Lake Manitoba Outlet Channel Shoreline Morphology Review

Final Report

15 November 2019

J D MOLLARD AND ASSOCIATES (2010) LIMITED

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JDMA Project #2018-026

Hatch Document Number: E358159-1000-228-230-0001 Rev. 0

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1 INTRODUCTION

Understanding the shoreline morphology within and adjacent to the channel inlet and outlet areas, and its historical evolution and stability, is required to assess the nature of ongoing erosion, sediment transport and deposition processes and their potential effect on the future long-term stability and sustainability of the inlet and outlet structures and their operation and maintenance.

This study consists of a shoreline morphology review of an approximately 2-km-long shoreline reach at the channel inlet and outlet areas (Map 1). Study results provide a general description of the present shoreline morphology, consider historical changes and related processes, and inform the sedimentation modelling team of shoreline morphology, erosion and sedimentation processes, and shore zone and substrate sediment characteristics to assist in guiding model development and validating model results against historical changes. This, in turn, allows for a better assessment of how shoreline processes may impact the project and, in turn, may be impacted by the project.

2 DATA SOURCES

Data sources used for the channel inlet and outlet areas include historical air photos, satellite imagery, LiDAR, bathymetry data, substrate data, field photographs, literature made available by the client, and information published in technical reports from earlier outlet channel investigations. Much of the data were used for both the channel inlet and outlet studies with only the air photos and bathymetry data being unique to each site. Below is a discussion of the datasets that were used for both the channel inlet and outlet.

Substrate data were made available from a previous AAE survey (2015/2016). The substrate data and description of materials were provided by AAE in their report: *Fisheries and Aquatic Habitat Baseline Assessment – Lake Manitoba Outlet Channel Route Options* (2016).

Field photographs were taken from previous reports by AAE, KGS, and North/South Consultants. These photos helped to identify various features along Watchorn Bay and Birch Bay as well as to describe the grain size of the beach material and nearshore substrate.

Photographs, visual observations and substrate samples were collected by the authors during two days of field reconnaissance in June 2019.

Several previous reports were reviewed to help understand the morphology of Watchorn Bay. These reports were provided by Manitoba Infrastructure and Transportation. In addition to these reports, other literature was consulted for this study. The literature used includes:

- AAE Tech Services Inc. Fisheries and Aquatic Habitat Baseline Assessment – Lake Manitoba Outlet Channel Route Options. November 2016.
- KGS Group. Assiniboine River and Lake Manitoba Basins Flood Mitigation Study LMB & LSM Outlet Channels Conceptual Design – Stage 2. January 2016.
- KGS Group. Investigations and Preliminary Engineering for LMB Outlet Channels Options C and D Summary Report. May 2017.
- Koohzare, A. A Physically Meaningful Model of Vertical Crustal Movements in Canada Using Smooth Piecewise Algebraic Approximation: Constraints for Glacial Isostatic Adjustment Models. Geodesy and Geomatics Engineering, University of New Brunswick Technical Report No. 246. April 2007.
- Manitoba Infrastructure and Transportation. Provincial Flood Control Infrastructure Review of Operating Guidelines A Report to the Minister of Manitoba Infrastructure and Transportation. August 2015.
- Manitoba Infrastructure and Transportation. Lake Manitoba Channel, Option D, Lake Manitoba and Lake St. Martin Test Hole Logs, Core Logs, and Laboratory Testing Results. May 2017.
- Manitoba Government. 2011 Flood: Technical Review of Lake Manitoba, Lake St. Martin and Assiniboine River Water Levels. October 2013
- SG Environmental Services Inc. Lake Manitoba Outlet Channels – Vegetation Technical Report. December 2016.

2.1 Channel Inlet

Historical air photos and other imagery sources were chosen for this location that encompass at least 2 km adjacent to the channel inlet. Historical air photos, satellite imagery, and ortho-imagery chosen for this

location and their attributes are listed in Table 1. The historical air photos and satellite imagery were used to map the shoreline along Watchorn Bay.

Table 1: Imagery used for the channel inlet (Watchorn Bay) study

Imagery date	Source	Air photo roll number	Scale/resolution	Lake elevation (metres)
05-Sept-1948	National Airphoto Library (NAPL)	A11781	15,000	247.85
14-May-1958	NAPL	A15968	40,000	247.79
13-August-1961	NAPL	A17414	15,000	247.67
01-July-1986	NAPL	A26940	60,000	247.62
31-July-1993	Manitoba Airphoto Library (MAPL)	MB93031	15,840	247.42
01-August-1996	Manitoba Land Inventory	-	2 m	247.78
15-July-2011	Google Earth	-	50 cm	249.06
17-May-2016	ESRI	-	50 cm	247.57
August-2017	Manitoba Infrastructure and Transportation	-	5 cm	247.81

A LiDAR dataset was also included with the 2017 imagery provided by Manitoba Infrastructure and Transportation and listed above. The bare-earth topographic data were used from this LiDAR dataset to describe landforms, map the raised beach ridge, and to map the shoreline. The 2017 LiDAR data and imagery covered approximately 1,500 metres on either side of the inlet channel including the inlet of Watchorn Creek, and all of Watchorn Provincial Park. The imagery extends up to 400 metres into the lake and does not cover an offshore island that is approximately 1,500 metres offshore or the inlet of Mercer Creek to the west of the inlet channel.

Bathymetry data were obtained from KGS Group (2014 survey) and AAE Tech Services Inc. (2015/2016 surveys). Both data sources have previously had depth converted to ground elevation; however, the vertical datums used for these data are not known. Where there is overlap between the datasets a comparison was made of their respective elevation (n=20). It was found that the average difference in reported ground elevations is 20 cm ± 9 cm (1 SD). A conversion between the HT2_2010 and CGG2013a datums reveals approximately 28 cm of difference in ground elevation between these geoids at Watchorn Bay. It may be possible that the largest amount of difference in elevation is due to using inconsistent datums between the two surveys, if in fact they were different.

2.2 Channel Outlet

Historical air photos and other imagery sourced were chosen for this location that encompass at least 2 km adjacent the channel outlet. Historical air photos, satellite imagery, and ortho-imagery chosen for this location and their attributes are listed in Table 2. The historical air photos and satellite imagery were used to map the shoreline along Birch Bay up to 1 km on either side of the outlet channel.

Table 2: Imagery used for the channel outlet (Birch Bay) study

Imagery date	Source	Air photo roll number	Scale/resolution	Lake elevation (metres)
28-Sept-1948	National Airphoto Library (NAPL)	A11780	20,000	N.A.
16-May-1958	NAPL	A15959	40,000	243.44
13-August-1961	NAPL	A17412	20,000	242.69
21-July-1977	NAPL	A24740	50,000	243.68
17-June-1993	Manitoba Airphoto Library (MAPL)	MB93016	15,840	242.82
01-July-1998	Manitoba Land Inventory	-	2 m	243.67
15-July-2011	Google Earth	-	50 cm	245.47
09-May-2014	ESRI	-	46 cm	244.40
August-2017	Manitoba Infrastructure and Transportation	-	5 cm	244.74

A LiDAR dataset was included along with the 2017 imagery provided by Manitoba Infrastructure and Transportation and listed above. The bare-earth topographic data were used from this dataset to describe landforms and to map the shoreline. The 2017 LiDAR data and imagery covered the outlet of Birch Creek into Birch Bay including 1,000 metres of shoreline east of the channel outlet. However, the 2017 imagery and LiDAR do not cover the shoreline northwest of the channel outlet nor do they cover a large part of the outlet channel. Therefore, there is no accurate ground elevation or 2017 imagery at these locations to compare to other historical air photos (Figure 1).

Figure 1: LiDAR and 2017 image coverage of Birch Bay.

Bathymetry data were obtained from AAE from a 2015/2016 survey. This bathymetry data covers Birch Bay, including up to 400 metres from the shoreline in the more open parts of the bay. No vertical datum was reported for these data.

3 METHODOLOGY

This study was undertaken at two locations: a) the channel inlet (Watchorn Bay, Lake Manitoba), and b) channel outlet (Birch Bay, Lake St. Martin). Study tasks were similar for the inlet and outlet areas with only minor differences due to differences in available data.

The first step for both inlet and outlet locations was to query hydrometric lake level data as well as wind data from surrounding station locations. Hydrometric data came from Environment and Climate Change Canada's Water Survey of Canada (WSC) while wind data came from Environment and Climate Change Canada's Meteorological Service of Canada (MSC). Figure 2 shows the location of the WSC and MSC gauge locations that were used in this study.

For lake level on Lake Manitoba the hydrometric gauge at Steep Rock (05LK002) was chosen as the preferred gauge as it is much closer to the inlet site than the gauge near Westbourne (05LL012). The gauge at Steep Rock has a continuous hydrometric record extending from 1923-present, with data up to 2017 published as "Approved" at the time of this study. For lake level on Lake St. Martin only one active gauge is located on the lake. The gauge near Hilbre (05LM005) has a continuous record extending from 1966-present, with data up to 2017 published as "Approved" at this time. Before 1966 there are data from a discontinued gauge at Sandy Bay (05LM003) that was active from 1950-1966. This record was merged with the active gauge to create a single time-series. The hydrometric records were used to evaluate fluctuations in lake level and compare them to the dates of historical imagery.

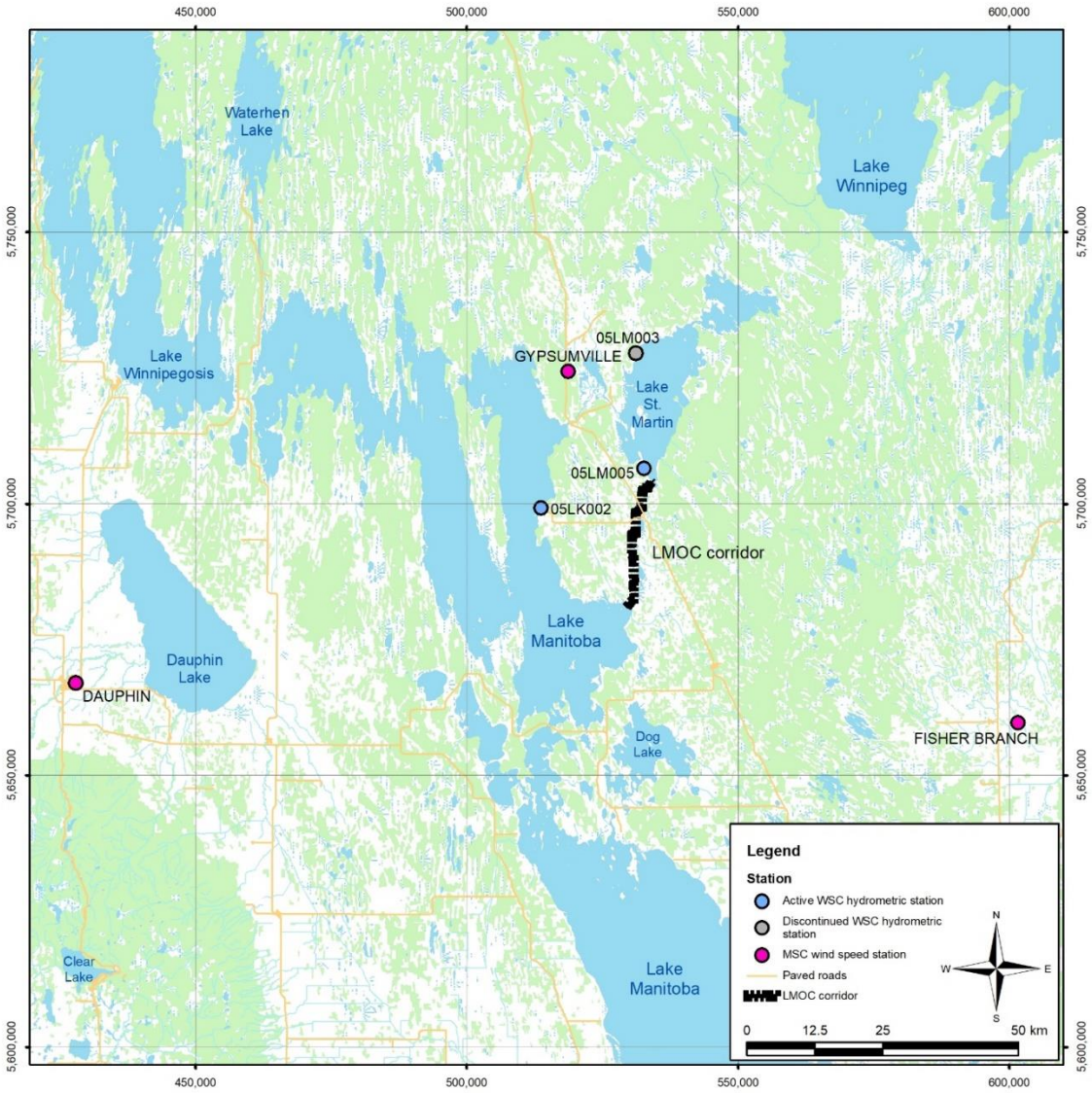


Figure 2: Location of LMOC corridor in relation to lake level and wind direction stations.

Wind data were used to qualitatively asses the direction and magnitude of wind at both the channel inlet and outlet locations. Wind data were obtained from the Dauphin, Fisher Branch and Gypsumville meteorological stations (Figure 2). Wind roses were constructed from the hourly data to identify the magnitude and direction of wind at each station. These sites are described below in Table 3.

Table 3: Wind stations near study areas

Station Name	Station ID	Period of record	Distance to LM	Distance to LSM
Dauphin	3779	1953-2016	103 km	112 km
Fisher Branch	8993	1994-2018	75 km	80 km
Gypsumville	3802	1966-1987	44 km	25 km

Historical air photos obtained from both the NAPL and MAPL (Table 1 and Table 2) were georeferenced using ortho-imagery from 1996/1998, 2014, and 2017 to provide suitable ground control across each frame. Once the air photos were corrected by aligning terrestrial features on the air photos to the orthoimages, shorelines were mapped on all imagery in both the inlet and outlet study areas. Following the mapping of the shorelines at each location, the shorelines were compared to each other, relative to water level, and changes in morphology or character of the shoreline were noted.

In order to use the bathymetry data some post-processing was required. To create seamless DEMs for both Watchorn Bay and Birch Bay the bathymetric datasets were merged together and then merged with the LiDAR dataset. This allowed for the construction of cross-sections at both the inlet and outlet locations that extended across the full nearshore slope onto the upland.

At Watchorn Bay, where there are two bathymetry data sets, areas of overlap were managed by selecting the 2014 KGS survey over the 2015/2016 AAE survey because the density of points was much greater in the KGS survey, allowing for more detail of the lake bottom to be defined. Points from the AAE survey were removed for a buffer of 50 metres around the KGS survey so that when they were combined into a single file there would be no sharp edge lines present. The bathymetric surveys were tied to the LiDAR to create a smooth surface running from onshore to offshore. The data gap along the shoreline between the edge of the ground in the LiDAR and nearest bathymetric points was interpolated as a smooth surface. Although this may not reflect the true character of the nearshore slope in this area the depths over the missing range are only in the order of 1-1.5 metres.

To create a seamless DEM at Birch Bay, the 2015/2016 AAE bathymetry was merged with the LiDAR dataset. Where there was no LiDAR coverage around the bay, reasonable ground elevations were assumed at the edge of the shoreline that could be seen in older imagery (1998 and 2014 imagery). This was done so that the nearshore slopes would not begin at a point inland, where it is clear from imagery these slopes do not exist. Water elevation in Lake St. Martin was relatively high (98^{th} percentile) during the LiDAR survey. As a result, some features around the channel outlet that are visible both underwater in 2017 imagery and in historical air photos do not show up in the LiDAR dataset. There is a slight expression of them in the bathymetry, however they are likely underrepresented.

In order to assess the substrate material and grain size at both the inlet and outlet locations, substrate mapping was reviewed from AAE's 2016 report: *Fisheries and Aquatic Habitat Baseline Assessment – Lake Manitoba Outlet Channel Route Options*.

On June 11 and 12, 2019, two engineers and a hydrologist from J.D. Mollard and Associates and Hatch visited the channel inlet and channel outlet locations on Lake Manitoba and Lake St. Martin, respectively. The purpose of the field trip was to make field observations on shoreline morphology, erosion and sedimentation processes, and to collect substrate samples. Locations visited are shown in Figure 3.

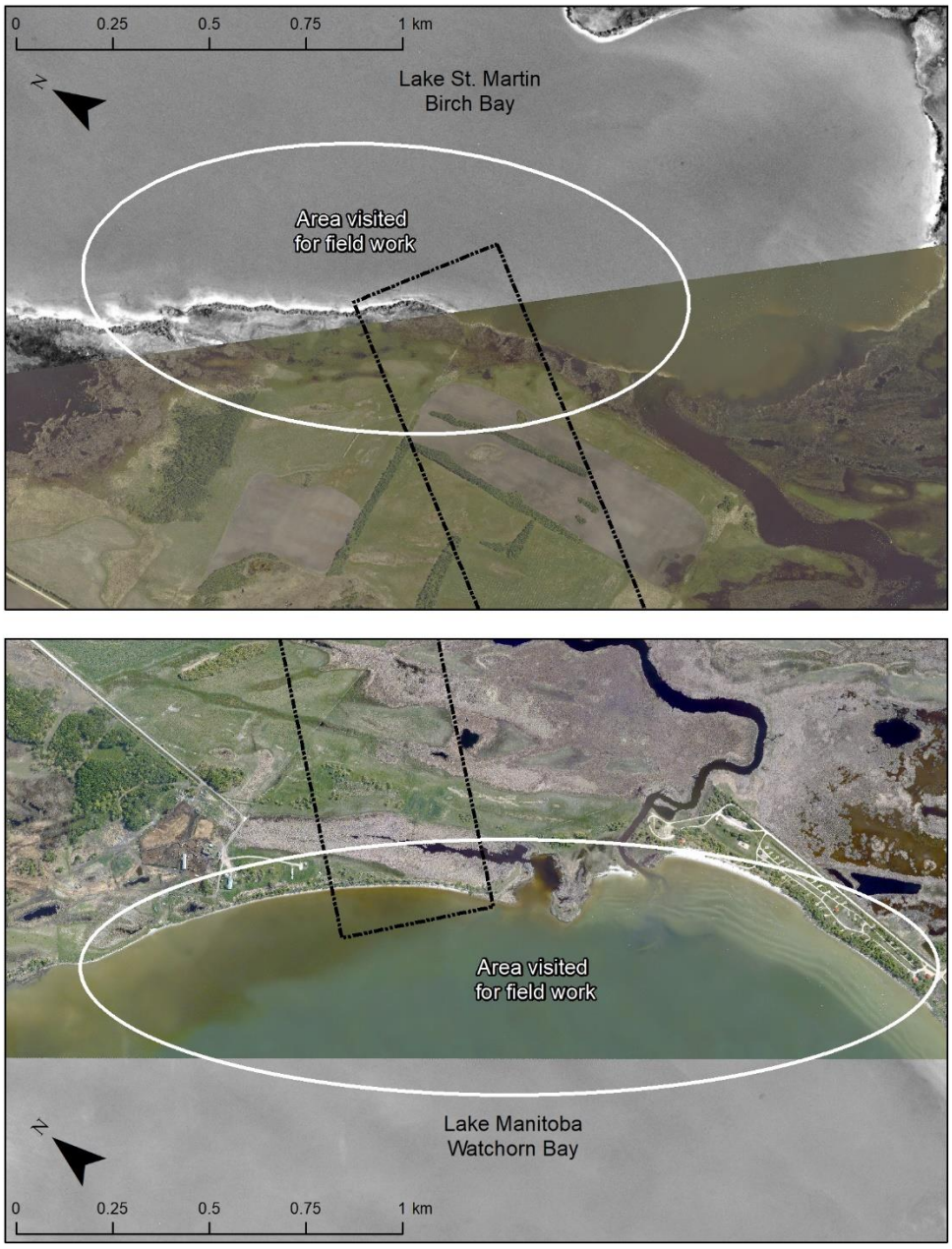


Figure 3: Location of sites visited in the field on June 11/12, 2019.

The study sites were accessed by boat and field work consisted of collecting substrate samples with a Ponar sampler and hand corer near the inlet and outlet locations. Sediment samples were photographed in the boat and then visually examined, hand textured and washed over a 1.18mm sieve. Visual observations of the beach and adjacent nearshore area were made from the boat and walking the nearshore area. Observations were summarized in field notes and photographed, including acquisition of UAV video coverage.

4 RESULTS - CHANNEL INLET

4.1 General Setting

The channel inlet is located near the centre of Watchorn Bay on the east side of Lake Manitoba's northern basin. Watchorn Bay is a large elliptical bay with a bay mouth width of approximately 5.2 km and an embayment that is recessed approximately 3.2 km into the east shoreline. The long axis of the bay is oriented approximately NE-SW resulting in fetch exposure to westerly to southwesterly winds. The maximum fetch is 26 km from the southwest. The westerly fetch is approximately 19 km with open water restricted to the southern half of this fetch direction. Map 2 shows an overview of Watchorn Bay.

Wind data from three MSC weather stations shown in Figure 2 were plotted as wind roses. Each station has a relatively unique wind profile which makes it difficult to say with certainty what the local wind conditions might be within Watchorn Bay. The wind roses for each station are shown in Figure 4. All three stations have a strong westerly component, which is the direction that exposes Watchorn Bay to the longest fetch. The Gypsumville and Fisher Branch stations have strong north and south components, which would not have a large impact in Watchorn Bay because it is much more protected from these directions than it is from the west and southwest. The Dauphin wind station has primary wind directions from the west and west-south-west. If this wind rose is used as the primary wind rose for wind exposure in Watchorn Bay, most of the wind exposure aligns with the greatest fetch exposure, putting the head of the bay at greatest exposure to wave action. However, the Dauphin station is the furthest station from Watchorn Bay and therefore perhaps less representative of conditions in the bay (Table 3).

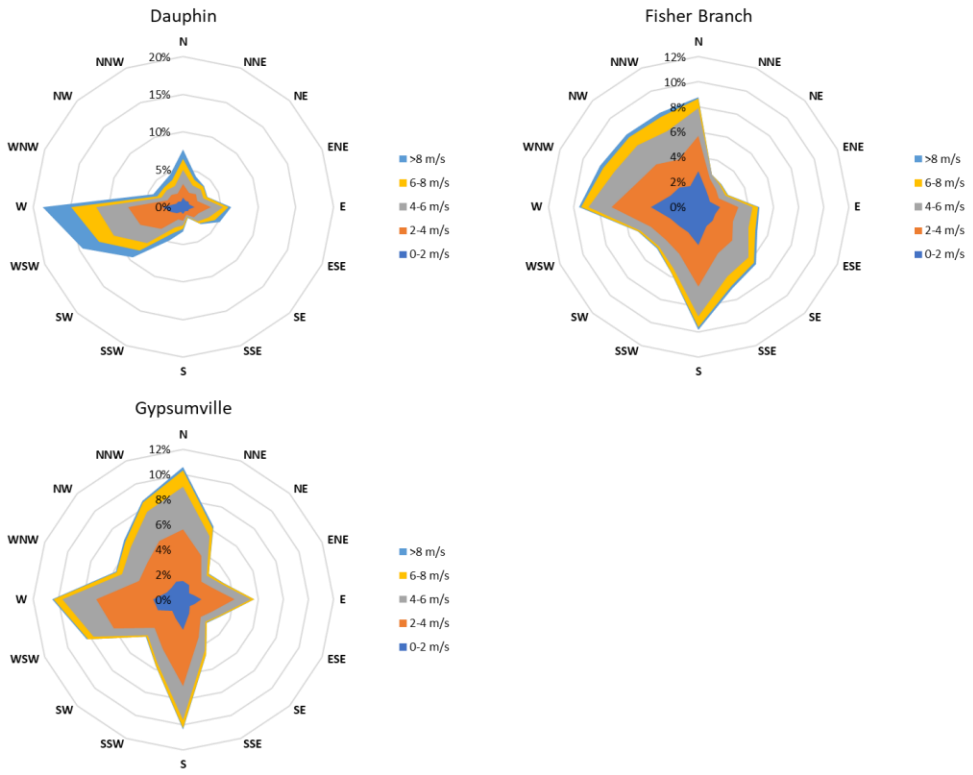


Figure 4: Wind rose of Dauphin station (1953-2016), Fisher Branch station (1994-2018), and Gypsumville station (1966-1987).

To determine the range of lake levels in Watchorn Bay, daily lake level data from the gauge at Steep Rock (05LK002) were obtained. Steep Rock is in the northern basin of Lake Manitoba and is the closest hydrometric gauge to Watchorn Bay. Figure 5 shows the daily hydrograph over the record, annual average hydrograph, and exceedance probability for lake levels.

There has been a range of 2.24 metres in lake level on Lake Manitoba since records have been kept (95-years). The daily hydrograph over the entire period shows greater fluctuation in level before 1961, which corresponds to when the Fairford River Water Control Structure was installed (Manitoba Infrastructure and Transportation 2015). Since this time, peaks and troughs in lake level have been attenuated. A notable exception is the 2011 event which appears to be the largest event on record and may have been enhanced by up to 0.1 metre by the operation of the Portage Diversion (Manitoba Government 2013). A summary of lake levels reported at the Steep Rock gauge (05LK002) and target operating levels are reported in Table 4.

Table 4: Lake Manitoba lake levels and statistics

Parameter	**Lake level (metres)**
1961 Lake Manitoba target lake level (812.3 ft)	247.59
Mid-60s adjusted target lake level (812.17 ft)	247.55
2001 Lake Manitoba operating range (810.5-812.5 ft)	247.04-247.65
2013 Lake Manitoba revised op. range (810-812 ft)	246.89-247.50
Mean lake level ± standard deviation	247.52 ± 0.28
Range of lake level	2.24
Maximum lake level (July 21, 2011)	249.11
75th Percentile lake level	247.64
50th Percentile (median) lake level	247.49
25th Percentile lake level	247.37
Minimum lake level (October 14, 1943)	246.86

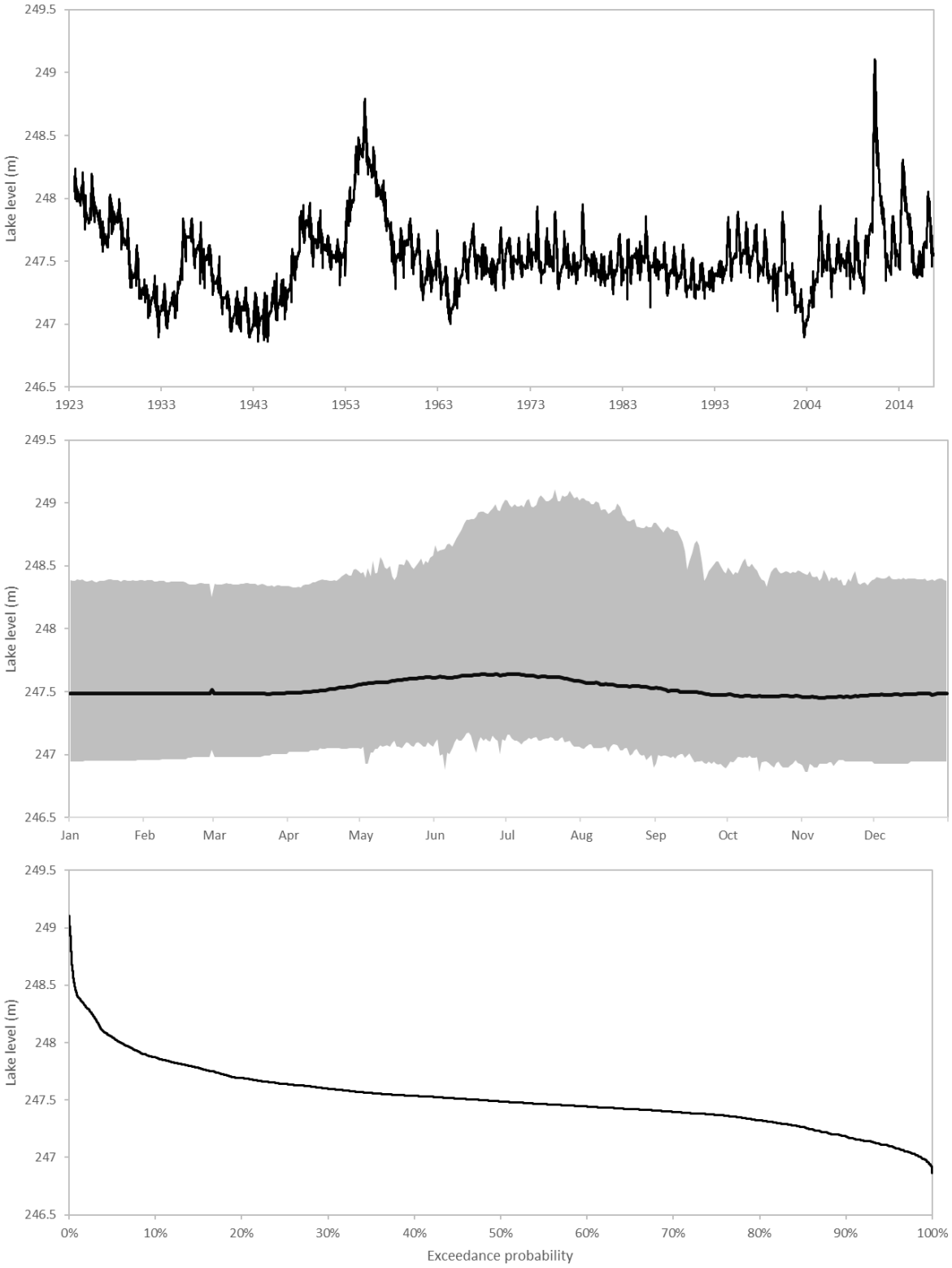


Figure 5: Lake Manitoba (05LK002) hydrometric summary showing daily hydrograph, annual average hydrograph and total range of flows, and exceedance probability curve.

Lake Manitoba is regulated by both inflow and outflow. In 2013, changes were made to the way that Lake Manitoba is regulated. Lake Manitoba can fluctuate between 246.89-247.50 m (810-812 feet). Above and below this range intervention is taken with respect to opening and closing the Fairford River Control Structure (Manitoba Infrastructure 2015). This range was 0.15 m higher (247.04-247.65 m) prior to the operating adjustment made in 2013.

4.2 Bathymetry

The bathymetry of Watchorn Bay is characterized by a gently sloping lake bottom that reaches depths of only 1-2 m approximately 500 m offshore. Maximum nearshore slopes are in the order of 0.5°-2.5° within approximately 25-100m of the shoreline. A 200 m-long island formed by a narrow ridge some 1,500 m offshore from the inlet area attests to the generally shallow water depths in the bay. The island can be seen in Map 2. Map 3 shows the bathymetry of Watchorn Bay while Map 4 shows four representative profiles across the study reach. Bedforms that extend approximately 100-200 m offshore along the Watchorn Beach shoreline indicate that incoming waves interact with the substrate at this location resulting in sediment movement in inshore and offshore directions and formation of low ridges and troughs parallel to the shoreline. These bedforms also indicate that nearshore downcutting due to wave action is likely negligible. Although the bedforms are not well captured in the bathymetry data they can be seen clearly in the 2017 aerial imagery (Map 2).

4.3 Substrate

Substrate data from sonar surveys are available for an area that extends approximately 750 m offshore from the proposed channel inlet area. Substrate data indicate a nearshore zone of dominantly sandy substrate out to approximately 60 m offshore near the inlet and 250 m offshore farther west (AAE 2016). Within this zone there is up to 10% boulder mix as well. Gravel with sand and silt substrate extends from as close as 60 m offshore to 750 m offshore in places. Elsewhere, large discontinuous areas of sand and gravel are located between approximately 250-750 m offshore (AAE 2016). The substrate mapping is displayed in Map 5. The results of substrate sampling are summarized in Section 4.5.

Field photographs show sand and gravel as the dominant material on Watchorn Beach (Figure 6). Near the inlet location beach sediment is considerably coarser, dominated by cobbles and boulders with sand washed into the interstices by wave run-up (Figure 7 and Figure 8) Sediment in the raised beach ridge includes boulders, cobbles and gravel.

Figure 6: Field photograph taken on June 11, 2019 at Watchorn Beach in Watchorn Bay. Photograph shows a primarily sand and fine gravel on the beach. Looking S.

Figure 7: Field photograph taken on June 11, 2019 near the inlet channel at Watchorn Bay. Photograph shows gravel, cobbles and boulders on the beach with sand washed up by wave run-up. Looking SE.

Figure 8: Field photograph taken on June 11, 2019 near the inlet channel at Watchorn Bay. Photograph shows gravel, cobbles and boulders on the beach with sand washed up by wave run-up. Looking NW.

Geotechnical borehole logs reported by KGS (2017) show clay, silt, and sand to be the dominant surface substrate layer in Watchorn Bay. It seems possible that the sand-gravel substrate reported by AAE (2016) represents a surficial veneer that was not recorded in the borehole logs. There are no grain size samples taken at surface from any of these borehole logs. Substrate sample results from the current study are summarized in Section 4.5.

4.4 Shoreline Morphology

The Watchorn Bay shoreline is marked by a raised beach ridge that extends almost continuously for more than a kilometre in both directions from the proposed channel inlet location (Map 2). The lakeward toe of the raised beach ridge coincides roughly with the upper extent of the modern beach (*i.e.*, roughly the normal high-water level of 247.5 to 248 m) and rises to approximately 1-2 m above this elevation. In some locations, a low beach ridge is present near the base of the larger beach ridge. This lower beach ridge has formed in modern times due to onshore sediment transport by wave action. Given that parts of the higher, abandoned, beach ridge are much higher than recorded lake levels, its formation likely dates to pre-historical times (*i.e.*, 1880s) when water levels are reported to have been at levels that are comparable to or perhaps even higher than the maximum recorded level of 249.1 m. It is also possible that glacio-isostatic rebound, reported to be approximately 0.9 cm/yr in this area, has played a role in the preservation of this feature (Koohzare 2007).

The extent of the abandoned beach ridge, mapped using 2017 LiDAR topographic data, is shown in Map 6 in comparison to 1948, 1961, 1993 and 2017 imagery. Comparison of its position in 2017 to historical air photos shows that there has been negligible change in its position over that time period, except for a

few minor local differences. For example, lower portions of the beach ridge would have been overtopped by high water levels in 2011 with accompanying sediment deposition landward of the ridge.

To further investigate historical changes in shoreline morphology, shoreline positions from multiple sets of historical air photos were mapped and compared. In doing so, it was important to consider water level differences in the air photos because small changes in water level result in large shifts on shoreline positions on gentle nearshore slopes. For example, nearshore slopes in Watchorn Bay range from 0.5° to 2.5°. On a 1° nearshore slope, a 10 cm change in water level results in a lateral shoreline shift of 5.7 m.

Map 7 and Map 8 show shoreline positions mapped from 1961/2016 and 1958/2017 imagery. Water levels on the dates being compared differed by only a few centimeters. Water levels in 1958 and 2017 were approximately 10-20 cm higher than in 1961 and 2016. These comparisons show that minimal change has occurred in shoreline position over these 55- and 59-year time periods.

In recent and earlier years, Lake Manitoba and other lakes in this region have experienced shoreline disturbances due to wind-driven ice rafting and ice push during spring break-up. News reports from 2013 show severe damage to lakeshore homes due to wind-driven ice at Ochre Beach in Dauphin Lake. Mollard and Janes (1984) report similar events on the south shore of Lake Manitoba in 1981. The morphology of parts of the abandoned beach ridge at Watchorn Bay is similar in appearance to those at Ochre Beach and the south end of Lake Manitoba – *i.e.*, a uniform curving lakeward margin modified by wave action and a more irregular landward margin resulting from irregular advances and thicknesses of lake ice having been pushed onshore, with varying amounts of entrained sediment contained within the ice.

Given the observations described in this section, the dominant shoreline processes operating in Watchorn Bay are driven by two main processes: 1) onshore and offshore transport of substrate sediment due to wave action under a range of water level, wind direction and wind velocity conditions operating in open water conditions; and 2) periodic onshore transport of sediment and remobilization of previously deposited shoreline sediment by lake ice rafting and ice push during spring breakup.

Examination of historical air photos over the past 69 years shows no evidence of sediment transport by longshore drift or appreciable amounts of lateral shoreline recession. While these processes may occur on a small scale, such changes are below the resolution that can be detected with the available air photos.

4.5 Field Reconnaissance – Channel Inlet

4.5.1 Channel Inlet Shore Zone Morphology

The channel inlet area and Watchorn Beach were visited on June 11, 2019.

The beach and nearshore area at the channel inlet are characterized by the following features (see Map 9):

1. Figure 9 shows a photograph of the shore zone near the proposed inlet centerline and a topographic cross-section created from LiDAR data. This cross-section is representative of general characteristics along this reach of shoreline.

2. A lower beach slope is inundated to different levels depending on lake level. When visited, the more gently sloping lower beach was approximately 5 m wide and the slope and beach materials extended into the shallow nearshore area for an underdetermined distance. Beach materials consisted of gravel, cobble and boulders. Fine sand is deposited on the lower part of the beach below a line of organic debris that marks the upper extent of wave run-up in spring 2019.
3. A steeper mid-beach slope rises up to an intermediate elevation beach ridge that consists of clean washed gravel and moderate sized boulders.
4. The upper beach slope rises above the beach ridge described in 3, above, and terminates at an eroded low scarp near the top of a larger raised beach ridge. The larger raised beach extends continuously across the entire inlet area and beyond. The upper beach slope is comprised of clean gravel and moderate sized boulders.
5. The vegetated top of the larger raised beach ridge rises slightly above the upper beach and is capped by very large boulders in many locations. These boulders were likely moved into this position by ice shove processes over a long period of time, possibly centuries. The current elevation of the larger raised beach ridge may also have been influenced by glacio-isostatic rebound.
6. In places, gravel has been deposited on top of and washed over the beach ridge indicating that maximum wave run-up has exceeded the top of the beach ridge during periods of extreme high-water levels (*e.g.*, in 2011).

Map 9 shows photographs taken near the proposed channel inlet location. The bottom sequence of photos (L-Q) illustrates the five nearshore zones described above.

The four photos in the upper left panel of Map 9 (A-D) provide examples of the large boulders that are located near the top of the raised beach ridge. Given the size and elevation of these boulders, the likely transport mechanism was ice rafting and ice shove under high-water level conditions. This interpretation is supported by observations of recent ice shove features on the lower beach slope. A number of these features are shown in the four photos in the upper right corner of Map 9 (H-K).

Field observations support the interpretation that the shore zone morphology in this part of Lake Manitoba is characteristic of a beach where constructive waves create a dominantly depositional rather than erosional environment. Moreover, the gradation of the beach sediments is dominantly coarse-textured ranging from gravel, cobbles, small and intermediate boulders to very large boulders. Deposition of sand is restricted to small amounts of sand washed onshore by wave action. This process may result in deposition of sand in the inlet when it is not in use, depending in part on the design of the inlet which has not yet been determined.

The coarse texture of beach sediments precludes longshore drift except perhaps during periods of extreme wind events and then likely only resulting in small displacements of sediment. Shallow offshore areas may experience some movement of sand substrate, but this could not be observed in the field.

The presence of ice rafting and ice shove processes was confirmed and should be assessed when considering inlet design options.

Digital UAV images of the channel inlet area are provided separately from this final report.

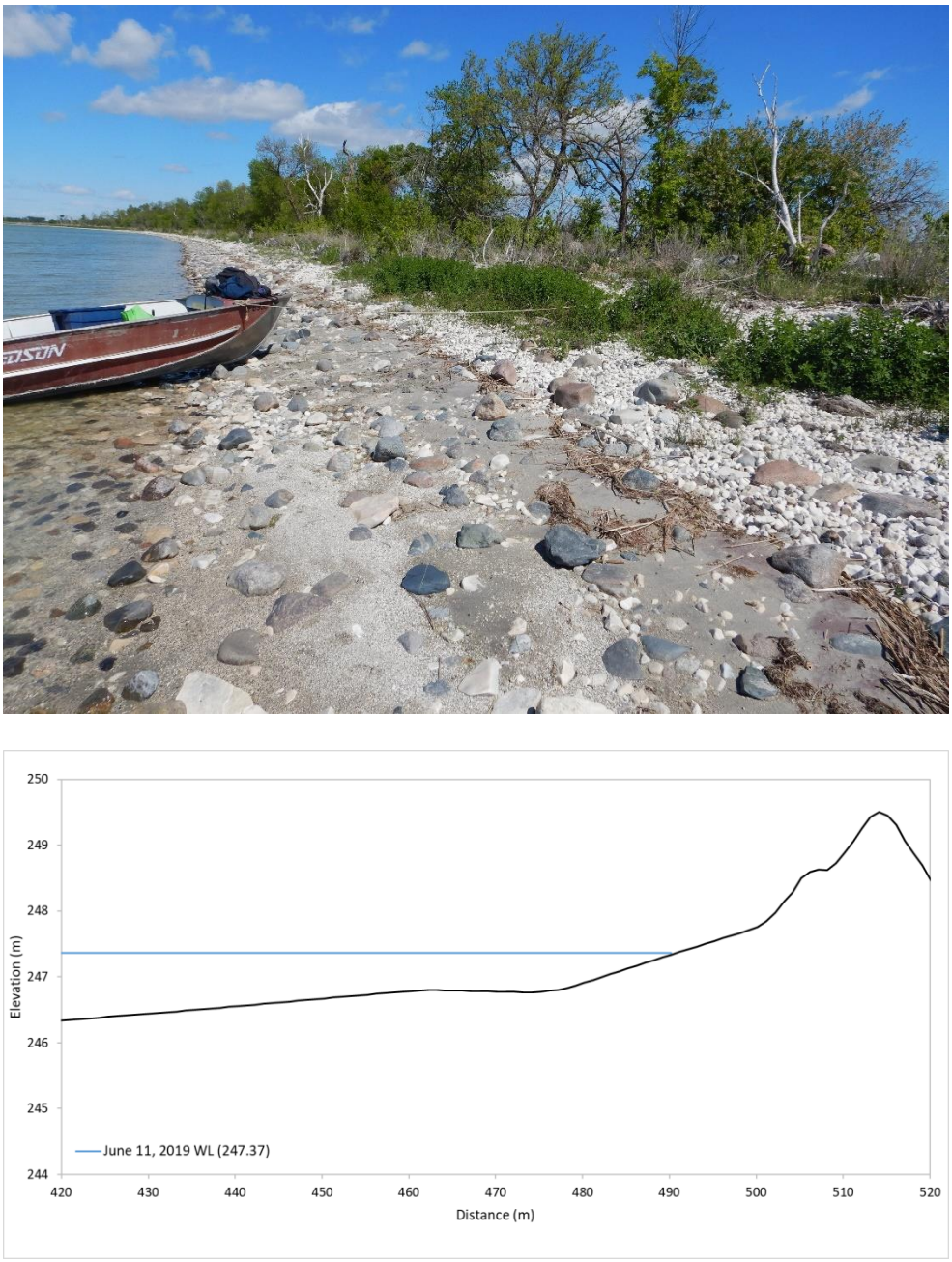


Figure 9: Field photograph of approximate channel centerline position in Watchorn Bay. The beach material is dominantly gravel, cobbles and boulders with sand washed into the interstices by wave run-up on the lower beach slope.

4.5.2 Substrate Sampling – Channel Inlet

Substrate samples were collected at four locations near the proposed inlet location. The sample locations are shown in Map 10 and sample characteristics are summarized in Table 5. Ponar sampling was unsuccessful due to the firmness of the dominantly sand substrate. However, substrate cores ranging from 15 to 30 cm in length were recovered with a hand sampler. In one location the core penetrated the underlying firm clay indicating a substrate depth of 25 cm. All samples were dominantly sandy substrate

passing through a 1.18 mm sieve with varying amounts of fine gravel particles. In all samples the gravel content was estimated to be less than 5% and the maximum particle size was 3 cm.

Comparison to AAE substrate mapping

Map 10 shows the location of substrate samples compared to AAE's substrate map. AAE's map shows three distinct areas as having dominantly sand, gravel with sand and silt, and sand and gravel. By comparison, substrate sampling showed dominantly sand substrate throughout the area with relatively small amounts of fine gravel estimated at less than 5% of the sample. It is important to note that AAE's mapping was based on sonar data which provides an interpretation based on the surface roughness or sonar-texture of the substrate surface. Core samples provide an indication of substrate type below the substrate surface.

Photographs of substrate samples and washed sieves are included in Appendix A.

Table 5: Description of substrate samples from near the channel inlet in Watchorn Bay, Lake Manitoba.

Sample Location	**1**	**2**	**3**	**4**
Water depth (m)	1.2	1.7	1.8	1.4
Bed elevation (m. CGVD)	246.2	245.7	245.6	246.0
Length of core recovered (cm)	15 and 30	15	15 and 25	30
Dominant material	Fine sand and silt	Fine sand and silt	Fine sand and silt	Fine sand and silt
Secondary material	Fine gravel	Fine gravel in upper 10 cm	Fine gravel in upper 5 cm	Gravel/clay plug at bottom of core
Amount of mineral sediment retained on 1.18mm sieve	Not sieved	<5%	<5%	<5%
Size retained	Pebbles up to 2cm	Coarse sand and fine gravel to 2cm	Coarse sand and fine gravel to 1cm	Coarse sand and fine gravel to 3cm

4.6 Field Reconnaissance - Watchorn Beach

Watchorn Beach in Watchorn Provincial Park was also visited in the field to help address potential questions as to whether it will be affected by the channel project. Photographs of features discussed below are shown on Map 11.

4.6.1 Watchorn Beach Shore Zone Morphology

Watchorn Beach consists of a wide gently sloping granular beach with exposure to southwest winds. The beach is groomed for use as a recreational beach by running harrows across the beach to maintain a uniform slope and remove vegetation.

Despite grooming, at least three beach levels are evident in the field, presumably corresponding to persistent recurring water levels. Beach sediment at the northwest end of the beach consists of sand and fine gravel transitioning to coarser sand and gravel towards the southeast. The southeast end of the recreational beach is marked by a sharp transition to a coarser boulder covered beach. The beach slope rises to an ancient raised beach which forms a broad ridge on which the main part of the campground is located. The raised beach ridge extends southeastward beyond the south end of the park.

Large offshore sand ripples on the lake bottom (bedforms), visible in aerial imagery, indicate a constructive wave environment where substrate sand is re-worked inshore and offshore by wave action. Transient deposits of in-wash sand were observed near the shoreline indicating that this process operates on a small scale as well. Small hand-placed ridges of rock were noted in two locations. In one case a small amount of sand had collected on one side of the ridge while in the other location no deposition of sand was noted. Although these observations represent a relatively short time period, they suggest that longshore drift may occur slowly over long time periods. The transition from coarser to finer beach sediment in a northwest direction is further evidence that perhaps longshore drift has been a factor in beach evolution over a longer time frame. It seems unlikely however that this mechanism would influence the proposed inlet structure as Watchorn Beach is approximately 750 m from the inlet location and the shoreline between Watchorn Beach and the inlet location is interrupted by two inlets and extensive areas with boulders in shallow water and on the beaches which would restrict the movement of sand by longshore drift.

5 RESULTS – CHANNEL OUTLET

5.1 General Setting

The channel outlet is located at the south end of Birch Bay which forms the southernmost shoreline of Lake St. Martin. Birch Bay is a long narrow bay with a bay mouth width of approximately 3 km and a length of 5 km. The width of the bay near the proposed outlet location is 1.2 km. The long axis of the bay is oriented approximately NNW-SSE with a 26 km-long fetch exposure to northerly winds. Although there is a long northerly fetch direction, the shoreline at the outlet location is oriented roughly NNW-SSE resulting in a shallow angle between the shoreline and the maximum fetch direction. Map 12 shows an overview of Birch Bay.

A review of the wind roses in Figure 4 shows that both the Fisher Branch and Gypsumville wind stations have strong northerly components which may expose the outlet location to greater wave energy. The Dauphin wind station only has a small northerly wind component. Given the large differences observed in these three stations it is unknown what wind vectors are dominant in Birch Bay.

To determine the range of lake levels in Birch Bay, daily lake level data from the gauge at Hilbre (05LM005) and the gauge at Sandy Bay (05LM003) were obtained and merged. Data from 05LM005 is from 1966-2016 while data from 05LM003 is from 1950-1966. Figure 5 shows the daily hydrograph from 1950-2017, annual average hydrograph, and exceedance probability of lake level.

Since water levels have been recorded on Lake St. Martin (68 years) there is a range of 3.35 metres in lake level. The daily hydrograph over the entire period shows a large amount of fluctuation over the period with perennially high lake levels from 2005-onwards. One standard deviation from the mean lake level is ± 0.63 metres which represents a significant range of 1.26 metres. This range is significantly higher than on Lake Manitoba. Lake St. Martin drains through the Dauphin River into Lake Winnipeg. A summary of lake levels reported at the Steep Rock gauge (05LK002) and target operating levels are reported in Table 6.

Table 6: Lake St. Martin lake levels and statistics

Parameter	**Lake level (metres)**
Emergency LSMEOC operating level (803 ft)	244.75
2001 Lake St. Martin operating range (797-800 ft)	242.93-243.84
Mean lake level ± standard deviation	243.50 ± 0.63
Range of lake level	3.35
Maximum lake level (July 21, 2011)	245.57
75th Percentile lake level	244.01
50th Percentile (median) lake level	243.43
25th Percentile lake level	242.97
Minimum lake level (October 14, 1943)	242.23

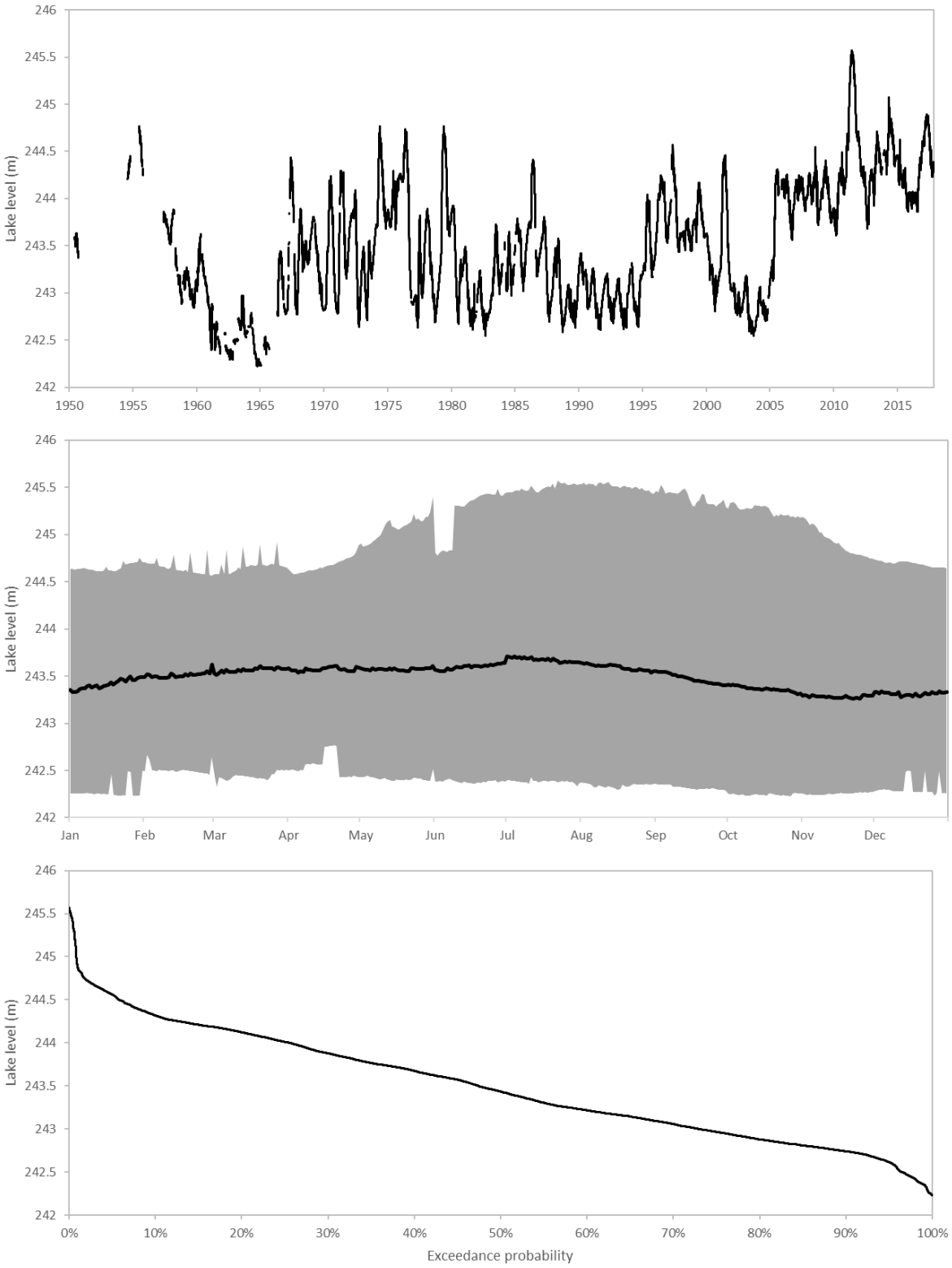


Figure 10: Lake St. Martin (05LM003 and 05LM005) hydrometric summary showing daily hydrograph, annual average hydrograph and total range of flows, and exceedance probability curve.

5.2 Bathymetry

The bathymetry of the Birch Bay is characterized by a gently sloping lake bottom with depths reaching 2-3 m approximately 400-500 m offshore (Map 13 and Map 14). Nearshore slopes range from 1°-2.5°. Map 14 shows four (4) bathymetric profiles along the western and southern shores of Birch Bay. In three of the four cases shown, the lake bottom slopes gently and uniformly into deeper portions of the bay. The one exception is profile XS-3 which crosses a submerged ridge approximately 200 m offshore. The top of this ridge, with an elevation of approximately 243.2 m, is exposed at low water levels. Its presence in historical air photos indicates that it is a long-lived geomorphic feature. Given that no bathymetric transect was taken overtop of this feature the actual elevation of it is unknown and may be underestimated in the cross section on Map 14. Figure 11 shows a typical view of the Birch Bay shoreline.

Figure 11: Field photograph of the shoreline of Birch Bay in Lake St. Martin. The beach sediment is mainly sand and gravel with scattered cobbles and boulders. Looking north.

5.3 Substrate

Substrate data from sonar surveys are available for an area that extends approximately 500 m offshore from the outlet area and across the south end of Birch Bay (Map 15). Near the proposed outlet location, substrate is dominated by gravel with sand (70/30 ratio) within approximately 125 m from the shore. Beyond this distance the substrate is mostly sand with scattered patches of gravel being present farther offshore in the central part of the bay. Figure 12 and Figure 13 show the range of sediment gradation along the Birch Bay shoreline while Figure 14 shows a sample of material taken from deeper in the lake. Substrate sampling results are summarized in Section 5.5.

Figure 12: Field photograph showing the shoreline of Birch Bay in Lake St. Martin. The beach sediment at this location is mainly gravel, cobbles and boulders with sand in the interstices. In the background aquatic vegetation grows along the shoreline where it is sheltered from north winds. Looking south.

Figure 13: Field photograph showing nearshore sand and gravel substrate in Birch Bay. Photograph is located near the centerline of the channel corridor. Looking south.

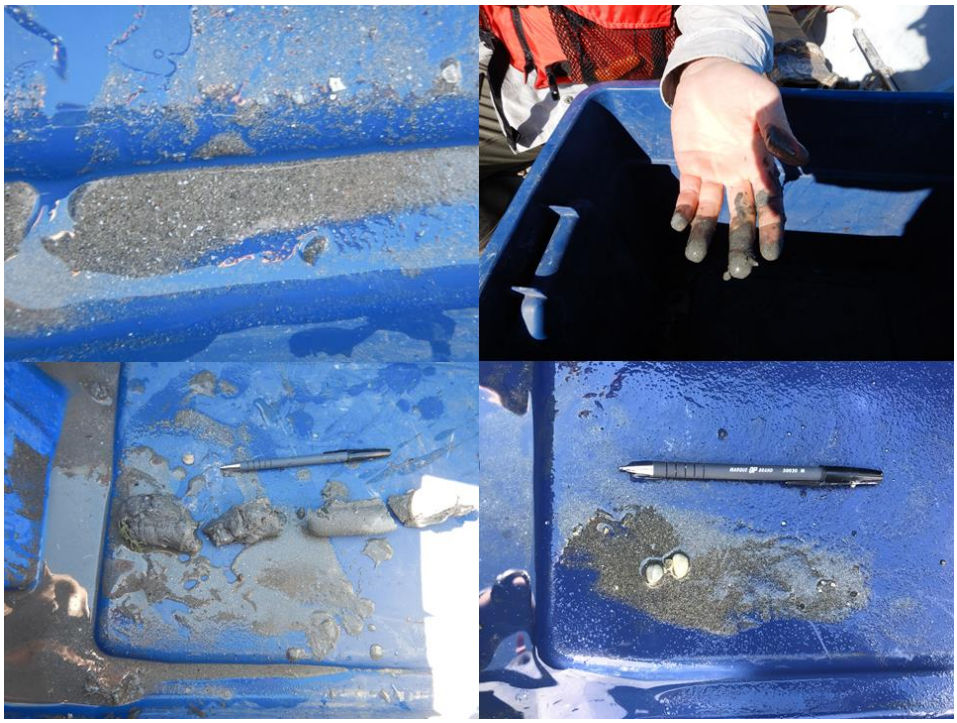


Figure 14: Field photographs showing sandy substrate retrieved in Birch Bay by hand core and Ponar samples.

5.4 Channel Outlet Shoreline Morphology

The shoreline morphology around Birch Bay is marked by extensive, discontinuous, raised beach ridges bordering a broad plain that extends 150-300 metres inland. The beach ridge and broad plain are inundated during periods of extreme high-water levels. Even so, trees established on the beach ridge remain standing and mark the location of the beach ridge under high-water conditions.

Comparison of historical air photos indicates that there has been negligible change in shoreline morphology over a 69-year period (1948-2017). 1958 is the earliest air photo record where the lake level is known. Comparing this image to 1998, 2011 and 2017 imagery in Map 16 illustrates the stability of the shoreline over a 59-year period. This is further illustrated by comparing the 1958 top-of-beach (edge of vegetation) line to the 1998, 2011 and 2017 air photos. Even though the water levels are different than in 1958 the position of this line is similar across the photos.

The 2011 image in Map 16 illustrates the extent of flooding across the nearshore plain under extreme high-water levels (245.47 m).

The offshore ridge near the mouth of Birch Creek is shown in 1961 and 2017 imagery in Map 17. This comparison illustrates that this geomorphic feature has been stable over this 56-year period. This feature is described as a boulder reef by AAE (2016). The origin of the boulders is not known. Possible origins include a lag deposit derived from the coarse fraction of underlying till, an accumulation of boulders pushed onto the ridge by ice action, or perhaps a combination of these processes.

In recent and earlier years, Lake Manitoba and other lakes in this region have experienced shoreline disturbances due to wind-driven ice rafting and ice push during spring break-up. News reports from 2013 show severe damage to lakeshore homes due to wind-driven ice at Ochre Beach in Dauphin Lake. Mollard and Janes (1984) report similar events on the south shore of Lake Manitoba in 1981.

Given these observations, the dominant shoreline processes operating in Birch Bay are understood to be driven by two main processes: 1) onshore and offshore transport of substrate sediment due to wave action under a range of water level, wind direction and wind velocity conditions in open water; and 2) onshore transport of offshore sediment and remobilization of previously deposited shoreline sediment due to lake ice rafting and ice push.

Examination of historical air photos over the past 69 years shows no evidence of significant sediment transport by longshore drift or appreciable amounts of landward shoreline recession. While it's possible that these processes occur on a local scale, the changes are below the resolution that can be confidently detected with the available air photos.

5.5 Field Reconnaissance – Channel Outlet

5.5.1 Channel Outlet Shore Zone Morphology

The beach and nearshore area at the channel inlet are characterized by the following features (see Map 18):

1. The shore zone area is characterized by a gently sloping lower beach slope that is inundated to different levels depending on lake level. When visited, the lower beach was approximately 10-15 m wide with a similar slope and beach materials extending below the shoreline for an underdetermined width. Lower beach materials mainly consist of gravel and scattered cobbles and boulders. North of the proposed outlet location, a well-developed low beach ridge comprised of sand and gravel marks the upper extent of wave run-up in spring 2019. The gentle beach slope extends above this beach ridge for another roughly 3-5 m where it steepens slightly and the concentration of boulders increased. A high-water mark that coincides with this low beach ridge is also evident to the south, but a beach ridge is not as well-developed to the south. The presence of the low beach ridge indicates that onshore transport of granular sediments by wave action occurs in this area. This process may result in deposition of sediment in the outlet when it is not in use, depending in part on the design of the outlet which has not yet been determined.
2. The absence of the lower recent small beach ridge south of the outlet centerline location may be the result of lower wave energy and/or less abundant sand along this part of the beach.
3. The upper extent of the beach is marked by a prominent raised beach ridge. The raised beach ridge is approximately 1-1.5 m high and likely represents a very old geomorphic feature formed over many centuries. The lakeward side of the raised beach ridge is marked by a concentration of medium to large boulders, some of which rest on top of the beach ridge. The beach ridge itself is comprised of wave washed gravel, sand and cobbles. It is also possible that some large boulders are buried within the beach ridge.

4. In places, gravel has been deposited on top of, and washed over, the beach ridge. This indicates that maximum wave run-up has exceeded the top of the beach ridge during periods of extreme high-water levels (*e.g.*, in 2011).
5. Many ice-shoved boulders are present on the beach, indicating that ice shove processes are very active at this location. Ice shove boulders are identified by the presence of a clear slide path on the lake side of the boulder and in some cases shoved debris on the landward side of the boulders, although these features become less visible over time if waves subsequently wash across the beach. The presence of clear ice shove slide paths suggests that many of the observed ice-shove boulders were displaced in spring 2019. The maximum amount of displacement measured was approximately 5 m. Boulders in shallow nearshore areas may be displaced by ice shove in subsequent years, and additional boulders may be transported towards the shore by ice rafting. Boulders may also be subjected to repeated ice shove over time, gradually moving closer and closer to the raised beach ridge. This process has created a concentration of boulders on the lakeward side of the raised beach ridge.
6. Approximately 250 m north of the proposed outlet location the beach and shallow nearshore area is vegetated with aquatic vegetation several metres out from the shoreline. This corresponds to a change in the orientation of the shoreline towards the southwest, resulting in sheltering of this part of the beach from wave action from northerly winds. The nature of the beach slope beneath the vegetation indicates that the beach has been subject to erosion in the past. Therefore, the condition of the vegetation is subject to change depending on prevailing wind conditions.

Digital UAV imagery of the channel outlet area is provided separately from this final report.

5.5.2 Substrate Sampling – Channel Outlet

Substrate samples were collected at seven locations in the vicinity of the proposed outlet location with the maximum distance from shore being 360 m. The sample locations are shown in Map 19 and sample characteristics are summarized in Table 7. Ponar sampling recovered a very small amount of sediment at six of the seven sites due to the firmness of the dominantly sandy substrate. One large Ponar sample was collected at a location where soft mud was encountered. In addition to attempts to collect Ponar samples, substrate cores ranging from 7.5 to 32 cm in length were recovered with a hand sampler. In five samples minor to no amount of sediment was retained on the 1.18 mm sieve apart from small shells. One sample (Sample 1) retained a small amount (<5%) fine gravel with particle sizes up to 1 cm. Sample 6 retained approximately 10-20% coarse sand and fine gravel on the 1.18 mm sieve with particles up to 2.5 cm in size. Sample 4, which was collected in 2.8 m water depth approximately 360 m offshore, encountered 14 cm of organic-rich mud in the upper part of the substrate. The mud was underlain by 18 cm of fine sand and silt.

Comparison to AAE substrate mapping

Map 19 shows the location of substrate samples compared to AAE's substrate map. No samples were collected from areas mapped as mostly gravel by AAE. Sand was found in areas mapped as mostly sand and small amounts of gravel were found in the area mapped as gravel and sand. However, substrate samples in these areas showed that the dominant material is sand. It is important to note that AAE's mapping was based on sonar data which provides an interpretation based on the surface roughness or

sonar-texture of the substrate surface. Core samples provide an indication of substrate type below the substrate surface.

Photographs of substrate cores and washed sieves are included in Appendix A.

Table 7: Description of substrate samples from near the channel outlet in Birch Bay, Lake St. Martin.

Sample Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Water depth (m)	1.2	1.4	2.0	2.8	2.1	1.0	1.1
Bed elevation (m. CGVD)	242.2	242.0	241.4	240.6	241.3	242.4	242.3
Length of core recovered (cm)	15	15	10	32	18	7.5	15
Dominant material	Fine sand and silt	Fine sand and silt	Fine sand and silt	Upper 14cm very soft organic rich mud Lower 18cm fine sand and silt	Fine sand and silt	Gravelly sand	Fine sand and silt
Secondary material	Fine gravel	N/A	N/A	Shells in upper 14cm	Shells in thin upper silty layer	N/A	N/A (few pebbles captured with Ponar)
Amount of mineral sediment retained on 1.18mm sieve	<5%	Minor	Minor	0	0	10-20%	0
Size retained	Coarse sand and fine gravel to 1cm	Coarse sand and fine gravel to 3mm	Coarse sand and fine gravel to 5mm	Only shells	Only shells	Coarse sand and gravel to 2.5cm	Only shells

6 CLOSING

Watchorn Bay and Birch Bay shorelines are characterized by constructive wave environments dominated by depositional rather than erosive processes. A review of historical imagery, wind and water level data at the channel inlet (Watchorn Bay) and channel outlet (Birch Bay) areas, shows that negligible shoreline recession has occurred in the 69-year record of historical imagery. The main mechanisms for sediment transport at both locations appear to be onshore and offshore transportation caused by wave action. Ice processes cause additional onshore movement of sediment, including displacement of large boulders. Longshore drift appears to be a minor process at both locations. Onshore sediment transport by wave action may result in deposition of sediment in the inlet and outlet areas when the channel is not in use. Nearshore substrate and structures may also be impacted by ice-shove processes which may include direct contact by floating ice and transport of boulders into the inlet and outlet areas.

The perimeter of Watchorn Bay on Lake Manitoba is marked by a long, gently curving raised beach ridge that extends up to 2 metres above normal water levels. The origin of this beach ridge appears to be pre-historic and the height of it above the lake may be, in part, due to isostatic rebound in the region. Since 1948 there appears to have been very little change to the beach ridge and adjacent shoreline as observed from historical air photos. Below this beach ridge the beach and lakebed slope very gently out to the edge of bathymetric coverage. The dominant beach materials are gravel, cobbles and boulders. The dominant substrate materials are sand and silt with a minor component of mostly fine gravel in some locations.

The perimeter of Birch Bay on Lake St. Martin is also marked by a raised beach ridge visible in the field and in LiDAR data covering a portion of the bay. The beach ridge is visible in historical imagery that shows the adjacent land being inundated, with the vegetation on the ridge standing out above the water level. The inland topography behind the beach ridge is a gentle plain, rising only 1-2 metres above normal water levels in places, resulting in large areas being inundated under high water level conditions (*e.g*. 2011). An offshore ridge at the mouth of Birch Creek protruded above water level when visited in the field. Imagery shows that this low ridge becomes inundated at high water levels. This ridge appears to have been largely stable since 1948 as has the nearby shoreline and beach ridge. Offshore, the lake bottom extends out on a very gentle slope which results in large areas of beach being exposed under low water levels. Dominant beach materials are gravel, cobbles and boulders, with many ice-shoved boulders noted in the field. Substrate sampling indicates that thin organic rich mud is present in deeper water (*i.e*, >2.8m). In shallower areas the substrate is dominantly fine sand with a small component of fine gravel (*i.e*. <20%) in places.

7 SIGNATURES

J.D. Mollard and Associates (2010) Limited

Lynden Penner, M.Sc. P.Geo, P.Eng.

Shayne MacDonald, M.Sc.

MAPS

5,705,000 5,700,000 5,695,000 5,690,000 5,685,000 5,680,000

535,000

530,000

Lake St. Martin

Birch Bay

Birch Creek

6

239

Goodison Lake

Reed Lake

237

Watchorn Creek

Watchorn Provincial Park

Lake Manitoba

Watchorn Bay

Mercer Creek

Rendalls Creek

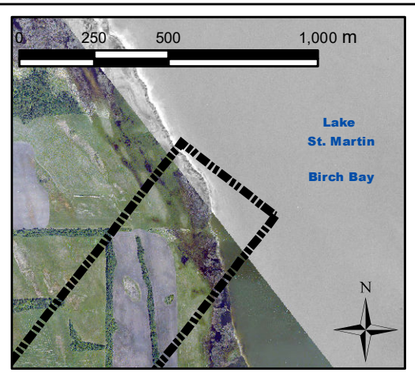
Christina Point

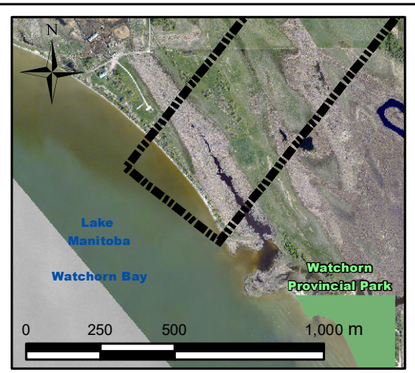
5,705,000 5,700,000 5,695,000 5,690,000 5,685,000 5,680,000

Legend

- Paved roads
- Unpaved roads
- Water courses
- Waterbodies
- Wetlands
- Forested areas
- Watchorn Provincial Park
- Outlet channel corridor

0 1.25 2.5 5 km





E N S W

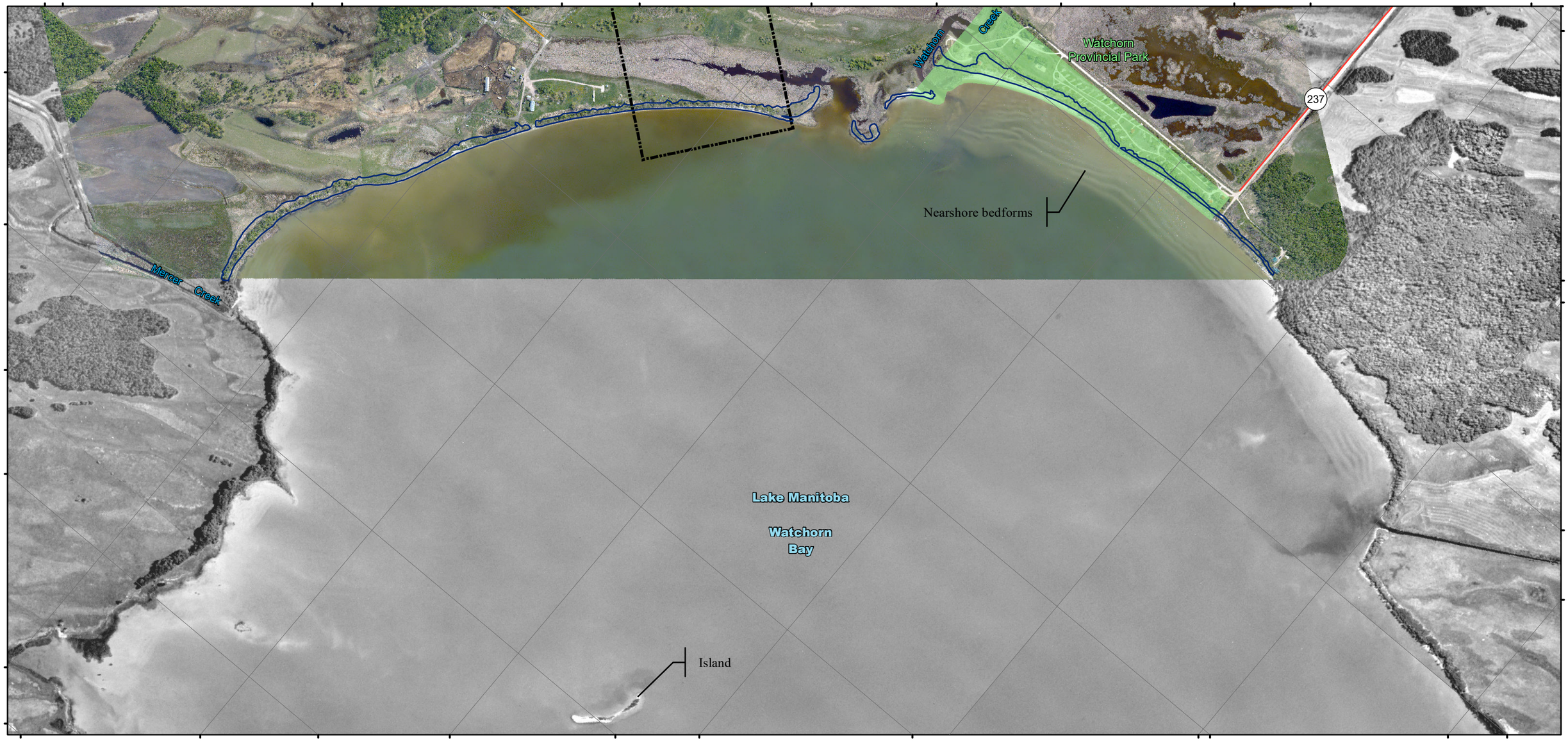
J D MOLLARD AND ASSOCIATES (2010) LIMITED

LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Overview of study area

Map 1	20-Jun-19	1:70,000	NAD83	UTM Zone 14N

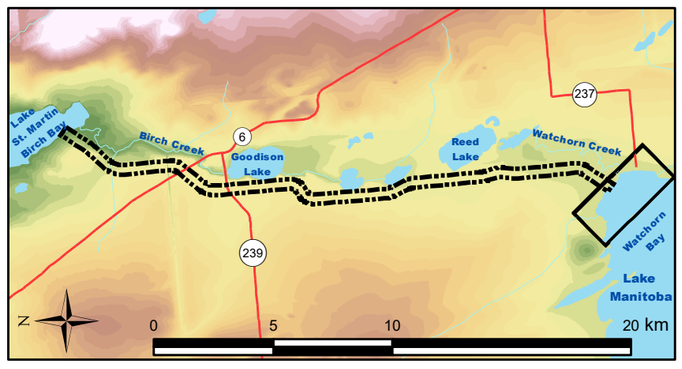
Reference map only; not for survey or legal use. Although all reasonable attempts have been made to ensure the accuracy of this mapping product, JDMA, their clients, subcontractors or affiliates assume no responsibility for any loss or inconvenience experienced as a result of errors or omissions in this map.



Legend

- Paved roads
- Unpaved roads
- Base of raised beach ridge
- Watchorn Provincial Park
- Outlet channel corridor

0 0.25 0.5 1 km



N E S W

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LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Overview of Watchorn Bay (Lake Manitoba) study area

Map 2	20-Jun-19	1:10,000	NAD83	UTM Zone 14N

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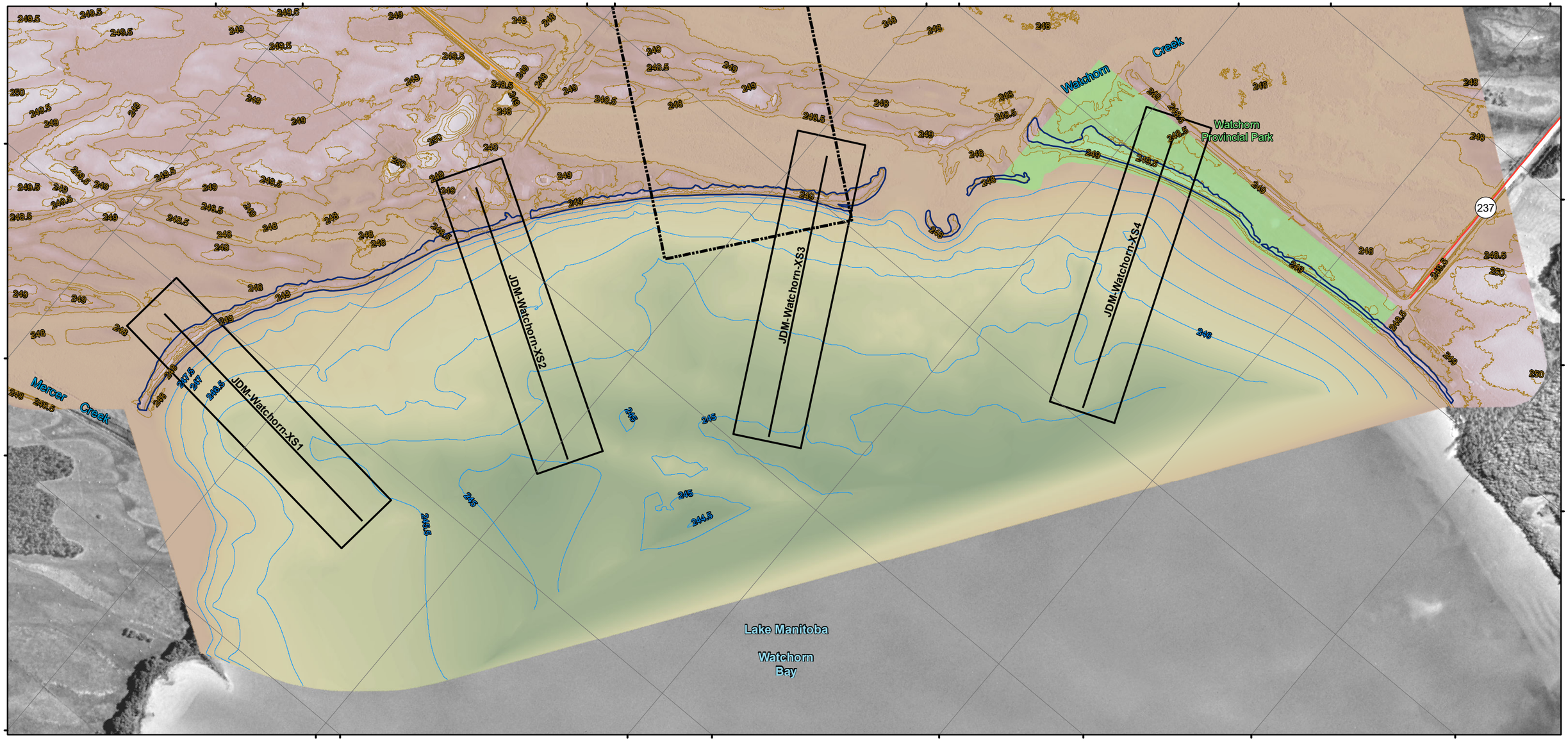


Legend

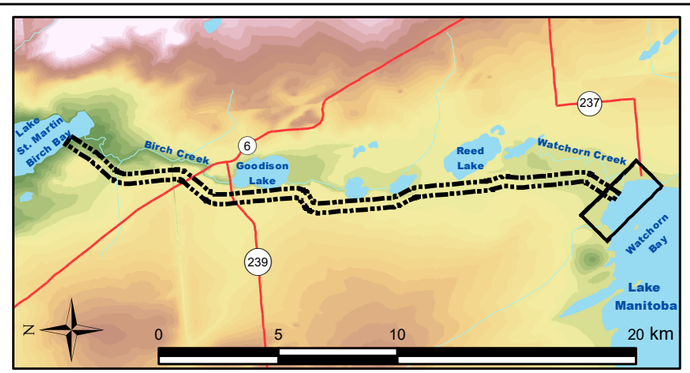
- Paved roads
- Unpaved roads
- Watchorn Provincial Park
- Outlet channel corridor
- Location of cross sections (Map 4)
- Base of raised beach ridge
- Contour - Bathymetric (0.5 m c.i.)
- Contour - Topographic (0.5 m c.i.)

Ground elevation

High : 252.417

Low : 244.419

0 0.25 0.5 1 km



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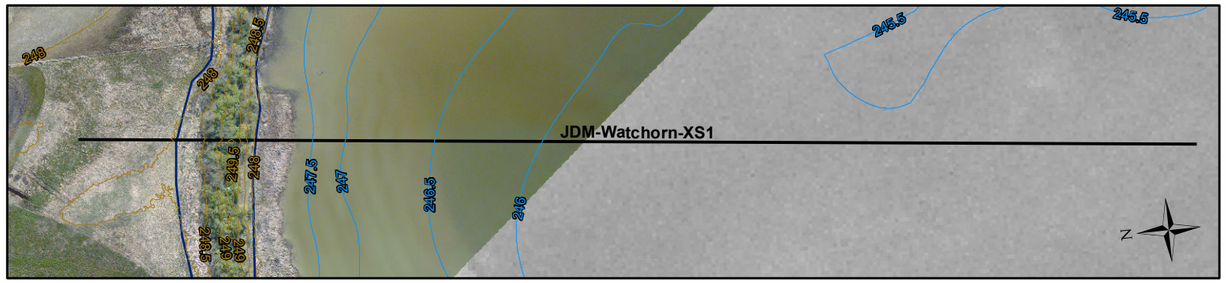
LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

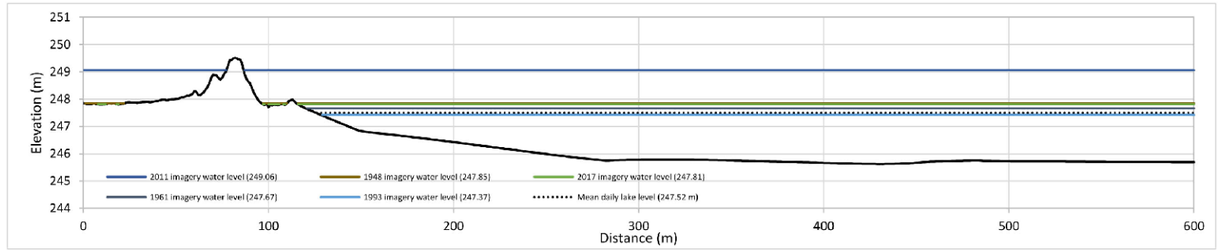
Bathymetry of Watchorn Bay

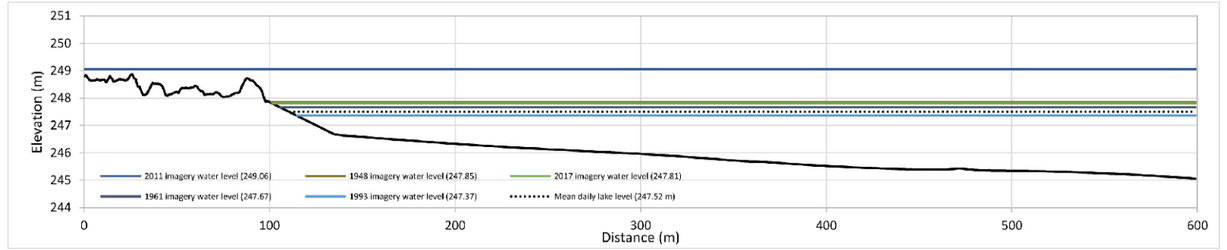
Map 3	20-Jun-19	1:8,000	NAD83	UTM Zone 14N

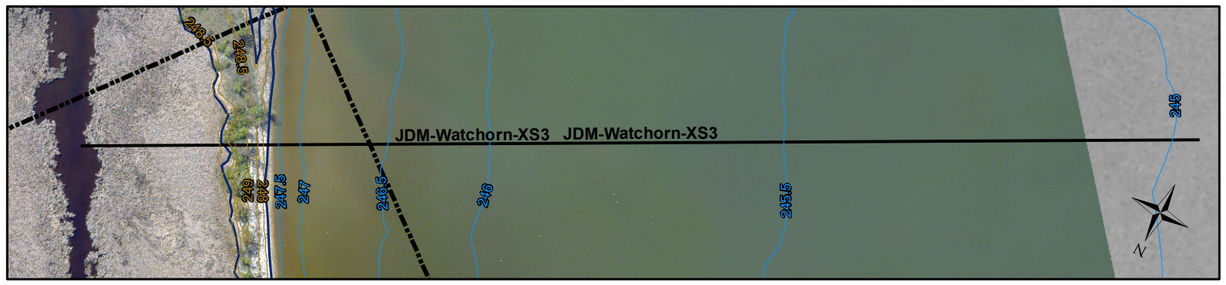
Reference map only; not for survey or legal use. Although all reasonable attempts have been made to ensure the accuracy of this mapping product, JDMA, their clients, subcontractors or affiliates assume no responsibility for any loss or inconvenience experienced as a result of errors or omissions in this map.

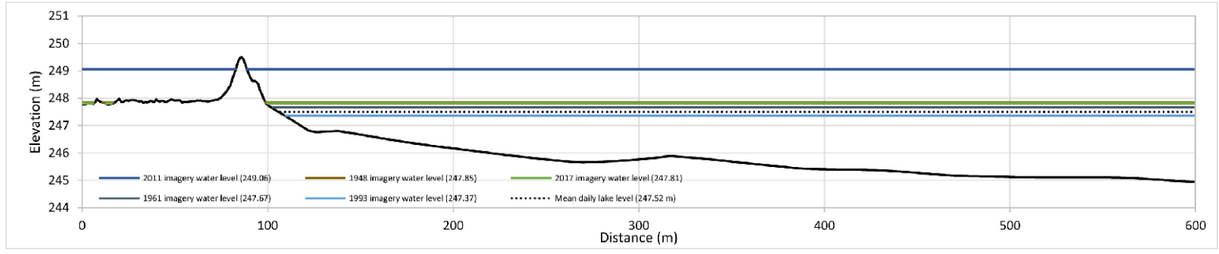
Map Sources: Topography © AAE, KGS, MIT, 1996 B&W imagery © MLI, Provincial park © MLI, Road network © NRCAN

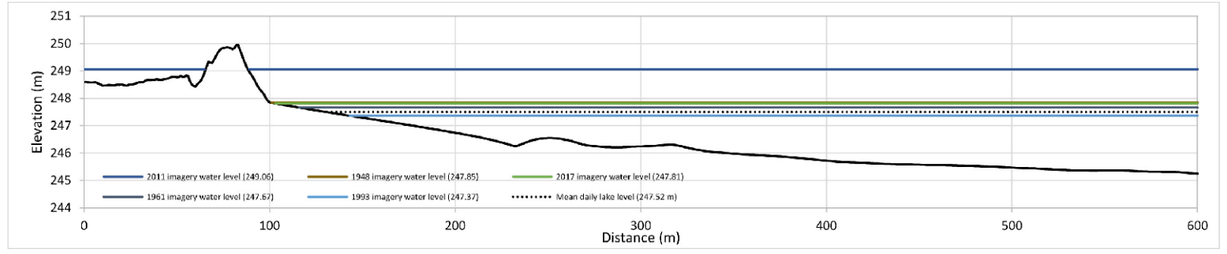








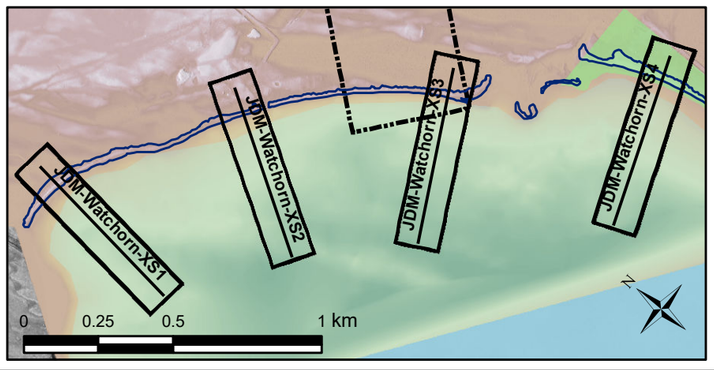




Legend

- Contour - Bathymetric (0.5 m c.i.)
- Contour - Topographic (0.5 m c.i.)
- Watchorn Bay offshore cross-sections
- Base of raised beach ridge
- Watchorn Provincial Park
- Outlet channel corridor

0 125 250 500 m



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LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Offshore cross sections in Watchorn Bay

Map 4	20-Jun-19	1:3,200	NAD83	UTM Zone 14N

Reference map only; not for survey or legal use. Although all reasonable attempts have been made to ensure the accuracy of this mapping product, JDMA, their clients, subcontractors or affiliates assume no responsibility for any loss or inconvenience experienced as a result of errors or omissions in this map.

529,500 5,682,500 530,000 5,681,500 530,500 5,681,000 531,000 5,680,500

529,000 5,682,500 528,500 5,682,000

531,000 5,680,000 530,500

Watchorn Creek

Watchorn Provincial Park

237

Nearshore bedforms

Mercer Creek

Lake Manitoba

Watchorn Bay

528,500 5,681,000 529,000 5,680,500 529,500 5,680,000 530,000

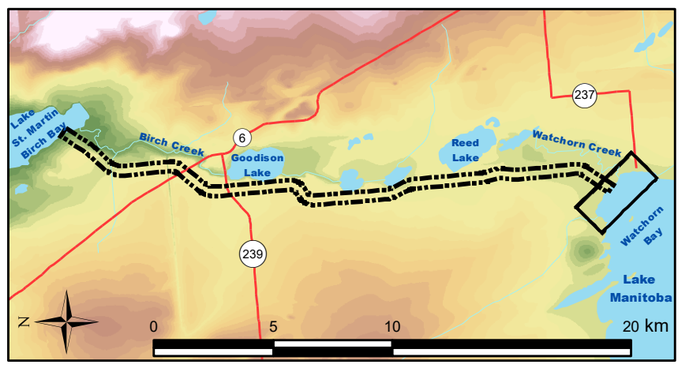
Legend

- Paved roads
- Unpaved roads
- Base of raised beach ridge
- Watchorn Provincial Park
- Outlet channel corridor

Extent of AAE substrate mapping

- Sand (>90%)
- Gravel with sand and silt (50%-30%-20%)
- Sand and gravel (50%-50%)

0 0.25 0.5 1 km



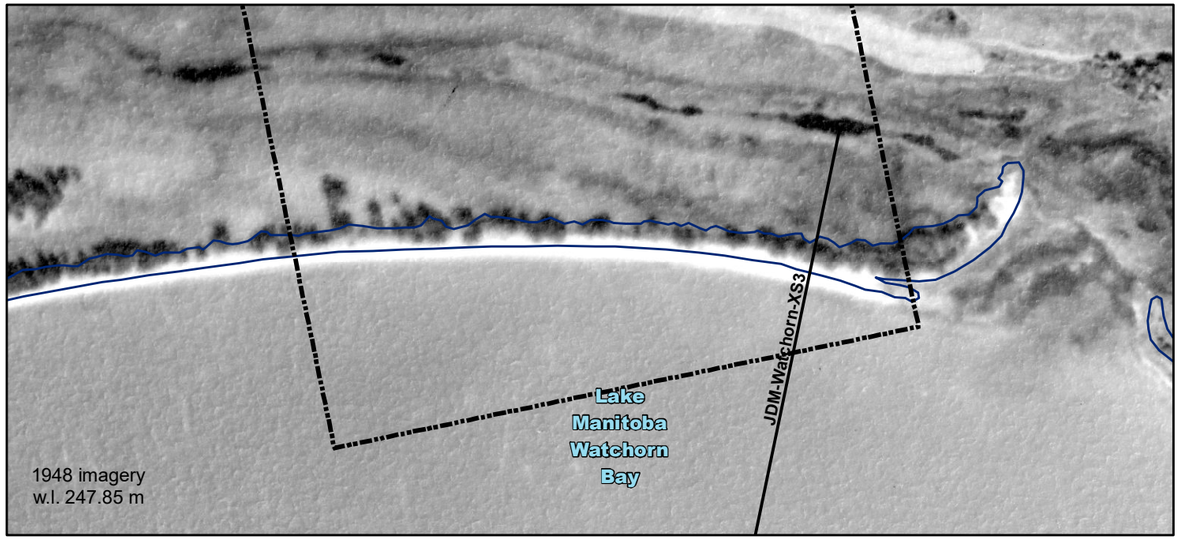
N E S W

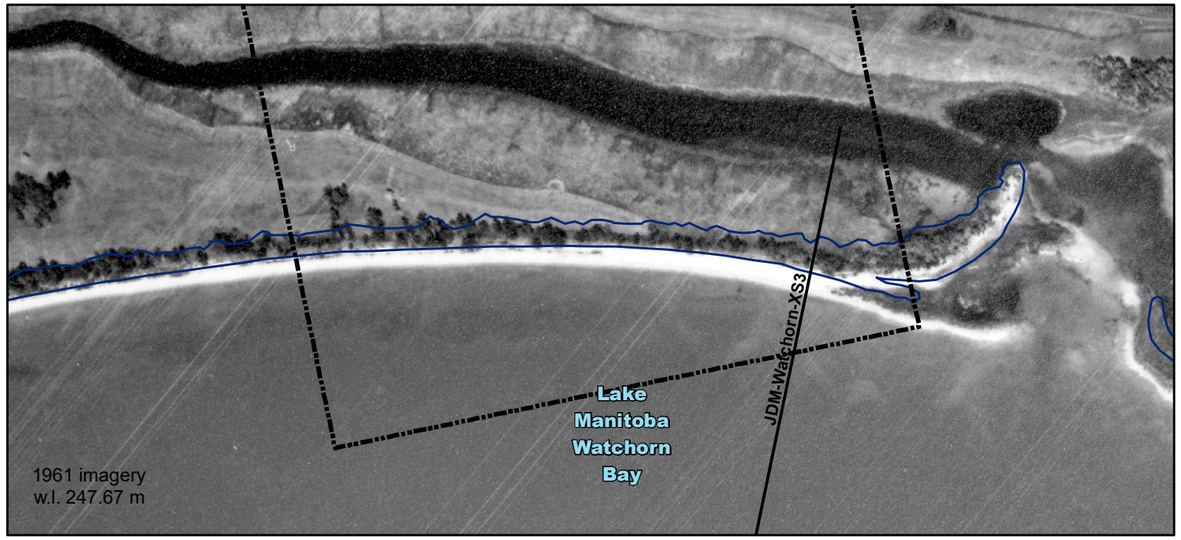
J D MOLLARD AND ASSOCIATES (2010) LIMITED

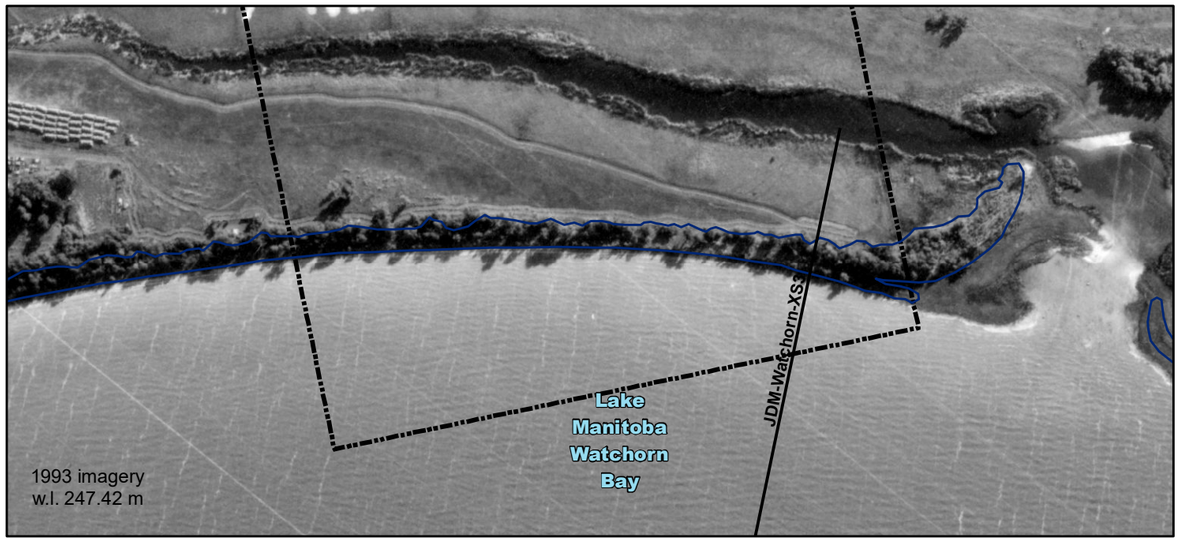
LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

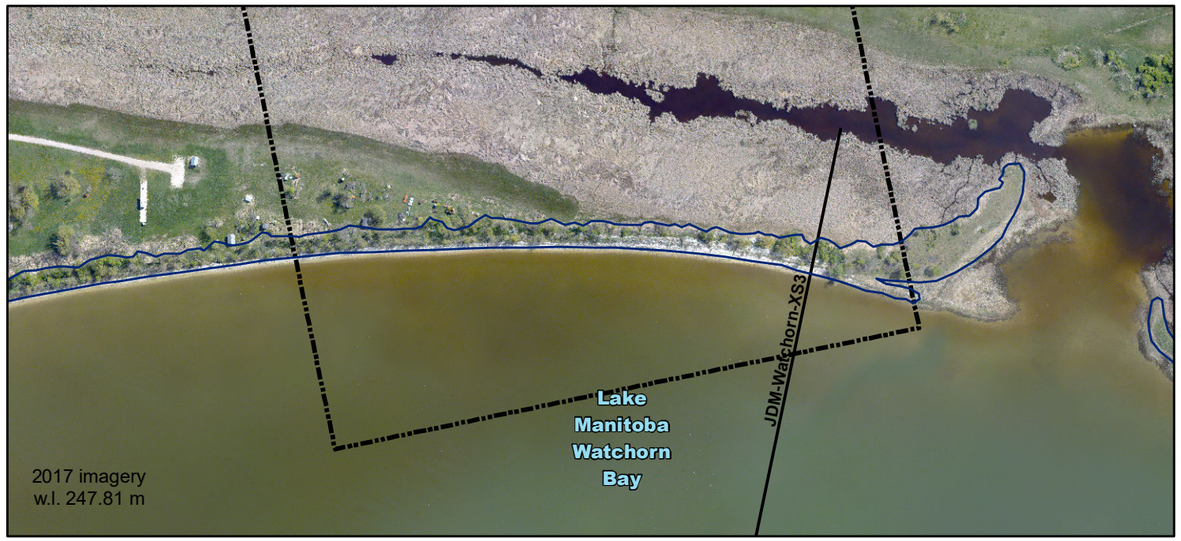
Substrate mapping of Watchorn Bay

Map 5	20-Jun-19	1:8,000	NAD83	UTM Zone 14N







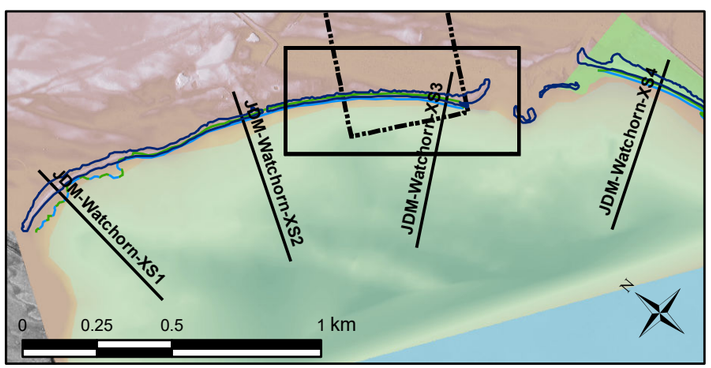


Legend

Base of raised beach ridge (mapped from 2017 LiDAR)

Outlet channel corridor

0 100 200 400 m



N E S W

J D MOLLARD AND ASSOCIATES (2010) LIMITED

LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Raised beach ridge shown on 1948, 1961, 1993, 2017 imagery

Map 6	20-Jun-19	1:4,000	NAD83	UTM Zone 14N

5,682,500 529,500 5,682,000 530,000 5,681,500 530,500 5,681,000 531,000

Watchorn Creek

237

529,000 5,682,500

5,682,000 528,500

Lake Manitoba

Watchorn Bay

0 25 50 100 m

0 25 50 100 m

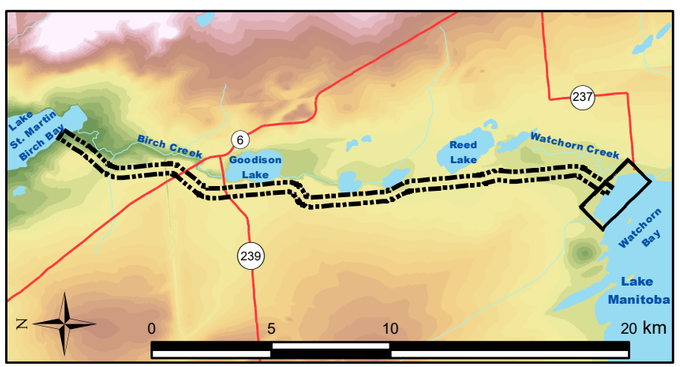
531,000 530,500 5,680,000

528,500 5,681,500 529,000 5,680,500 529,500 5,680,000 530,000

Legend

- Paved roads
- Unpaved roads
- Base of raised beach ridge
- 1961 edge of water (w.l. 247.67 m)
- 2016 edge of water (w.l. 247.57 m)
- Outlet channel corridor

0 0.2 0.4 0.8 km



N E S W

J D MOLLARD AND ASSOCIATES (2010) LIMITED

LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

1961/2016 Watchorn Bay shorelines overlaid on LiDAR

Map 7	20-Jun-19	1:6,900	NAD83	UTM Zone 14N

Reference map only; not for survey or legal use. Although all reasonable attempts have been made to ensure the accuracy of this mapping product, JDMA, their clients, subcontractors or affiliates assume no responsibility for any loss or inconvenience experienced as a result of errors or omissions in this map.

Map Sources: Topography © AAE, KGS, MIT, Road network © NRCAN

5,682,500 529,500 5,682,000 530,000 5,681,500 530,500 5,681,000 531,000

529,000 5,682,500 528,500 5,682,000

531,000 530,500 5,680,000

Watchorn Creek

237

Lake Manitoba

Watchorn Bay

0 25 50 100 m

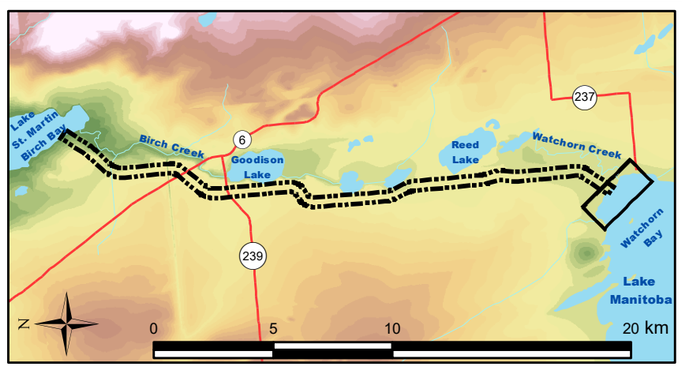
0 25 50 100 m

528,500 5,681,500 529,000 5,680,500 529,500 5,680,000 530,000

Legend

- Paved roads
- Unpaved roads
- Base of raised beach ridge
- 1958 edge of water (w.l. 247.79 m)
- 2017 edge of water (w.l. 247.81 m)
- Outlet channel corridor

0 0.2 0.4 0.8 km



N E S W

J D MOLLARD AND ASSOCIATES (2010) LIMITED

LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

1958/2017 Watchorn Bay shorelines overlaid on LiDAR

Map 8	20-Jun-19	1:6,900	NAD83	UTM Zone 14N

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Map Sources: Topography © AAE, KGS, MIT, Road network © NRCAN

Large boulders on and near the top of the raised beach ridge


A


B


C


D

View towards the approximate centerline of the proposed channel inlet (G) and towards the centerline from the west (E) and east (F).


E


F


G

Evidence of ice-shove processes on beach

H

I

J

K

L

Sand deposited on coarse sediment on lower beach slope. Upper reach of sand and washed organic debris indicates high-water line from Spring 2019. Beach sand can also be transported offshore when it is eroded and re-suspended during falling water levels.


M

Gravel, cobbles, and small boulders on mid- to upper beach slope. Low scarp and edge of vegetation indicate high-water line in recent years.


N

Gravel, cobbles, and small boulders on mid- to upper beach slope. Low scarp and edge of vegetation indicate high-water line in recent years. Washed organic debris indicates high-water line in Spring 2019. Boat is parked near the centerline of the proposed channel inlet.


O

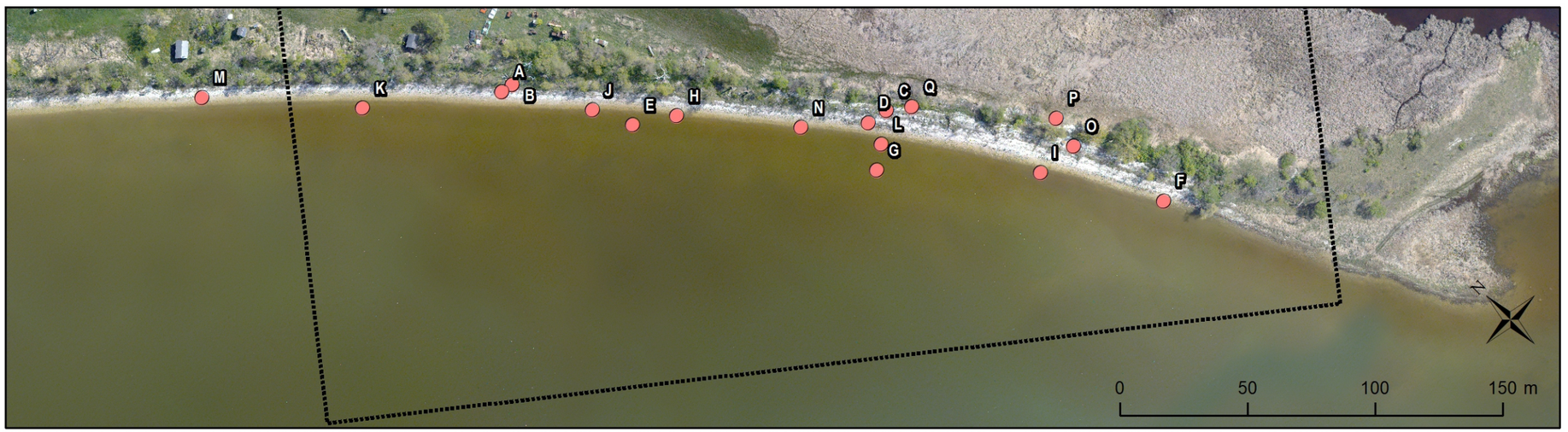
Large boulder on top of the raised gravel beach ridge that extends across this entire shoreline reach. Boulder likely transported by ice-shove processes under high-water conditions. Raised beach is likely an ancient feature and possibly raised in elevation by glacio-isostatic rebound.


P

Gravel deposited on the back side (landward side) of the raised beach ridge. Indicates water overtopped the beach ridge at this location in the recent past, likely during the 2011 flood event.


Q

Gravel exposed in a 60 cm deep test pit beside a large boulder on top of the raised beach ridge. It is possible that large boulders are present throughout the height of the beach ridge intermixed with granular beach sediment.



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LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Field photos at the channel inlet location, Lake Manitoba

Map 9	19-Jun-19	1:2,000	NAD83	UTM Zone 14N

Field photos taken 11-June-2019

5,682,000

530,000

529,500

5,682,000

5,681,000

530,000

Watchorn Provincial Park

Sample #: 4
Water depth (m): 1.4 m
Length of core recovered (cm) 30 cm
Dominant material: Fine sand and silt
Secondary material: Grave; clay plug at bottom of core
Amount of mineral sediment retained on 1.18 mm sieve: <5%
Top size retained: up to 3 cm

Sample #: 1
Water depth (m): 1.2 m
Length of core recovered (cm) 15/30 cm
Dominant material: Fine sand and silt
Secondary material: Fine gravel
Amount of mineral sediment retained on 1.18 mm sieve: N/A
Top size retained: up to 2 cm

Sample #: 2
Water depth (m): 1.7 m
Length of core recovered (cm) 15 cm
Dominant material: Fine sand and silt
Secondary material: Fine gravel in upper 10 cm
Amount of mineral sediment retained on 1.18 mm sieve: <5%
Top size retained: up to 2 cm

Lake Manitoba

Watchorn Bay

Sample #: 3
Water depth (m): 1.8 m
Length of cores recovered (cm) 15 & 25 cm
Dominant material: Fine sand and silt
Secondary material: Fine gravel in upper 5 cm
Amount of mineral sediment retained on 1.18 mm sieve: <5%
Top size retained: up to 1 cm

5,681,500

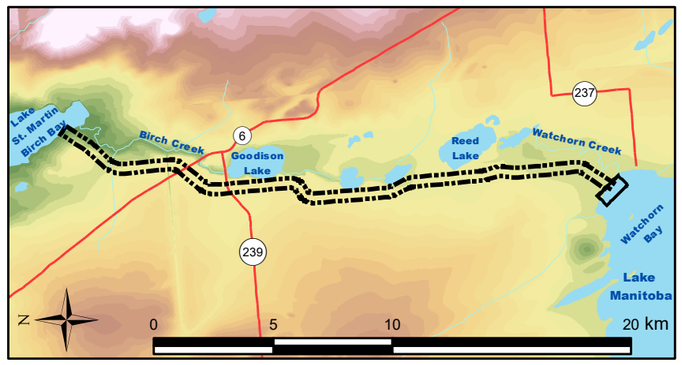
529,500

5,681,000

Legend

- Substrate samples
- AAE Substrate mapping
  - Sand (>90%)
  - Gravel with sand/silt (50%-30%-20%)
  - Sand and gravel (50%-50%)
- Watchorn Provincial Park
- Outlet channel corridor
- Contour - Bathymetric (0.5 m c.i.)
- Contour - Topographic (0.5 m c.i.)

0 75 150 300 m



N E S W

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LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Sample locations at the inlet location in Watchorn Bay

Map 10	20-Jun-19	1:3,000	NAD83	UTM Zone 14N

Coarse sandy and fine gravel sediment at northwest end of Watchorn Beach (A:B).


A


B


C


D

Raised beach ridge adjacent to Watchorn Beach. This is an ancient feature whose elevation may have been raised by glacio-isostatic rebound over many centuries (C:D).

Photographs indicating the transient nature of onshore movement of sand in the nearshore area at Watchorn Beach. (E) shows a buildup of sand near the shoreline. (F) shows an absence of send adjacent to a small hand-built 'groin' indicating the lack of onshore sand movement at this location. (G) shows deposition of sand on the sheltered side of a small hand-built rock ridge indicating a minor amount of onshore sand movement at this location.

E


F


G

Coarser gravel beach sediment toward the southeast end of Watchorn Beach (H:I)


H


I


J

Abrupt transition to gravel, cobble, and boulder beach at southeast end of Watchorn Beach. Grass and trees are growing on a raised beach ridge above the wave-washed beach. Some large boulders are present on the raised beach ridge.

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LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Field photos at Watchorn Bay Provincial Park

Map 11	20-Jun-19	1:2,000	NAD83	UTM Zone 14N

Field photos taken 11-June-2019

534,000 5,706,000 5,705,500 534,500 5,705,000 535,000 5,704,000 535,500 5,703,500 5,703,000 536,000 5,702,500

533,500 5,706,000 533,000 532,500 5,705,500 532,000

536,000 535,500 5,701,500 535,000 534,500

Lake
St. Martin

Birch
Bay

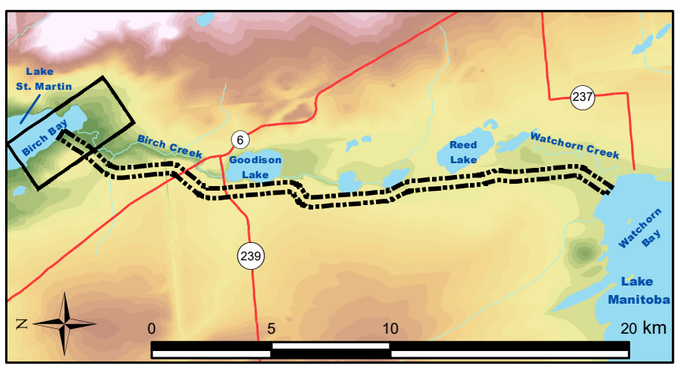
Birch
Creek

532,000 5,705,000 5,704,500 532,500 5,704,000 5,703,500 533,000 5,703,000 533,500 5,702,000 534,000 5,701,500

Legend

- Paved roads
- Unpaved roads
- Outlet channel corridor

0 0.25 0.5 1 km



E N W S

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LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Overview of Birch Bay (Lake St. Martin) study area

Map 12	20-Jun-19	1:12,000	NAD83	UTM Zone 14N

Reference map only; not for survey or legal use. Although all reasonable attempts have been made to ensure the accuracy of this mapping product, JDMA, their clients, subcontractors or affiliates assume no responsibility for any loss or inconvenience experienced as a result of errors or omissions in this map.

5,705,500 534,500 5,704,500 535,000 5,704,000 5,703,500 535,500 5,703,000

534,000 5,705,500 533,500 533,000 5,705,000 534,500 535,500 5,702,500 535,000

Lake St. Martin

Birch Bay

Birch Creek

JDM-Birch-XS1

JDM-Birch-XS2

JDM-Birch-XS3

JDM-Birch-XS4

240.5 241 242 243.5 244 244.5 245 246 246.5 247 247.5 248 249

533,000 5,704,500 5,704,000 533,500 5,703,500 5,703,000 534,000 5,702,500

Legend

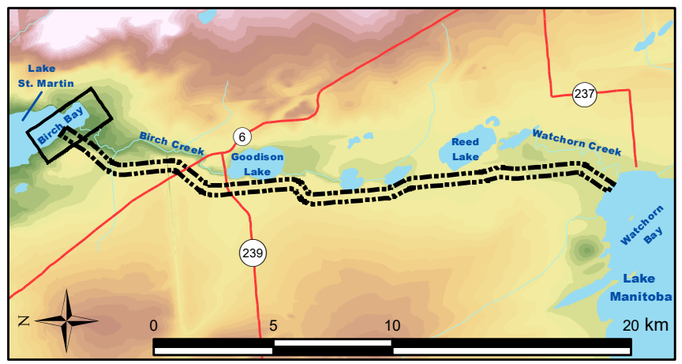
- Paved roads
- Unpaved roads
- Outlet channel corridor
- Location of cross sections (Map 10)
- Contour - Bathymetric (0.5 m c.i.)
- Contour - Topographic (0.5 m c.i.)

Ground elevation

High : 251.174

Low : 240.232

0 0.25 0.5 1 km



N E S W

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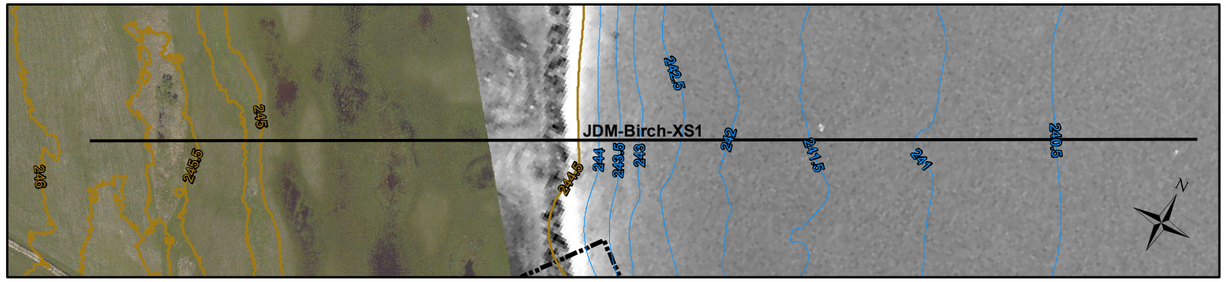
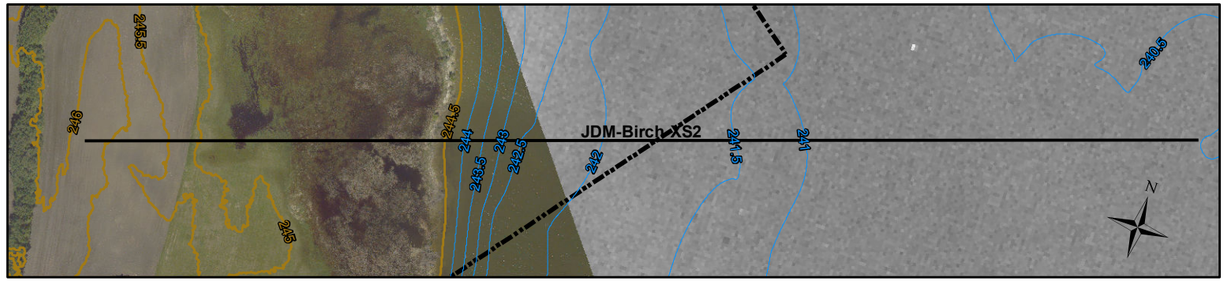
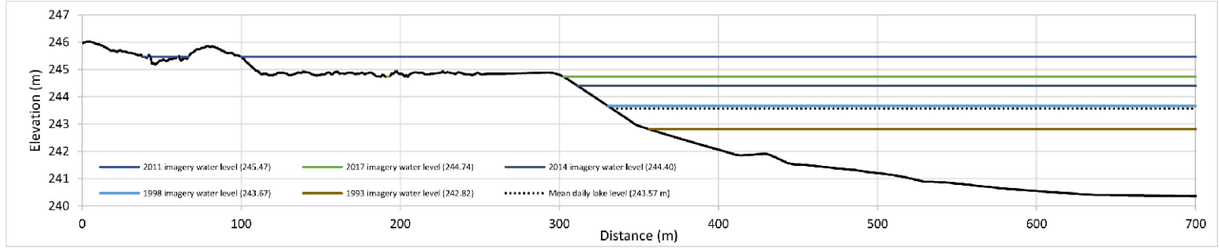
LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

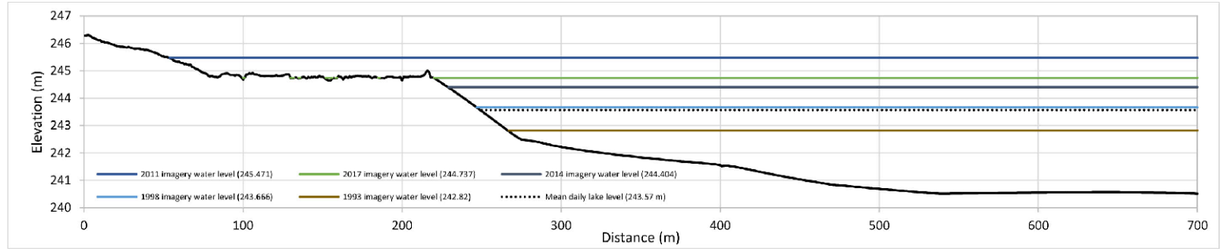
Bathymetry of Birch Bay

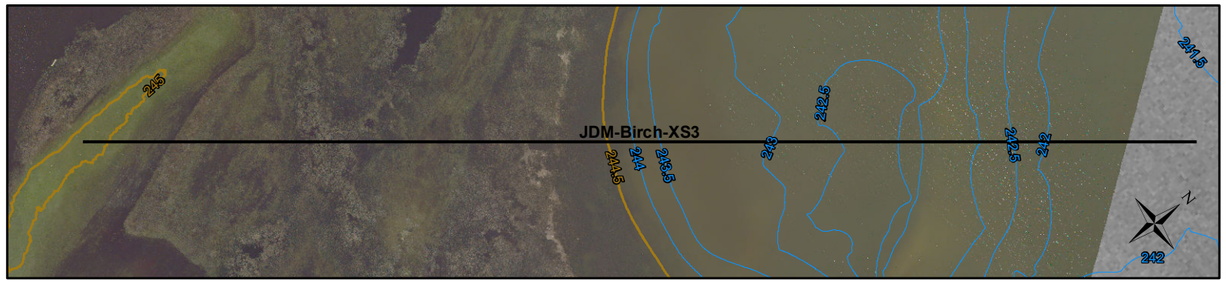
Map 13	20-Jun-19	1:8,000	NAD83	UTM Zone 14N

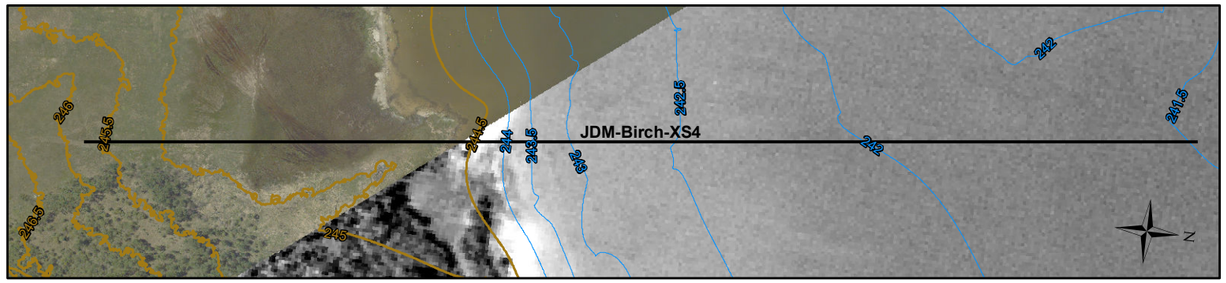


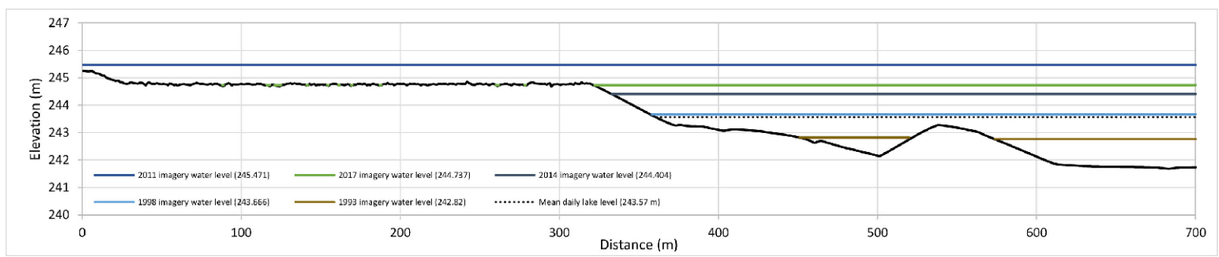


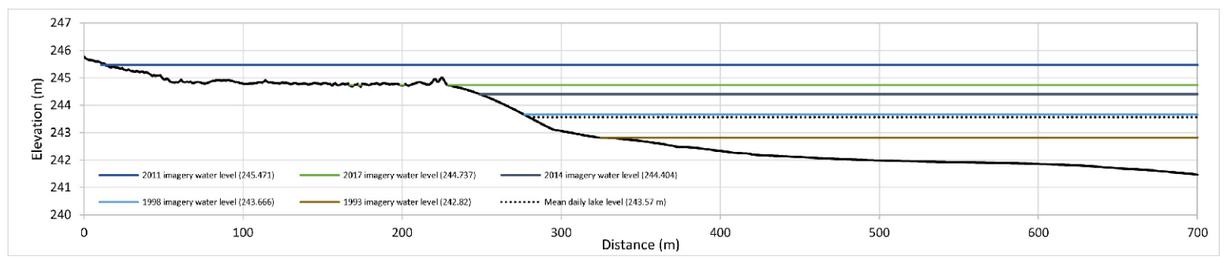








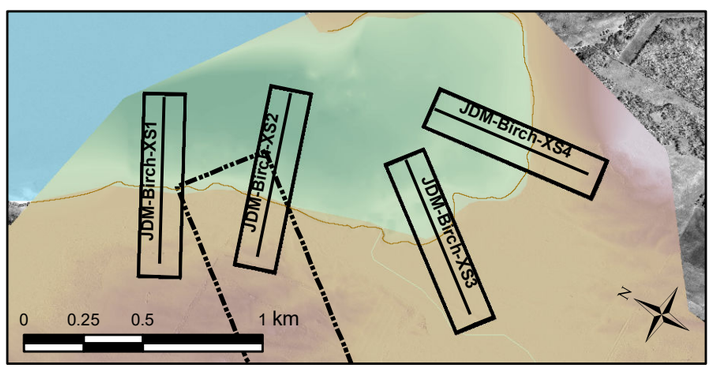




Legend

- Contour - Bathymetric (0.5 m c.i.)
- Contour - Topographic (0.5 m c.i.)
- Birch Bay offshore cross-sections
- Outlet channel corridor

0 125 250 500 m



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LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Offshore cross sections in Birch Bay

Map 14	20-Jun-19	1:3,770	NAD83	UTM Zone 14N

5,705,500 534,500 5,704,500 535,000 5,704,000 5,703,500 535,500 5,703,000

534,000 5,705,500 533,500 533,000 5,705,000

535,500 5,702,500 535,000 534,500

Lake
St. Martin

Birch
Bay

Birch
Creek

533,000 5,704,500 5,704,000 533,500 5,703,500 5,703,000 534,000 5,702,500

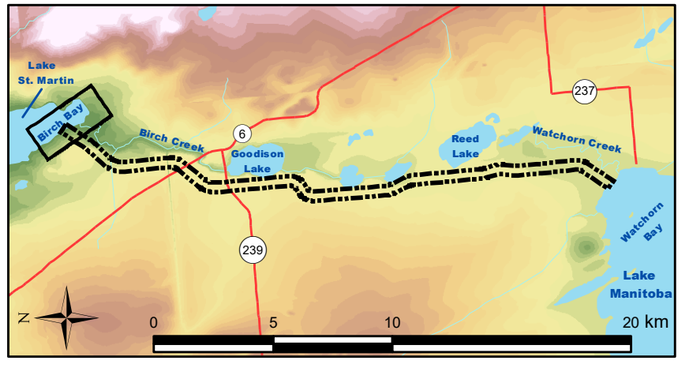
Legend

- Paved roads
- Unpaved roads
- Outlet channel corridor

Extent of AAE substrate mapping

- Gravel with sand (70%-30%)
- Mosly sand (>90%)
- Mostly gravel (>90%)

0 0.25 0.5 1 km



N E S W

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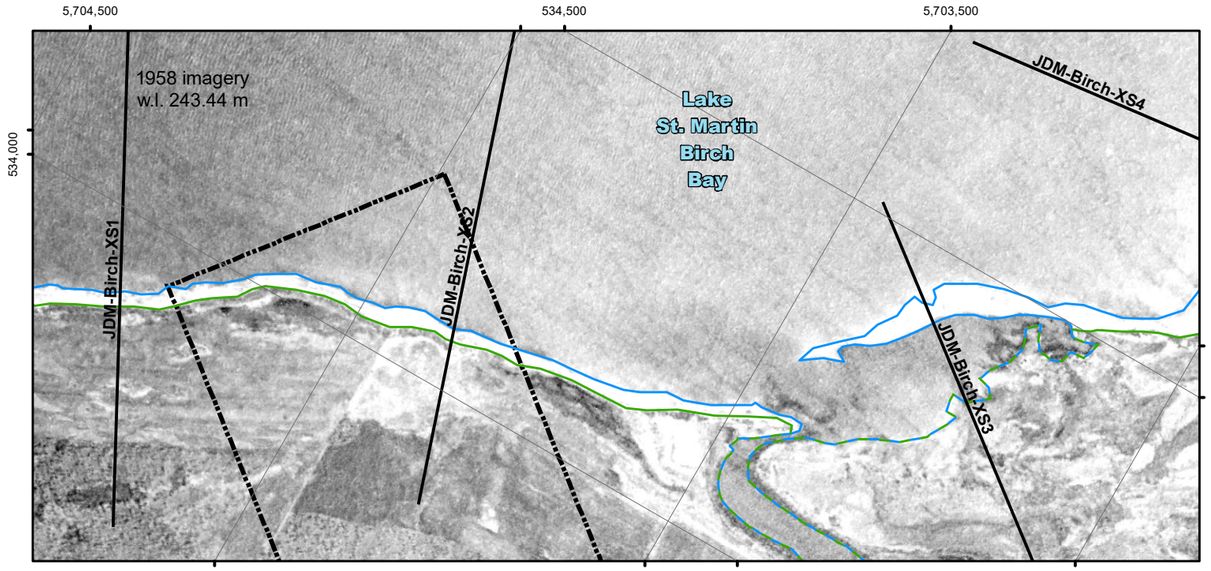
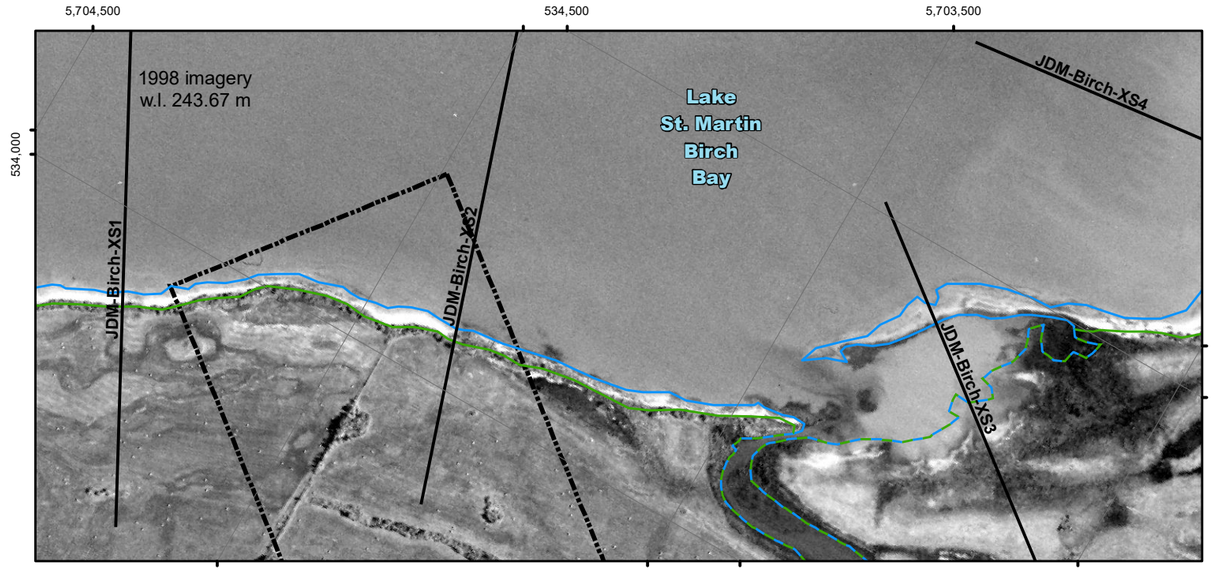
LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

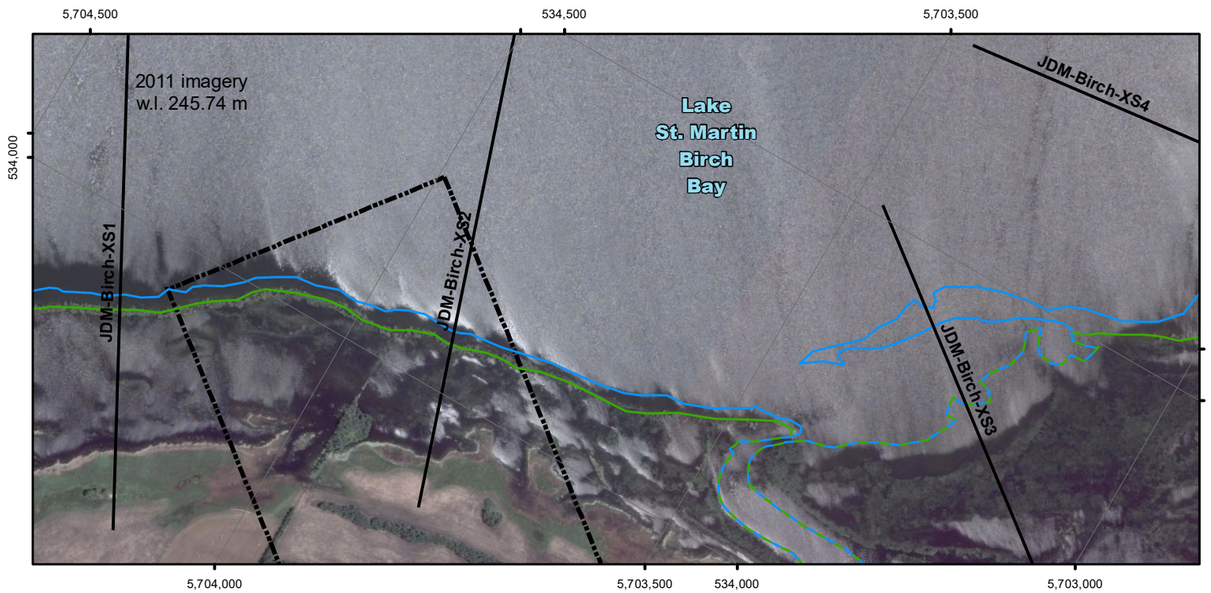
Substrate mapping of Birch Bay

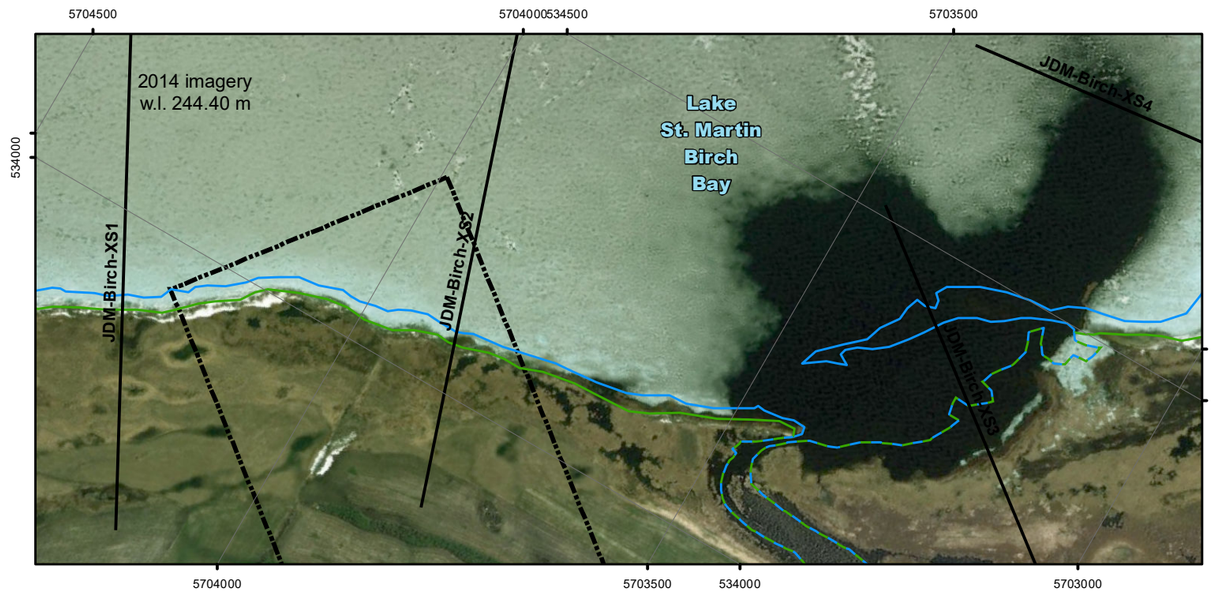
Map 15	20-Jun-19	1:8,000	NAD83	UTM Zone 14N

Map Sources: Substrate © AAE, 2017 colour imagery © MII, 1996 B&W imagery © MLI, Road network © NRCAN





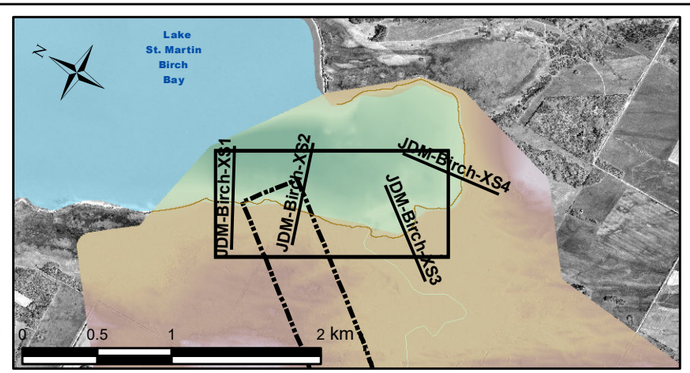




Legend

- Edge of vegetation (1958)
- Edge of water (1958)
- Edge of water & edge of vegetation (1958)
- Birch Bay offshore cross-sections
- Outline channel corridor

0 0.25 0.5 1 km



N E S W

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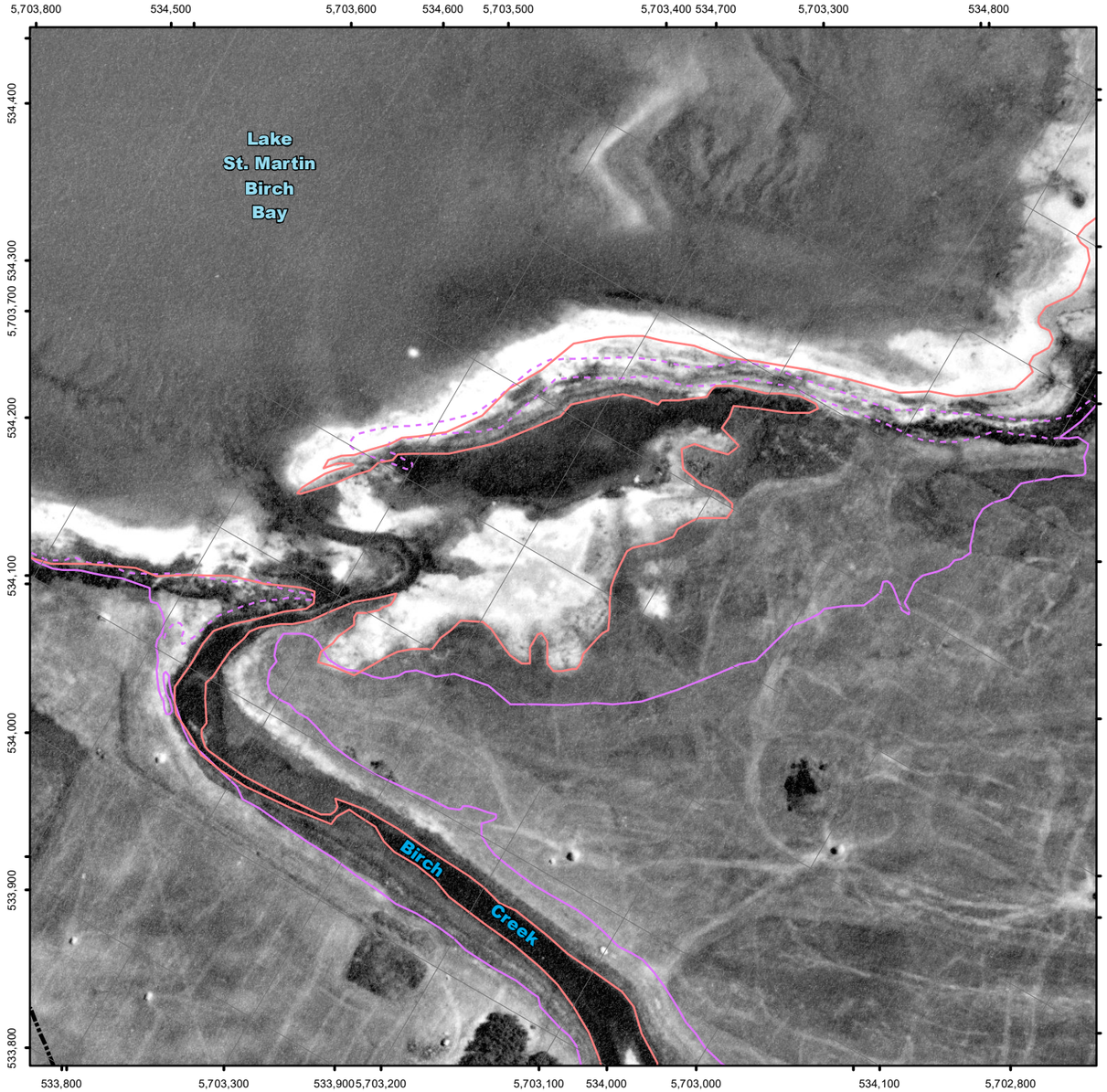
LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

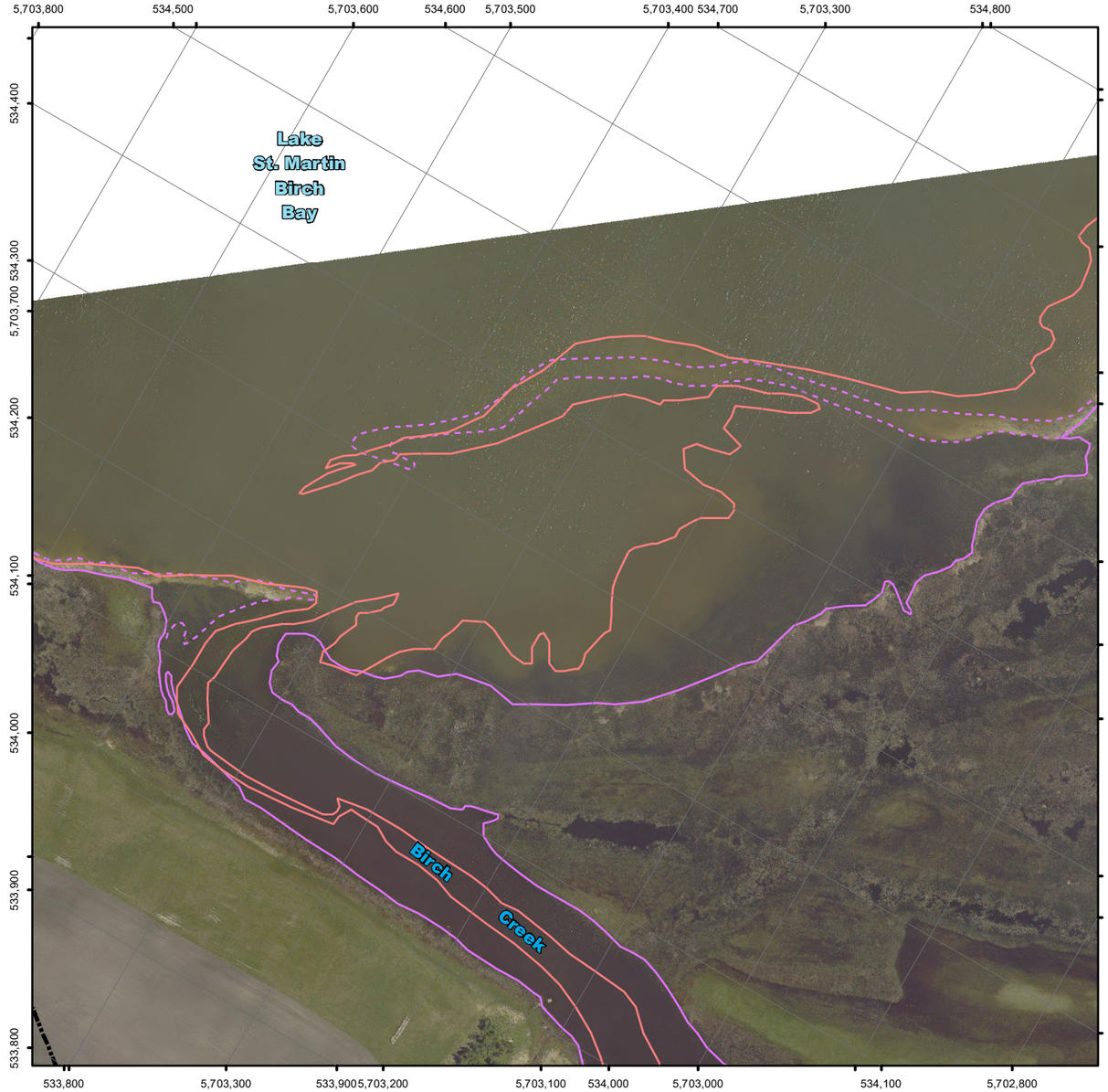
1958 shoreline mapped on 1958, 1998, 2011, 2014 imagery

Map 16	21-Jun-19	1:8,000	NAD83	UTM Zone 14N

Reference map only; not for survey or legal use. Although all reasonable attempts have been made to ensure the accuracy of this mapping product, JDMA, their clients, subcontractors or affiliates assume no responsibility for any loss or inconvenience experienced as a result of errors or omissions in this map.

Map Sources: 1958, imagery © NAPL, 1998 imagery © MLI, 2011 imagery © Google, 2014 imagery © ESRI

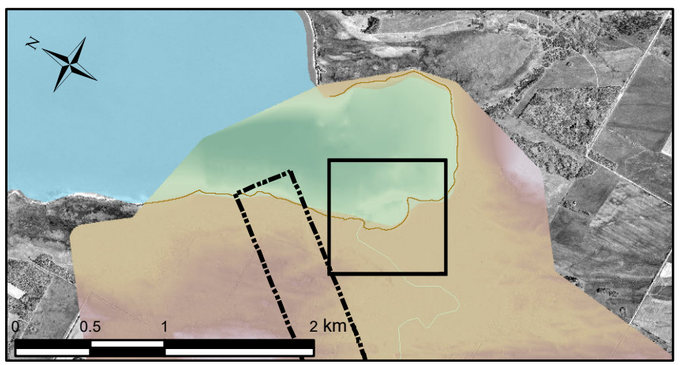


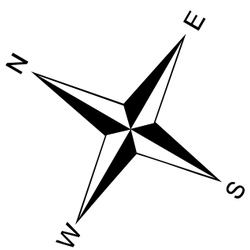


Legend

- 1961 edge of vegetation (1961 w.l. 242.69 m)
- 2017 edge of vegetation (2017 w.l. 244.74 m)
- 2017 Submerged bars (2017 w.l. 244.74 m)
- Outlet channel corridor

0 125 250 500 m





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LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Birch Creek outlet features

Map 17	21-Jun-19	1:4,000	NAD83	UTM Zone 14N

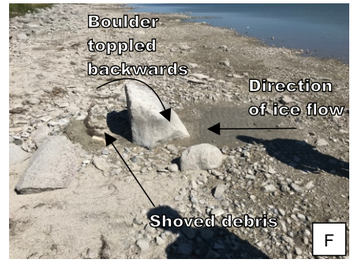
Reference map only; not for survey or legal use. Although all reasonable attempts have been made to ensure the accuracy of this mapping product, JDMA, their clients, subcontractors or affiliates assume no responsibility for any loss or inconvenience experienced as a result of errors or omissions in this map.

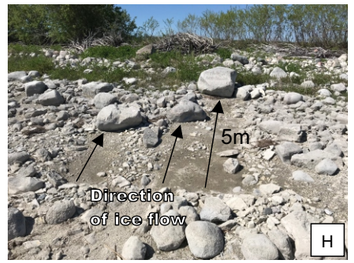
Map Sources: 2017 colour imagery © MIT, 1996 B&W imagery © MLI, Road network © NRCAN

Gravel washed over the crest of the raised beach ridge

A recent granular beach ridge

Sand deposited in quiet water near the shore





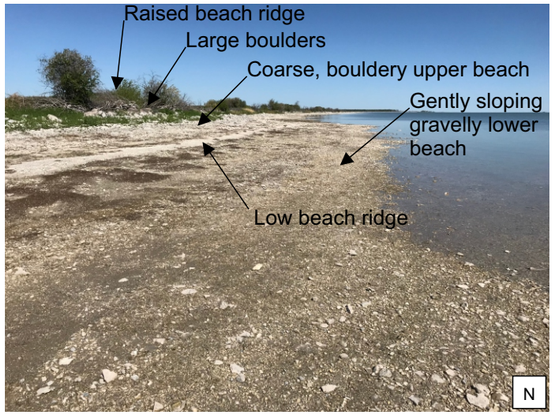
Ice shoved boulders. Up to 5m displacement noted

Boulder zone on upper beach zone

Top of raised beach ridge

Gravel beach sediment and nearshorer substrate

Ice-shove boulders on lake side of raised beach ridge



View north of approximate centerline

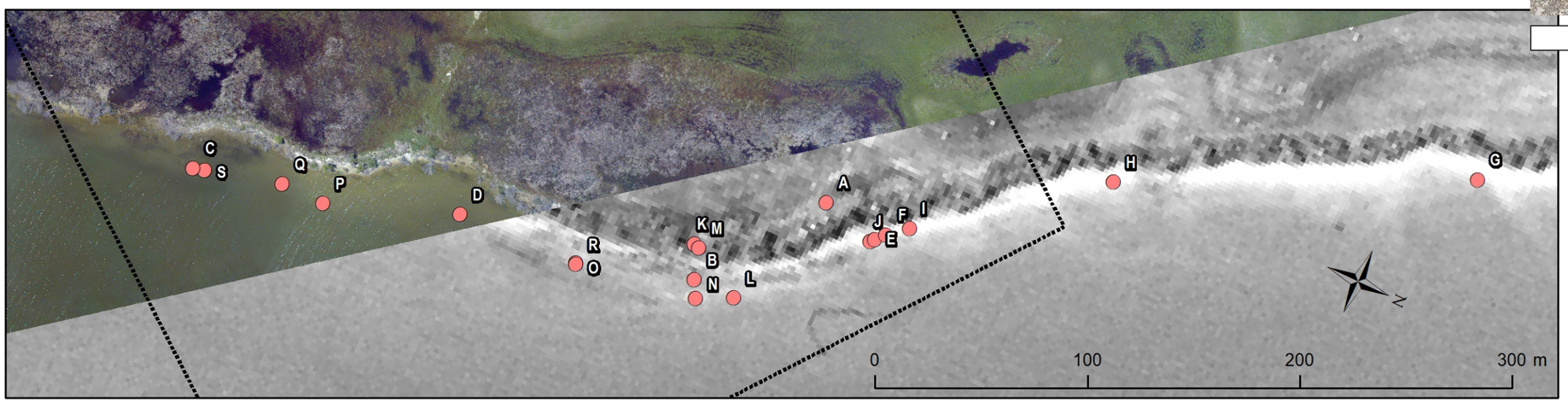
View south of approximate centerline

Boulder zone on upper beach slope

Transition to vegetated shoreline

Gravel substrate near shoreline

Gravel and sand sediment along vegetated shoreline



J D MOLLARD AND ASSOCIATES (2010) LIMITED

LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Field photos of at the channel outlet location, Lake St. Martin

Map 18	20-Jun-19	1:2,000	NAD83	UTM Zone 14N

Reference map only; not for survey or legal use. Although all reasonable attempts have been made to ensure the accuracy of this mapping product, JDMA, their clients, subcontractors or affiliates assume no responsibility for any loss or inconvenience experienced as a result of errors or omissions in this map.

Field photos taken 12-June-2019

5,704,000 534,500

Lake St. Martin

Sample #: 4
Water depth (m): 2.8 m
Length of core recovered (cm) 32 cm
Dominant material: Upper 14 cm very soft organic rich mud.
Lower 18 cm fine sand and silt
Secondary material: Shells in upper 14 cm
Amount of mineral sediment retained on 1.18 mm sieve: 0
Top size retained: Only shells

Sample #: 5
Water depth (m): 2.1 m
Length of core recovered (cm) 18 cm
Dominant material: Fine sand and silt
Secondary material: Shells in thin upper silty layer
Amount of mineral sediment retained on 1.18 mm sieve: 0
Top size retained: Only shells

Sample #: 3
Water depth (m): 2.0 m
Length of core recovered (cm) 10 cm
Dominant material: Fine sand and silt
Secondary material: N/A
Amount of mineral sediment retained on 1.18 mm sieve: Minor
Top size retained: up to 5 mm

Birch Bay

241

Sample #: 2
Water depth (m): 1.4 m
Length of core recovered (cm) 15 cm
Dominant material: Fine sand and silt
Secondary material: N/A
Amount of mineral sediment retained on 1.18 mm sieve: Minor
Top size retained: up to 3 mm

Sample #: 6
Water depth (m): 1.0 m
Length of core recovered (cm) 7.5 cm
Dominant material: Gravelly sand
Secondary material: N/A
Amount of mineral sediment retained on 1.18 mm sieve: 10-20%
Top size retained: up to 2.5 cm

Sample #: 7
Water depth (m): 1.1 m
Length of core recovered (cm) 15 cm
Dominant material: Fine sand and silt
Secondary material: N/A
Amount of mineral sediment retained on 1.18 mm sieve: 0
Top size retained: Only shells

Birch Creek

243.5
244
244.5

Sample #: 1
Water depth (m): 1.2 m
Length of core recovered (cm) 15 cm
Dominant material: Fine sand and silt
Secondary material: Fine gravel
Amount of mineral sediment retained on 1.18 mm sieve: <5%
Top size retained: up to 1 cm

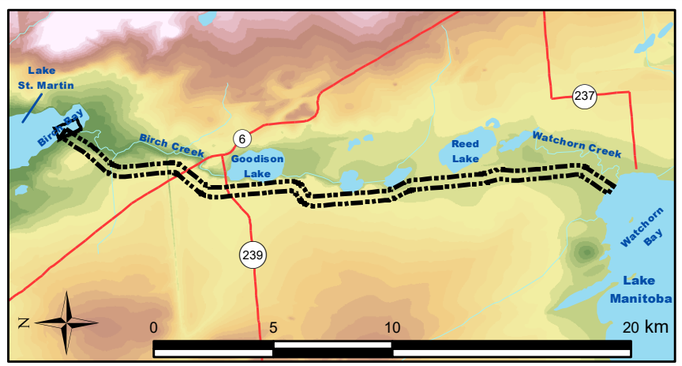
239
242.5
244
244.5

5,703,500
534,500
534,000
5,704,000
5,703,500

Legend

- Substrate samples
- AAE Substrate mapping
  - Gravel and sand (70%-30%)
  - Mostly sand (>90%)
  - Mostly gravel (>90%)
- Outlet channel corridor
- Contour - Bathymetric (0.5 m c.i.)
- Contour - Topographic (0.5 m c.i.)

0 75 150 300 m



N E S W

J D MOLLARD AND ASSOCIATES (2010) LIMITED

LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Sample locations at the outlet location in Birch Bay

Map 19	20-Jun-19	1:2,500	NAD83	UTM Zone 14N

APPENDIX A – PHOTOLOG OF SUBSTRATE SAMPLES

Watchorn Bay Sample 1

Photo ID: DSCN 3585
Dominant material: Fine sand and silt
Secondary material: Fine gravel
Top size: 2 cm
Description: Material extracted from bed using hand auger.

Photo ID: DSCN 3587
Dominant material: Fine sand and silt
Secondary material: Fine gravel
Top size: 2 cm
Description: Material extracted from bed shown in a pail. Pen for scale.

Photo ID: DSCN 3589
Dominant material: Fine sand and silt
Secondary material: Fine gravel
Top size: 2 cm
Description: Material extracted from bed shown in a pail. Pen for scale.

Watchorn Bay Sample 2

Photo ID: DSCN 3590
Dominant material: Fine sand and silt
Secondary material: Fine gravel in upper 10 cm
Top size: 2 cm
Description: Material extracted from bed using hand auger.

Photo ID: DSCN 3591
Dominant material: Fine sand and silt
Secondary material: Fine gravel in upper 10 cm
Top size: 2 cm
Description: Material extracted from bed shown in a pail. Pen for scale points to the top of the core.

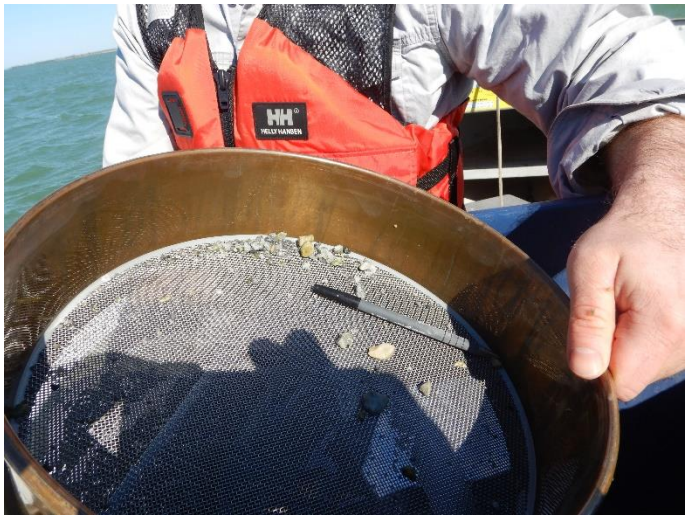


Photo ID: DSCN 3593
Dominant material: Fine sand and silt
Secondary material: Fine gravel in upper 10 cm
Top size: 2 cm
Description: Material extracted from bed shown washed through a 1.18 mm sieve plate.

Watchorn Bay Sample 3

Photo ID: DSCN 3595
Dominant material: Fine sand and silt
Secondary material: Fine gravel in upper 5 cm
Top size: 1 cm
Description: Material extracted from bed using hand auger.

Photo ID: DSCN 3596
Dominant material: Fine sand and silt
Secondary material: Fine gravel in upper 5 cm
Top size: 1 cm
Description: Material extracted from bed shown in a pail. Pen for scale points to the top of the core.

Photo ID: DSCN 3597
Dominant material: Fine sand and silt
Secondary material: Fine gravel in upper 5 cm
Top size: 1 cm
Description: Material extracted from bed shown washed through a 1.18 mm sieve plate.

Watchorn Bay Sample 4

Photo ID: DSCN 3600
Dominant material: Fine sand and silt
Secondary material: Gravel and clay plug at bottom of core
Top size: 3 cm
Description: Material extracted from bed using hand auger.

Photo ID: DSCN 3601
Dominant material: Fine sand and silt
Secondary material: Gravel and clay plug at bottom of core
Top size: 3 cm
Description: Material extracted from bed shown in a pail. Pen for scale points to the top of the core.

Photo ID: DSCN 3602
Dominant material: Fine sand and silt
Secondary material: Gravel and clay plug at bottom of core
Top size: 3 cm
Description: Material extracted from bed shown washed through a 1.18 mm sieve plate.

Birch Bay Sample 1

Photo ID: DSCN 3746
Dominant material: Fine sand and silt
Secondary material: Fine gravel
Top size: 1 cm
Description: Material extracted from bed using hand auger.

Photo ID: DSCN 3748
Dominant material: Fine sand and silt
Secondary material: Fine gravel
Top size: 1 cm
Description: Material extracted from bed shown in a pail. Pen for scale points to the top of the core.

Photo ID: DSCN 3749
Dominant material: Fine sand and silt
Secondary material: Fine gravel
Top size: 1 cm
Description: Material extracted from bed shown washed through a 1.18 mm sieve plate.

Birch Bay Sample 2

Photo ID: DSCN 3751
Dominant material: Fine sand and silt
Secondary material: N/A
Top size: 3 mm
Description: Material extracted from bed using hand auger.

Photo ID: DSCN 3752
Dominant material: Fine sand and silt
Secondary material: N/A
Top size: 3 mm
Description: Material extracted from bed shown on a sieve plate. Pen for scale points to the top of the core.

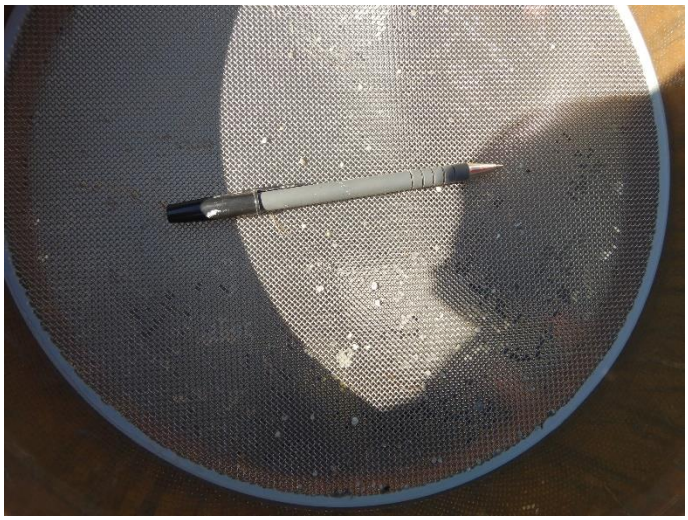


Photo ID: DSCN 3753
Dominant material: Fine sand and silt
Secondary material: N/A
Top size: 3 mm
Description: Material extracted from bed shown washed through a 1.18 mm sieve plate.

Birch Bay Sample 3

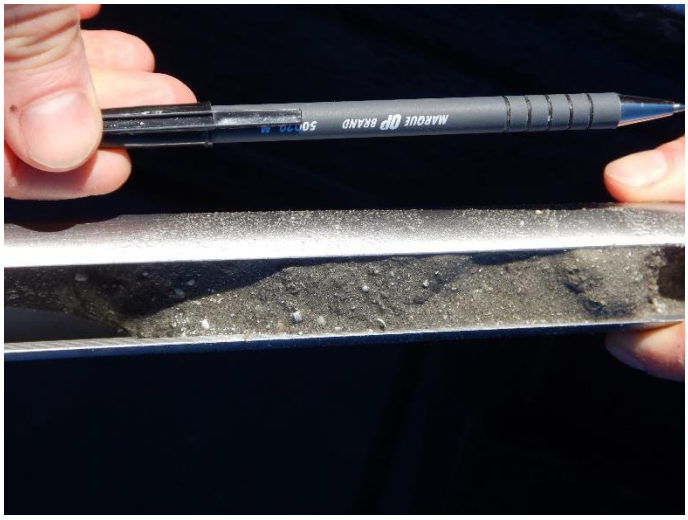


Photo ID: DSCN 3761
Dominant material: Fine sand and silt
Secondary material: N/A
Top size: 5 mm
Description: Material extracted from bed using hand auger.

Photo ID: DSCN 3762
Dominant material: Fine sand and silt
Secondary material: N/A
Top size: 5 mm
Description: Material extracted from bed shown on a sieve plate. Pen for scale points to the top of the core.

Photo ID: DSCN 3763
Dominant material: Fine sand and silt
Secondary material: N/A
Top size: 5 mm
Description: Material extracted from bed shown washed through a 1.18 mm sieve plate.

Birch Bay Sample 4

Photo ID: DSCN 3765
Dominant material: Upper 14 cm very soft organic rich mud, lower layer is fine sand and sit
Secondary material: Shells in upper 14 cm
Top size: N/A
Description: Photo shows the Ponar grab sampler material extracted from the lake bed.

Photo ID: DSCN 3767
Dominant material: Upper 14 cm very soft organic rich mud, lower layer is fine sand and silt
Secondary material: Shells in upper 14 cm
Top size: N/A
Description: Material extracted from bed shown washed through a 1.18 mm sieve plate. No mineral sediments were retained. Only small shells were retained on the sieve.

Photo ID: DSCN 3769
Dominant material: Upper 14 cm very soft organic rich mud, lower 18 cm fine sand and silt
Secondary material: Shells in upper 14 cm
Top size: N/A
Description: Material extracted from bed using hand auger.

Birch Bay Sample 5

Photo ID: IMG 0522
Dominant material: Fine sand and silt
Secondary material: Shells in thin upper silty layer
Top size: N/A
Description: Material extracted from bed using hand auger.

Photo ID: IMG 0523
Dominant material: Fine sand and silt
Secondary material: Shells in thin upper silty layer
Top size: N/A
Description: Material extracted from bed shown on a sieve plate. Pen for scale points to the top of the core.

Photo ID: IMG 0525
Dominant material: Fine sand and silt
Secondary material: Shells in thin upper silty layer
Top size: N/A
Description: Material extracted from bed shown washed through a 1.18 mm sieve plate.

Birch Bay Sample 6

Photo ID: IMG 0527
Dominant material: Gravelly sand
Secondary material: N/A
Top size: 2.5 cm
Description: Material extracted from bed using hand auger.

Photo ID: IMG 0528
Dominant material: Gravelly sand
Secondary material: N/A
Top size: 2.5 cm
Description: Material extracted from bed shown on a sieve plate. Pen for scale points to the top of the core.

Photo ID: IMG 0529
Dominant material: Gravelly sand
Secondary material: N/A
Top size: 2.5 cm
Description: Material extracted from bed shown washed through a 1.18 mm sieve plate.

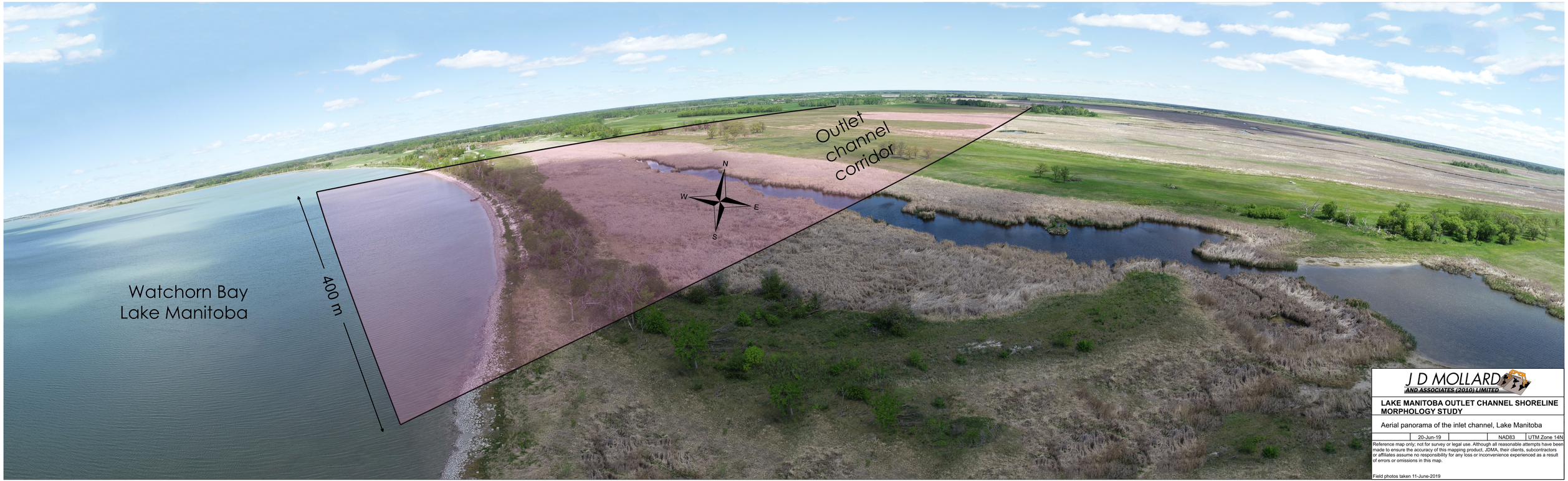
Birch Bay Sample 7

Photo ID: IMG 0531
Dominant material: Fine sand and silt
Secondary material: N/A
Top size: N/A
Description: Material extracted from bed using hand auger.

Photo ID: IMG 0532
Dominant material: Fine sand and silt
Secondary material: N/A
Top size: N/A
Description: Material extracted from bed shown on a sieve plate. Pen for scale points to the top of the core.

Photo ID: IMG 0533
Dominant material: Fine sand and silt
Secondary material: N/A
Top size: N/A
Description: Material extracted from bed shown washed through a 1.18 mm sieve plate.

APPENDIX B – POSTER MAPS OF INLET AND OUTLET LOCATIONS



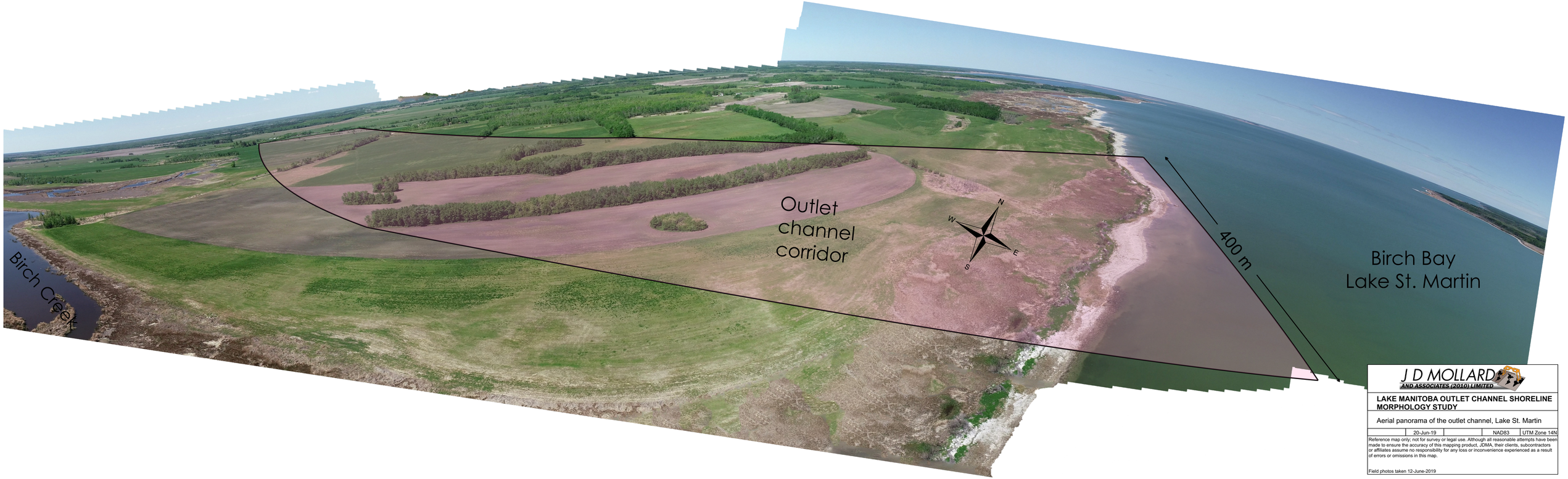
J D MOLLARD AND ASSOCIATES (2010) LIMITED

LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Aerial panorama of the inlet channel, Lake Manitoba

	20-Jun-19		NAD83	UTM Zone 14N

Field photos taken 11-June-2019



J D MOLLARD AND ASSOCIATES (2010) LIMITED

LAKE MANITOBA OUTLET CHANNEL SHORELINE MORPHOLOGY STUDY

Aerial panorama of the outlet channel, Lake St. Martin

	20-Jun-19		NAD83	UTM Zone 14N

Field photos taken 12-June-2019