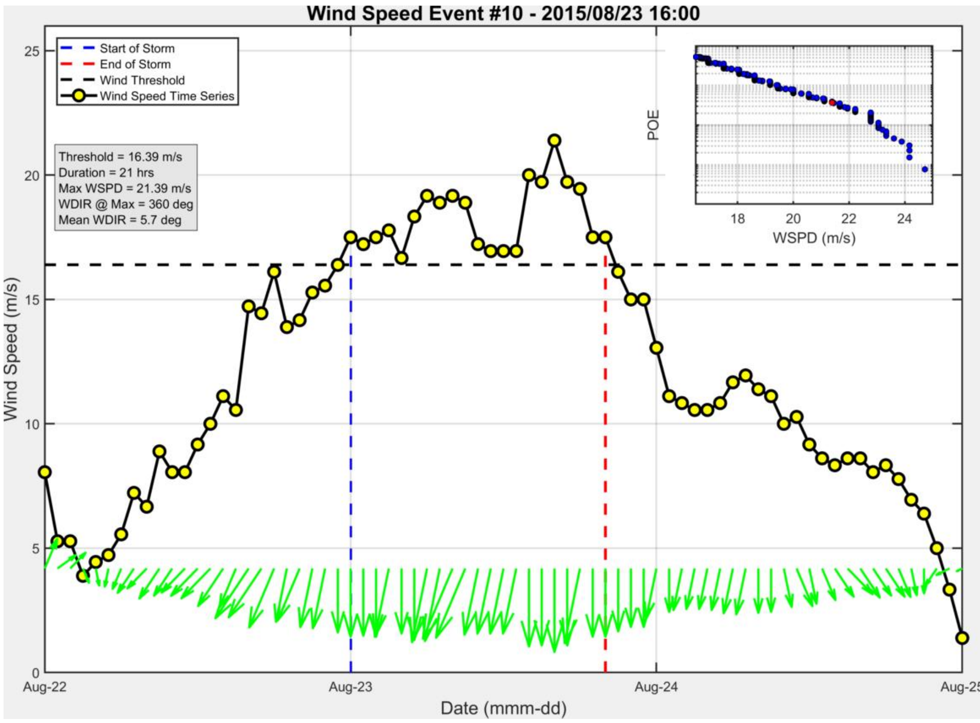


Figure 3.11 Storm Events from the Berens River Station

The George Island station is more exposed to the north winds on Lake Winnipeg than the Berens River station and thus additional storms were selected to evaluate sediment transport for the existing shoreline conditions. Figure 3.12 presents Storm 10 which is a large storm with winds from the north at 21 m/s, and Storm 32 which features winds from the north north-east at 18 m/s.



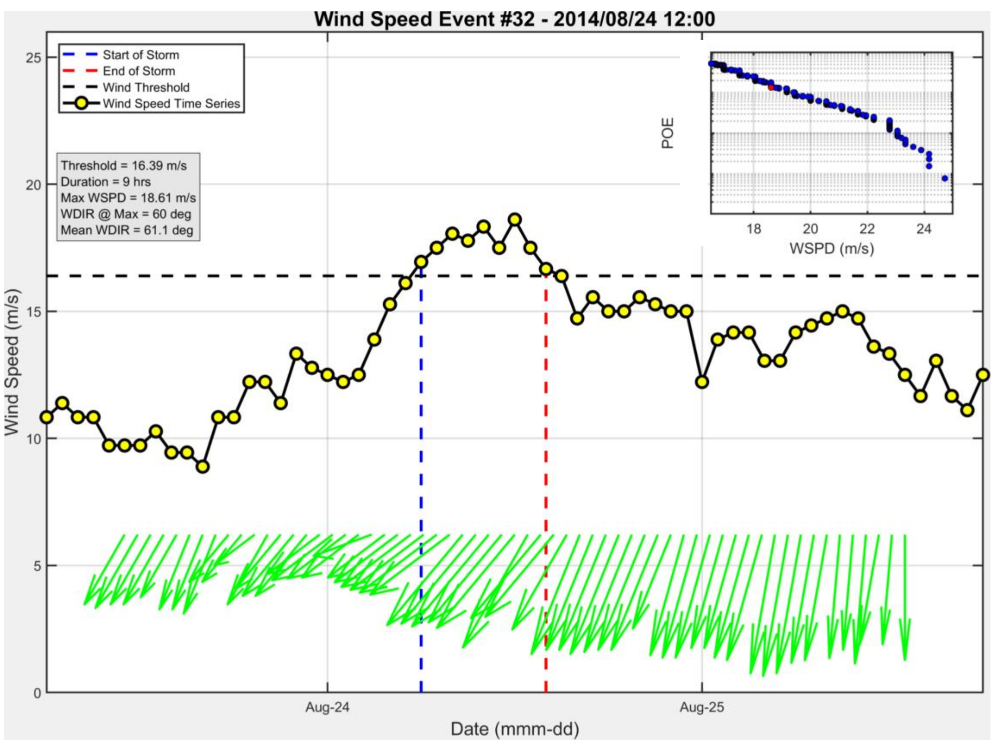
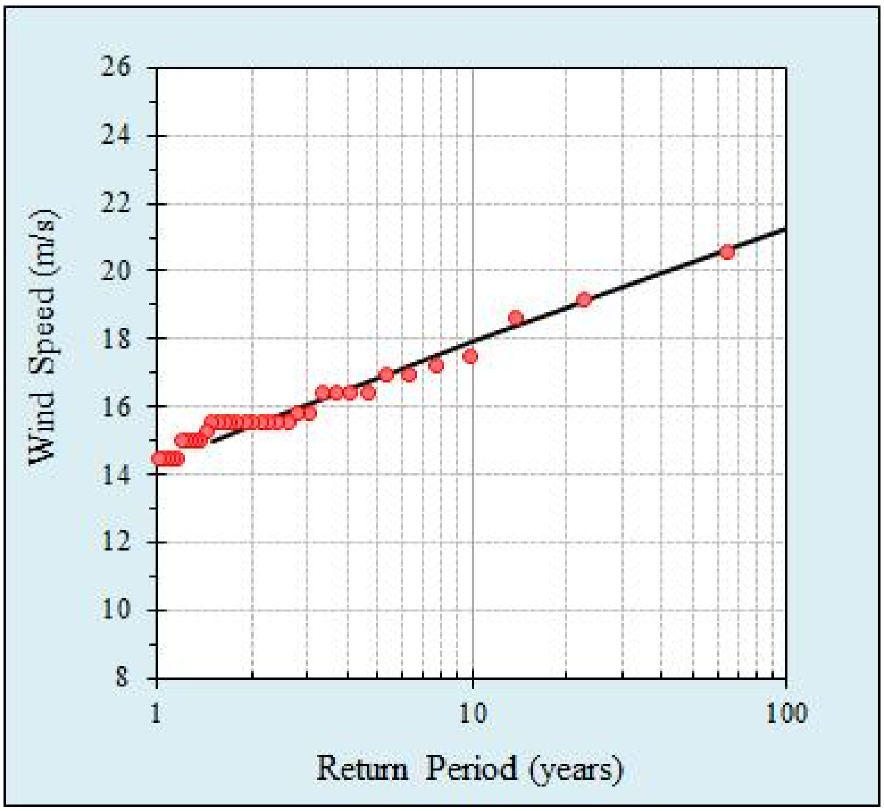


Figure 3.12 Storm Events from the George Island Station

3.2.2 Extreme Value Analysis for Windstorms

To estimate the return period for the storms identified in Section 3.2.1, an extreme-value analysis was completed on the winds from various stations close to the study area. The results for the Berens River station are presented in Figure 3.13. The Weibull distribution provided a good fit (0.99) and was selected over other probability distributions such as GEV, which also featured a good fit (0.99) but the tail of the probability distribution was concave upward.

The return periods are presented in the table in Figure 3.13. A 10-year return period storm features wind speeds of 18 m/s, while a 100-year return period storm features wind speeds of 21.3 m/s.



Probability Distribution for Berens River Winds
(*Weibull Distribution, Correlation: 0.99*)

Return Period	WSPD (m/s)
1	14.3
2	15.5
5	16.9
10	17.9
20	18.9
25	19.3
50	20.3
100	21.3

Return Period for Peak Wind Speed during a Storm

Figure 3.13 Probability Distribution and Return Periods for the Berens Island Winds

Based on the return periods in Figure 3.13, Wind Event #1 from Berens River is approximately a 50-year return period. Wind Event #31 features a return period of 1-year and a storm of this magnitude would be expected to occur at least once per year, on average.

As discussed previously, the George Island station featured higher wind speeds than Berens River, attributed to greater exposure to over-water winds. Further extreme-value analysis will be presented on historical windstorms for the preliminary and final design phases of the project.

3.3 Numerical Modeling by KGS Group

In support of the shoreline morphology analysis, KGS Group developed two-dimensional lake models for both Lake Winnipeg and Lake St. Martin, which were used to assess flows, water levels, wave conditions and shoreline current. The models were developed using DHI's two-dimensional modelling software, MIKE 21, which contains a number of different modules. The modules used for this work included the hydrodynamic module, which was primarily used to assess flows and water levels in the lakes, and the spectral wave model which was used to simulate wave height, period and direction for use in the shoreline geomorphology assessment.

The model domains included the entire area of both lakes, as shown on Figures 3.14 and 3.15. The finite element mesh for each model was developed such that it varied in density depending on location. Both meshes had the highest density in the areas of interest, including the Lake St. Martin Outlet Channel inlet and outlet. A high mesh density was also used in constrictions, including the narrows of both lakes, as well as areas with complex geometries, such islands or sand bars.

The Lake Winnipeg spectral wave model was calibrated and validated using data recorded at the north basin buoy in Lake Winnipeg. The buoy records wind speed and direction, as well as the significant wave height and significant wave period. From the recorded data, two wind events, including the July 2008 and June 2010 wind storms, were selected for model calibration. Model results for significant wave height and significant wave period were compared to the recorded data at the buoy. Model parameters that affect wave generation and breaking were altered until a good fit was achieved between the modelled and recorded wave data.

A third wind event, the September 2009 storm, was chosen from the buoy data for model validation. The model was simulated using the calibrated parameters and the resulting significant wave height and significant wave direction simulated by the model were compared to those measured at the buoy. It was determined that there was good agreement between the modelled and measured data.

A similar calibration and validation process was not undertaken for Lake St. Martin because detailed wind and wave calibration data was not available. Instead, the calibrated Lake Winnipeg parameters were directly applied to the Lake St. Martin model. Given the proximity and similar characteristics of the two lakes, this approach was deemed acceptable.

The calibrated models were used to simulate a number of wind events on Lake Winnipeg and Lake St. Martin. In order to determine how the initial lake level can affect the development of waves, the wind events were simulated for a range of lake levels. Three levels were used for Lake Winnipeg: low (217.0 m), average (217.5 m), and high (218.0 m). Only one lake level was selected for Lake St. Martin, 244.14 m, which corresponds to the design water level for the north basin. The model results from these simulations, including significant wave height, significant wave period, and wave direction were provided to Zuzek Inc. for use in the shoreline morphology assessment.

Further details on the development, calibration, and analyses completed with the numerical models are included in the KGS Preliminary Design Report.

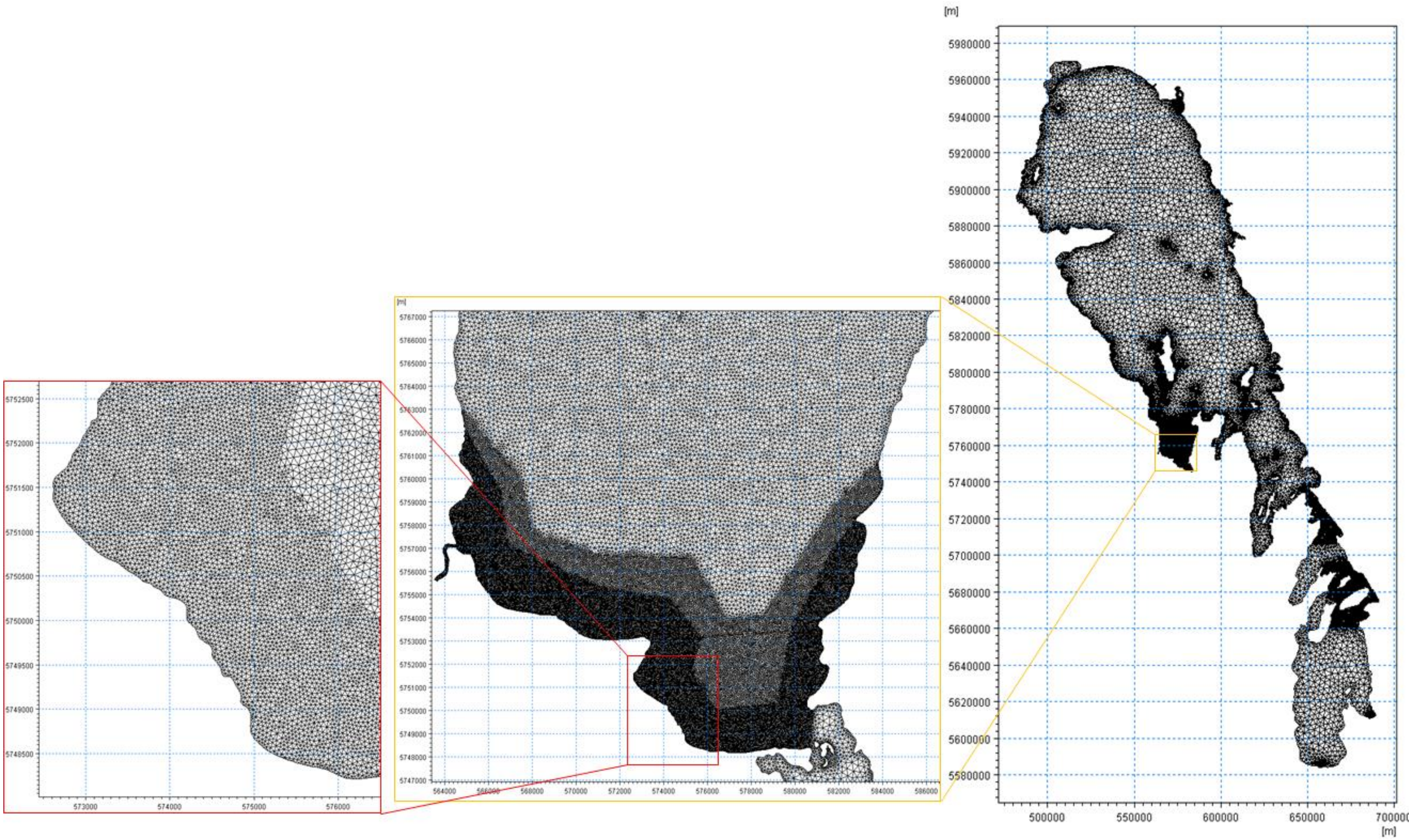


Figure 3.14 Lake Winnipeg MIKE21 Model Domain

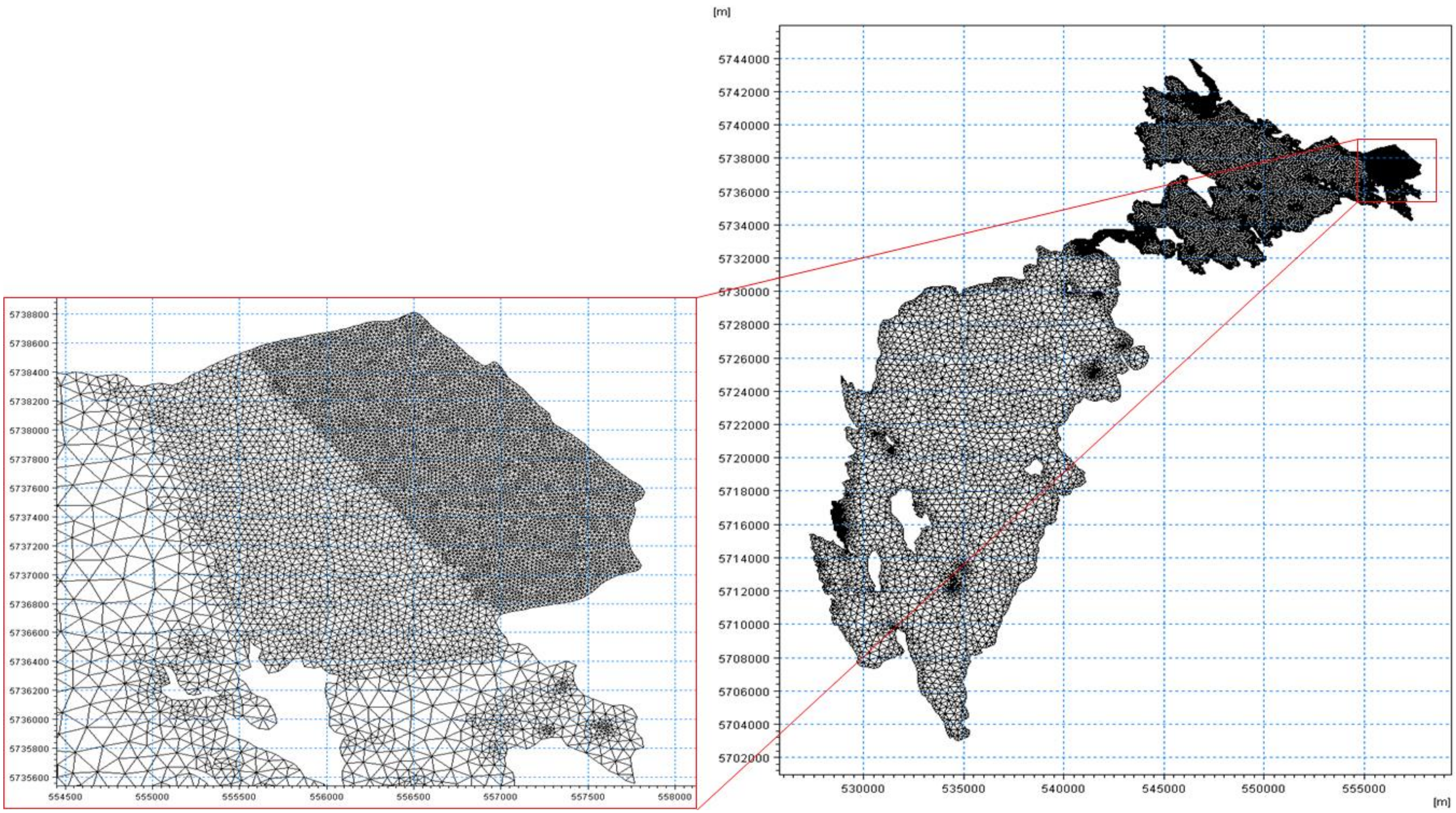


Figure 3.15 Lake St. Martin MIKE21 Model Domain

3.4 Sediment Transport Pathways

Longshore sediment transport is responsible for the movement of sand alongshore and accumulation in depositional features, such as sand spits, along lake and ocean shorelines. When waves approach the shoreline breaking occurs in shallow depths and often over bar features. The breaking process creates turbulence in the water column and suspends sand-sized particles in the water column (as well as silts and clays). When the waves approach at oblique angles, as depicted in Figure 3.16, they generate longshore currents that transport the suspended sediment along the shoreline (CEM, 2002). As waves approach the waters edge, swash-zone processes move sand grains along the beach at oblique angles, as seen in Figure 3.16.

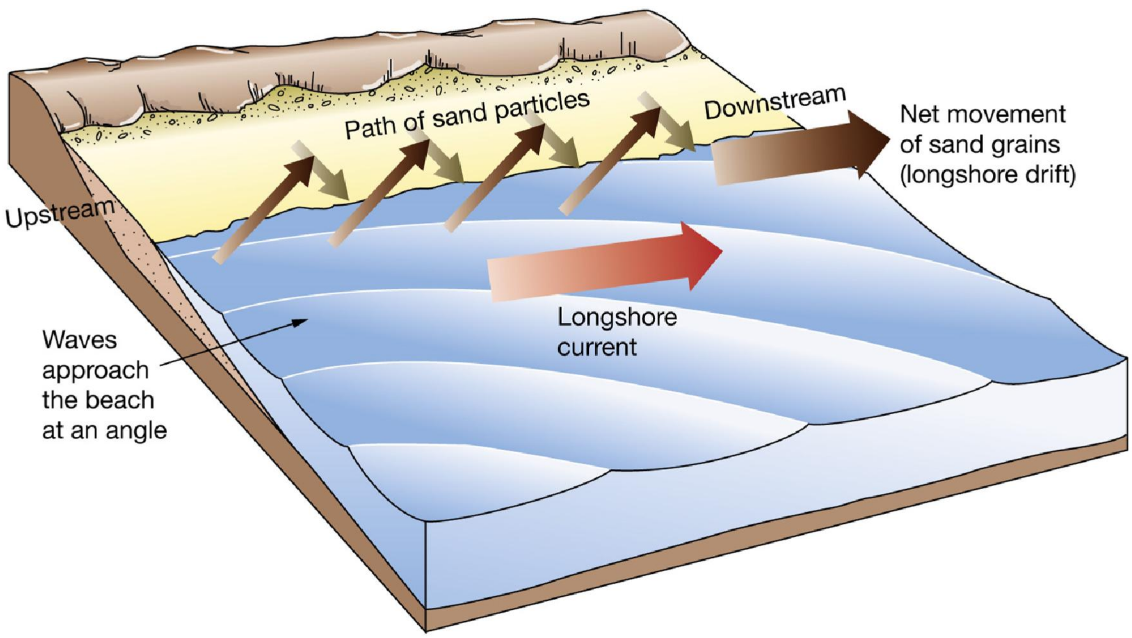


Figure 3.16 Conceptual Diagram of Longshore Sediment Transport

The potential for longshore sediment transport to move sand along the shoreline during storm events was evaluated in Sturgeon Bay at ten locations with the MIKE21 wave height predictions from the KGS Group, as described in Section 3.3. The 10 profile locations, extending from the Dauphin River Mouth to the Sturgeon Bay Park Reserve, are noted in Figure 3.17. At each of the 10 profile locations, hourly wave conditions were extracted at 13 save points across the profile during storms to characterize the changes in the wave conditions due to depth and wave refraction/diffraction. The location of the 13 save points for Profile 7 are noted on Figure 3.17.

To date, the focus for the sediment transport analysis has been three storms identified from the George Island Station; #10, 11, and 32, completed at three water levels (217.0 m, 217.5 m, and 2018 m CGVD). The CERC formula (CEM, 2002) was applied to the wave data to estimate potential sediment transport at each of the ten profiles. The CERC formula is an energy flux model and therefore requires breaking wave conditions to make estimates of longshore sediment transport for the hourly wave inputs. For each hour of data, the methodology checks for breaking waves from save point 13 to 1. The first occurrence of breaking waves is noted, and the equation is applied to predict potential sediment transport in cubic metres.

Figure 3.17 Sediment Transport Profiles and the Location of the 13 Profile 7 Save-Points from the MIKE21 Model

It should be emphasized that the CERC formula calculates ‘potential’ sediment transport rates at a given beach profile, assuming there is an unlimited updrift sediment supply and the entire profile is covered in a thick layer of sand. Based on our observations from the field, Sturgeon Bay does not feature unlimited sediment supply and the locations of sandy substrate are typically limited to the shallow nearshore zone and often associated with sand bars. Therefore, the volumetric estimates from the equation must be carefully evaluated against substrate conditions, since breaking waves across a cobble-boulder substrate will not move sand along the shoreline.

As discussed in Section 2.3.1, differences in the lake bottom depths from the MIKE21 model DEM and the SOLIX cross-sections collected in June 2019 were identified. East of Willow Point, the model bathymetry was generally deeper and did not feature detailed bed features, such as the nearshore sand bars at Profile 7 (Figure 3.18). The reason for this difference is being evaluated.

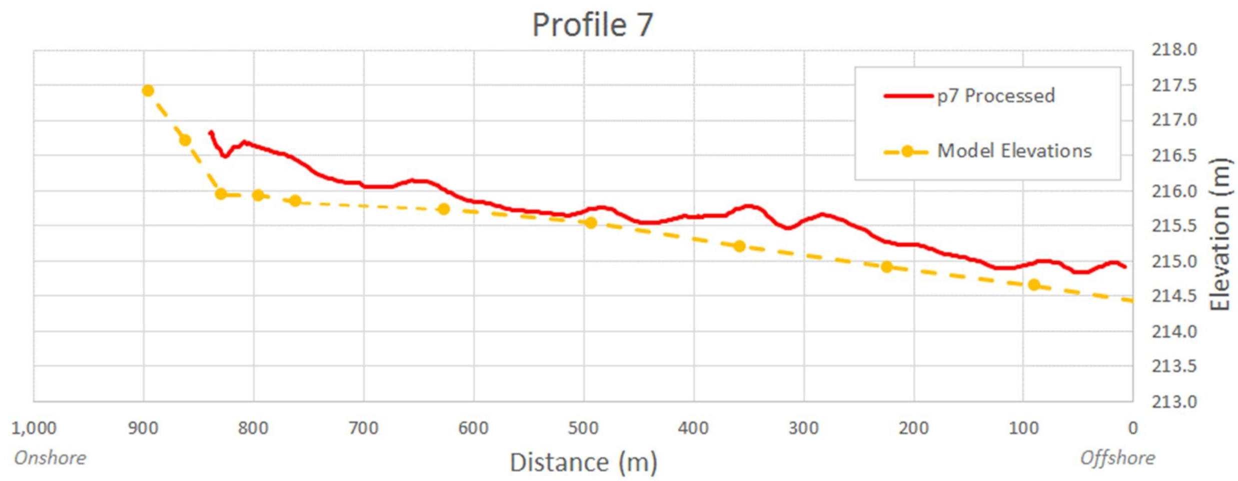


Figure 3.18 Profile 7 SOLIX Bathymetry and Output from the MIKE21 Model

When the SOLIX depths for Profile 7 were used with the CERC formula for Storm 32 from George Island, the potential sediment transport volume was approximately 2,500 m^3 to the west. With the depths from the MIKE21 model bathymetry, very little wave breaking occurred due to the deeper depths and the transport potential decreases to 150 m^3 to the west for the same storm.

Once the reason for the difference in the depths is resolved, the longshore sediment transport calculations will be re-run for Sturgeon Bay for the preliminary and final design stages of the project.

It should also be noted that the sediment transport routines with the CERC formula were not applied to Lake St. Martin, since longshore sediment transport is not a process that influences shoreline evolution or the re-distribution of sediments.

3.5 Sediment Budget for Existing Conditions

Given the small wave climate on Lake St. Martin near the inlet, the presence of large headlands, and an irregular shoreline, longshore sediment transport processes do not re-distribute sediment alongshore, as they do on Sturgeon Bay. Large cobbles and boulders that are eroded from the glacial till are largely left in place, as the fine sediments (silts and clays) are transported into the deeper part of the lake. There is sorting of sediments in headland features, as seen in Figure 2.13, but these pebbles/cobbles/boulders are not transported alongshore by the local wave climate. Ice push may be responsible for re-distributing and concentrating some of the larger boulders.

Conversely, sediment transport processes do re-distribute sand along the Sturgeon Bay shoreline, from the mouth of the Dauphin River to the Sturgeon Bay Park Reserve. To summarize the various sediment sources, transport pathways, and deposition environments, a conceptual sediment budget for the existing shoreline conditions was prepared and is summarized in Figure 3.19. The primary sediment sources, transport pathways, and sinks are described:

- **Sediment Sources** – for the shoreline of Sturgeon Bay, we are primarily interested in sand and pebbles. While silts and clays are eroded from the glacial till, they are not stable in the beach environment and are eventually transported to deep water and deposited in the mud zone offshore:

  - Large cobble and pebble shoals were observed in the Dauphin River upstream of the mouth, as seen in Figure 3.19. Similar material was collected with a ponar grab sample at the mouth of the river. Therefore, the Dauphin River may be a small source of cobbles and pebbles for the shoreline sediment budget.

  - The shoreline between the Dauphin River Mouth and Willow Point features a long-term erosion rate. The retreat of the shoreline and downcutting on the lake bottom will generate new sand, pebble, and cobble material for the shoreline sediment budget. Refer to Figure 3.19.

  - South of Willow Point, two sections of eroding shoreline also produce new material for the shoreline sediment budget.

- **Transport Pathways** – the sediment transport analysis is ongoing, as the questions are resolved about the differences in the model bathymetry and recent SOLIX data collection. Several preliminary trends are noted and presented graphically in Figure 3.19:

  - North-west Storms: sediment is transported from the Dauphin River mouth to the Sturgeon Bay Park Reserve. The amount of bypassing at Willow Point cannot be quantified with the CERC methodology. Only a small amount of bypassing is assumed. There is potential for sediment to move southward along the back side of Willow Point.

  - North Storms: the sediment transport patterns between the Dauphin River Mouth and Willow Point are still being investigated. There appears to be a sediment transport pathway from Willow Point south towards the location of the proposed outlet and it continues east towards the Sturgeon Bay Park Reserve. Sediment moves through the proposed outlet location but does not accumulate permanently.

  - North-east Storms: while the fetch for these storms is smaller than events from the north, the initial modeling suggests there is a convergence of transport potential from Lines 8 and 7 towards the proposed outlet, and Line 6. In other words, currents from north-east storms converge and result in temporary deposition on the lakebed at the proposed outlet location. However, as mentioned in the previous bullet, it appears this sediment does not accumulate permanently.

- **Sediment Sinks** – in a conventional sediment budget, sediment sinks are depositional environments and the shoreline is either stable or migrating lakeward. The Sturgeon Bay sediment budget is an anomaly in that the two predominant sediment sinks are eroding:

  - West Side of Willow Point: the west side of Willow Point is a sediment sink, with the presence of a high coastal ridge constructed of sand and large depositional lobes of sand migrating into the marsh. However, the shoreline features a long-term erosion rate.

- Outlet Location: the proposed outlet location appears to be a temporary sink for sediment when currents from north-east storms converge and deliver sediment to the area. The analysis completed to date suggests this sink is temporary, as north-west and north storms both have the potential to transport sediment out of the area towards the Reserve to the east.

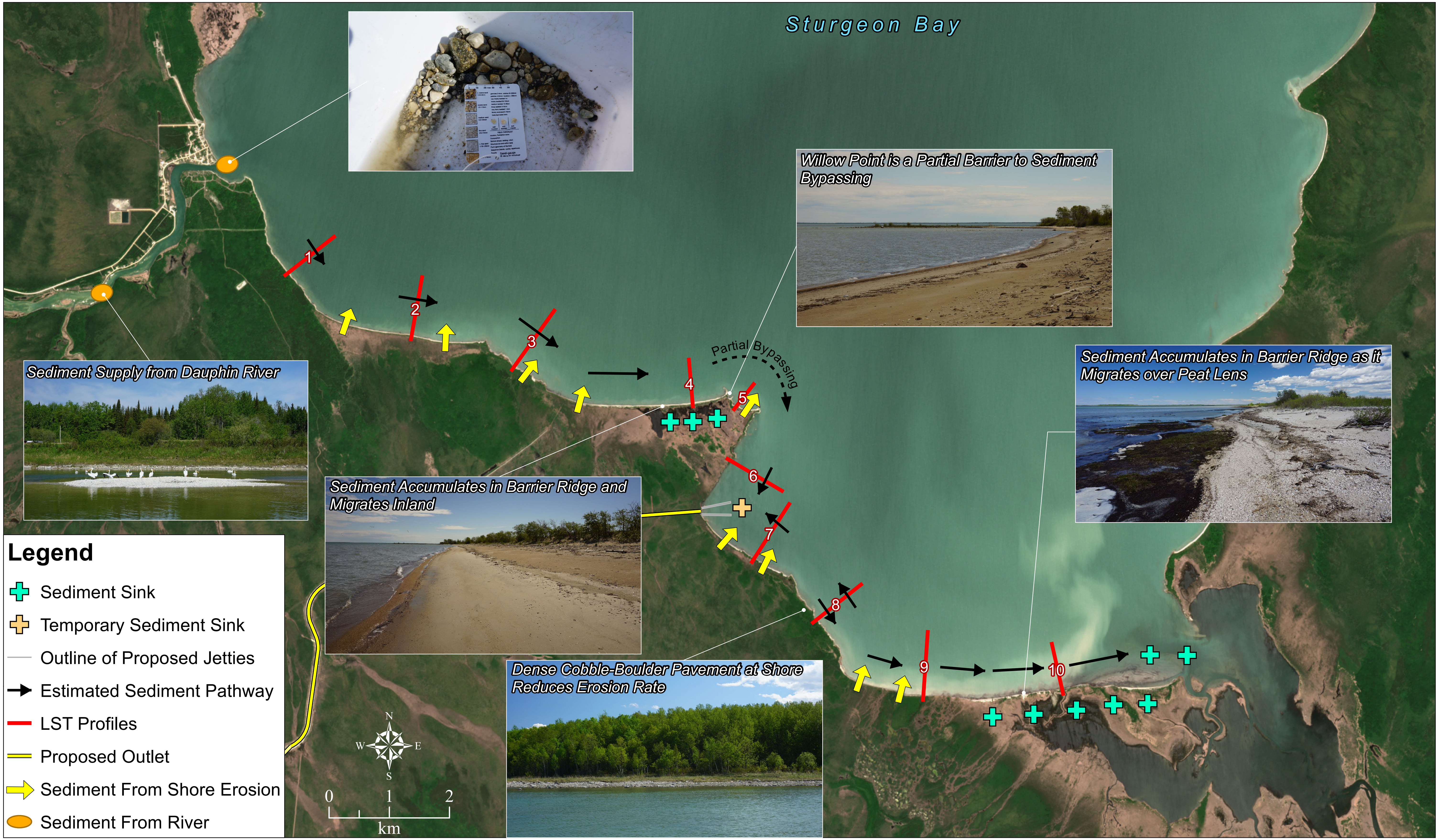
- Sturgeon Bay Park Reserve: The barrier beach that shelters the Reserve from Lake Winnipeg waves is migrating landward at 4 m to 7 m per year. While it migrates, large volumes of sediment are trapped in the depositional sand lobes in the marsh. As the barrier migrates inland, sediment is permanently removed from the littoral zone and deposited into the embayment.

The sediment budget findings indicate the proposed outlet location, in the lee of Willow Point, is a preferred location over the shoreline west of Willow Point and near the Sturgeon Bay Park Reserve. These are higher energy environments and also sediment sinks, which could lead to sedimentation in the outlet channel. The current proposed location features a lower risk of sedimentation once in operation.

The Sturgeon Bay sediment budget for the existing conditions is unusual in that the two primary depositional areas are also eroding. Typically, depositional environments in sediment budgets are either stable but more commonly accretional, with the shoreline migrating lakeward. One potential explanation for the erosional trend in the Sturgeon Bay sediment budget is the role of isostatic rebound. Since the retreat of the last continental glaciers, the earth's crust across Canada has been rebounding (rising). Since the ice stayed longer in northern Canada around Hudson Bay than in the south, the amount of compression of the earths crust was greater, and today the associated rate of rebound is also greater. Refer to the uplift map for Canada in Figure 3.20 based on information from the Canadian Base Network (Henton et al, 2016).

The earth's crust at the north end of Lake Winnipeg is rising by roughly 0.4 m/century, while the south end is rising by roughly 0.2 m/century. The difference means the water surface relative to the surrounding land is rising by roughly 0.2 m/century at the southern end of Lake Winnipeg. This theory has been verified with radio-carbon dating of submerged tree stumps found at the southern end of lake Winnipeg, that grew above the lake surface and were then subsequently submerged by the lake's encroachment to the south (H.Thorleifson, web).

If half the Lake Winnipeg differential is applied to Sturgeon Bay, the lake surface is rising by approximately 0.1 m/century relative to the land surface. Over a 500-year period, the lake surface would be 0.5 m higher than the land in Sturgeon Bay. This process may explain the inland migration of the barrier beaches on the west side of Willow Point and at the Sturgeon Bay Park Reserve, when the sediment budget results suggest they should be depositional environments and migrating lakeward (or at least stable). However, the shoreline is slowly being flooded due to isostatic rebound and erosion of the peat is occurring faster than the deposition of sand and gravel from longshore sediment transport. Plus, as the barrier beaches sink relative to the static lake level, it is easier for waves to overtop the crest of the barrier and transport sediment into the marsh. This process creates the depositional lobes observed in the field and noted in Figures 3.7 and 3.9.



STURGEON BAY

Figure 3.19 Sturgeon Bay Sediment Budget for Existing Conditions

Background Image: ESA Sentinel 2A Satellite dated June 18, 2019

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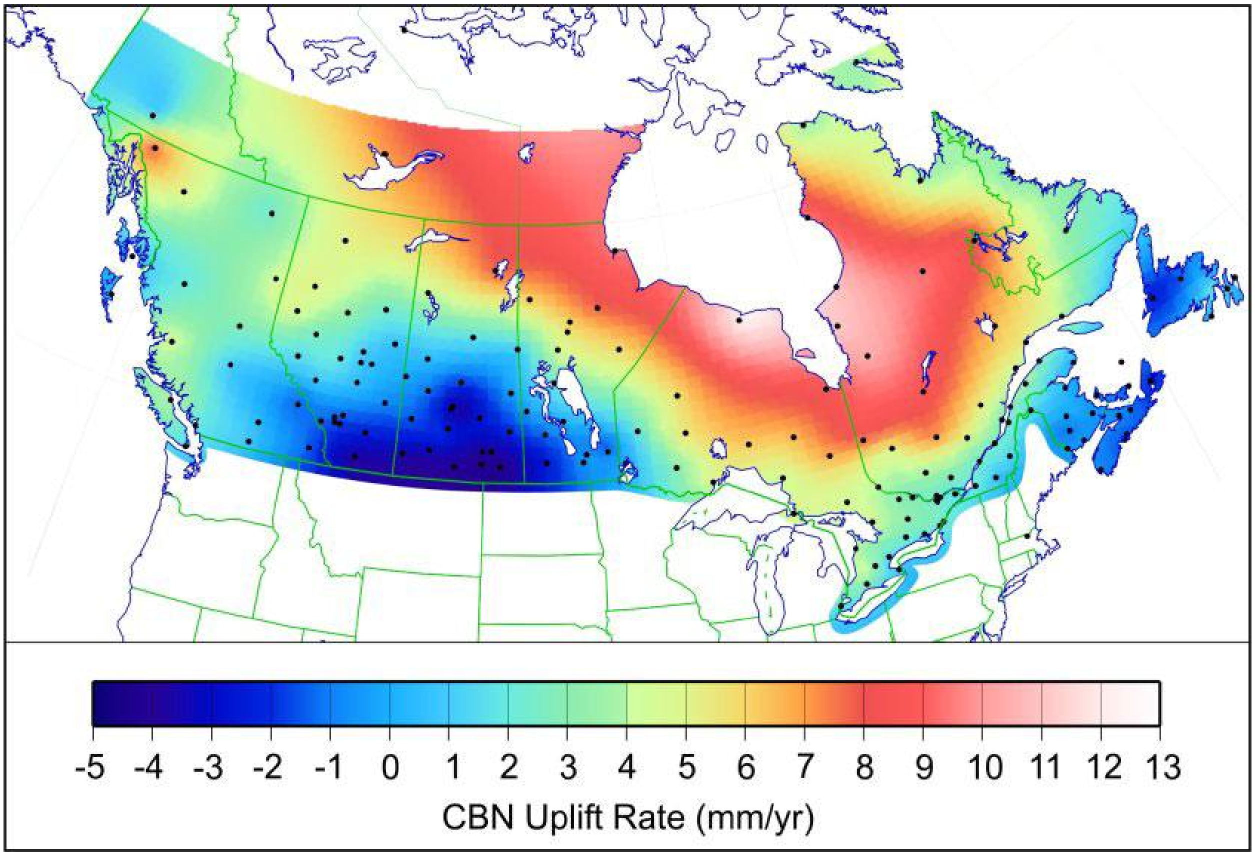

Figure 3.20 Differential Rates of Isostatic Rebound across Canada (Henton Et la, 2016)

4.0 FINDINGS

Section 4.0 summarises our key findings for the inlet on Lake St. Martin and the outlet on Sturgeon Bay. Next steps for our investigation are also outlined.

4.1 Lake St. Martin Inlet

Lake St. Martin is a small lake with two sub-basins. The proposed inlet is in the smaller northern basin. The open water fetch is only 12 km to the south-west. The key findings from the baseline shoreline assessment are summarized:

- The shoreline morphology is dominated by headlands and sheltered embayments, including the northern-most embayment which is the location of the proposed inlet.

- The headlands are self-armouring features that form when the glacial till features a higher concentration of cobbles and boulders than surrounding shorelines.

- Due to the small wave climate and irregular shoreline, longshore sediment transport is not a dominant process for shoreline evolution on Lake St. Martin.

- Based on long-term changes in the vegetation line near the inlet, the shoreline and lake bottom has been very stable since at least 1948. Erosion is not an active process influencing the morphology of the shoreline near the inlet or the adjacent shorelines.

- Due to the gentle nearshore slopes, water level extremes (highs and lows) can result in the migration of the water's edge upslope and downslope, but this should not be confused with shoreline erosion or deposition. It is simply the wetting and drying of a stable shoreline.

- Water level fluctuations do influence the migration of vegetation communities, including submerged aquatic vegetation, emergent vegetation, and meadow marsh. These changes are natural for a shoreline with gentle nearshore slopes and natural fluctuations in lake levels.

- The underlying glacial sediment is often covered by a thin veneer of sand, pebbles, and cobbles. Larger concentrations of clastic beach deposits were limited but were occasionally found adjacent to headland features. This observation suggests there are minimal sources of sediment (i.e., very little shoreline erosion) and limited mechanisms to move sediment in an alongshore direction by currents due to the shoreline morphology and small wave climate.

- The emergency relief channel at Reach 1 was observed and only one small deposit of sand was observed to the east of the inlet. It does not appear the operation of this channel resulted in significant erosion or sedimentation along the shoreline at Reach 1.

Based on these findings from the baseline shoreline assessment, it does not appear long engineered jetty structures protruding into the lake will be required at the inlet. However, it may be necessary to stabilize the shoreline at outlet and the channel banks to reduce the potential for erosion. Further recommendations will be provided as the inlet design progresses.

4.2 Sturgeon Bay Outlet

Sturgeon Bay is part of the Lake Winnipeg northern basin and is exposed to an open water fetch of 220 km to the north. Key findings from the baseline shoreline assessment are summarized:

- The shoreline between the mouth of the Dauphin River and Willow Point features a long-term erosion rate. Eroded sediment is transported to the south-west and accumulates in the sand ridge on the west side of Willow Point. This region could be considered a sub-littoral cell, with some leakage (or bypassing) of sediment to the south-east.

- The south or back-side of Willow Point is a peat shoreline and actively eroding. The eroded peat debris accumulates along the water's edge, including near the location of the proposed outlet.

- When the channel is not in operation, if the base flow is not significant, it may become a zone of sediment and debris accumulation (including peat).

- The shoreline to the south-east of the outlet is eroding at approximately 0.25 m/yr.

- Sediment eroded from the shoreline east of the proposed outlet is transported towards the Sturgeon Bay Park Reserve by storms from the north-west and north.

- Storms from the north-east generate currents and transport sediment south along Willow Point and from the east at the Reserve towards the west (towards the proposed outlet). These storms result in the convergence of sediment transport from the north and south-east, which partly contributes to the shallow depths in this region. The accumulation of sediment in this region appears to be temporary.

- The largest sediment sink in the study area is the barrier beach system at the Sturgeon Bay Park Reserve. However, this barrier is migrating inland due to washover events and possibly submergence due to the differential isostatic rebound rates from north to south on Lake Winnipeg.

- The proposed outlet location in the lee of Willow Point features a lower risk of sedimentation than the depositional shoreline west of Willow Point and along the Sturgeon Bay Park Reserve.

Based on the knowledge gained during the Baseline Shoreline Assessment, some form of engineered jetties will be required at the outlet where lake bottom excavation is planned. These structures will minimize sediment and debris accumulation in the channel, especially when not operated at full capacity. The evaluation of the jetty requirements and design (i.e., spatial extent, orientation, material, etc.) will continue during the preliminary design phase of the project with additional numerical modeling and sediment transport calculations.

4.3 Next Steps

Further sediment transport simulations will be completed to support the preliminary and final design of the inlet and outlet, including the evaluation of sedimentation potential during storm events at different lake levels. The evaluation of stabilizing structures at the inlet and outlet, such as jetties, will also continue. Finally, the influence of the proposed inlet and outlet on shoreline evolution, both near- and far-field, will also be investigated as the overall design is advanced.

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