MANITOBA INFRASTRUCTURE

Lake Manitoba and Lake St. Martin Outlet Channels

Analysis of Physical Impacts to Rivers within the Hydraulic System

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Limitations

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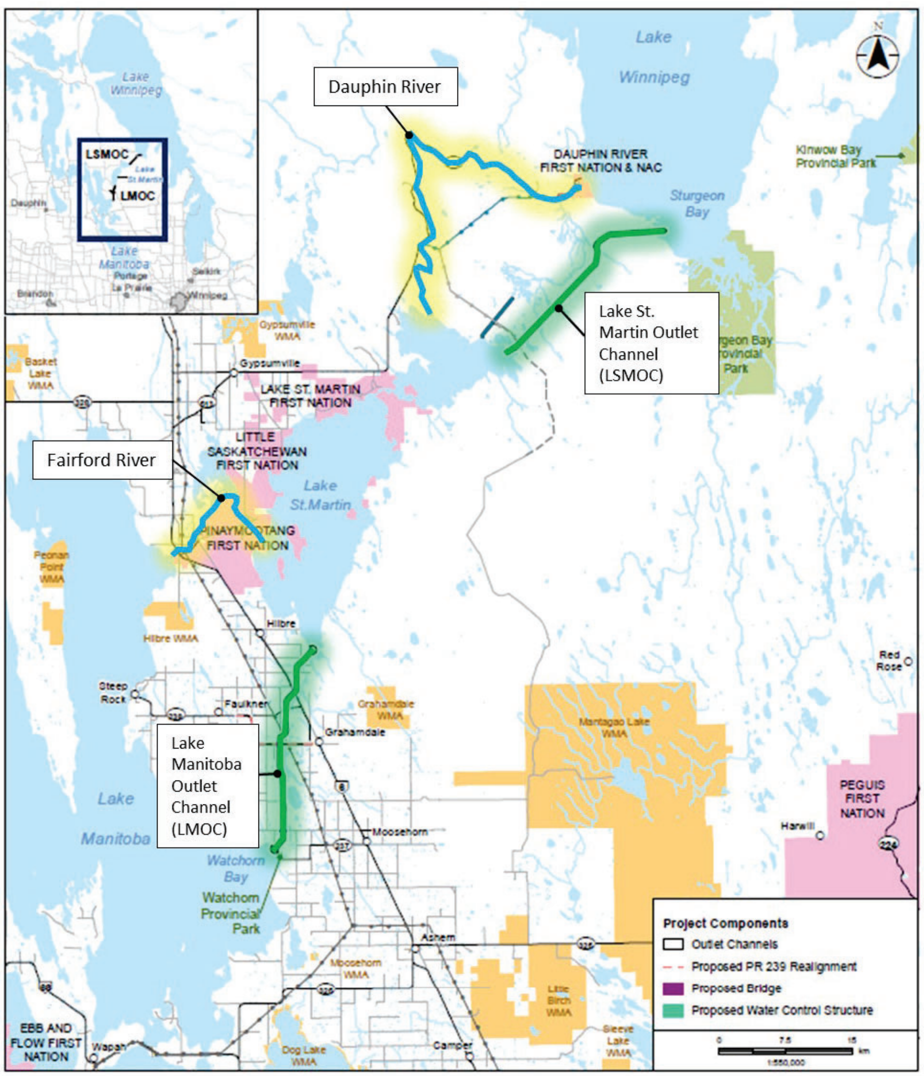
1.0 INTRODUCTION

1.1 Background of Flow System

The Lake Manitoba Outlet Channel (LMOC) and Lake St. Martin Outlet Channel (LSMOC) are collectively referred to as the "Project" herein. They will provide additional pathways to convey water from Lake Manitoba to Lake St. Martin, and from Lake St. Martin to Lake Winnipeg. Outflows from Lake Manitoba and Lake St. Martin are currently conveyed solely by the Fairford River and Dauphin River, respectively. Operation of the outlet channels will alter the hydraulic flow regimes of these rivers, which may consequently influence the fluvial geomorphological processes and river ice processes in the rivers. A map of the Project is shown in Figure 1.

FIGURE 1: MAP OF PROJECT AREA



The Fairford River flows from the northeast edge of Lake Manitoba, through Lake Pineimuta, to Lake St. Martin. The primary flow path is approximately 17 km long, but the river branches into multiple smaller reaches in the delta region through Lake Pineimuta. Flooding on Lake Manitoba between 1899 and 1901 led to the excavation of an additional outlet channel to increase flows in the Fairford River. The Province subsequently constructed a concrete control dam near the inlet of the Fairford River in 1933 to limit flows during dry years (LM&LSMRRC, 2013).

In 1961, the Fairford River Water Control Structure (FRWCS) was completed, consisting of a new stoplog control structure with excavation works to increase the discharge capacity of the outlet from Lake Manitoba. The current structure is composed of 11 bays, with one bay containing a fishway. Stoplogs are inserted in each bay to control outflows from Lake Manitoba. The operating guidelines of the FRWCS have changed over its lifetime. Initially, the guidelines were set to maintain a stable water level on Lake Manitoba of El. 247.55 m (812.17 ft), with a minimum outflow of 1.4 m^3/s (50 cfs). These rules were modified based on recommendations by the Lake Manitoba Regulation Review Advisory Committee in 2003 due to the adverse effects on Lake St. Martin. The current operating guidelines take into consideration water levels on both Lake Manitoba and Lake St. Martin, and minimum outflow requirements on the Fairford River.

Lake Pineimuta is a shallow wetland complex with a surface area of approximately 39 km^2. The area is comprised of deltaic deposits formed through centuries of deposition from floodwaters passing through the low lying wetland, particularly in the southern portion of the lake (LMRRC, 2003). Operation of the FRWCS has resulted in increased variability in water levels in Lake Pineimuta. Numerical modeling conducted by UMA Engineering for Indian and Northern Affairs Canada (INAC) demonstrated that the maximum annual range of water levels on Lake Pineimuta increased by approximately three-fold. It also showed that the maximum water level on Lake Pineimuta was over two feet higher than under natural conditions (LMRRC, 2003).

The Dauphin River is approximately 52 km long, flowing from the north basin of Lake St. Martin to Lake Winnipeg. Flow in the Dauphin River is not directly regulated. Over the first 40 km, the river gradient is relatively flat (approximately 0.029%). This upper reach is characterized by numerous channel meanders, low banks, and relatively low water velocities. The lower 12 km of the Dauphin River has an average slope of approximately 0.16%, roughly five times steeper than the upper reach. The lower reach is straighter with steeper banks and has relatively high water velocities. Typical flow velocities can range between 0.5 m/s to 1.5 m/s over the upper reach, and increase to approximately 2 m/s in the lower reach (KGS Group, 2016).

1.2 Objective and Overview of Report

The objective of this study is to evaluate the impacts of the Project on the flow regimes of the Dauphin and Fairford Rivers, and physical processes pertaining thereto. The variation in flows in the rivers through the historical hydrologic regime (1915-2017), including both flood and non-flood periods, were calculated for the Pre-Project and Post-Project operation scenarios. In this context, the “Pre-Project” environment (baseline) refers to the existing flow system and infrastructure (i.e. with the FRWCS in place). The “Post-Project” environment refers to the flow system with the addition of the LMOC and LSMOC. Changes to channel hydraulics at the 10^{th}, 50^{th}, and 90^{th} percentile flows are quantified, and potential impacts on fluvial geomorphological processes and river ice process are examined. Riverbank slope stability analyses were not included in the scope of this study. Impacts on habitat and ecology are being reviewed separately.

Separate studies, conducted in parallel with this study, address impacts of the Project on flow patterns within Lake Manitoba, Lake St. Martin (including the Narrows), and Lake Winnipeg. That work is documented in separate reports. Shoreline geomorphological studies were also undertaken as part of the engineering design for the outlet channels (Zuzek, 2020a, 2020b; JD Mollard, 2019).

Section 2.0 includes field observations of the Pre-Project conditions in the Fairford and Dauphin Rivers made during a site visit in June 2019.

Section 3.0 presents an analysis of historical aerial photographs and fluvial geomorphological changes that have occurred over the last several decades in the Pre-Project environment. Changes to flow percentiles in the Fairford and Dauphin Rivers as a result of the Project are quantified, and results of numerical modeling of open channel hydraulics and river ice processes are presented.

Section 4.0 describes potential impacts of the Project on fluvial geomorphology, taking into consideration existing rates of riverbank erosion and results of the numerical modeling.

Finally, major conclusions from this study are presented in Section 5.0.

2.0 PHASE 1 SURVEYS OF RIVERBANK AND SUBSTRATE

A Phase 1 survey of the riverbanks and substrate material was conducted by KGS Group and Zuzek Inc. in June 2019.

2.1 Boat Survey and Instrument Deployment

The entire main channel of the Fairford River was traversed by boat, but only the lower 3 km of the Dauphin River was navigable by boat due to shallow water depths and areas of high velocity. The remainder of the Dauphin River was surveyed at discrete locations where the river was accessible from Provincial Road 513.

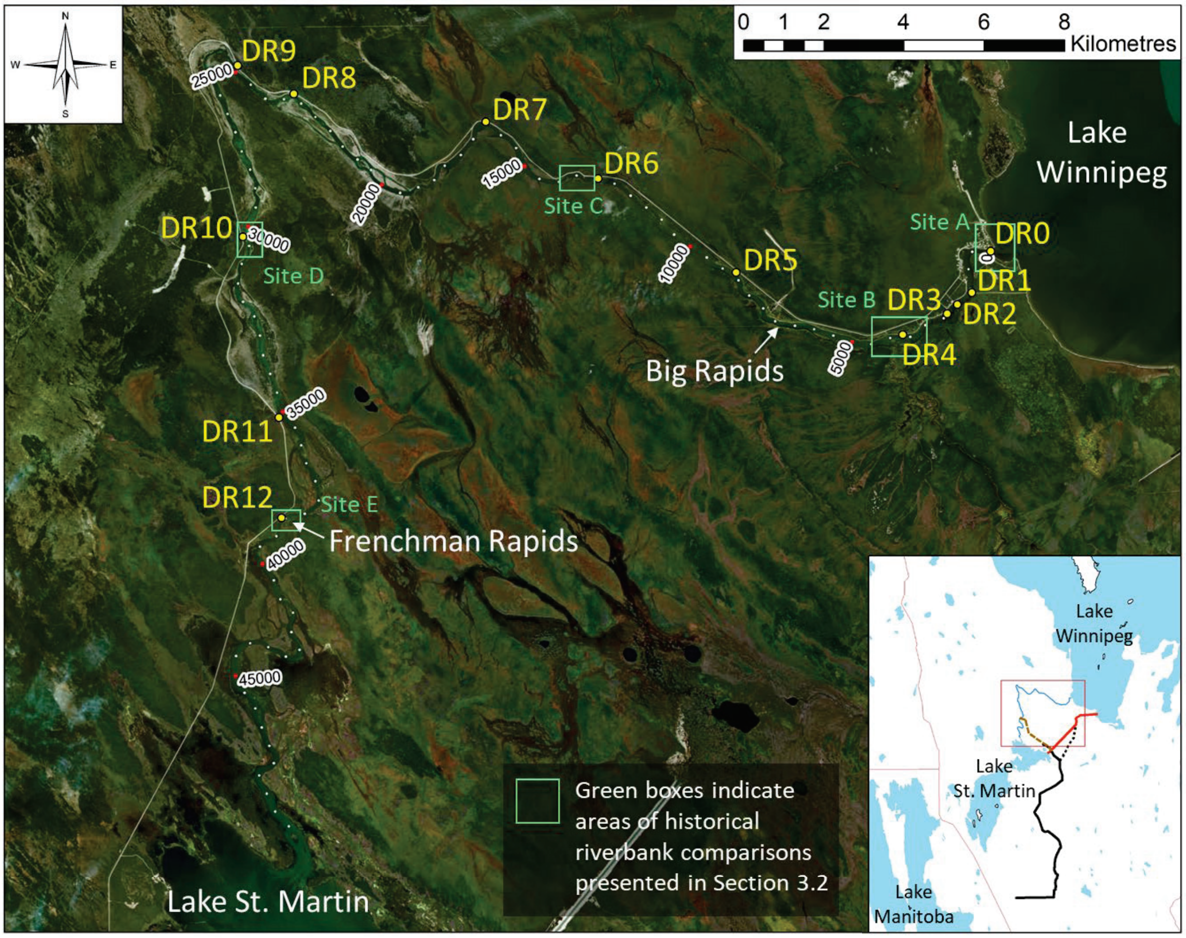
At the time of the survey, the flow in the Fairford River was approximately 88 m^3/s (data from Water Survey of Canada gauge 05LM001), while the flow in the Dauphin River was approximately 96 m^3/s (data from Water Survey of Canada gauge 05LM006). As later shown in Section 3.3, this corresponds roughly to the 60^{th} percentile summer flow on each river (i.e. a typical non-flood flow condition).

During the boat survey, continuous depth recordings and sonar imaging data were collected along the centreline of the river with SOLIX, a single-beam bathymetric system (Zuzek Inc., 2020). Visual observations of the riverbanks were recorded and photographed. Ponar grab samples were collected at discrete locations to verify the substrate information from the sonar imaging. Continuous substrate mapping was not included in the scope of the Phase 1 surveys.

2.2 Observations of the Dauphin River

A map of the Dauphin River is shown in Figure 2. Annotated locations along the river (DR1, DR2, etc.) correspond to photographs and Ponar grabs included in Appendix A. A subset of these locations was selected as detailed observation sites, described below. Historical changes in the riverbanks at these sites are reviewed in In Section 3.2, and an overview of the modeling results at these locations is provided in Section 4.0.

FIGURE 2: MAP OF OBSERVATION LOCATIONS ON THE DAUPHIN RIVER



2.2.1 DETAILED OBSERVATIONS AT SITE A – DR0

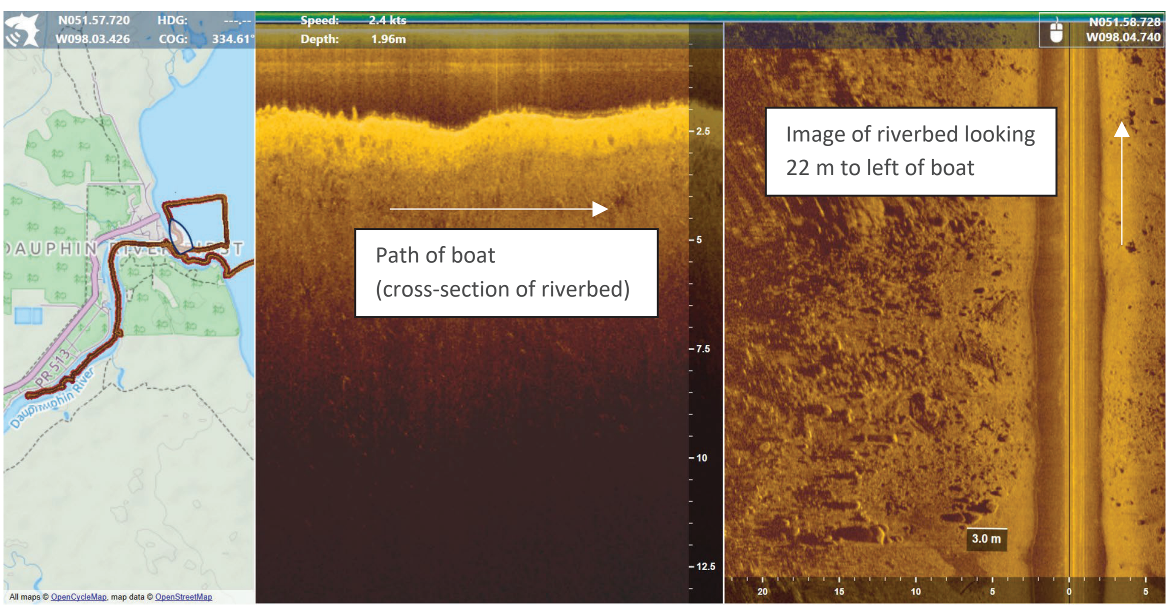
Site A (DR0) is located at the mouth of Dauphin River in Lake Winnipeg. Key observations are summarized in Table 1. Field turbidity measurements taken on June 13, 2019 ranged from 5.0-5.5 Nephelometric Turbidity Units (NTU).

TABLE 1: DETAILED OBSERVATIONS AT SITE A – DR0

Riverbank Description:	The banks of the river mouth have been armoured with large boulders (field stone) in select locations. The protection continues along the shoreline to the north. Upstream of the mouth the banks provide access to numerous boat docks.
Geology:	At the mouth of the river, unprotected sections of bank feature exposures of glacial till and signs of some erosion. Upstream of the river mouth, the banks were observed to be generally stable, with isolated areas of slumping and bank erosion. The bed of the river at the mouth featured a mix of sand, pebbles, cobbles, and boulders (see substrate sample photograph and sonar imaging).

Photographs: Sediment from bed of river at the mouth (left) and north bank of river (right).

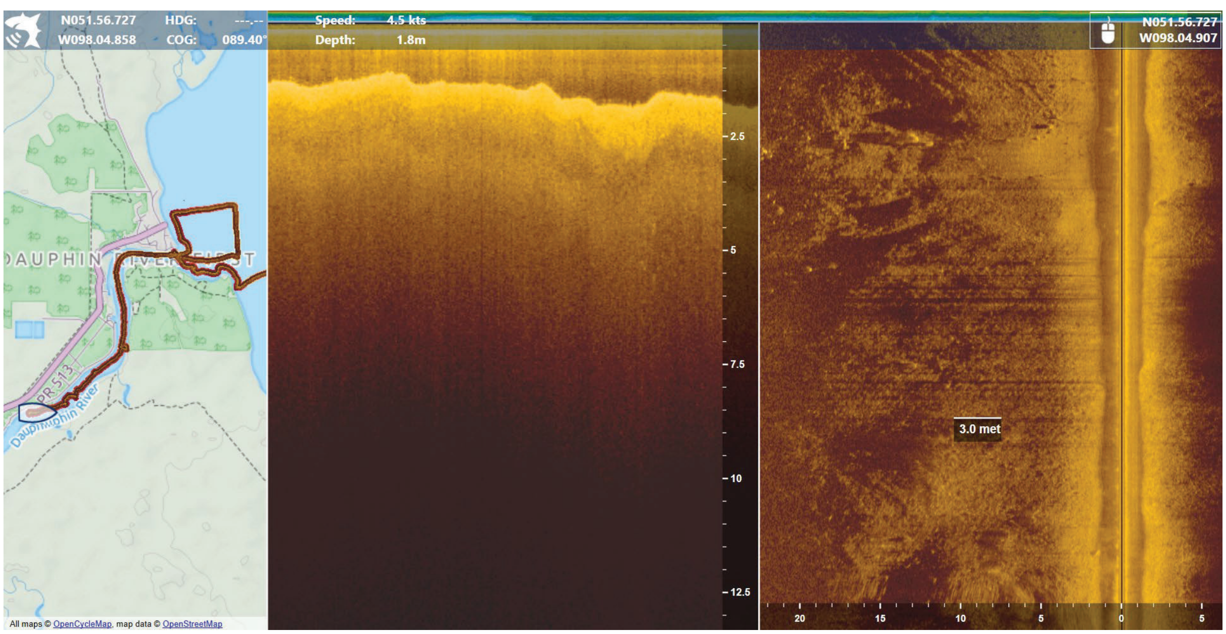
Sonar Imaging: Mixed substrate conditions, from sand to boulders.



2.2.2 DETAILED OBSERVATIONS AT SITE B – DR4

Site B (DR4) is located approximately 4 km upstream of Lake Winnipeg. Key observations are summarized in Table 2. A field turbidity measurement near DR4 taken on June 13, 2019 indicated a turbidity of 5.90 NTU.

TABLE 2: DETAILED OBSERVATIONS AT SITE B – DR4

Riverbank Description:	Vegetated riverbank with isolated locations of erosion. Vulnerable to high water levels and velocities during peak flow events. At low flows, the exposed bedrock protects the bank from erosion. See photographs.
Geology:	Exposed limestone bedrock at waterline capped with glacial sediment. Sonar mapped large-scale bed features of pebbles and cobbles with occasional boulders, which is consistent with field observations.
Photographs: North riverbank (left) and bedrock exposure at toe of bank (right).  	
Sonar Imaging: Large scale bars and shoals captured in cross-section (left) and bottom image (right). 	

2.2.3 DETAILED OBSERVATIONS AT SITE C – DR6

Site C (DR6) is located approximately 13 km upstream of Lake Winnipeg. Key observations are summarized in Table 3. A field turbidity measurement near DR6 taken on June 13, 2019 indicated a turbidity of 5.94 NTU.

TABLE 3: DETAILED OBSERVATIONS AT SITE C – DR6

Riverbank Description:	Vegetated upper bank with glacial till exposed in erosion scarp at the waterline. Bank erosion is sensitive to high current velocities during high water events. Road shoulder is very close to the eroding riverbank in some locations.
Geology:	Exposed glacial till in eroding riverbanks. No bedrock exposures visible.

Photographs: Shoulder of road at crest of the riverbank, looking upstream.


Eroding riverbanks (north bank, left, and south bank, right).


Eroding north riverbank close to roadway looking downstream (left) and upstream (right).


Sonar Imaging: No sonar imaging collected (not navigable).

2.2.4 DETAILED OBSERVATIONS AT SITE D – DR10

Site D (DR10) is located approximately 30 km upstream of Lake Winnipeg. Key observations are summarized in Table 4. A field turbidity measurement near DR10 taken on June 13, 2019 indicated a turbidity of 6.41 NTU.

TABLE 4: DETAILED OBSERVATIONS AT SITE D – DR10

Riverbank Description:	Vegetated upper bank with eroding till exposed in a small erosion scarp in the toe of the bank. Vulnerable to undercutting during high river levels and strong currents. Large boulders visible in the river due to shallow depths. Stable during average and low water levels.
Geology:	Exposed glacial till in toe of banks features high cobble and boulder content.

Photographs: Minor toe erosion along west riverbanks looking downstream (left) and upstream (right).


Soft glacial till at the waterline (left) and large boulders in shallow water close to the bank (right).


East bank of river (view from west bank) features a minor erosion scarp.

Sonar Imaging: No sonar imaging collected.

2.2.5 DETAILED OBSERVATIONS AT SITE E – DR12

Site E (DR12) is located approximately 38.5 km upstream of Lake Winnipeg. Key observations are summarized in Table 5. A field turbidity measurement near DR12 taken on June 13, 2019 indicated a turbidity of 8.12 NTU.

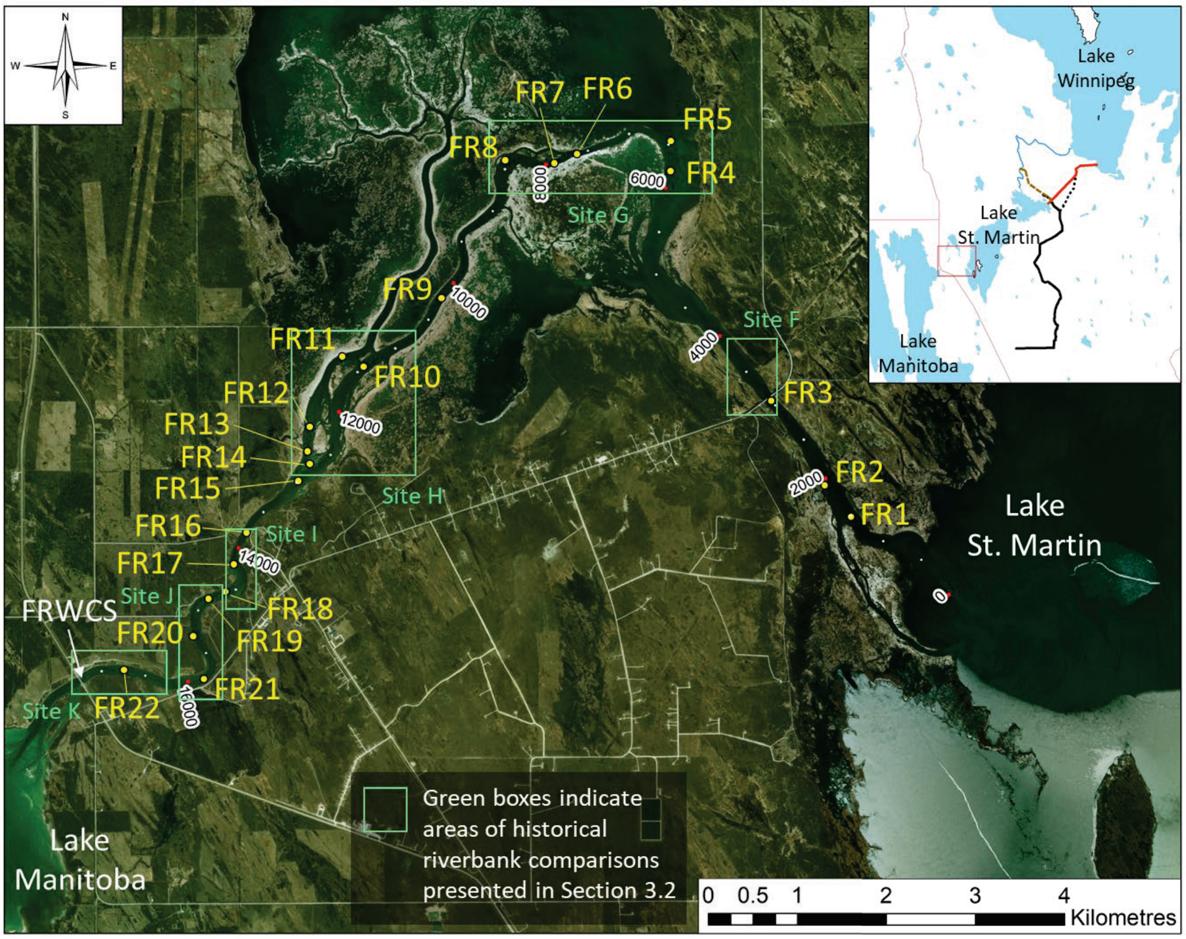
TABLE 5: DETAILED OBSERVATIONS AT SITE E – DR12

<table>
<tr><td>Riverbank Description:</td><td>Low bank shoreline with active erosion.</td></tr>
<tr><td>Geology:</td><td>Glacial till with high concentration of rock fragments.</td></tr>
<tr><td colspan="2">Photographs: Actively eroding west riverbank, looking downstream (left) and inland at parking area (right).
 
Eroding west bank looking upstream (left) and tension crack in bank (near handheld GPS unit).
 
Stable conditions on the southeast bank.
</td></tr>
<tr><td colspan="2">Sonar Imaging: No sonar imaging collected.</td></tr>
</table>

2.3 Observations of Fairford River

Figure 3 shows a map of the Fairford River. Annotated locations along the river (FR1, FR2, etc.) correspond to photographs and Ponar grab samples included in Appendix A. A subset of these locations was selected as detailed observation sites, described below. Historical changes in the riverbanks at these sites are reviewed in Section 3.2, and an overview of the modeling results at these locations is provided in Section 4.0.

FIGURE 3: MAP OF OBSERVATION LOCATIONS ON THE FAIRFORD RIVER



2.3.1 DETAILED OBSERVATIONS AT SITE F – FR3

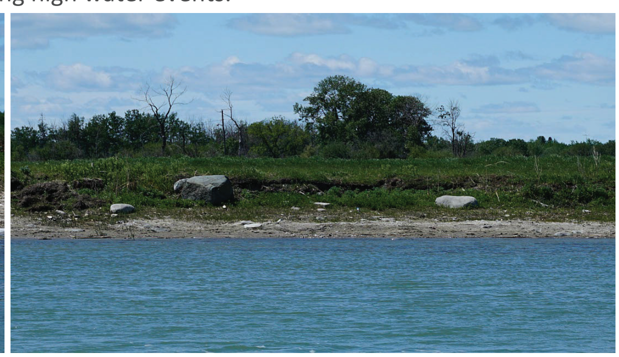
Site F (FR3) is located approximately 3 km upstream of Lake St. Martin. Key observations are summarized in Table 6. A Ponar grab attempted immediately upstream of the bridge on June 11, 2019 did not retrieve any bottom sediment as the bottom was rocky. A turbidity measurement near FR3 indicated a turbidity of 9.75 NTU.

TABLE 6: DETAILED OBSERVATIONS AT SITE F – FR3

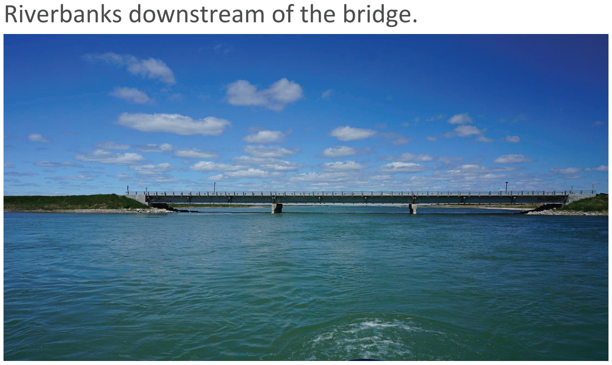
Riverbank Description:	Site F covers the channel that connects Lake Pineimuta to Lake St. Martin upstream of Fairford Road bridge. Riverbanks are low and generally stable.
Geology:	Glacial till with high concentration of cobbles and boulders.

Photographs: Stable vegetated riverbanks.


Some slumping of the riverbank, possibly triggered during high water events.

Riverbanks downstream of the bridge.




Sonar Imaging: No sonar imaging collected.

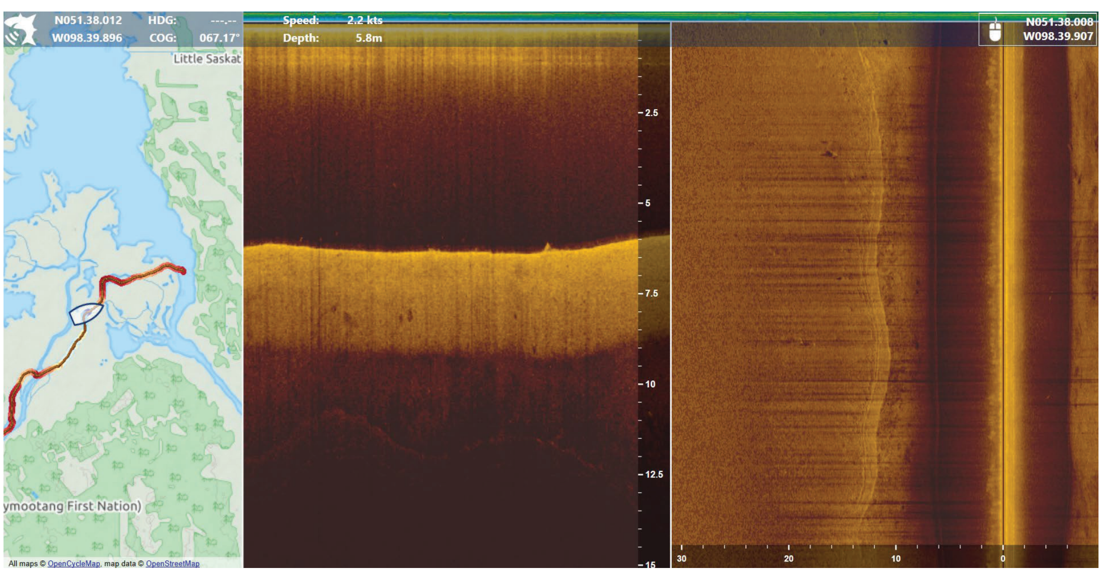
2.3.2 DETAILED OBSERVATIONS AT SITE G – FR6

Site G (FR6) is located approximately 7.5 km upstream of Lake St. Martin. Key observations are summarized in Table 7. Ponar grabs taken on June 11, 2019 indicated the substrate is comprised of small pebbles and coarse to fine sand at FR6. The turbidity measured in the field was 11.20 NTU.

TABLE 7: DETAILED OBSERVATIONS AT SITE G – FR6

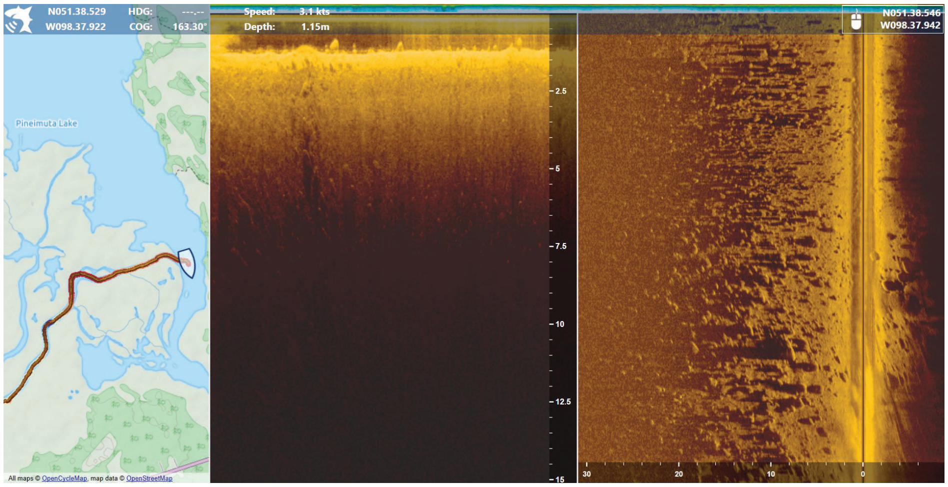
<table>
<tr><td>Riverbank Description:</td><td>The riverbank is defined by dense stands of emergent vegetation.</td></tr>
<tr><td>Geology:</td><td>Based on the sonar imagery, it appears the Lake Pineimuta delta has formed over previously scoured glacial sediment. In other words, the depositional muddy deposits are interspersed with exposures of glacial sediment or re-worked cobbles/boulders. Refer to the sequence of sonar imagery below, starting from a point between FR9-FR8 and FR5.</td></tr>
<tr><td colspan="2">Photographs: River bottom sample at FR6 and typical picture of emergent vegetation along riverbanks.


</td></tr>
<tr><td colspan="2">Sonar Imaging: Deepest section of delta that was surveyed, with mud bottom (between FR9-FR8).

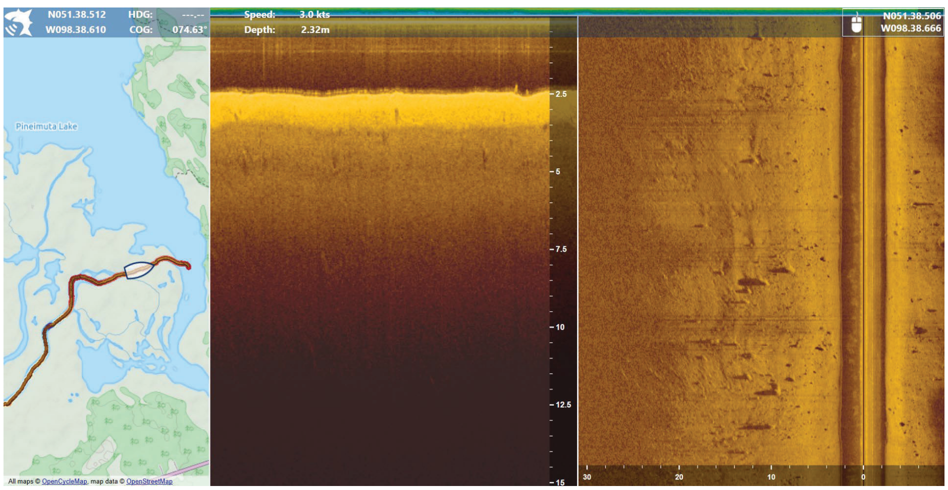


</td></tr>
</table>

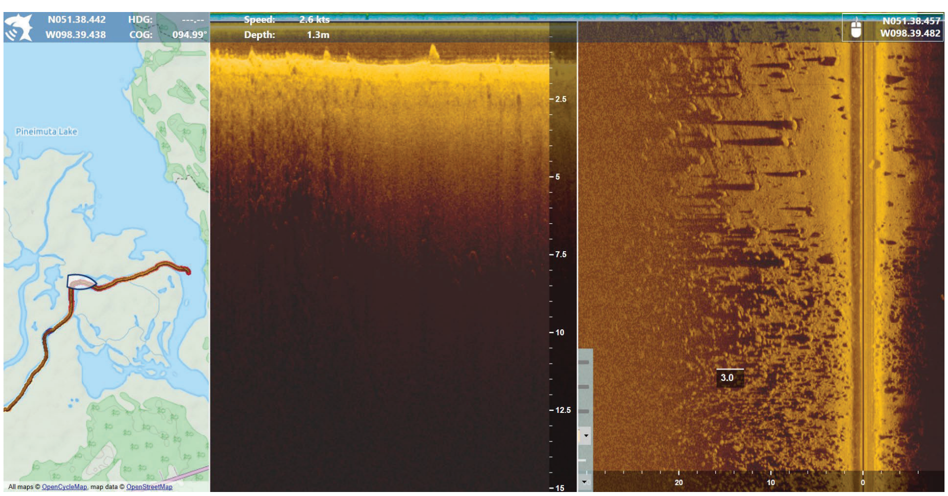
Transition to cobble/boulder substrate at edge of delta (FR5). Very shallow.



Fine sediment with occasional cobble/boulder in the middle of Site G (FR6).



Cobble boulder ridge may have influenced the river morphology/orientation. Shallow depths at FR8.



2.3.3 DETAILED OBSERVATIONS AT SITE H – FR12

Site H (FR12) is located approximately 12 km upstream of Lake St. Martin. Key observations are summarized in Table 8. A Ponar grab taken on June 11, 2019 just upstream of FR12 (near FR14) returned a single stone with some coarse sand, while another Ponar grab taken downstream of FR12 (near FR11) returned a mixture of silty sand.

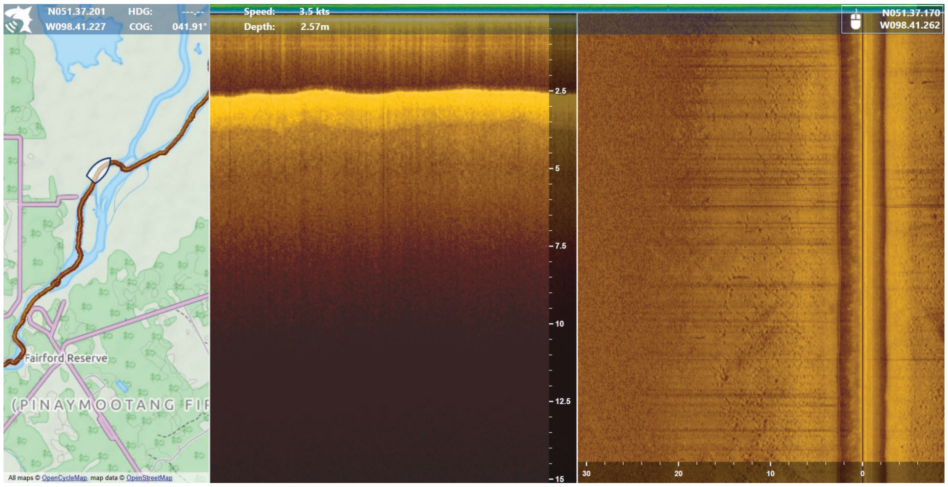
TABLE 8: DETAILED OBSERVATIONS AT SITE H – FR12

Riverbank Description:	Site H is a transition area from confined flow of the Fairford River to the Lake. At the Pineimuta Delta the riverbanks are generally defined by dense stands of emergent vegetation and/or exposures of glacial sediment and beach deposits.
Geology:	In the transition area from the river to the delta, the sonar mapped large cobble-boulder fields, as seen further upstream at Site I. This was confirmed with the Ponar sample that only returned a single cobble (see picture below). At the northern limit of Site H the lake bottom transitions to a depositional environment with sand and fines (silts/clays), confirmed with both the sonar imaging and Ponar grab sample results (picture below).

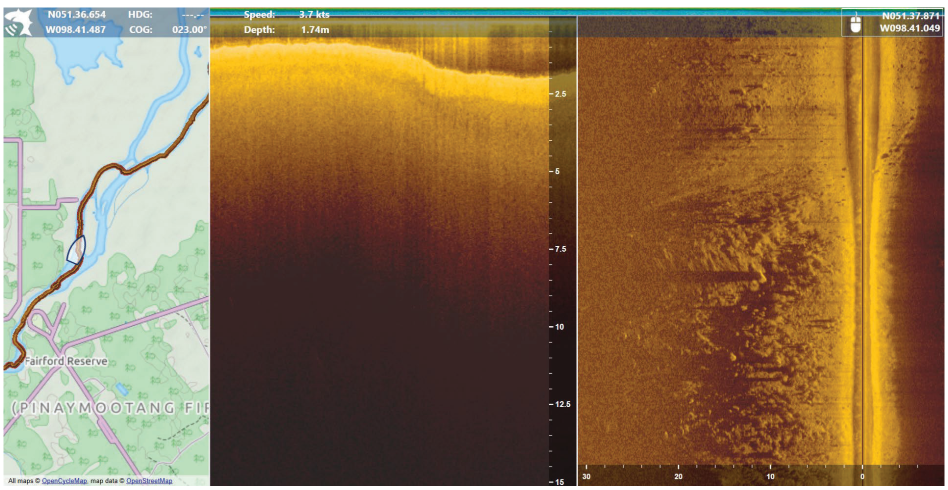
Photographs: Typical riverbanks at Site H (west bank, left, and east bank, right)

Ponar sample from FR14 (single cobble, left) and FR11 (silt sand, right)

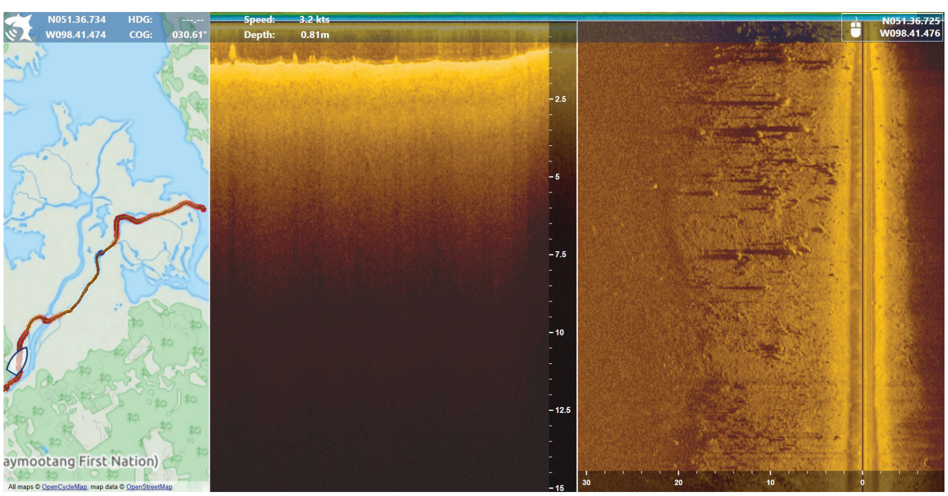
Sonar Imaging: Fine sediment bottom (sand, silt, clay).



Transition from shallow cobble/boulder substrate to deeper region with fine sediment.



Mixed bottom with some cobbles and boulders and fine sediment.



2.3.4 DETAILED OBSERVATIONS AT SITE I – FR17

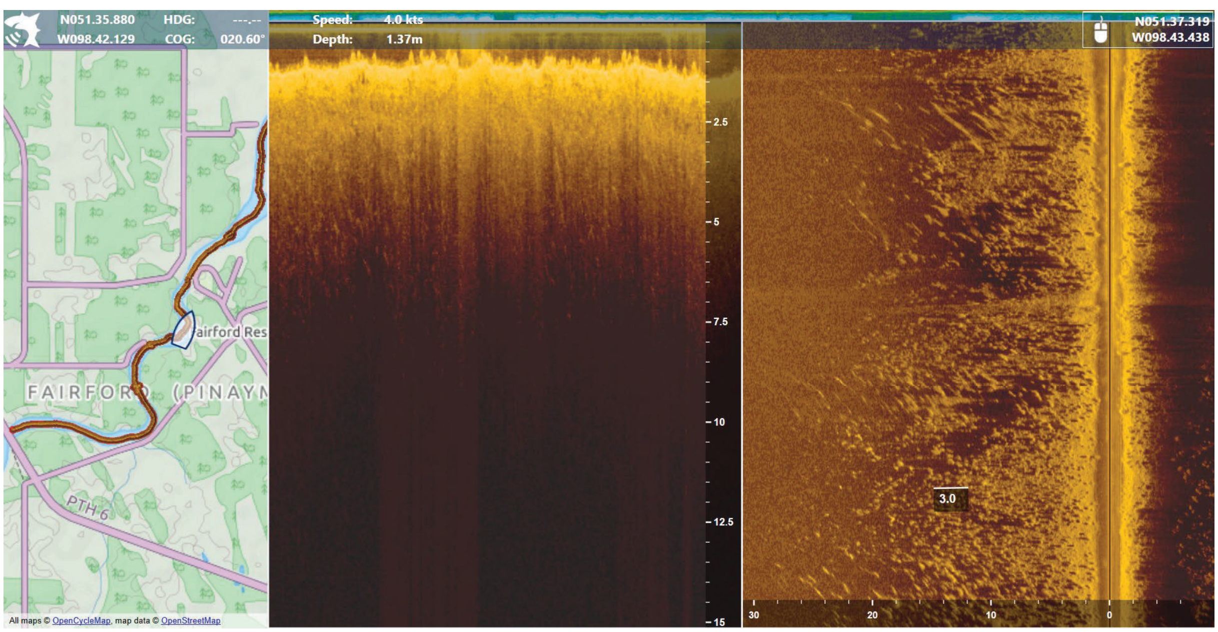
Site I (FR17) is located approximately 14 km upstream of Lake St. Martin. Key observations are summarized in Table 9. The site featured some residential buildings on the east bank of the river.

TABLE 9: DETAILED OBSERVATIONS AT SITE I – FR17

Riverbank Description:	Low bank at waters edge on east side of the river, with signs of instability and erosion, including slumps and exposed deck foundation.
Geology:	Glacial till with cobbles and boulders observed in the eroding riverbanks. Extensive lag deposit on the riverbed.

Photographs: Slump blocks along the riverbank (left) and exposed foundation of deck (right).

Sonar Imaging: Cobble boulder lag deposit covers the riverbed at Site I.



2.3.5 DETAILED OBSERVATIONS AT SITE J – FR20

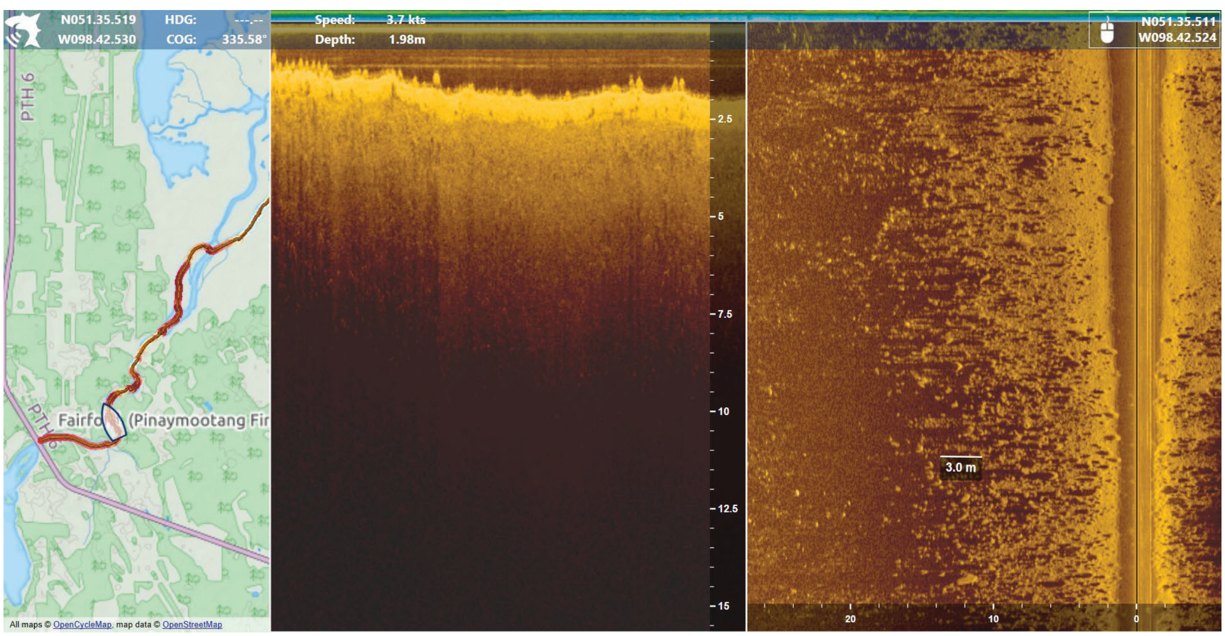
Site J (FR20) is located approximately 15 km upstream of Lake St. Martin. Key observations are summarized in Table 10. A field turbidity measurement taken on June 11, 2019 indicated a turbidity of 9.35 NTU.

TABLE 10: DETAILED OBSERVATIONS AT SITE J – FR20

Riverbank Description:	Active erosion observed along the west bank of the river. Vulnerable to large flow events with a high water surface elevation and strong currents. See exposed roots of dead tree below. At low water levels, the banks are not impacted by erosion.
Geology:	Soft glacial till with high concentration of cobble exposed in the eroding bank.

Photographs: Eroding bank with exposed roots of dead tree (left) and soft till exposed in eroding bank (right).

Sonar Imaging: Extensive cobble boulder lag on the riverbed.



2.3.6 DETAILED OBSERVATIONS AT SITE K – FR22

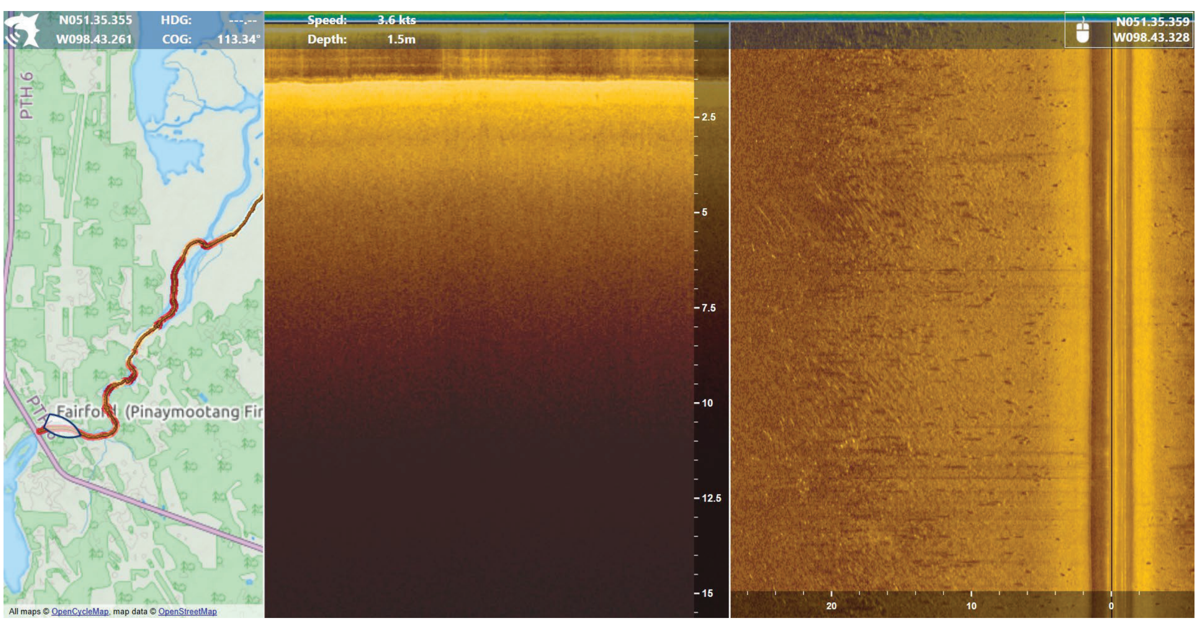
Site K (FR22) is located approximately 17 km upstream of Lake St. Martin, immediately downstream of the Fairford River Water Control Structure (FRWCS). Key observations are summarized in Table 11.

TABLE 11: DETAILED OBSERVATIONS AT SITE K – FR22

Riverbank Description:	The Site K riverbanks on the north shore are 2-3 m high, with the south side featuring a gentle slope without a bank. No sign of erosion on the south bank. Active erosion scarp along the entire north bank of Site K which is sensitive to water levels (only threated at high water levels).
Geology:	Exposed glacial till in the eroding banks.

Photographs: Eroding north riverbank and cobble beach (left). Recreational vehicles parked above the bank. Sediment from river excavation in the 1960s stockpiled near the hydro towers in photo on right.

Sonar Imaging: Mixed bottom substrate with fine sediments and cobbles. The riverbed at Site K was extensively excavated in 1961 to increase the conveyance capacity of the river, so the bottom conditions are not natural.



3.0 ANALYSIS OF FLOW SYSTEM

3.1 Theoretical Limits of Erosion

The theoretical limits of erosion of various grain sizes present in the Fairford and Dauphin Rivers provide context to the potential changes to the fluvial geomorphological processes that would result from the Project.

The initiation of particle movement occurs when the applied shear stress in the channel exceeds the shear stress required to initiate movement of the particle (the so-called "critical shear stress"). For non-cohesive sediments, the critical shear stress is a function of the particle size; larger particles have greater resistance to erosion. The U.S. Geological Survey (USGS) has published theoretical values of critical shear stress for a range of grain sizes of sediment based on the application of Shield's diagram (USGS, 2008), shown in Table 12.

Shear stress is difficult to measure or visualize directly. An alternate means of identifying the potential for erosion and deposition is also commonly defined by the minimum water velocity required to initiate movement (the so-called "critical water velocity"). The Hjulstrom curve, shown in Figure 4, illustrates the critical erosion and deposition velocities for a range of particle sizes. The curves take into consideration the cohesive properties of clays and silts, resulting in increasing critical erosion velocities with decreasing grain sizes at the lower end of the grain sizes shown. The minimum water velocities at which sediment of a given class will erode or deposit are included in Table 12.

FIGURE 4: HJULSTROM CURVE

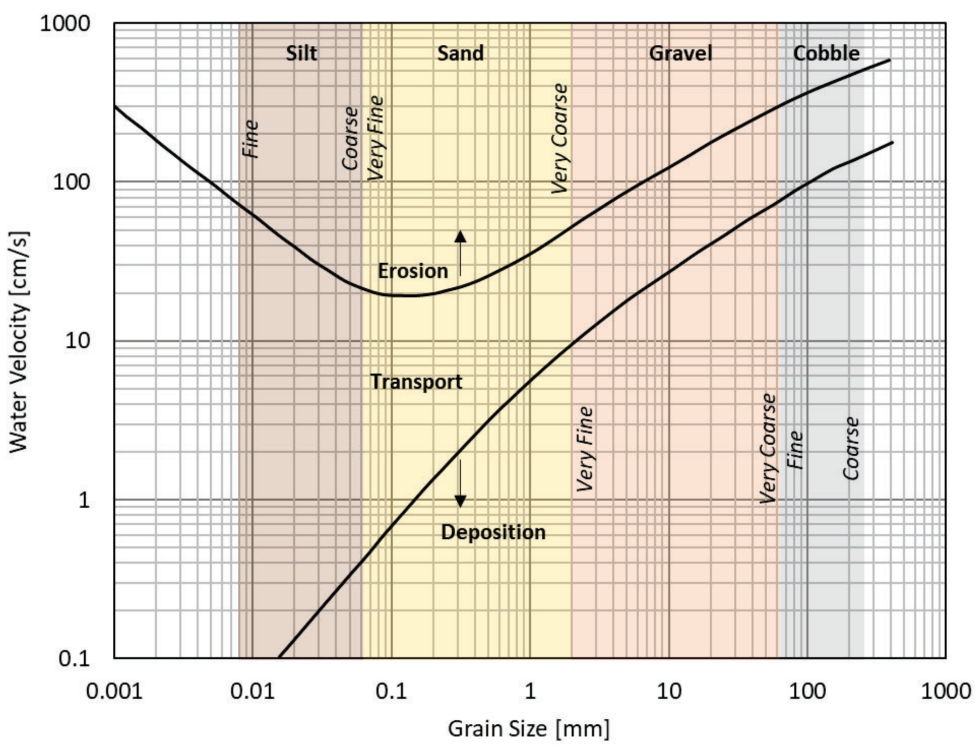


TABLE 12: CRITICAL SHEAR STRESSES AND VELOCITIES FOR EROSION AND DEPOSITION OF SEDIMENTS

Class	Range of Particle Diameters [mm]	Critical Erosion Shear Stress [Pa]	Erosion Velocity [m/s]	Deposition Velocity [m/s]
Silt	0.0078 – 0.0625	0.0378 – 0.110	0.74 – 0.21	0.0005 – 0.0042
Sand	0.0625 – 2.0	0.110 – 1.3	0.21 – 0.52	0.0042 – 0.095
Gravel	2.0 – 64	1.3 – 53.8	0.52 – 3.04	0.095 – 0.77
Cobble	64 – 256	53.8 – 223	3.04 – 5.10	0.77 – 1.47

The glacial till which forms portions of the beds of the Dauphin and Fairford Rivers includes a range of particle sizes from clays to cobbles and boulders. The cohesive properties of the fine particles, density of the in-situ material, and degree of cementing all influence the erodibility of the till, and generally increase the erosion resistance of the material above the values predicted for a non-cohesive material.

The material composition and properties of the glacial till can vary from site to site along the rivers. In addition, the state of knowledge of erodibility of glacial tills is less advanced than for non-cohesive sediments. These factors lead to difficulty in the definition of a precise threshold of erosion that is representative of the till. When broken down and "softened", the particles within the till would exhibit erosion thresholds similar to those presented in Table 12 for the given particle size. Conversely, the critical velocity and shear stress for a dense, cemented till unit could be in excess of 1.2 m/s and 10 Pa, respectively.

3.2 Historical Changes in Riverbanks

Historical aerial photographs from six temporal periods, including 1961, 1963, 1970, 1992, 1993, and 1994 were received from GeoManitoba. The historical images were geo-referenced with ArcGIS software using recent orthophotographs as the base. The methodology and approach for consideration of horizontal errors in the geo-referenced imagery were described in Zuzek Inc. (2020).

Riverbanks were digitized for the geo-referenced historical aerial photographs. They were then compared to the location of the riverbank in the recent orthophotography (2011 and 2013). Only locations where the bank could be clearly identified were digitized. When the rate of change was greater than the horizontal positional accuracy of the photographs, rates of change were measured (e.g., 0.2 m/yr of recession). When the difference in the bank position was within the accuracy of horizontal positioning of the photographs, the banks were considered to be stable. The results are summarized for the two river systems at the detailed observation sites.

3.2.1 DAUPHIN RIVER

Comparison of the bank position from the early 1960s to the 2011/2013 were generated for six locations on the Dauphin River noted in Figure 2. The location and results are summarized:

- **Site A – DR0** (Figure 5): Site A is located at the mouth of the Dauphin River. From 1963 to 2011 the lake shoreline, north of the mouth, has eroded at 0.2 m/yr. The riverbanks at the mouth have been stable. However, as noted in Table 1, portions of the banks have been stabilized with shoreline protection.
- **Site B – DR4** (Figure 6): The south bank features a large riverine wetland and the waterline position has been stable. Most of the north bank has been stable, with a small section featuring a recession rate of 0.15 m/yr from 1963 to 2011. The toe of the riverbank features a bedrock exposure. Thus, the riverbank is only vulnerable to erosion during high flow conditions (high water levels and velocities reach the upper bank).
- **Site C – DR6** (Figure 7): Along the south bank of the river at Site C there has been some retreat of the vegetation line (up to 0.2 m/yr). The north riverbank has been retreating towards the road for several decades. The bank recession rate is 0.2 m/yr. As seen in the ground photographs in Table 3, the riverbank is the shoulder of the road. Bank erosion will accelerate during high water levels and strong currents if shear stress exceeds the resisting properties of the glacial till.
- **Site D – DR10** (Figure 8): Located approximately 30 km upstream of Lake Winnipeg, Site D is stable with minor toe erosion, which is captured in the comparison of the tree/vegetation lines in Figure 8.
- **Site E – DR14** (Figure 9): Site E is centred on a small parking area off the road. Active bank erosion was observed in the field, as documented in Table 5. Comparison of the 1963 to 2011 vegetation line supports the field observations, with a long-term recession rate identified in Figure 9.

Of the five detailed observation sites reviewed (A to E), bank erosion varied from:

- only present in isolated locations (Sites A and B),
- to minor scarping at the bank toe (Site E), and
- active recession at Sites C and E.

The lake shoreline at Site A north of the river mouth was receding at 0.2 m/yr , but portions have subsequently been protected with field stone.

3.2.2 FAIRFORD RIVER

Historical imagery was compared to the 2011 orthophotograph at six locations on the Fairford River and the Lake Pineimuta delta, as noted in Figure 3.

- **Site F – FR3** (Figure 10): The riverbanks have been stable from 1961 to 2011 at Site F, even with the extensive flooding that occurred in 2011. These findings are consistent with the site observations noted in Table 6.
- **Site G – FR6** (Figure 11): The north bank of the river has been stable for 50 years, as seen in Figure 11. The south bank has eroded 4.5 m (0.25 m/yr), but this could be attributed to the flooding in 2011. Overall, the delta tributaries have been very stable over the last 50 years.
- **Site H – FR12** (Figure 12): The Fairford River splits into two channels at Site H as it enters the delta. The 1961 to 2011 waterline comparison indicated the banks of the river have been very stable over the last 50 years.

- **Site I – FR17** (Figure 13): The east riverbank was analyzed at Site I from 1961 to 2011. As seen in Figure 13, the southern portion of the site has been stable, but the norther limits of the bank feature a small recession rate (0.18 m/yr). Slump failures were observed in the field, which supports the findings from the historical aerial analysis.
- **Site J – FR20** (Figure 14): The west bank of Site J is receding at 0.15 m/yr. This is particularly evident when the 2011 treeline was overlaid on the 1961 aerial in Figure 14. In the field, an erosion scarp was identified, along with exposed three roots which support the finding. Based on the height of the erosion scarp, the banks will be most vulnerable to erosion during high water events.
- **Site K – FR22** (Figure 15): Site K is located immediately downstream of the FRWCS. The south bank of the river features a gentle slope and has been generally stable for the last 50 years. Conversely, an eroding bank is found along the north bank of Site K. With the water levels during the field work in June 2019, a narrow beach was located along much of the north bank. This beach suggests the banks are only vulnerable to erosion during high water levels.

Historical changes in the riverbanks were documented at six detailed observation sites F to K on the Fairford River. Sites F and H have been stable. Most of Site G was also stable, with some possible retreat of the emergent vegetation. However, the results were not conclusive due to the high water level conditions in the 2011 orthophotograph. Bank erosion was documented at Sites I to K, ranging from 0.15 to 0.18 m/yr. The site observations suggest these sites are sensitive to high water levels and peak flow conditions, as the toe of slope was dry during the site visit and in some cases protected by a beach deposit.

FIGURE 5: COMPARISON OF HISTORICAL POSITIONS OF RIVERBANKS AT SITE A – DR0

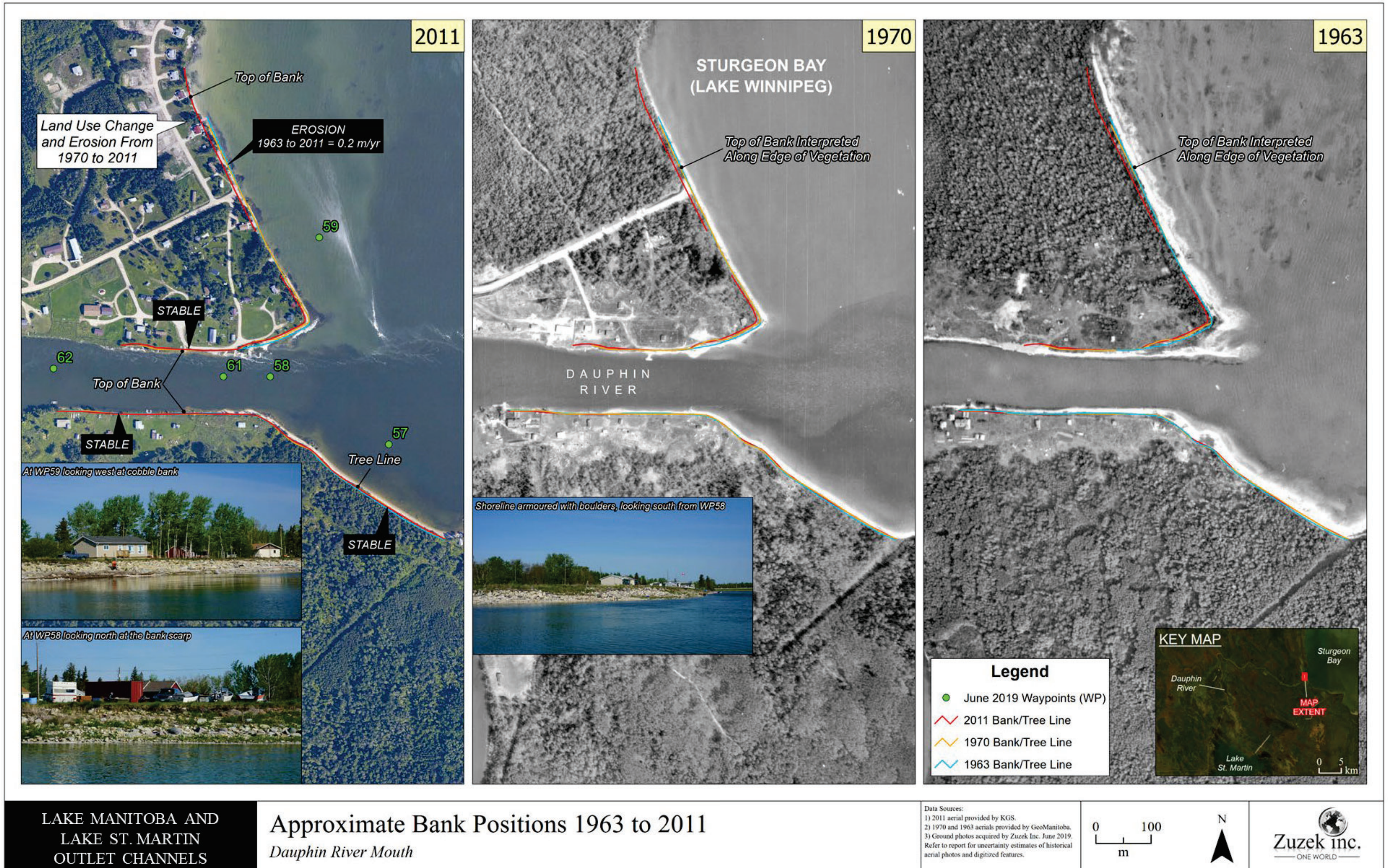


FIGURE 6: COMPARISON OF HISTORICAL POSITIONS OF RIVERBANKS AT SITE B – DR4

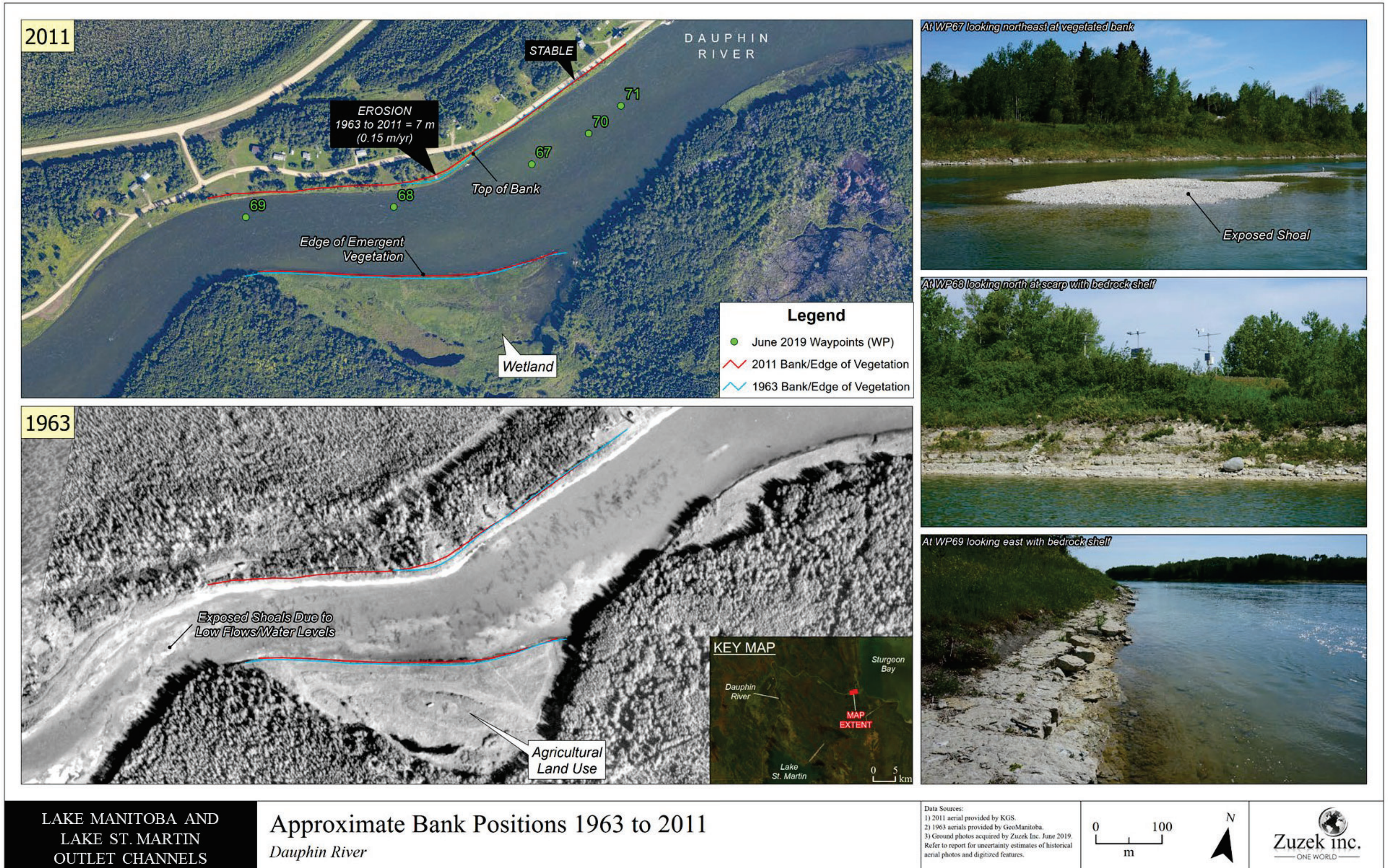
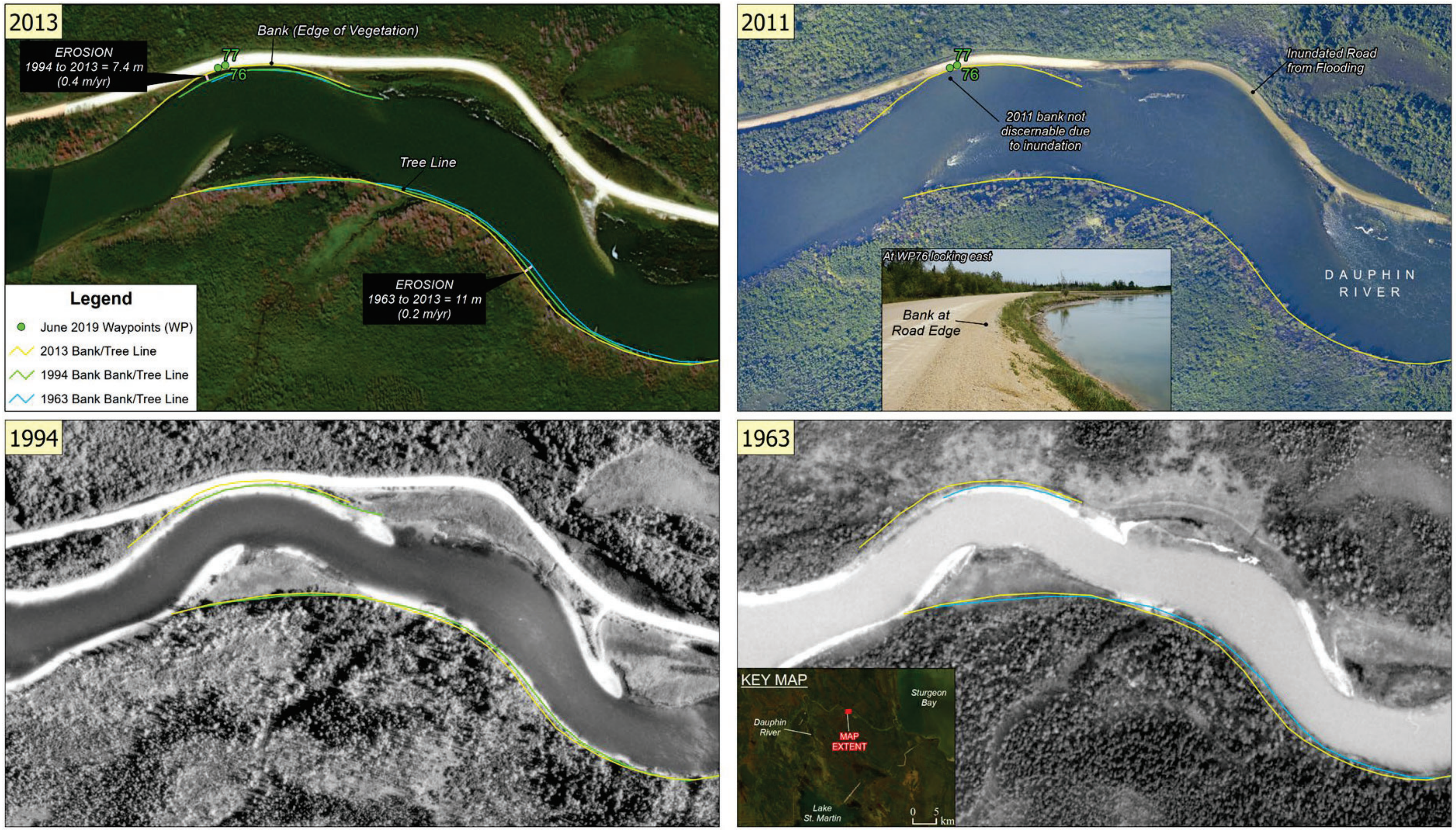


FIGURE 7: COMPARISON OF HISTORICAL POSITIONS OF RIVERBANKS AT SITE C – DR6



LAKE MANITOBA AND LAKE ST. MARTIN OUTLET CHANNELS

Approximate Bank Positions 1963 to 2013

Dauphin River

Data Sources:
1) 2011 aerial provided by KGS.
2) 1994 and 1963 aerials provided by GeoManitoba.
3) Ground photos acquired by Zuzek Inc. June 2019.
4) 2013 Esri World Imagery Basemap.
Refer to report for uncertainty estimates of historical aerial photos and digitized features.

0 100 m

N

Zuzek inc. ONE WORLD

FIGURE 8: COMPARISON OF HISTORICAL POSITIONS OF RIVERBANKS AT SITE D – DR10

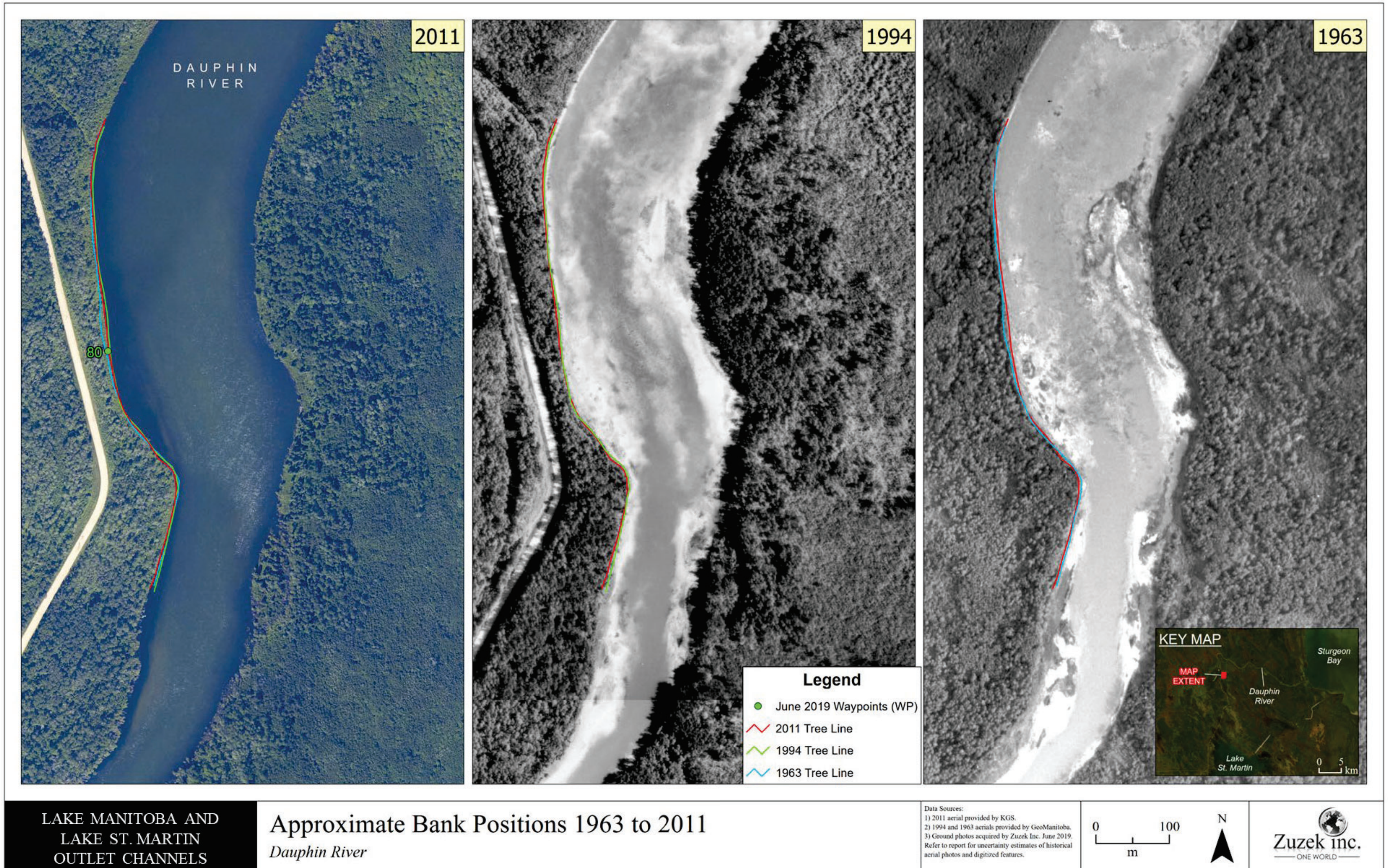


FIGURE 9: COMPARISON OF HISTORICAL POSITIONS OF RIVERBANKS AT SITE E – DR14

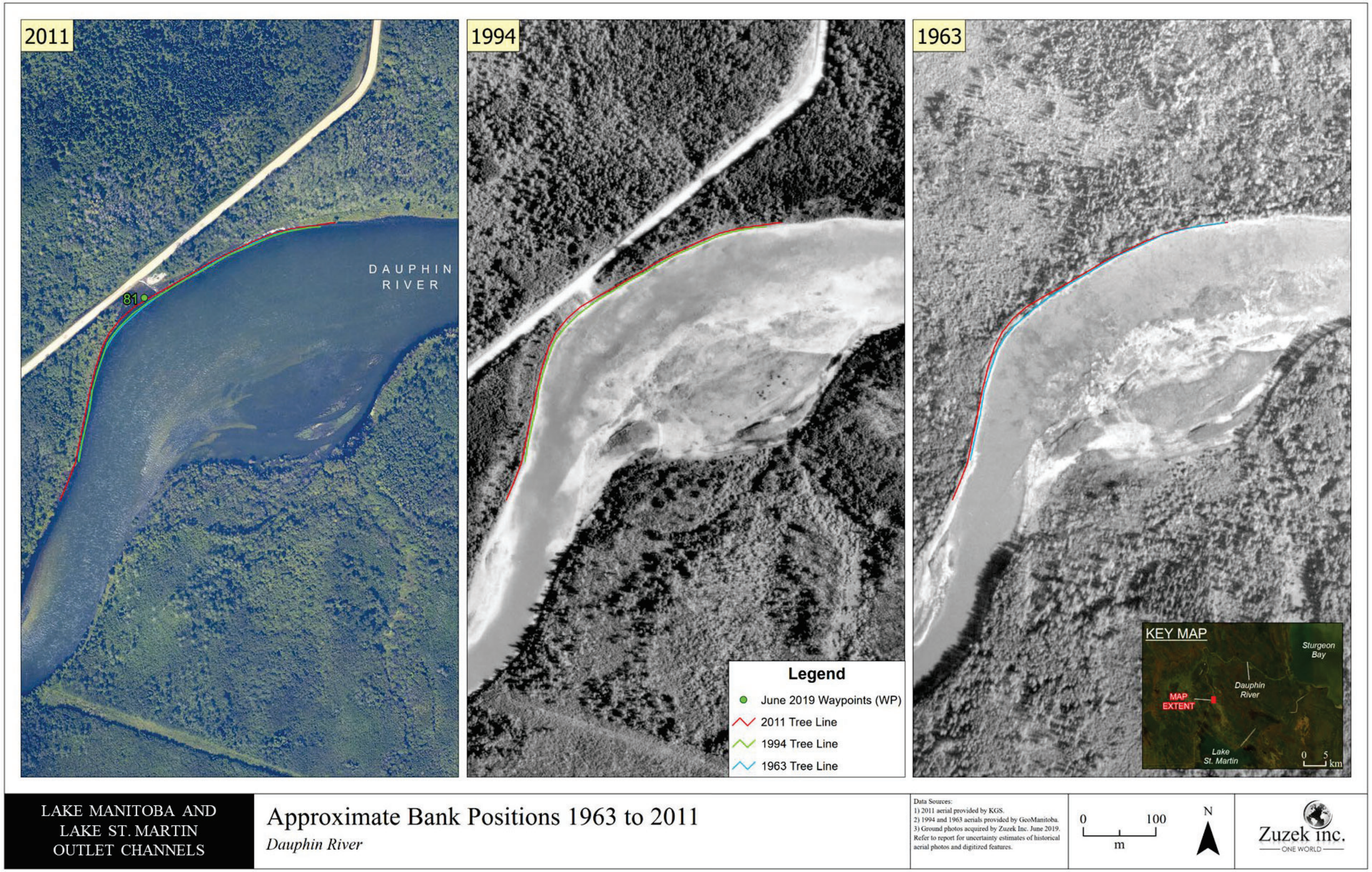


FIGURE 10: COMPARISON OF HISTORICAL POSITIONS OF RIVERBANKS AT SITE F – FR3

FIGURE 11: COMPARISON OF HISTORICAL POSITIONS OF RIVERBANKS AT SITE G – FR6

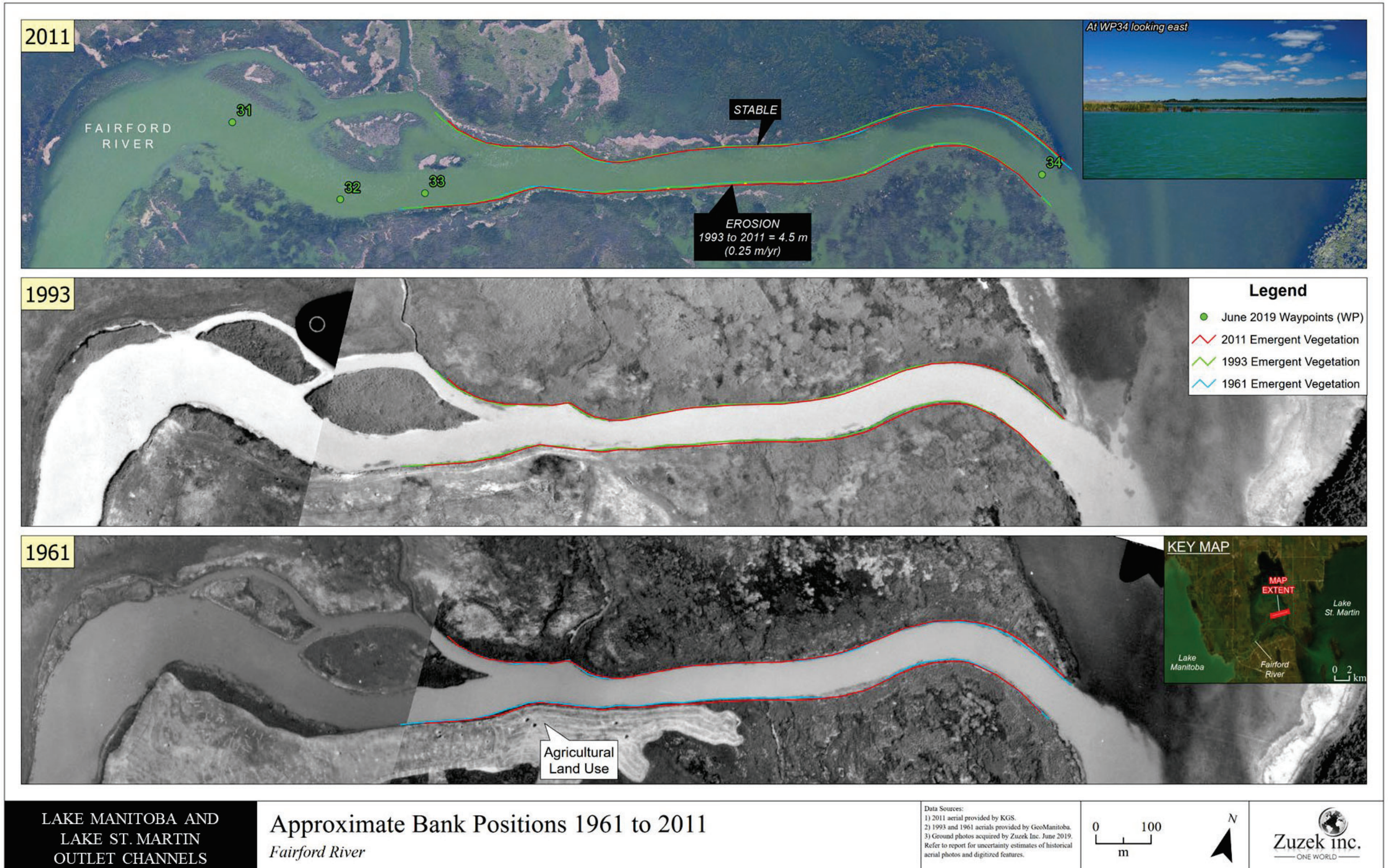


FIGURE 12: COMPARISON OF HISTORICAL POSITIONS OF RIVERBANKS AT SITE H – FR12

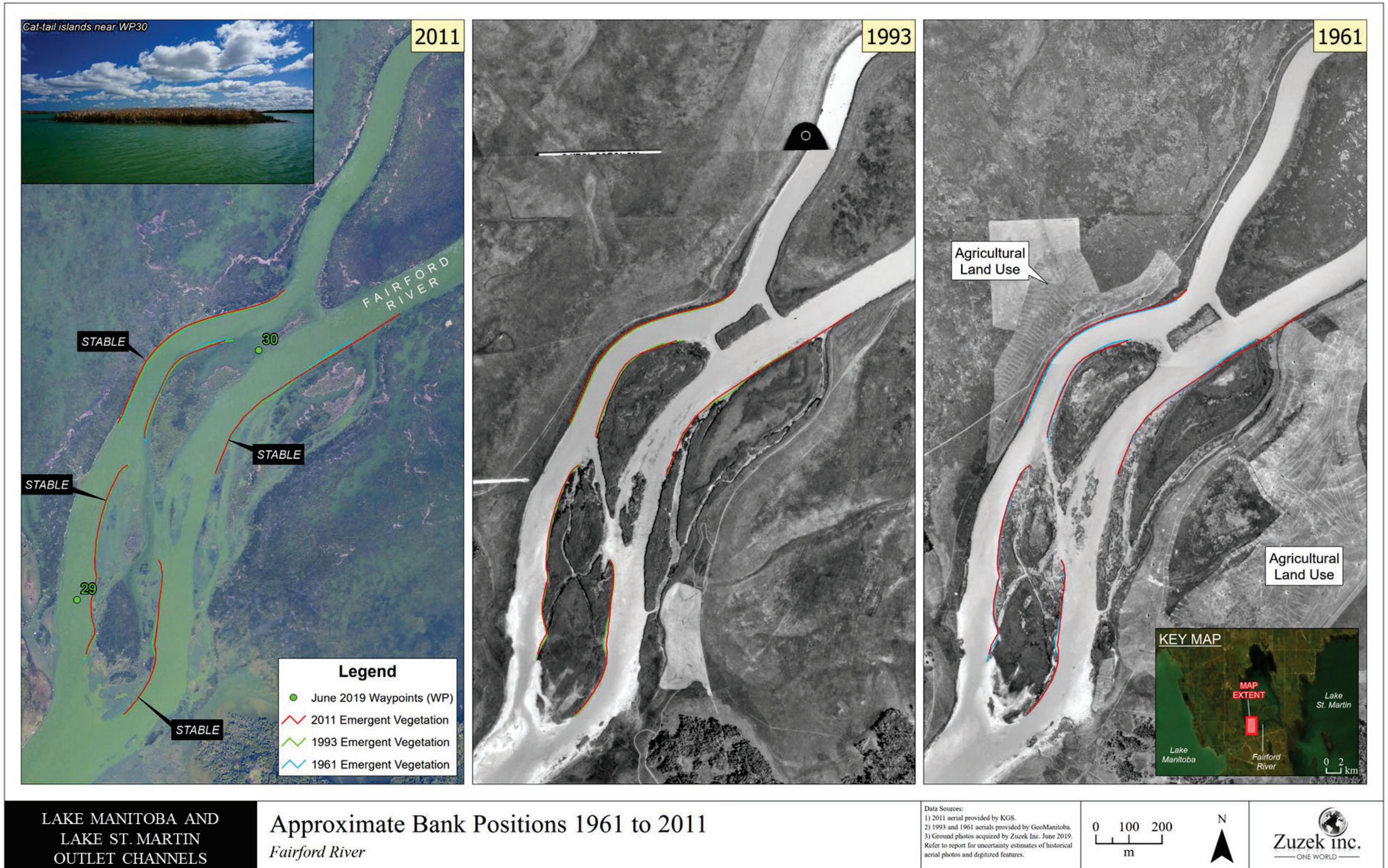


FIGURE 13: COMPARISON OF HISTORICAL POSITIONS OF RIVERBANKS AT SITE I – FR17

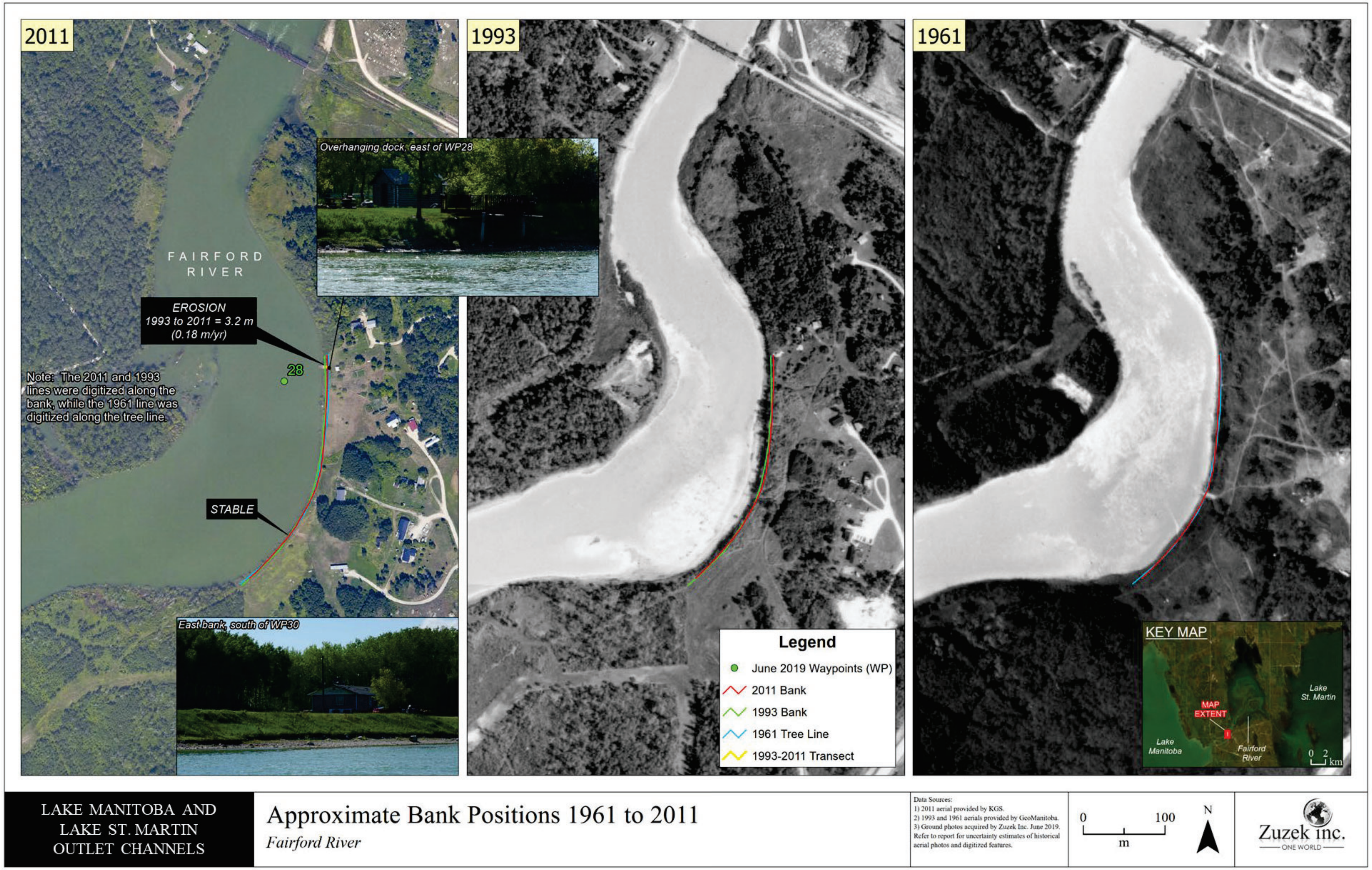


FIGURE 14: COMPARISON OF HISTORICAL POSITIONS OF RIVERBANKS AT SITE J – FR20

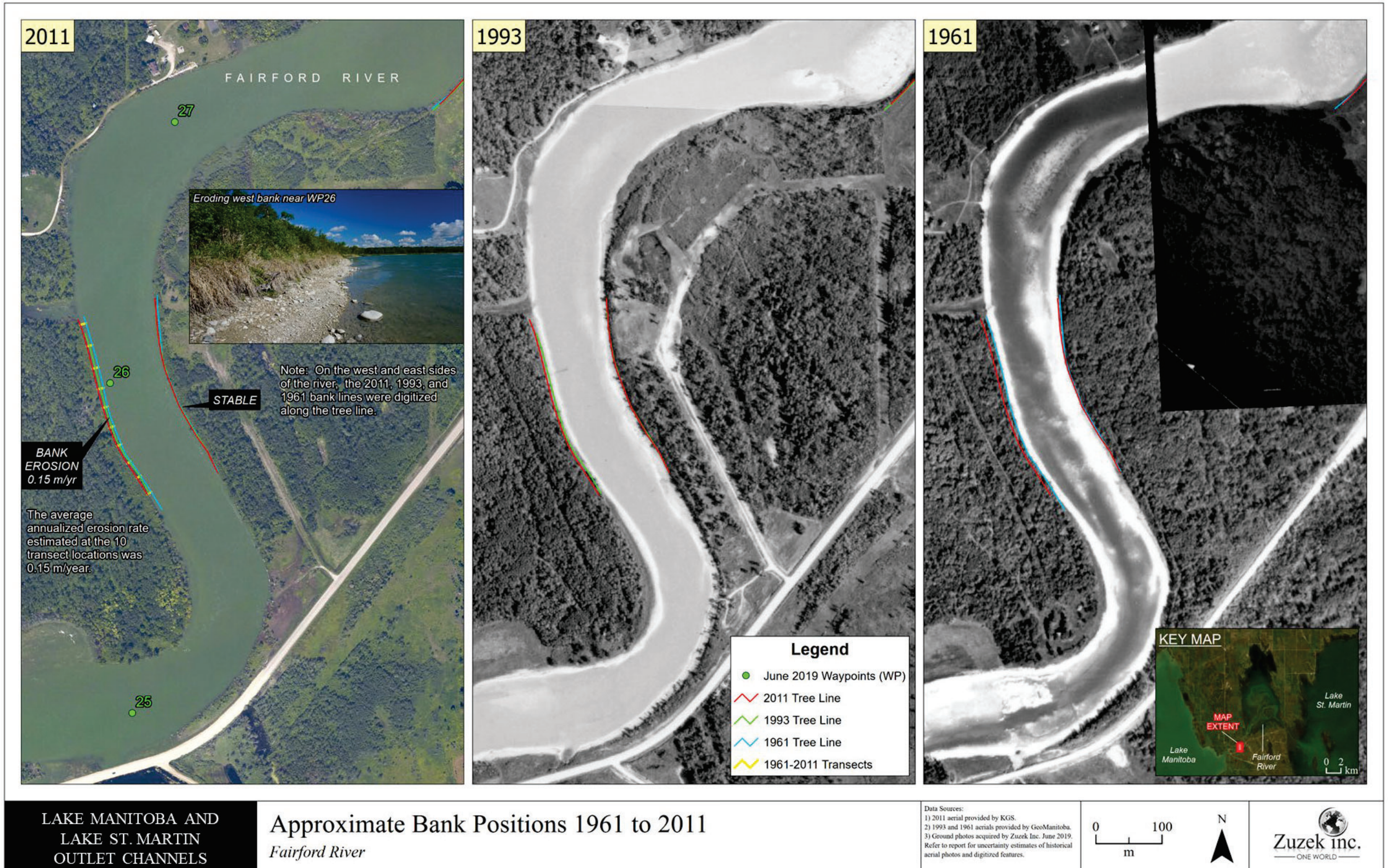
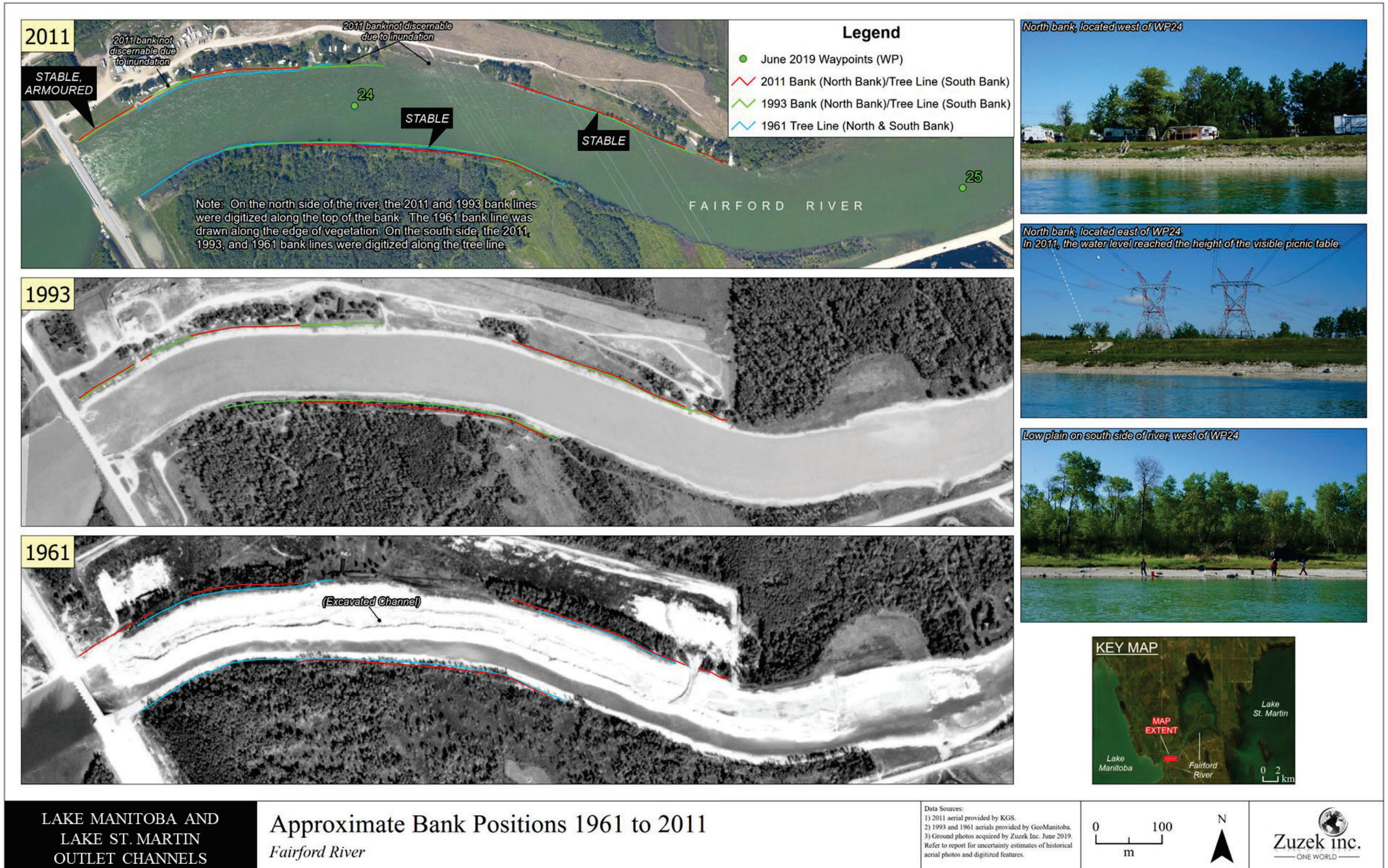


FIGURE 15: COMPARISON OF HISTORICAL POSITIONS OF RIVERBANKS AT SITE K – FR22



3.3 Project Effects on Flow Percentiles

Manitoba Infrastructure developed an Excel-based water balance model to compute daily flows and water levels in the Pre-Project and Post-Project environment (i.e. without and with the LSMOC and LMOC in place) from 1915-2017. The model has developed through several iterations as the designs of the LMOC and LSMOC have advanced. Refinements have also been added to assist the evaluation of the effects of various operating strategies and assumptions (e.g. winter flow restrictions, type of water control structure, and frequency of gate adjustments).

Revisions to the Excel model take into consideration the impact of the "Narrows" on water levels in the south and north basins of Lake St. Martin. The revised model incorporates the results of two-dimensional modeling performed by KGS Group to quantify the head loss between the basins at a range of flows. The model is described in a technical memorandum dated November 3, 2020, titled "Integration of Modified Lake St. Martin Permanent Outlet Channel Design Configuration and Lake St. Martin Narrows into Lake Manitoba and Lake St. Martin Hydrological Water Balance Model" (MI, 2020).

A summary of assumptions in the water balance model (as of November 2020) that forms the basis of the analysis presented herein are as follow:

- Revised rating curves for the LSMOC and LMOC reflecting the most up-to-date designs as of November 2020. The LSMOC WCS is a 4-bay structure and the rating curve accounts for additional excavation at the inlet which was required to meet the design flow requirement accounting for head loss between the basins of Lake St. Martin.
- Vertical gate water control structures for both the LSMOC and LMOC to control flows in the outlet channels. The gates can also be operated in the winter, if required.
- Winter flow restrictions of 90 m^3/s for the LMOC and 150 m^3/s for the LSMOC are imposed.
- Ice-affected rating curves for the channels and rivers are assumed to apply from December 1 to April 30.
- Riparian flow of 1.4 m^3/s in the LSMOC during non-operation periods, with a provision to reduce or eliminate the riparian flow during periods of drought to maximize flows in the Dauphin River.
- Treatment of Lake St. Martin as two separate basins, with differential water levels caused by head loss through the Narrows.

Outputs from this model, including daily flows and water levels through the system, were provided to KGS Group by MI.

The duration curves of daily flows in the Fairford River and Dauphin River are shown in Figure 16 and Figure 17, respectively, and the 10th, 50th, and 90th percentile flows are tabulated in Table 13 and Table 14. For the purposes of comparison and selection of representative flows for numerical model inputs (Sections 3.4 and 3.5), the annual flow period was divided into a "summer" period (open water; May 1 to November 30) and "winter" period (ice covered; December 1 to April 30). In general, the Project reduces the frequency of high flow events on both the Fairford River and Dauphin River. It therefore has a greater effect on river flows at the high percentiles (i.e. flood conditions) than the low percentiles (i.e. drought conditions). The 10th, 50th, and 90th percentile flows are representative of the spectrum of flow changes caused by the Project, and were used for subsequent analyses to assess potential impacts of the Project on the flow regimes of the two rivers.

FIGURE 16: DURATION CURVE OF FAIRFORD RIVER FLOWS

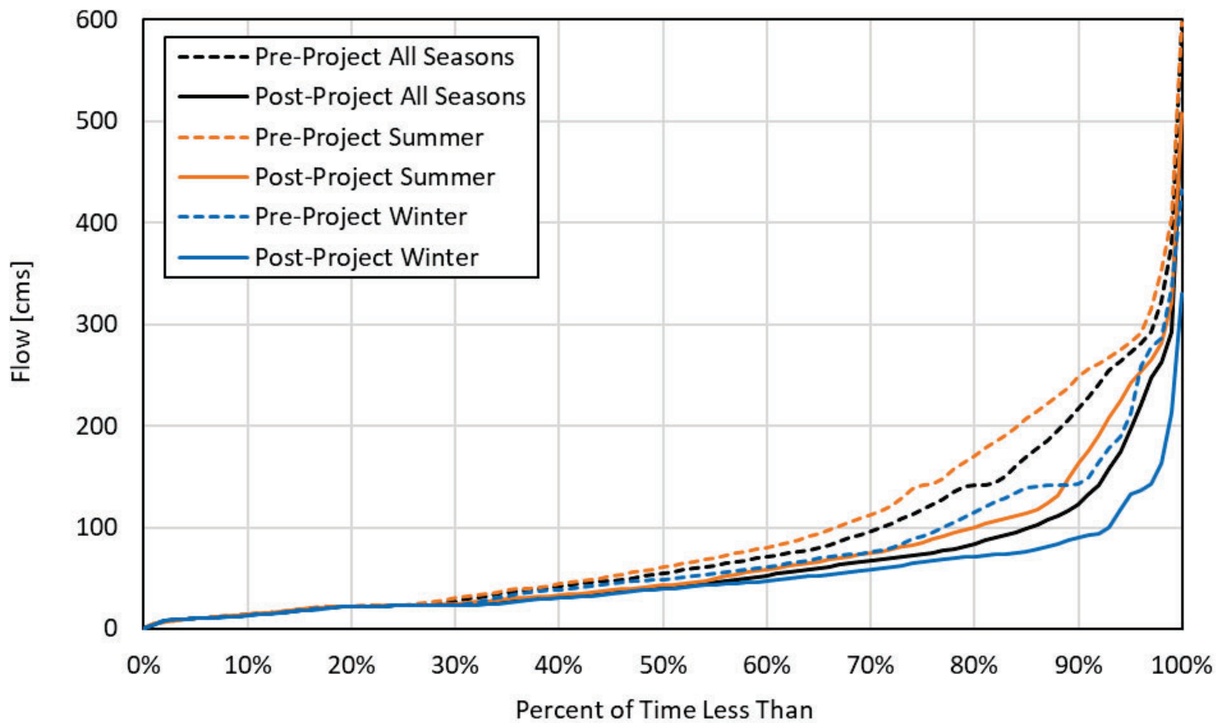


TABLE 13: PERCENTILES OF FAIRFORD RIVER FLOWS

	Discharge [cms]								
	All Seasons			Summer			Winter		
Percentile	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**	**10th**	**50th**	**90th**
Pre-Project	14.0	55.0	217.1	14.5	61.1	248.9	13.3	49.0	143.0
Post-Project	14.0	41.4	123.2	14.5	42.8	163.0	13.2	39.5	90.2
Change	-	-13.6	-93.9	-	-18.3	-85.9	-0.1	-9.5	-52.8

FIGURE 17: DURATION CURVE OF DAUPHIN RIVER FLOWS

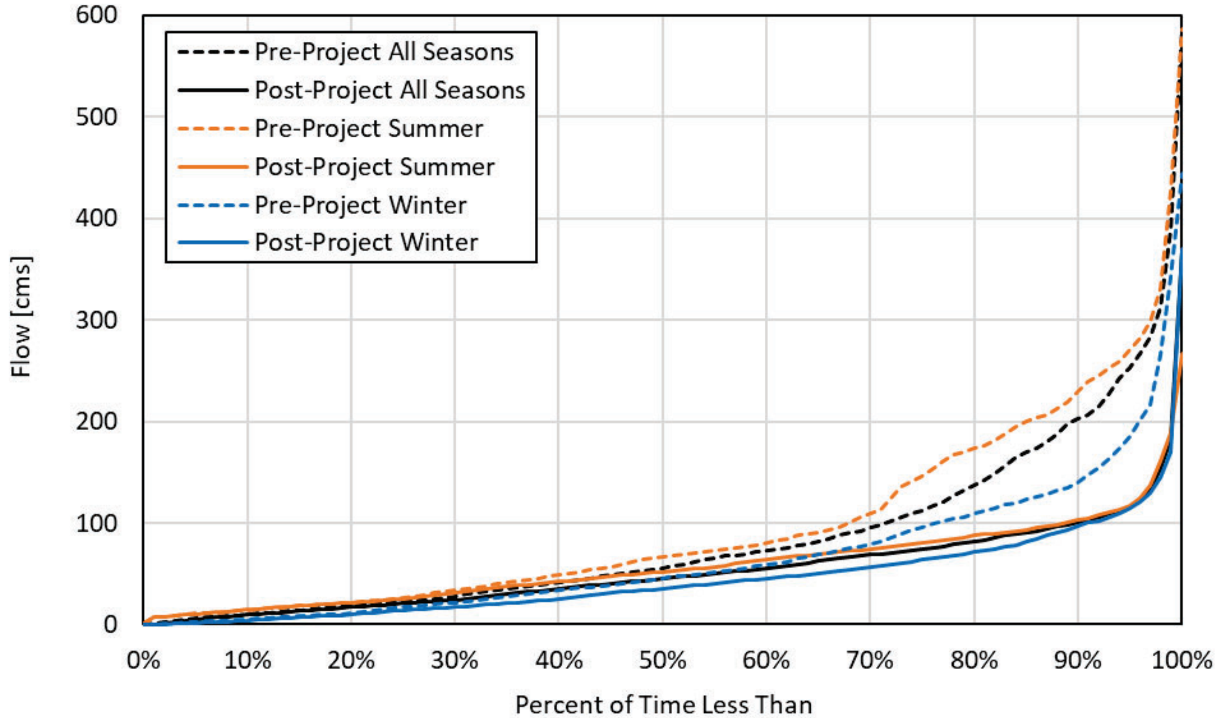


TABLE 14: PERCENTILES OF DAUPHIN RIVER FLOWS

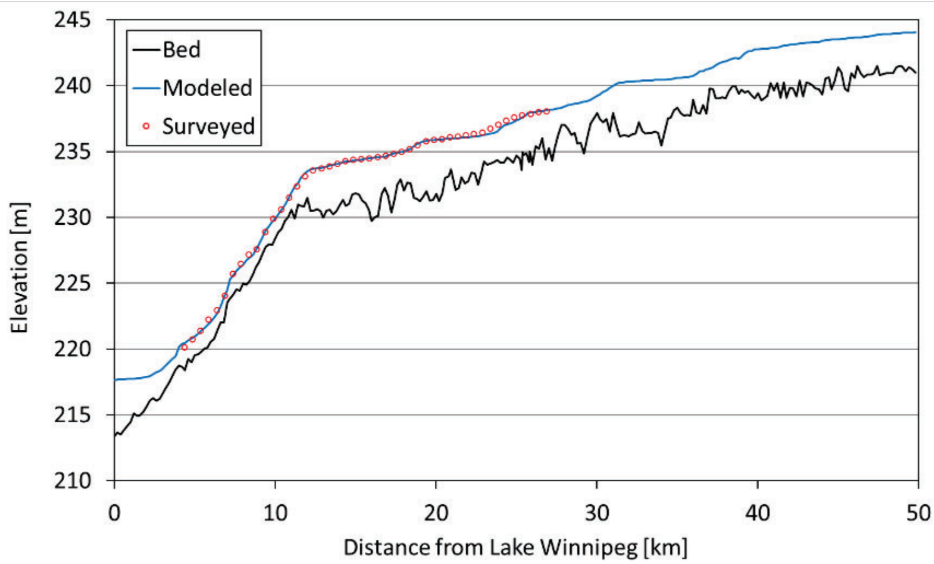
	Discharge [cms]								
	All Seasons			Summer			Winter		
Percentile	10th	50th	90th	10th	50th	90th	10th	50th	90th
Pre-Project	10.1	55.9	202.6	14.2	67.2	228.8	5.1	45.8	139.2
Post-Project	9.5	45.3	100.9	14.5	52.0	103.1	4.2	35.5	97.2
Change	-0.6	-10.6	-101.7	+0.3	-15.2	-125.7	-0.9	-10.3	-42.0

3.4 Assessment of Hydraulic Conditions with Open Water

3.4.1 DAUPHIN RIVER

A one-dimensional (1D) HEC-RAS model of the Dauphin River was previously developed by KGS Group as part of Phase 4100 – Initial Engineering Support for Environmental Assessment. The model cross sections were developed from bathymetric surveys conducted in 2011, 2013, and 2014 and LiDAR collected in 2011. The model was calibrated to the water surface profile measured during the bathymetric survey conducted in June 2013, when the flow in the Dauphin River was 248 m^3/s. This dataset was selected for calibration because the flow magnitude was most comparable to the flows that will be run for this study. The calibration result, shown in Figure 18, was deemed to be adequate for the purposes of comparing the incremental changes to the river hydraulics as a result of the project. The calibrated model was used to assess changes to channel hydraulics as a result of the Project at the 10^{th}, 50^{th}, and 90^{th} percentiles of summer flows.

FIGURE 18: CALIBRATION OF DAUPHIN RIVER MODEL



A study was conducted by Manitoba Hydro (MH) on the effects of the outlet channels on water levels on Lake Winnipeg. MH concluded that the change to water levels would be very small, and not discernible in the context of existing water level variations (Manitoba Hydro, 2019). Figure 19 shows a duration curve of daily water levels averaged over gauges located in the north basin of Lake Winnipeg after the regulation of the lake came into effect in 1976. The summer water levels at the 10^{th}, 50^{th}, and 90^{th} percentiles are El. 217.18 m, El. 217.67 m, and El. 217.99 m, respectively. For simplicity, the Dauphin River flows at the 10^{th} percentile were run with the water level on Lake Winnipeg at the 10^{th} percentile as a downstream boundary condition. The same method was used for the 50^{th} and 90^{th} percentiles.

The setups for the model simulations are summarized in Table 15. The high gradient of the lower Dauphin River limits the effect of the Lake Winnipeg level on flow hydraulics to a short reach near the outlet. Thus, the hydraulic properties along most of the river are insensitive to the Lake Winnipeg level.

FIGURE 19: DURATION CURVE OF WATER LEVELS ON NORTH BASIN OF LAKE WINNIPEG (POST-1976 REGULATION)

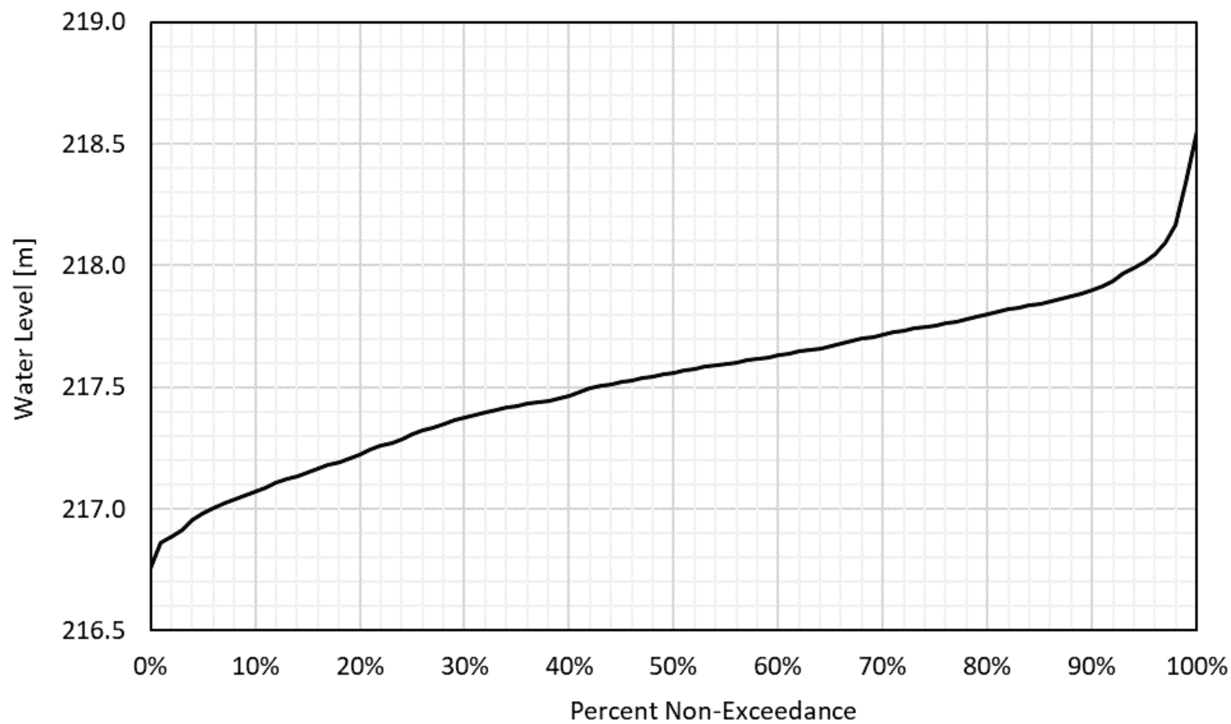


TABLE 15: BOUNDARY CONDITIONS FOR SIMULATIONS OF OPEN WATER ON DAUPHIN RIVER

Case	Dauphin River Flow [m³/s]	Water Surface El. on Lake Winnipeg [m]
Pre-Project 10th Percentile	14.2	217.2
Post-Project 10th Percentile	14.5	217.2
Pre-Project 50th Percentile	67.2	217.7
Post-Project 50th Percentile	52.0	217.7
Pre-Project 90th Percentile	228.8	218.0
Post-Project 90th Percentile	103.1	218.0

The model results for summer flows under Pre-Project and Post-Project conditions at the 10th percentile for the Dauphin River are shown in Figure 20 to Figure 22. The small change in flow at the 10th percentile results in a negligible change to the hydraulic conditions in the Dauphin River (note that the blue Pre-Project line is plotted underneath the red Post-Project line in the figures). The negligible changes to velocity and shear stress would not change the potential for sediment erosion or deposition. Note that there are several locations where the model computes sharp spikes in water velocity and shear stress. These areas are coincident with localized zones of high bed slope. Because of the shallow water depths at low flows, these areas essentially act as rapids. At greater flows, the water depths submerge the local steep sections of the river, and the velocities and shear stresses are reduced.

The model results for summer flows under Pre-Project and Post-Project conditions at the 50th percentile for the Dauphin River are shown in Figure 23 to Figure 25. Similar to the 10th percentile flows, the change in flow at the 50th percentile does not result in any appreciable changes to the flow hydraulics or potential for erosion or deposition of bed material.

The model results for summer flows under Pre-Project and Post-Project conditions at the 90th percentile for the Dauphin River are shown in Figure 26 to Figure 28. The reduction in flows at the 90th percentile caused by the Project reduces the water depths and concomitant flow properties that are exceeded 10% of the time. As shown in Figure 27, the water velocity in the upper reach (km 11-50) typically ranges from 0.5-1.5 m/s. In the lower reach (km 0-11), the velocity typically ranges from 1.0-2.5 m/s. As shown in Figure 28, the shear stress in the upper reach is typically less than approximately 5 Pa, with some local areas exceeding 10 Pa and reaching up to 20 Pa. In the lower reach, shear stresses are consistently greater than 10 Pa, and reach 40-50 Pa in some areas.

Despite these changes, the potential for erosion and deposition would not be substantially changed by the Project. The maximum critical erosion velocity and shear stress for a range of sediment classes are overlaid in Figure 27 and Figure 28. As shown, the general class of particle that could potentially be eroded in the river remains unchanged. Since the Post-Project velocities and shear stresses are slightly lower than the Pre-Project values, it is expected that the potential for erosion would be reduced.

FIGURE 20: PROFILE OF OPEN WATER SURFACE IN THE DAUPHIN RIVER – SUMMER FLOWS AT 10TH PERCENTILE

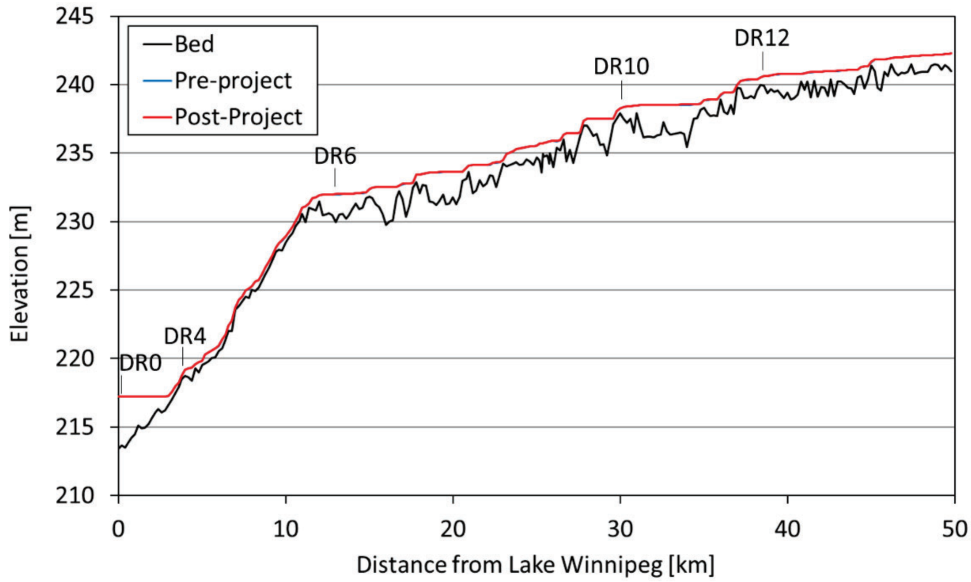


FIGURE 21: VELOCITIES IN THE DAUPHIN RIVER – SUMMER FLOWS AT 10TH PERCENTILE

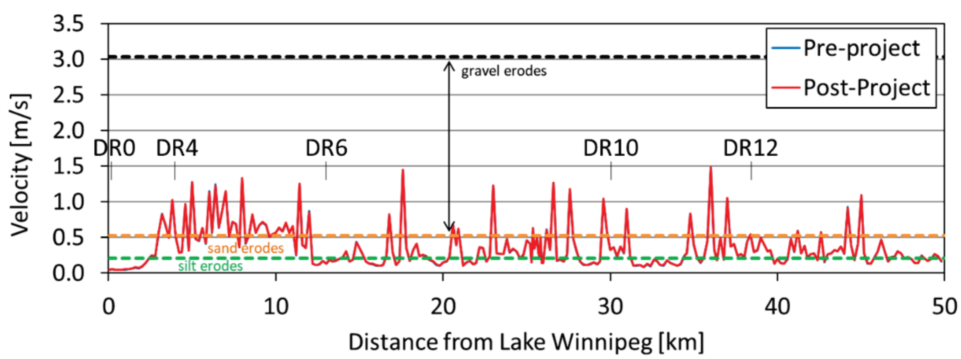


FIGURE 22: SHEAR STRESSES IN THE DAUPHIN RIVER – SUMMER FLOWS AT 10TH PERCENTILE

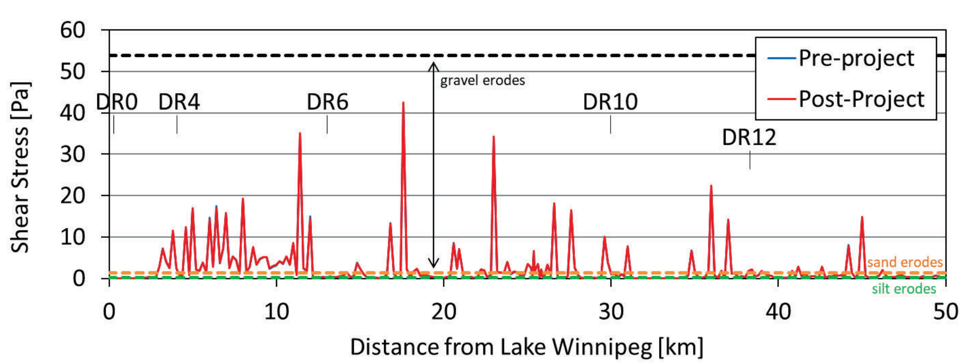


FIGURE 23: PROFILE OF OPEN WATER SURFACE IN THE DAUPHIN RIVER – SUMMER FLOWS AT 50TH PERCENTILE

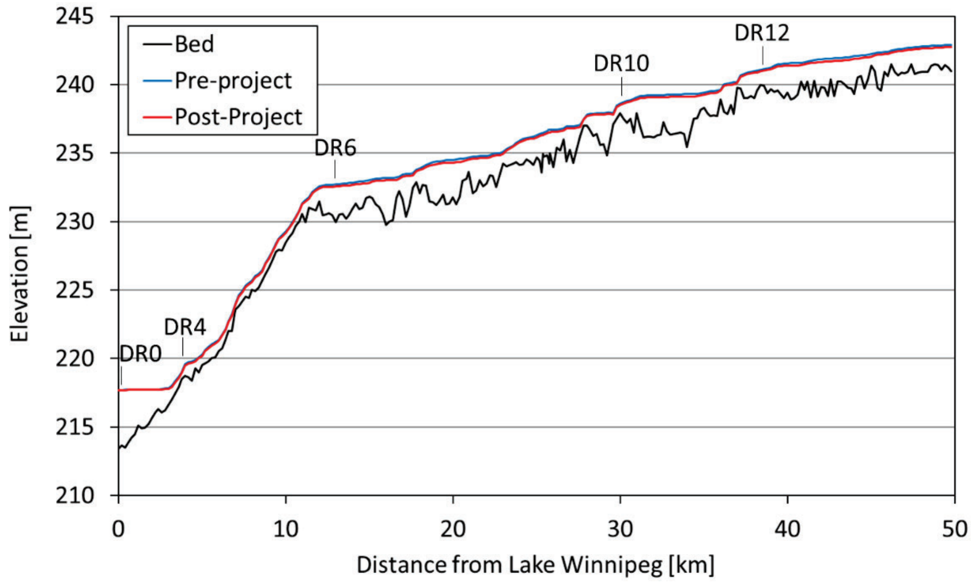


FIGURE 24: VELOCITIES IN THE DAUPHIN RIVER – SUMMER FLOWS AT 50TH PERCENTILE

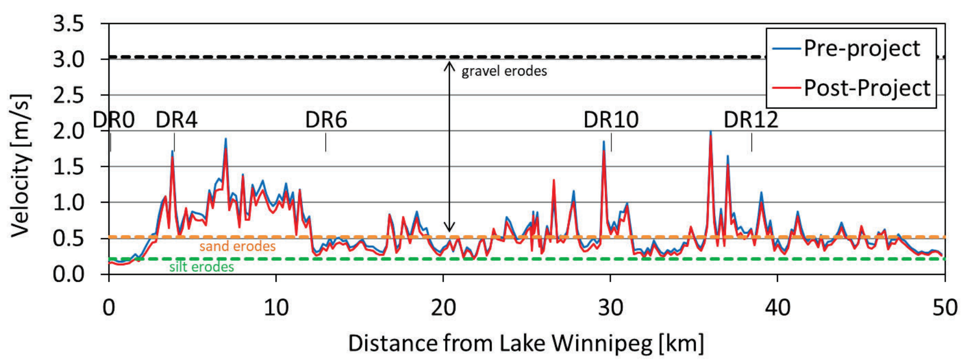


FIGURE 25: SHEAR STRESSES IN THE DAUPHIN RIVER – SUMMER FLOWS AT 50TH PERCENTILE

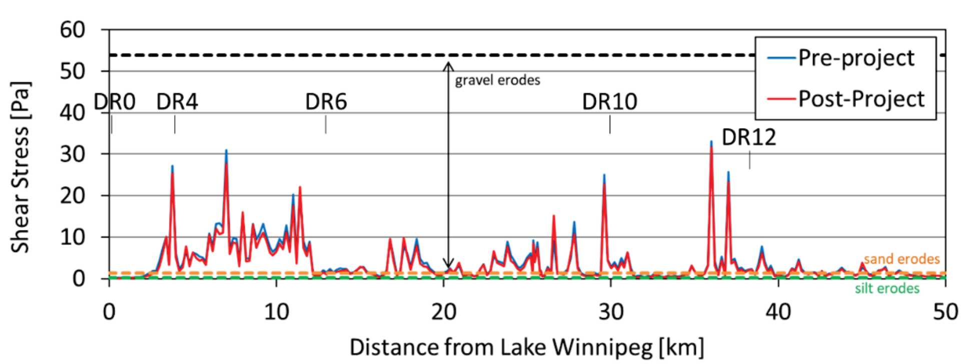


FIGURE 26: PROFILE OF OPEN WATER SURFACE IN THE DAUPHIN RIVER – SUMMER FLOWS AT 90TH PERCENTILE

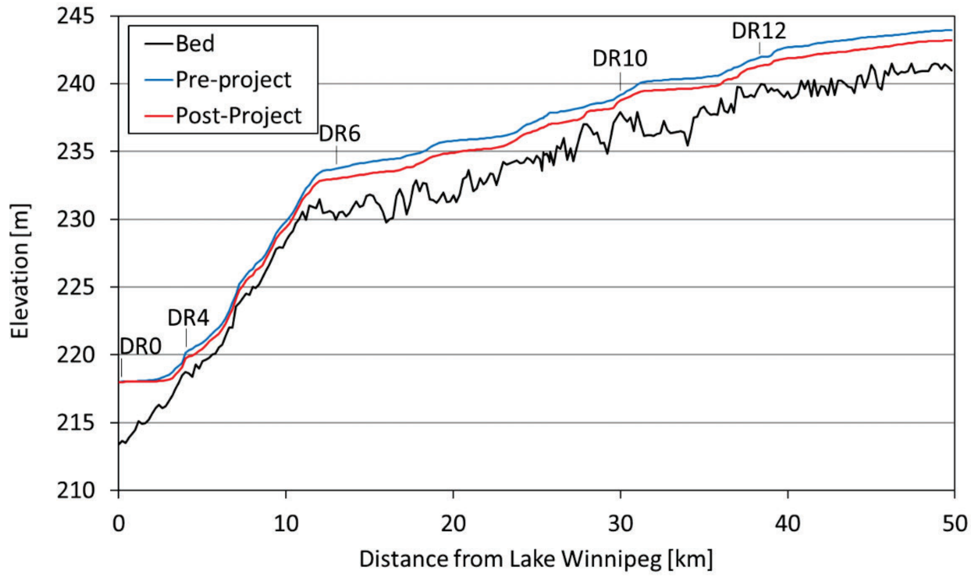


FIGURE 27: VELOCITIES IN THE DAUPHIN RIVER – SUMMER FLOWS AT 90TH PERCENTILE

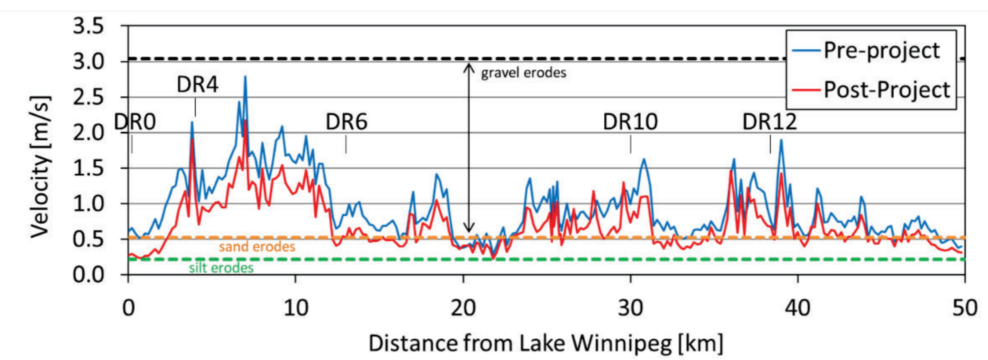
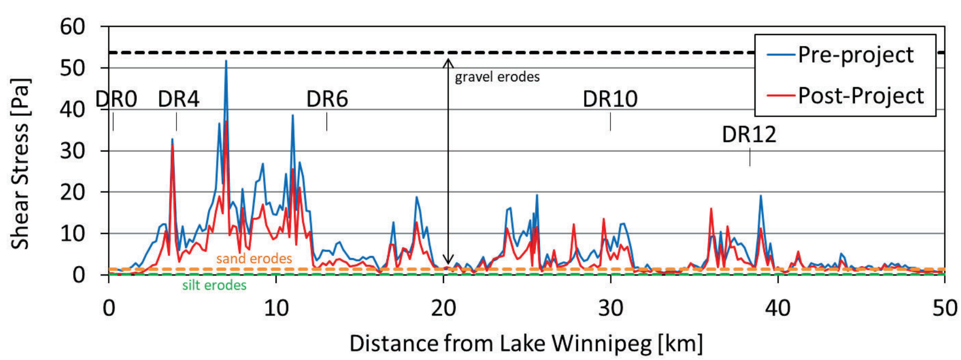


FIGURE 28: SHEAR STRESSES IN THE DAUPHIN RIVER – SUMMER FLOWS AT 90TH PERCENTILE



The computed velocities in the upper and lower reaches (demarcated by the break in slope approximately 11 km from Lake Winnipeg), and the average times for water to travel through the entire 52 km length of the Dauphin River, are shown in Table 16. As shown, the Project effectively reduces flow velocities at each of the percentiles and increases travel time through the river, with a greatest effect at the largest flows.

TABLE 16: DAUPHIN RIVER RESIDENCE TIMES

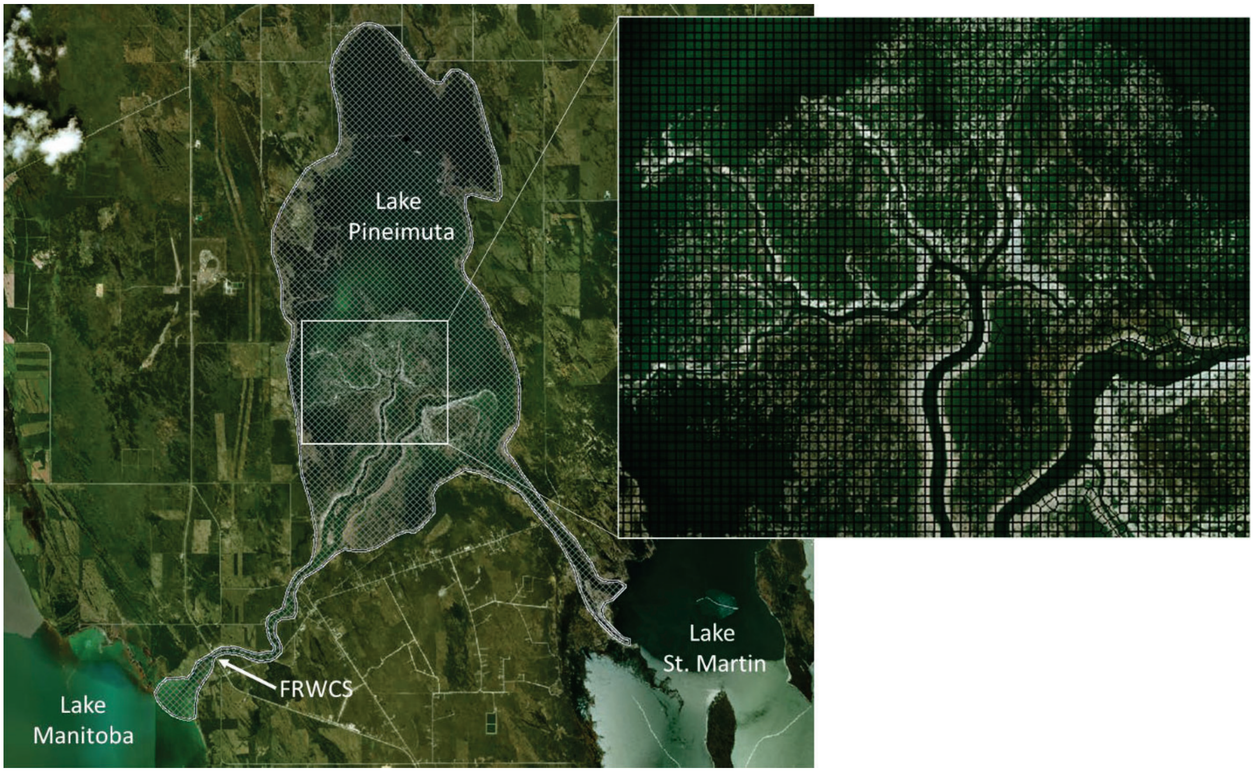
			Average Velocity [m/s]		
Scenario	Percentile	Flow [m^3/s]	Upper Reach	Lower Reach	Travel Time [hr]
Pre-Project	10	14.2	0.31	0.51	61.4
Post-Project	10	14.5	0.32	0.52	60.6
Pre-Project	50	67.2	0.54	0.84	27.9
Post-Project	50	52.0	0.49	0.76	31.5
Pre-Project	90	228.8	0.82	1.39	17.3
Post-Project	90	103.1	0.62	0.98	23.7

3.4.2 FAIRFORD RIVER

Due to the complex flow patterns of the Fairford River through Lake Pineimuta, a two-dimensional (2D) modeling approach was employed to assess the project effects on the hydraulics of this portion of the flow system. A 2D HEC-RAS model was developed using available bathymetry and LiDAR contours of the area. The LiDAR was captured during the flood of 2011 when a significant area of the Lake Pineimuta wetland was inundated and peak flows in the Fairford River exceeded 600 m^3/s. Therefore, the LiDAR coverage is not complete and the Digital Elevation Model (DEM) does not capture the low-lying overbank areas in the delta region and through Lake Pineimuta.

The Fairford River model extends from Lake Manitoba to Lake St. Martin as shown in Figure 29. The Fairford River Water Control Structure (FRWCS) was included in the model as an inline structure with open stoplog bays. HEC-RAS uses a subgrid model to capture the underlying terrain within each cell. Therefore, a constant grid spacing of 50 m was used in the model to increase computational efficiency while still capturing the detailed flow paths of the Fairford River through Lake Pineimuta.

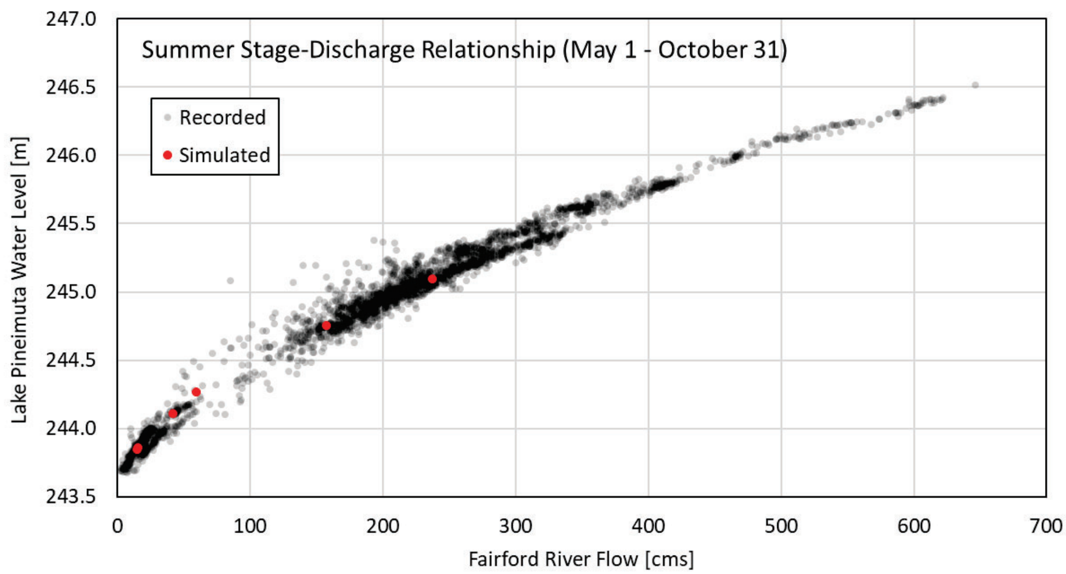
FIGURE 29: EXTENT OF MODEL ALONG FAIRFORD RIVER



Historical measurements of water levels along the Fairford River are scarce. Water levels at the northern edge of Lake Pineimuta were recorded at Water Survey of Canada gauge 05LM801 from 2001-2018. The Manning roughness in the HEC-RAS model was modified such that the simulated stage-discharge relationship matched the recorded relationship between water level in Lake Pineimuta and flow through the FRWCS. A constant Manning roughness of 0.025 was found to produce a satisfactory fit to the recorded data, as shown in Figure 30.

In actuality, the Manning roughness may vary along the length of the Fairford River. However, there is an absence of field data to justify local changes to the Manning roughness (e.g. water level records at multiple locations along the river). Consequently, a constant value of 0.025 was estimated and deemed to be representative of the general properties of the Fairford River. Additionally, the intent of the model application is to identify changes in the hydraulics of the river caused by the project. Consequently, any small inaccuracies in the model will be applied equivalently to both the Pre-Project and Post-Project results. This would suppress any small errors and would not significantly change the conclusions.

FIGURE 30: RECORDED AND SIMULATED STAGE-DISCHARGE RELATIONSHIP OF FAIRFORD RIVER FLOWS AND LAKE PINEIMUTA WATER LEVELS



The Fairford River model was run with the 10th, 50th, and 90th percentile flows in the Pre-Project and Post-Project environments. The water level in Lake St. Martin (downstream boundary condition) was based on the same percentile as the flow (e.g. the Pre-Project lake level at the 10th percentile was used as the boundary condition for the Pre-Project flow at the 10th percentile, etc.). A summary of the flows and water levels used in the simulations is shown in Table 17.

TABLE 17: BOUNDARY CONDITIONS FOR SIMULATIONS OF OPEN WATER IN FAIRFORD RIVER

Case	Fairford River Flow [m^3/s]	Water Level on Lake St. Martin [El. in m]
Pre-Project 10th Percentile	14.5	242.69
Post-Project 10th Percentile	14.5	242.70
Pre-Project 50th Percentile	61.1	243.17
Post-Project 50th Percentile	42.8	243.11
Pre-Project 90th Percentile	248.9	244.29
Post-Project 90th Percentile	163.0	243.92

The simulated two-dimensional velocities representative of the condition at the 10th percentile in the Pre-Project and Post-Project environments are shown in Figure 31. The water surface profiles, velocities, and shear stresses along the centreline of the main channel are shown in Figure 32, Figure 33, and Figure 34, respectively. These figures show that there is negligible difference in hydraulics at flows representative of the 10th percentile.

FIGURE 31: DEPTH AVERAGED VELOCITY IN FAIRFORD RIVER – SUMMER FLOWS AT 10TH PERCENTILE

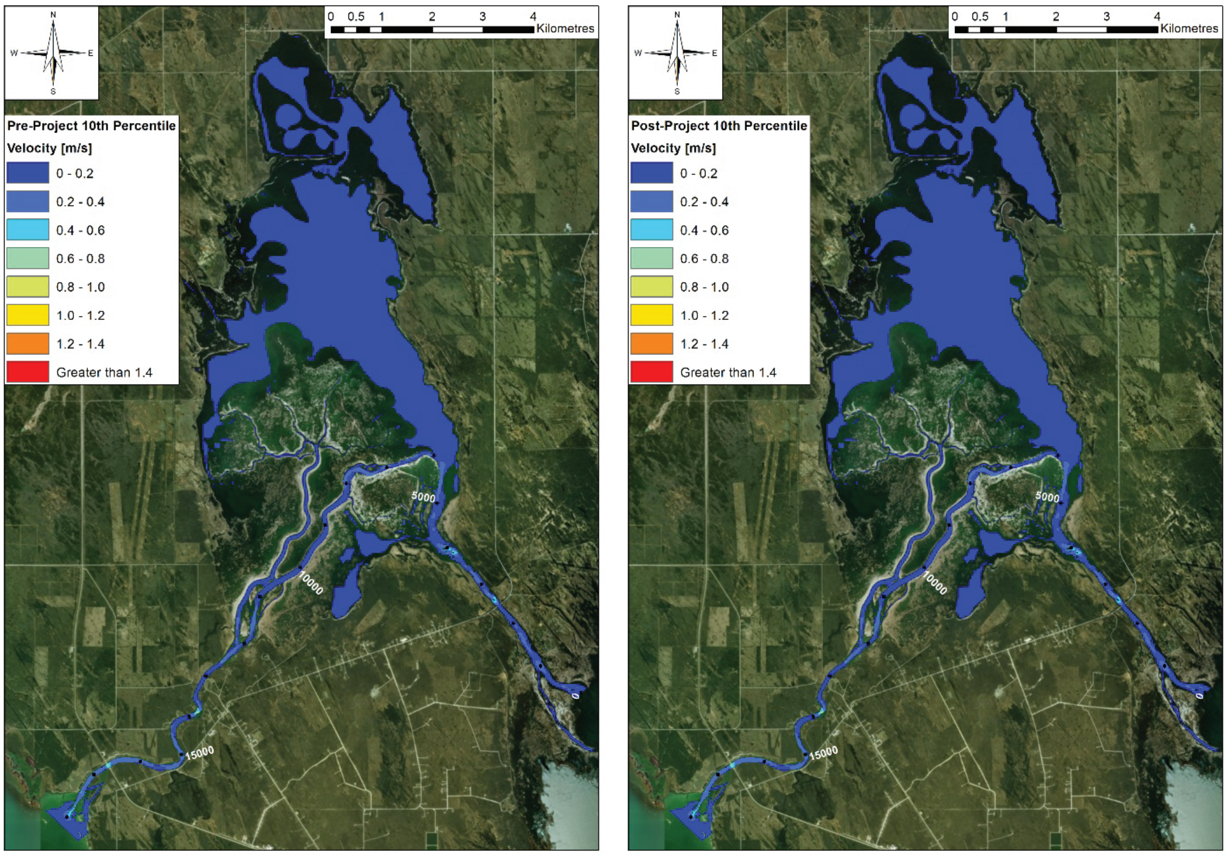


FIGURE 32: WATER SURFACE PROFILE ALONG MAIN CHANNEL OF FAIRFORD RIVER – SUMMER FLOWS AT 10TH PERCENTILE

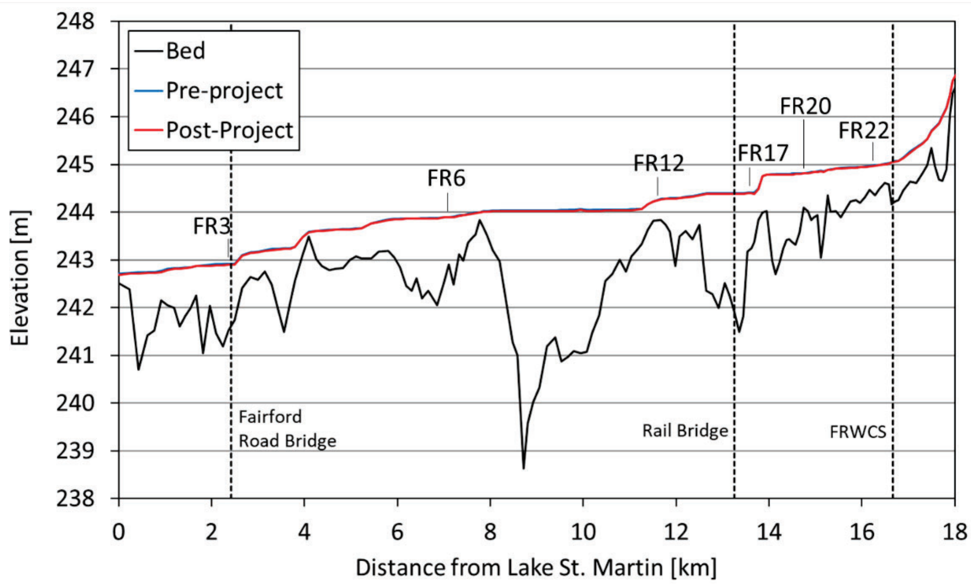


FIGURE 33: VELOCITY ALONG MAIN CHANNEL OF FAIRFORD RIVER – SUMMER FLOWS AT 10TH PERCENTILE

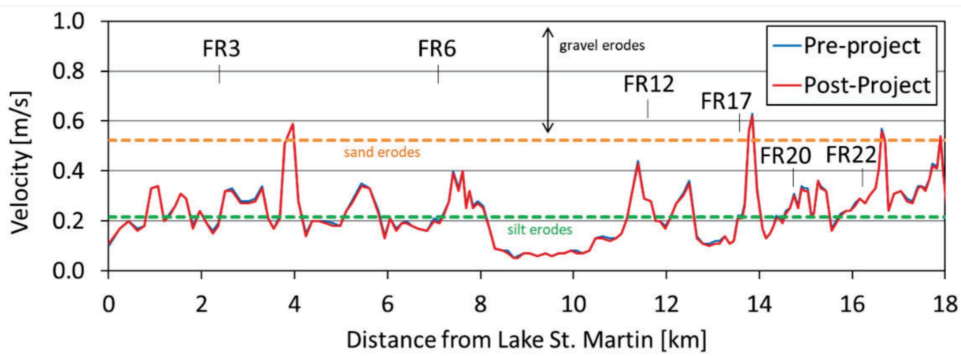
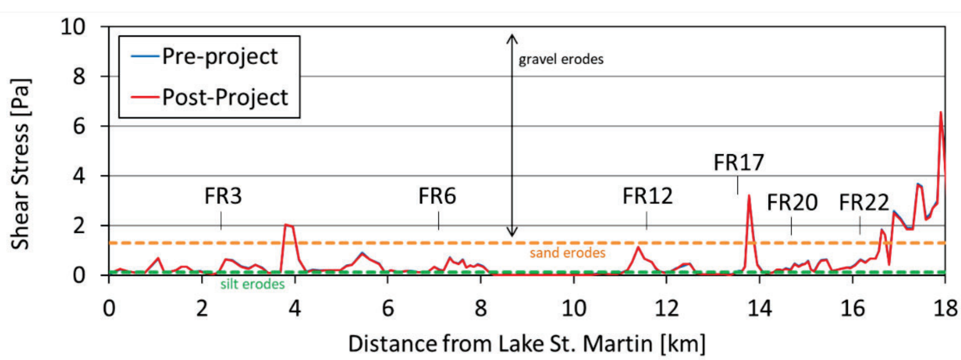


FIGURE 34: SHEAR STRESS ALONG MAIN CHANNEL OF FAIRFORD RIVER – SUMMER FLOWS AT 10TH PERCENTILE



The simulated two-dimensional velocities representative of the 50th percentile condition in the Pre-Project and Post-Project environments are shown in Figure 35. The water surface profiles, velocities, and shear stresses along the centreline of the main channel are shown in Figure 36, Figure 37, and Figure 38, respectively. The reduction in flow at the 50th percentile due to the effect of the Project results in reduced velocities and shear stresses along the length of the Fairford River. However, the changes are relatively small and would not significantly change the class of sediment that would be expected to erode at various points along the river.

FIGURE 35: DEPTH AVERAGED VELOCITY IN FAIRFORD RIVER – SUMMER FLOWS AT 50TH PERCENTILE

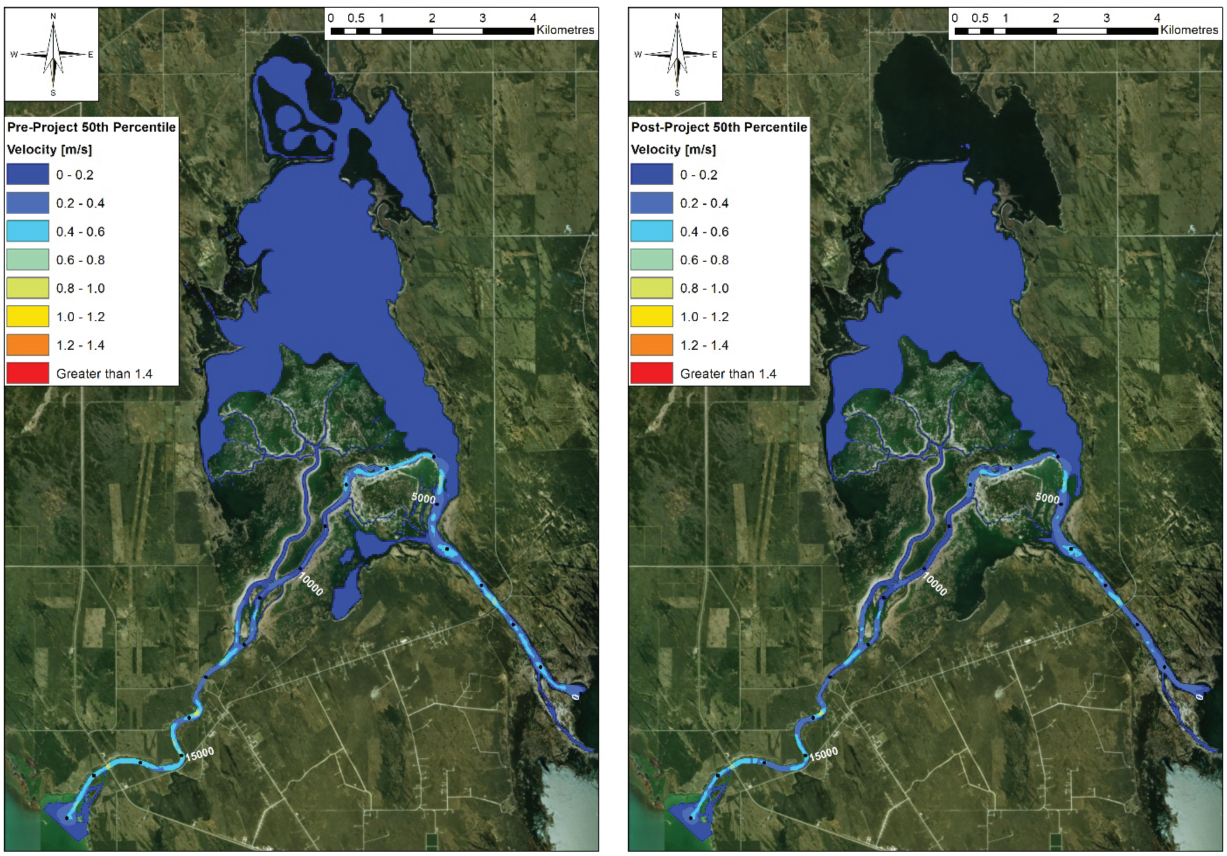


FIGURE 36: WATER SURFACE PROFILE ALONG MAIN CHANNEL OF FAIRFORD RIVER – SUMMER FLOWS AT 50TH PERCENTILE

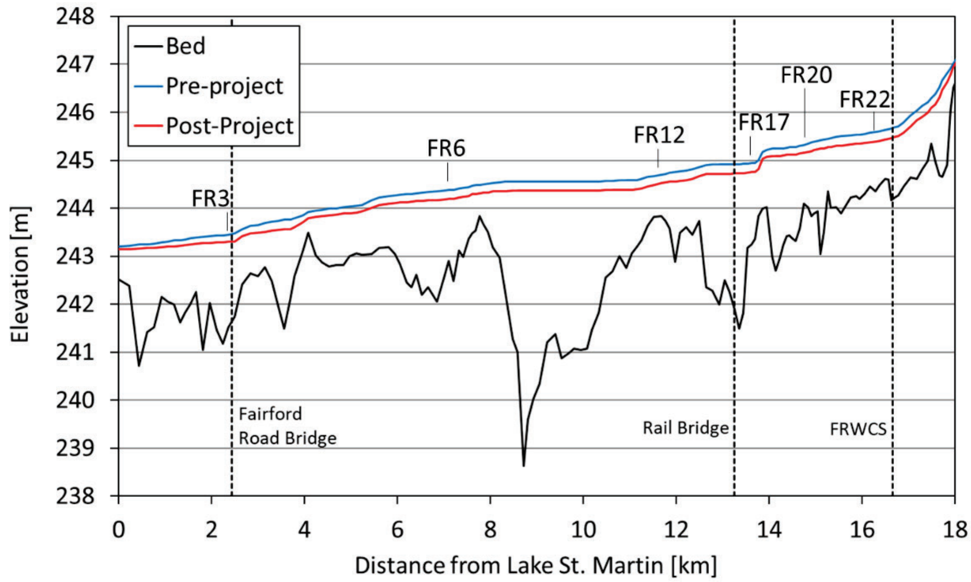


FIGURE 37: VELOCITY ALONG MAIN CHANNEL OF FAIRFORD RIVER – SUMMER FLOWS AT 50TH PERCENTILE

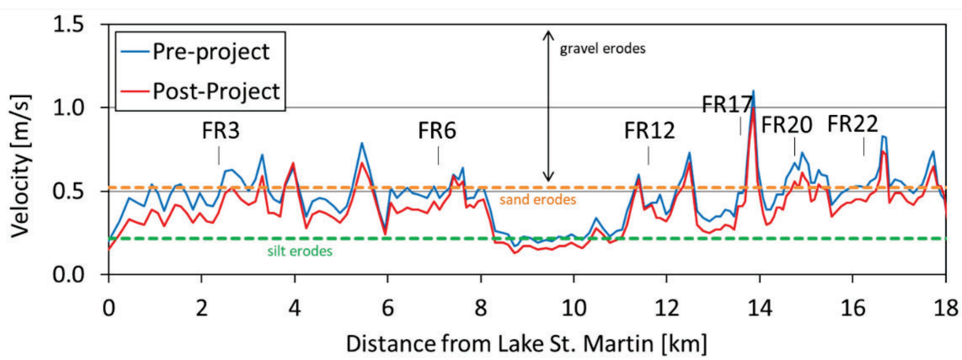
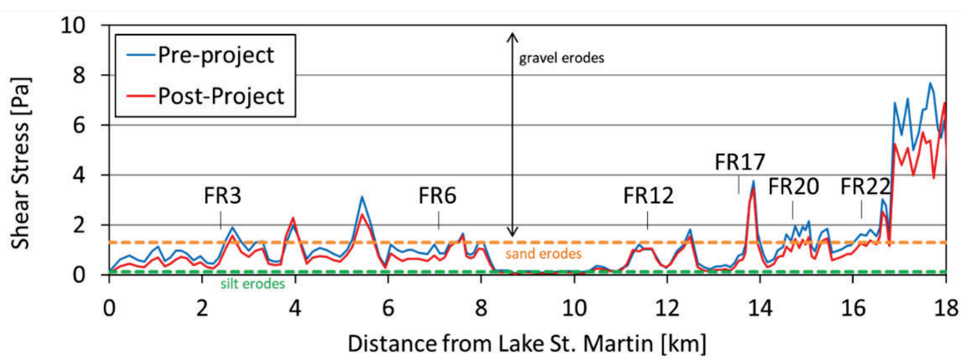


FIGURE 38: SHEAR STRESS ALONG MAIN CHANNEL OF FAIRFORD RIVER – SUMMER FLOWS AT 50TH PERCENTILE



The simulated two-dimensional velocities representative of the 90th percentile condition in the Pre-Project and Post-Project environments are shown in Figure 39. The water surface profiles, velocities, and shear stresses along the centreline of the main channel are shown in Figure 40, Figure 41, and Figure 42, respectively. The reduction in flow due to the Project at the 90th percentile results in reduced velocities and shear stresses along the length of the Fairford River. The lesser velocities and shear stresses would reduce the rate of sediment movement at the 90th percentile flow condition.

FIGURE 39: DEPTH AVERAGED VELOCITY IN FAIRFORD RIVER – SUMMER FLOWS AT 90TH PERCENTILE

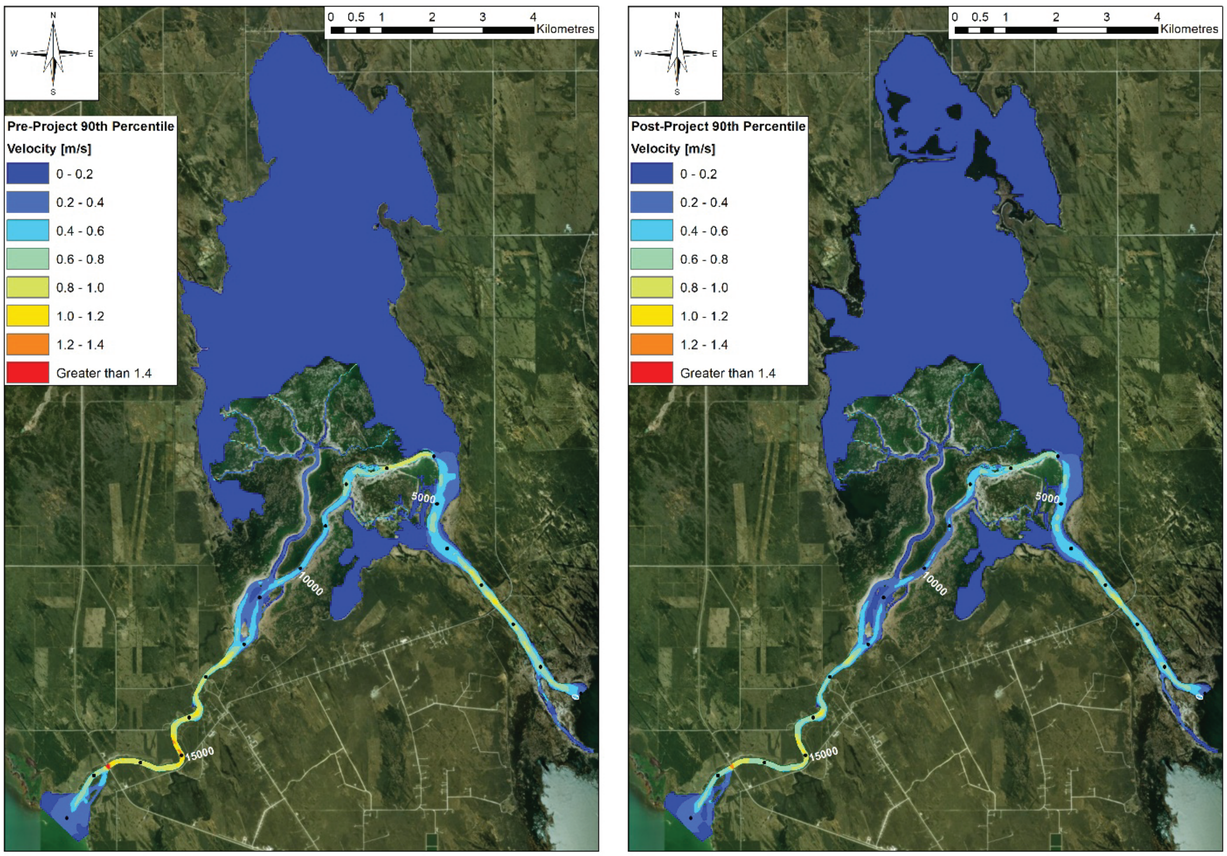


FIGURE 40: WATER SURFACE PROFILE ALONG MAIN CHANNEL OF FAIRFORD RIVER – SUMMER FLOWS AT 90TH PERCENTILE

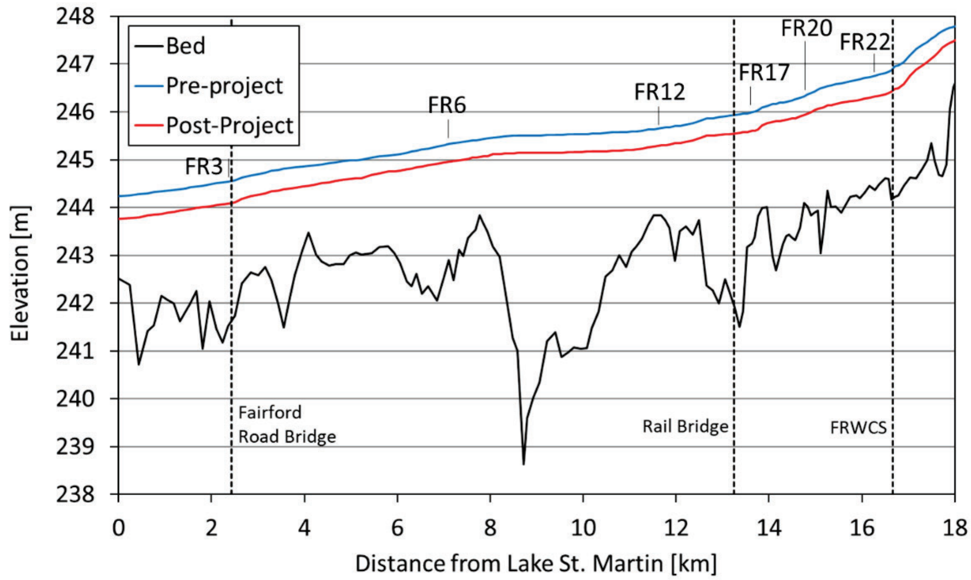


FIGURE 41: VELOCITY ALONG MAIN CHANNEL OF FAIRFORD RIVER – SUMMER FLOWS AT 90TH PERCENTILE

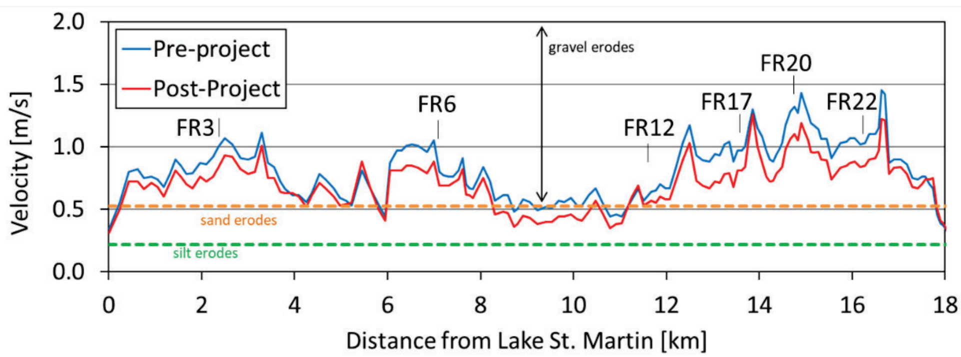
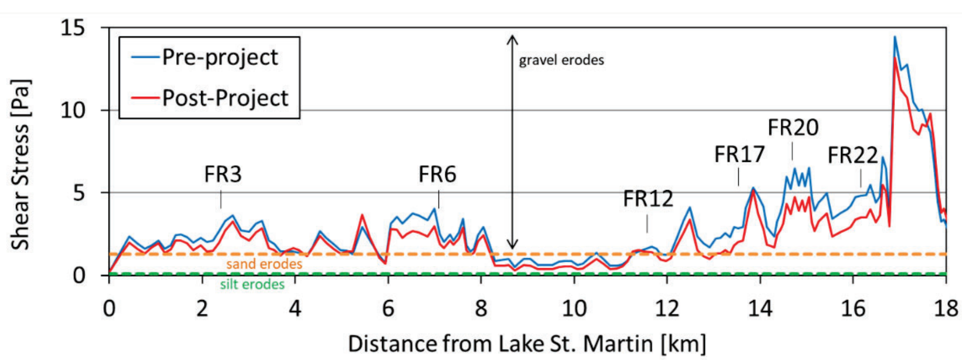


FIGURE 42: SHEAR STRESS ALONG MAIN CHANNEL OF FAIRFORD RIVER – SUMMER FLOWS AT 90TH PERCENTILE



Water velocities extracted along the main flow path of the Fairford River through Lake Pineimuta were used to compute the travel time through the system for flows at the 10th, 50th, and 90th percentiles, shown in Table 18.

TABLE 18: FLOW SPLITS AND RESIDENCE TIME IN THE FAIRFORD RIVER

Scenario	Percentile	Total Flow [m³/s]	Flow to Lake [m³/s]	Flow Along Main Channel [m³/s]	Average Velocity Along Main Channel [m/s]	Travel Time [hr]
Pre-Project	10	14.5	0	14.5	0.24	30.0
Post-Project	10	14.5	0	14.5	0.24	30.0
Pre-Project	50	61.1	2.7	58.4	0.47	12.3
Post-Project	50	42.8	0.9	41.9	0.40	15.1
Pre-Project	90	248.9	43.9	205.0	0.82	6.8
Post-Project	90	163.0	23.3	139.7	0.71	7.9

3.5 Assessment of Ice Conditions

3.5.1 NUMERICAL MODEL

KGS Group's proprietary river ice model, VARY-ICE, was used to assess the project impacts on ice processes in the Dauphin River and Fairford River. VARY-ICE is a one-dimensional (1D) coupled hydraulic and river ice model, which is capable of simulating a variety of ice processes including ice cover advancement by juxtaposition, under-ice transport and deposition, ice erosion, and ice cover retreat by shoving. The model computes the variation in water levels corresponding to the state of the ice cover as the simulation proceeds in discrete time steps. VARY-ICE has proven to be a reliable tool through many decades of application and success in simulating ice cover formation on several rivers across Canada.

The modeling performed herein represents the theoretical ice profile that would form with a constant supply of ice and under a constant flow (i.e. steady state condition). In reality, the variations in the combination of air temperature and hydraulic conditions would dictate the timing of ice cover formation and the rate at which it advances in the rivers. The ice cover simulated by the model represents a cover that forms mechanically and progresses in the upstream direction as incoming ice is added to the ice cover. The ice cover is assumed to have a constant thickness across the entire cross section, with all flow passing underneath the cover.

The numerical ice modeling focused on the portions of the rivers where a fragmented, mechanically thickened ice cover would likely develop. It is in these areas where changes to the winter flow regime would have the greatest impact on the ice cover thickness and ice-affected increases of water. In slow moving portions of the rivers, thermal ice growth (border and skim ice) would dominate the formation of the ice cover. In these areas, changes to flows would affect the rate at which border ice grows, but the overall effect on water levels and ice thickness would be small.

3.5.2 DAUPHIN RIVER

3.5.2.1 Overview of Pre-Project Ice Processes

The ice processes in the Dauphin River are notably different in the upper, low gradient reach compared to the lower, high gradient reach. During winter, water flowing from Lake St. Martin and into the Dauphin River cools and forms frazil ice. The shallow depth of Lake St. Martin reduces the residual heat capacity of the lake water, allowing ice to begin to form in the river within a few hundred metres of the lake. The frazil ice volume increases in the downstream direction, and the frazil slush forms competent ice pans which are transported downstream with the flow. Border ice forms in the low velocity regions near the riverbanks and in the side channels of the upper reach.

Approximately 11 km from Lake Winnipeg, the river gradient increases abruptly. The fast-moving water in this reach limits the extent of border ice growth and frazil pans are transported downstream with the flow to Lake Winnipeg. A smooth, thermal ice cover grows in Lake Winnipeg early in the winter. Incoming frazil pans and slush can be swept under the lake ice cover or may juxtapose against the lake ice cover depending on the hydraulic conditions at the outlet. Typically, during high flows, the frazil pans are swept under the lake ice cover and are transported further into the lake where they are eventually deposited as velocities decline. This forms a hanging ice dam, and causes the upstream water levels to gradually increase. Eventually, the increase in water level allow incoming frazil pans to accumulate ("juxtapose") against the lake ice cover, and the leading edge of the cover begins to progress upstream. Due to the high gradient of the lower reach, the ice cover typically experiences several "consolidation" events as it advances upstream. This refers to the collapse and mechanical thickening of the ice cover in response to the external forces of gravity and water shear which grow as the ice cover lengthens. The thickness and roughness of the consolidated cover can raise water levels by several metres (as much as 3-5 m in some areas). A photograph of a rough, consolidated ice cover on the lower Dauphin River is shown in Figure 43.

FIGURE 43: CONSOLIDATED ICE COVER ON THE LOWER DAUPHIN RIVER

When the ice front progresses to the upper reach, it generally advances much faster via juxtaposition (surface packing) of the ice pans. Some mechanical thickening of the ice cover in the upstream reach can occur, but not nearly to the same extent as in the lower reach. Provincial Road 513 has been flooded in the past due to ice-affected increases in water level on the upper reach. If the flow is sufficiently low, border ice may completely bridge across sections of the upper reach early in the winter. In this case, an ice cover quickly forms over portions of the upper reach. This cuts off the ice supply to downstream and also insulates the water flowing in the river. Consequently, the ice cover in the lower reach takes longer to form.

Once an ice cover forms, open water leads typically develop as the flowing water melts and erodes the ice along the preferential flow paths. Evidence of this process is shown in Figure 43, where an open lead developed in the centre of the river and subsequently formed a smooth thermal ice cover. As air temperatures rise in the spring, open water leads form and grow in size as the ice cover decays and melts.

As shown in Figure 17, the general effect of the project is a reduction in winter flows on the Dauphin River, with a greatest reduction at the high percentiles (i.e. a low frequency of high winter flows). The overall qualitative effects of this modified winter flow regime are as follow:

- Greater likelihood of ice cover bridging in the upper reach, initiating a solid ice cover and cutting off frazil ice supply to the lower reach. This could result in a longer period of ice cover formation in the lower reach.
- Reduced thickness of fragmented ice covers in the upper reach. Lower flows will promote juxtaposition of surface ice and limit the severity of ice cover consolidations.
- Reduced thickness of the consolidated ice cover in the lower reach. The ice cover thickens in response to external forces (primarily gravity and water shear). Decreased flows will reduce the forces acting on the ice cover.

- Reduced severity of hanging ice dam formations at the Lake Winnipeg outlet. Incoming ice will be swept under the lake ice cover and deposit in the hanging ice dam until hydraulic conditions are calm enough to allow the incoming ice pans to juxtapose. At very high flows, the water level must increase more before this juxtaposition process can begin.
- Fewer open water leads that develop in the ice cover over the winter. The reduced flow and water velocity will not erode the ice cover as readily, potentially leading to increased ice coverage on the surface of the river.

3.5.2.2 Numerical Modeling

The formation of an ice cover on the Dauphin River is complex, and there are several factors that determine the peak ice thickness and ice-affected water levels. In addition to the magnitude of the flow, ice cover formation is dependent on weather conditions (e.g. air temperature, solar radiation). Furthermore, there are several complexities related to river ice that are difficult to predict, such as bridging of border ice, grounding of the ice cover, and erosion of the ice cover by flowing water. For these reasons, the simulated ice profiles in the Pre-Project and Post-Project environments presented in this section should be used for comparative purposes with the understanding that there are limitations to the state of the art in modeling these complex processes.

A 1D river ice model was developed using KGS Group's proprietary software, VARY-ICE. The model is capable of simulating the key process of ice cover shoving and mechanical thickening common to the Dauphin River. The VARY-ICE model extends from Lake St. Martin to Lake Winnipeg, and uses the same cross sections and bathymetric sources as the HEC-RAS model.

The parameters in the VARY-ICE model used for calibration are as follows:

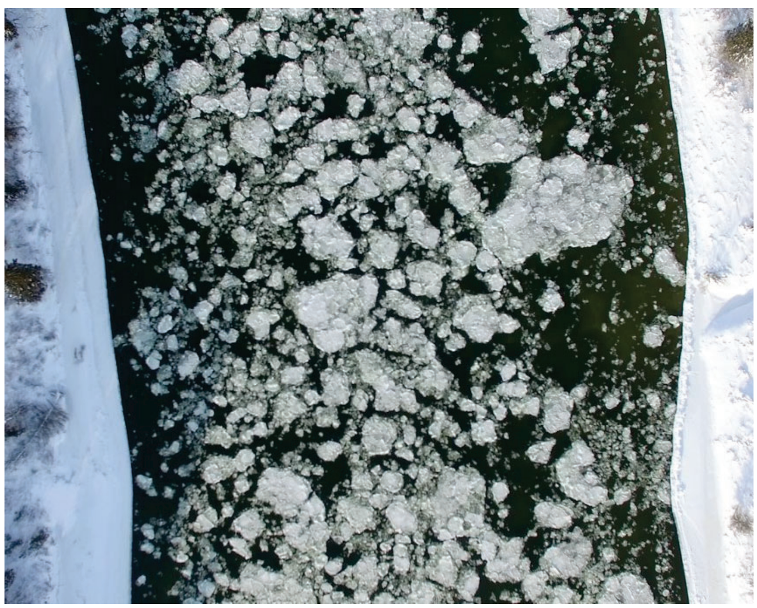
- **VMAX** – Deposition velocity for under-ice transport (typical values range from 0.8 m/s to 1.2 m/s).
- **VERODE** – Velocity at which the underside of the ice cover will erode (typical values range from 1.2 m/s for fresh frazil ice to 2.5 m/s for solid ice floes).
- **K1*TAN(PHI)** – Ratio of shear stress at banks to streamwise stress within the ice cover (typical values range from 0.25 to 0.35).
- **KICE** – Passive strength coefficient for the fragmented ice cover (typical values range from 5-6).
- **FRCRIT** – Critical Froude number, below which surface ice can juxtapose (pack) against the leading edge (typical values range from 0.8-0.12).
- **VNICE** – Manning roughness coefficient of undersurface of the ice cover at 0.1 m thickness (typical value approximately 0.01).
- **VNN2** – Multiplication factor for Manning roughness coefficient of ice cover at 8.0 m thickness (typical values range from 10-15, resulting in a Manning n of ice cover at 8.0 m thickness ranging from 0.10 to 0.15).
- **VNCHAN** – Manning roughness coefficient of river bed.

The model was calibrated to water levels in the river in November 2010 (during the period of ice cover formation). Photographic and anecdotal evidence was used to reconstruct approximate water levels at five locations along the river (KGS Group, 2016). The average flow at this time was 190 m^3/s.

The value of the critical Froude number reported in the literature typically ranges from 0.08-0.12. When this value was applied to the Dauphin River model, the simulated ice profile showed several "steps" in the upper reach as a result of this entrainment and deposition process. This resulted in a simulated water surface profile that was higher than the observed water levels.

Observations of ice cover advancement on the Dauphin River by Wazney et al. (2019) and Lindenschmidt et al. (2012) suggest that incoming ice mostly remained at the surface when reaching the ice front. Ice pans traveling several kilometres from Lake St. Martin are typically quite competent due to the agglomeration of pans into larger rafts which can freeze a surface crust (these rafts can be several tens of square metres in plan area, as shown in Figure 44; note the river width is on the order of 150 m). The critical Froude number of 0.08-0.12 is better suited for frazil slush or small pans that can be easily swept under an ice cover. The critical Froude number for larger ice rafts could be much greater, as the larger rafts are less susceptible to entrainment or underturning at the leading edge of the ice cover.

FIGURE 44: LARGE ICE RAFTS IN THE UPPER DAUPHIN RIVER



To better reflect these observations, the critical Froude number was raised to 0.3 to minimize its influence on ice cover formation. This effectively resulted in the cover thickening mainly in response to the external forces acting on it. The cover in the lower reach was not sensitive to this change, but the ice profile in the upper reach more closely matched the observed water levels.

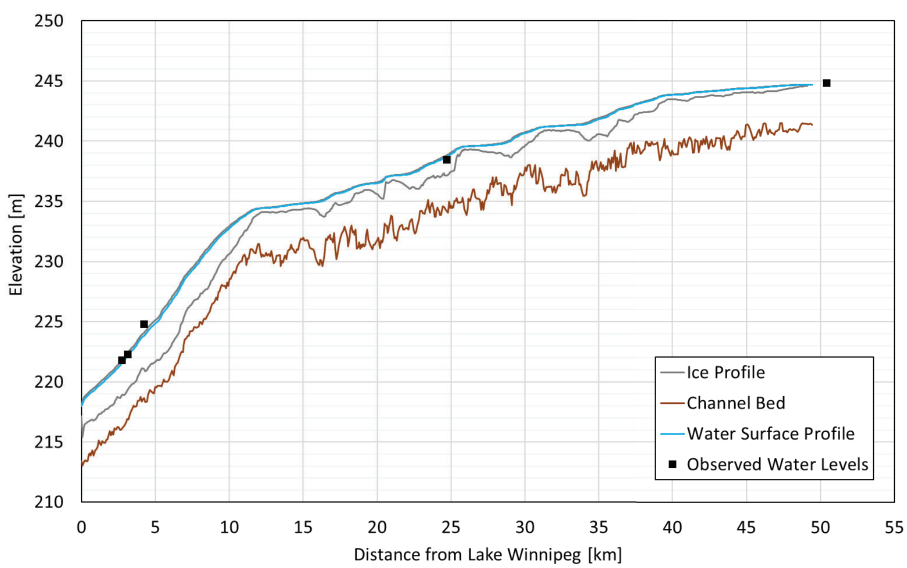
The strength coefficient, KICE, was set to a value of 4.5, which is slightly below the typical range of 5-6. The ice cover in the Dauphin River has been observed to undergo severe consolidations (shoves) as it progress up the lower reach. During these consolidations, water levels can rise 1-2 m in a matter of approximately 10 minutes, and the momentum of the collapsing ice cover and surge of water released from storage may "over thicken" the cover beyond what would be predicted by the steady state discharge. This process of over-thickening was documented by David Andres in his monitoring of freeze-up of the Peace River in Alberta (Beltaos, 1995). This justified the selection of a reduced strength parameter to represent this dynamic process that is not captured by the model.

The calibrated model parameters are shown in Table 19, and the simulated ice profile is shown in Figure 45.

TABLE 19: ICE MODEL PARAMETERS

Parameter	VMAX	VERODE	K1*TAN(PHI)	KICE	FRCRIT	VNICE	VNN2	VNCHAN
Value	1.1 m/s	1.5 m/s	0.25	4.5	0.30	0.01	15	0.028

FIGURE 45: SIMULATED ICE PROFILE IN THE DAUPHIN RIVER CALIBRATED TO WATER LEVELS OF NOVEMBER 2010 (Q = 190 CMS)



The calibrated model of the Dauphin River was then run with the winter flows at the 10th, 50th, and 90th percentiles in the Pre-Project and Post-Project environments. The water level in Lake Winnipeg was selected based on the duration curve of winter levels shown in Figure 19, using the same percentile as the flow (i.e. the flows at the 10th percentile were paired with the lake water levels at the 10th percentile, etc.). The flow and boundary conditions used for the Dauphin River ice model runs are presented in Table 20.

TABLE 20: BOUNDARY CONDITIONS FOR SIMULATIONS OF ICE COVER DEVELOPMENT IN THE DAUPHIN RIVER

Case	Dauphin River Flow [cms]	Lake Winnipeg Water Level [El. in m]
Pre-Project 10th Percentile	5.1	217.0
Post-Project 10th Percentile	4.2	217.0
Pre-Project 50th Percentile	45.8	217.5
Post-Project 50th Percentile	35.5	217.5
Pre-Project 90th Percentile	139.2	217.8
Post-Project 90th Percentile	97.2	217.8

The flows at the 10th percentile are sufficiently low that thermal ice growth would dominate the ice cover formation along the majority of the Dauphin River. At these low flows, border ice would likely bridge at multiple locations in the upper reach (and possibly even in some areas in the lower reach) due to the low water velocities. The winter flows at the 10th percentile in the Pre- and Post-Project environments are sufficiently close in magnitude that there would be no measurable change in the ice processes.

For the flows at the 50th percentile, the water velocities in the upper reach are sufficiently low that bridging by border ice would still play a significant role in the ice cover formation. In the lower reach where velocities are high, the ice cover would form through accumulation and consolidation of ice pans. The simulated ice profiles are shown in Figure 46. The average computed ice thicknesses in the lower reach are 2.18 m and 2.07 m in the Pre-Project and Post-Project environments, respectively, and the top of ice profiles are similar. As shown in Figure 47, the under-ice water velocities in the lower reach range from approximately 0.4-0.6 m/s, and are similar in the Pre-Project and Post-Project environments. Note also that the water velocities along the majority of the river (with the exception of the area near Lake Winnipeg) decrease in the presence of an ice cover. This suggests that the potential for erosion of the river bed generally decreases in the winter with the formation of an ice cover.

FIGURE 46: ICE PROFILES IN THE LOWER DAUPHIN RIVER – WINTER FLOWS AT 50TH PERCENTILE

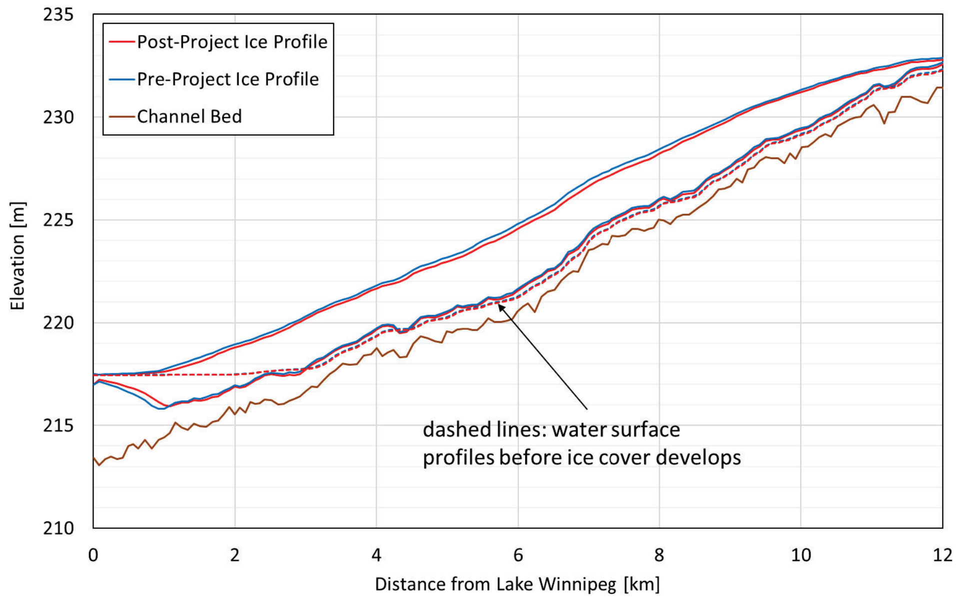
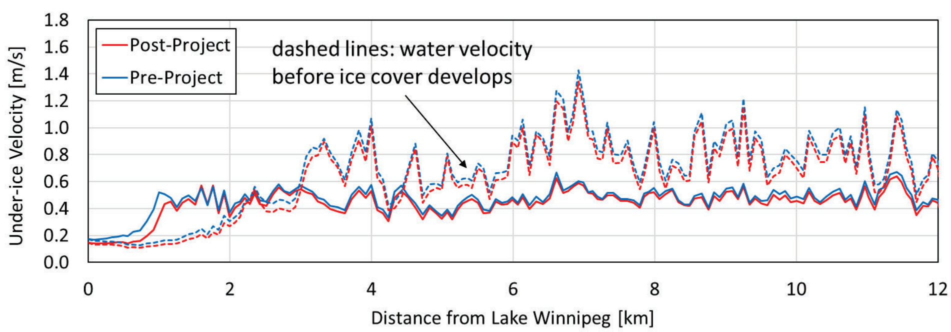


FIGURE 47: UNDER-ICE VELOCITIES IN THE LOWER DAUPHIN RIVER – WINTER FLOWS AT 50TH PERCENTILE



The simulated ice profiles in the lower reach for flows at the 90th percentile are shown in Figure 48. The average ice cover thicknesses in the lower reach in the Pre-Project and Post-Project environments are 2.73 m and 2.46 m, respectively. As shown in Figure 49, the under-ice water velocities range from approximately 0.5-0.8 m/s, with the Pre-Project velocity exceeding the Post-Project velocity by approximately 0.1 m/s consistently.

In the upper reach, the average ice thicknesses in the Pre-Project and Post-Project environments are 0.69 m and 0.60 m, respectively, as shown in Figure 50. The greater flow and thicker ice profile in the Pre-Project environment results in an ice profile that is approximately 0.5 m higher than in the Post-Project environment. The under-ice water velocities are marginally greater in the Pre-Project environment, exceeding the Post-Project velocities by approximately 0.09 m/s on average, as shown in Figure 51.

FIGURE 48: ICE PROFILES IN THE LOWER DAUPHIN RIVER – WINTER FLOWS AT 90TH PERCENTILE

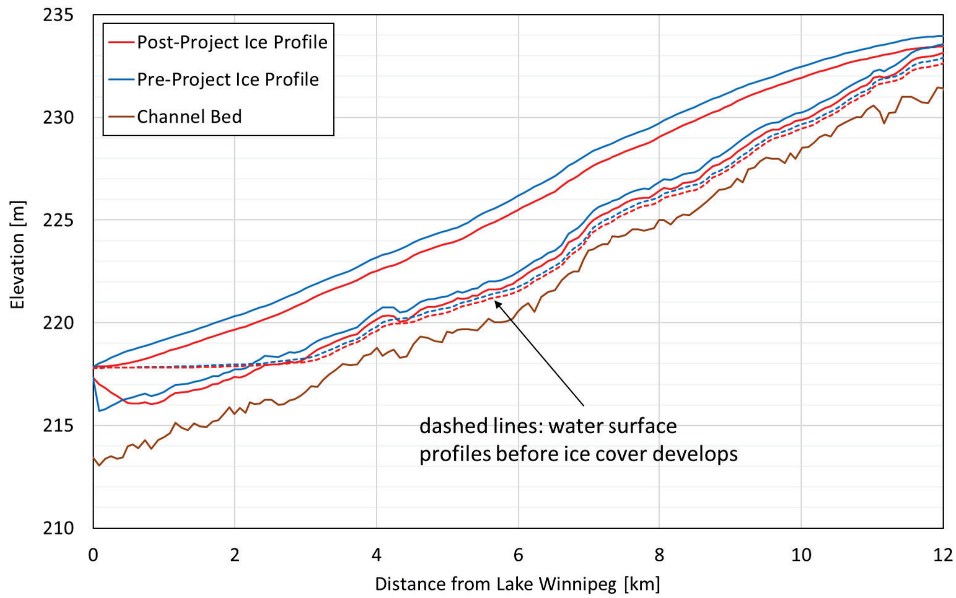


FIGURE 49: UNDER-ICE VELOCITIES IN THE LOWER DAUPHIN RIVER – WINTER FLOWS AT 90TH PERCENTILE

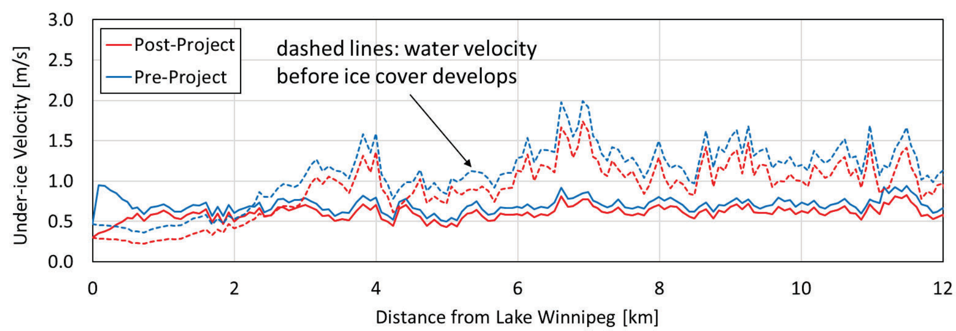


FIGURE 50: ICE PROFILES IN THE UPPER DAUPHIN RIVER – WINTER FLOWS AT 90TH PERCENTILE

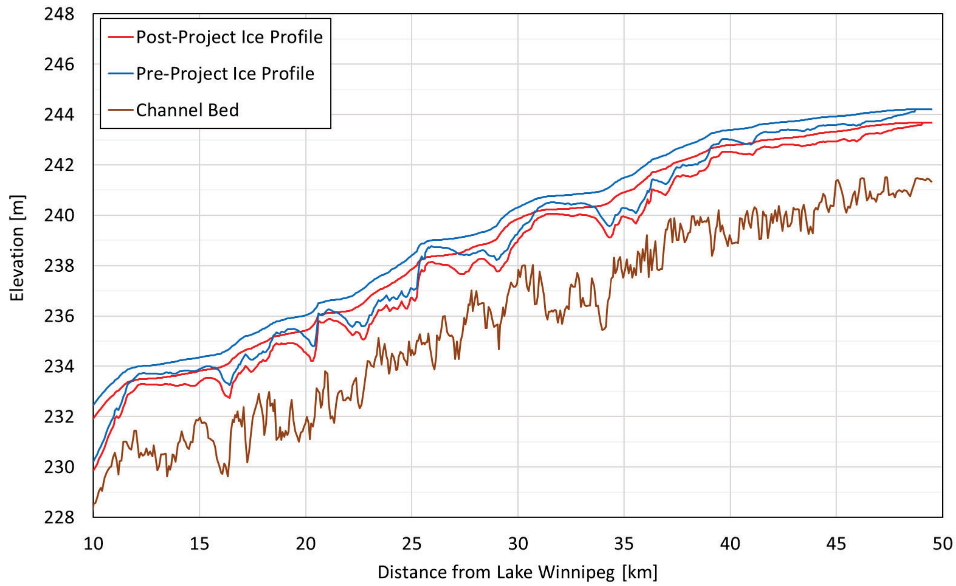
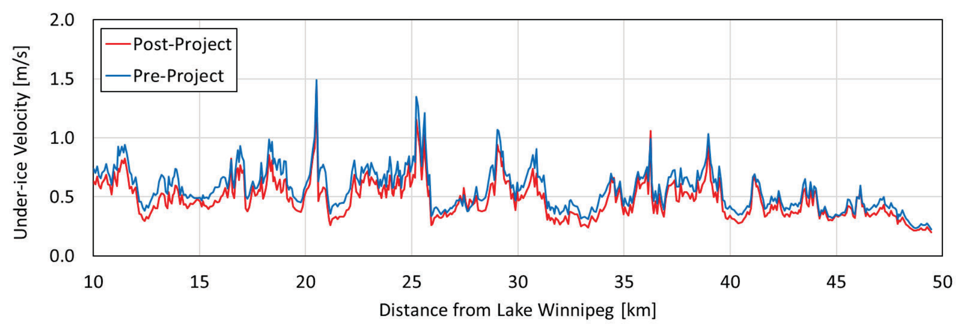


FIGURE 51: UNDER-ICE VELOCITIES IN THE UPPER DAUPHIN RIVER – WINTER FLOWS AT 90TH PERCENTILE



In general, the changes to the winter flow regime as a result of the Project are relatively small. They are not anticipated to significantly impact the ice processes on the Dauphin River. The general reduction in winter flows in the Post-Project environment will result in thinner ice covers where the consolidation process dominates. They may also contribute to enhanced border ice formation due to reduced water velocities. This represents a benefit of the Project in a flood mitigation context, as the likelihood of ice jam related flooding on the Dauphin River will be reduced.

In the Pre-Project environment, a massive hanging ice dam forms at the outlet of the Dauphin River in Lake Winnipeg during intermittent high flow winters. Water velocities under the hanging ice dam are likely sufficient to erode sediment deposits. Thus, it is supposed that the infrequent formation of a hanging ice dam flushes out sediments that may have been transported through the Dauphin River and deposited at the river mouth. Since the Project would have the effect of reducing the magnitude and frequency of high flow winters, this process of periodic erosion would be suppressed. This could potentially lead to slow aggradation of the lake bottom at the river mouth over time. However, the rate of erosion and flux of sediments through the Dauphin River will also be suppressed by the Project because of the reduction in flows which would slow the process of aggradation. It is anticipated that the net rate of aggradation would be low, and the net changes in bed elevation may not be measurable over the life of the Project.

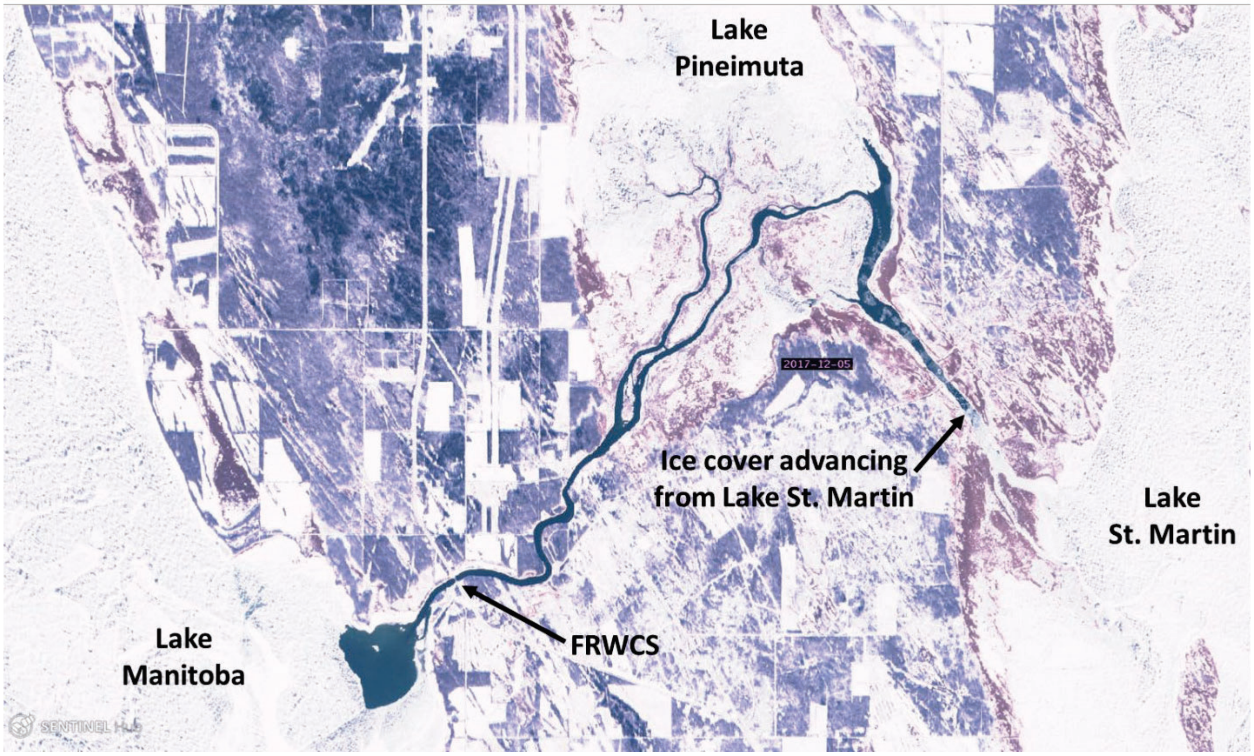
3.5.3 FAIRFORD RIVER

3.5.3.1 Overview of Ice Processes in Pre-Project Conditions

The primary channel of the Fairford River is approximately 17 km long, and the water surface typically slopes from El 247.0-247.7 m in Lake Manitoba to El 242.9-243.8 m in Lake St. Martin. The outflows from the FRWCS are normally limited in magnitude in the winter to promote the formation of a stable ice cover in the Fairford River and reduce the severity of frazil ice formation in the Dauphin River downstream. Under these conditions of low flow, ice formations on the river both upstream and downstream of the FRWCS do not substantially influence the outflow capacity from the lake.

The majority of Lake Pineimuta typically freezes over with a thermally grown ice cover early in the winter. The two channels of the Fairford River take more time to develop an ice cover, and may remain open through the majority of the winter in some years. A review of recent satellite imagery indicates that border ice may bridge across the river at certain locations, initiating ice covers at various points along the river. An ice front also progresses upstream from the thermal ice cover on Lake St. Martin. Throughout the winter, the ice coverage can change drastically, as the various ice covers advance and retreat in response to flow conditions and air temperatures. Figure 52 shows the extent of ice cover on December 5, 2017 at which time the flow through the FRWCS was 208 m^3/s. Note the lake ice covers and open water in the main channels of the Fairford River. Note also the open water area at the outlet of Lake Manitoba; this area takes considerable time to freeze over due to the high velocities, and may not completely freeze over throughout the entire winter.

FIGURE 52: SENTINEL SATELLITE IMAGE OF ICE COVERAGE ON DECEMBER 5, 2017 (Q = 208 CMS)



3.5.3.2 Numerical Modeling

A 1D river ice model of the Fairford River was developed in VARY-ICE. The model geometry was created from cross sections cut from the bathymetric data along the main channel of the Fairford River from the FRWCS to Lake St. Martin, as shown in Figure 53. The absence of water level and ice measurements for calibration required that standard parameters be used in the model. These are the same as those used for the Dauphin River model, but the critical Froude number for ice entrainment was set to 0.12, and the strength parameter KICE was set to 5.0 (since there was no evidence to support deviating from these typical values). The boundary conditions for the simulations of the Fairford River ice development are summarized in Table 21.

FIGURE 53: CROSS SECTIONS IN THE VARY-ICE MODEL OF THE FAIRFORD RIVER

TABLE 21: BOUNDARY CONDITIONS FOR SIMULATIONS OF ICE COVER DEVELOPMENT IN THE FAIRFORD RIVER

Case	Fairford River Flow [cms]	Lake St. Martin Level [m]
Pre-Project 10th Percentile	13.3	242.71
Post-Project 10th Percentile	13.2	242.74
Pre-Project 50th Percentile	49.0	243.27
Post-Project 50th Percentile	39.5	243.23
Pre-Project 90th Percentile	143.0	244.06
Post-Project 90th Percentile	90.2	243.74

A fundamental assumption adopted in the modeling was that all the flow will travel through the south branch of the river (i.e. the discharge remains constant along the entire length of the model). Examination of model outputs from the 2D HEC-RAS model suggests that nearly 100% of the flow travels through the south branch at flows less than approximately 60 m^3/s. At a flow of 157 m^3/s, 87% of the flow travels through the south branch, while 13% traveled through the north branch into Lake Pineimuta.

At winter flows for the 10th percentile for the Pre-Project and Post-Project scenarios, velocities through the majority of the Fairford River are typically less than 0.4 m/s, with several areas less than 0.2 m/s. At these velocities, thermal ice growth would dominate the process of ice cover formation. Since the winter flow at the 10th percentile is changed negligibly by the project, thus it is not expected that the river ice processes would change at this flow percentile.

At the winter flow for the Pre-Project 50th percentile, velocities are still sufficiently low that thermal ice growth and border ice bridging are expected to dominate ice cover formation. Since the flows are slightly lower in the Post-Project environment, thermal ice may form more quickly than in the Pre-Project environment.

At the winter flow for the Pre-Project 90th percentile, ice cover formation via juxtaposition and advancement of surface ice occurs, however border ice may still be able to bridge at some specific locations along the river. The simulated ice profiles for the Pre-Project and Post-Project conditions are shown in Figure 54. The combination of greater discharge and higher Lake St. Martin water level results in a higher ice profile in the Pre-Project environment compared to the Post-Project environment. As shown in Figure 55, under-ice water velocities are also greater in the Pre-Project environment by approximately 0.1 m/s.

FIGURE 54: ICE PROFILES IN THE FAIRFORD RIVER – WINTER FLOWS AT 90TH PERCENTILE

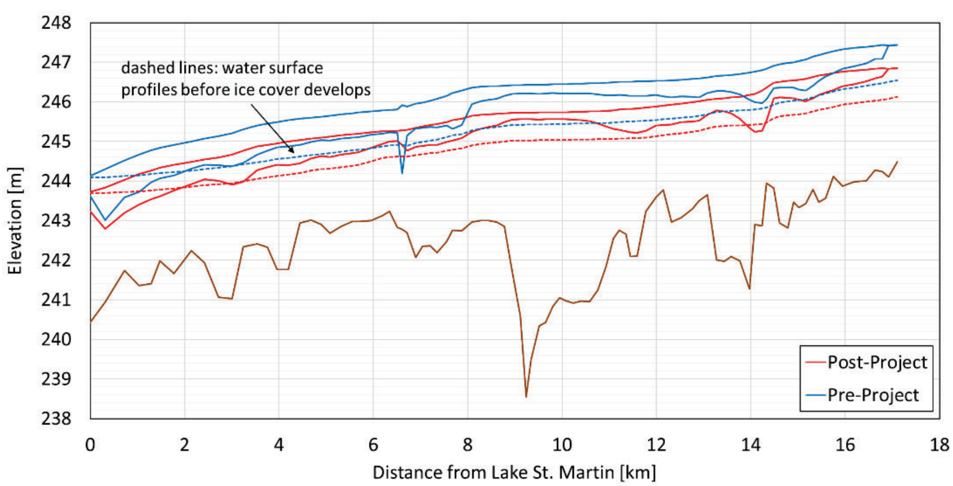
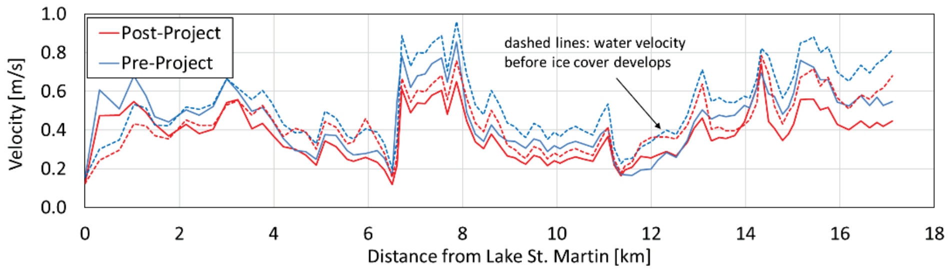


FIGURE 55: UNDER-ICE VELOCITIES IN THE FAIRFORD RIVER – WINTER FLOWS AT 90TH PERCENTILE



In general, changes to the Fairford River winter flow regime as a result of the project would not significantly affect the ice processes, particularly at flows corresponding to the mid to low percentiles where changes would be relatively small. The small reduction in flows in the Post-Project environment would likely allow border ice to more easily form and bridge laterally across the water surface along the main channels of the river. At the high flow percentiles, the difference in Pre-Project and Post-Project flows would be greater. With the Project in place, the occurrence of high winter flow events would be reduced, which would mean that bridging of border ice laterally across the river is likely to occur more often. In areas that develop a mechanically thickened, fragmented ice cover, the thickness of the ice cover would be reduced due to the reduced hydraulic forces acting on the cover.

4.0 ASSESSMENT OF POTENTIAL CHANGES TO FLUVIAL GEOMORPHOLOGY

The following sections present key results of the numerical models at the detailed observation sites along the Dauphin and Fairford Rivers, and a discussion of potential changes to fluvial geomorphological processes caused by the Project.

4.1 Dauphin River

A summary of key results from the hydraulic modeling at the detailed observation sites on the Dauphin River are presented in Table 22. For the Dauphin River, the water surface elevation (WSE), velocity, and bed shear stress are unchanged for the Pre-Project and Post-Project flow conditions at the 10th percentile. There would be no measurable changes in geomorphic response of the river under the Post-Project conditions for these low flows.

For the flows at the 50th percentile, the WSE at the sites with active erosion (Sites C and E) would be roughly 0.15 m lower than the conditions observed during the field work on June 13, 2019. The velocities and bed shear stress would also be slightly lower. Therefore, under the flows at the 50th percentile the rate of bank recession due to the hydraulic conditions in the river would be expected to decrease and be low.

TABLE 22: SUMMARY OF RESULTS AT DETAILED OBSERVATION SITES ON THE DAUPHIN RIVER

		Modeled Change Due to Project		
Flow Condition	**Site**	**WSE [m]**	**Velocity [m/s]**	**Shear Stress [Pa]**
10th Percentile	A - DR0	-	-	-
	B - DR4	-	-	+0.02
	C - DR6	+0.01	-	+0.01
	D - DR10	-	-	+0.01
	E - DR12	-	-	+0.02
50th Percentile	A - DR0	-	-0.04	-0.07
	B - DR4	-0.08	-0.09	-0.98
	C - DR6	-0.15	-0.06	-0.39
	D - DR10	-0.08	-0.06	-0.40
	E - DR12	-0.12	-0.03	-0.10
90th Percentile	A - DR0	-	-0.33	-1.23
	B - DR4	-0.40	-0.30	-4.74
	C - DR6	-0.73	-0.33	-3.37
	D - DR10	-0.42	-0.26	-2.12
	E - DR12	-0.63	-0.10	-0.31

For the flow at the 90th percentile (Pre-Project), the WSE would be 0.75 to 1.0 m higher than the conditions observed on June 13, 2019 at Sites C and E. However, the Post-Project flows at these sites would be roughly 0.6-0.7 m lower, along with reductions in current velocities and bed shear stress as noted in Table 22. The flow conditions would be similar to the water surface elevation observed on June 13, 2019 when the toe of the riverbank was dry. Therefore, the threat of bank erosion would be substantially reduced compared to the Pre-Project flow conditions.

Regarding the future evolution of the riverbed, the upper reaches are gently sloping along the channel and depths are shallow (Sites A to C). The projected reduction in the flow velocities and bed shear stress may reduce the rate of downcutting on the riverbed, which would also reduce the threat of future bank erosion. For the lower reaches of the river with a steep gradient (Sites D and E), the sonar imaging mapped complex large scale bed features (cobble shoals) and mixed substrate areas near the mouth. The rate these bed features migrate may be reduced in the Post-Project scenario. However, it is not anticipated that this will have any negative impact of the geomorphological evolution of the river. In addition, the reduction in current velocities and bed shear stresses will reduce the downcutting of the riverbed adjacent to the banks and this will further reduce the rate of future recession. Depositional processes are not expected to change significantly, as the change in the flow regime is most pronounced at the percentiles of high flow where the potential for deposition is already low.

4.2 Fairford River

A summary of key results from the hydraulic modeling at the detailed observation sites on the Fairford River is presented in Table 23. There are no changes in the flow system at the flows for the 10th percentile and thus there is no projected changes to the geomorphic response of the river.

Sites F to H on the delta have been stable since the early 1960s and the projected reductions in the WSE, current velocities, and bed shear stress for the flows at the 50th and 90th percentiles would not alter the stability of the riverbanks from a geomorphic perspective in these areas.

For Sites I to K, bank erosion was documented. During the June 11, 2019 field observations, the flows were at approximately the 63rd summer percentile for the Pre-Project condition. The WSE was below the toe of the banks that were eroding. As documented in Table 23, the Post-Project WSE for the flows at the 50th percentile are lower than the Pre-Project condition. It would therefore be lower than the conditions observed during KGS Group's field work when the toe of the bank was dry. Therefore, at Sites I to K, the bank erosion should decrease in the future for the Post-Project flows at the 50th percentile.

At the Pre-Project flows for the 90th percentile, the WSE at Sites I to K would be roughly 1 m higher than the conditions observed on June 11, 2019. The average reduction in the WSE for Sites I to K in the Post-Project scenario is 0.41 m. This would result in water levels roughly 0.6 m higher than observed on June 11, 2019 for the Post-Project flows at the 90th percentile. This would likely result in currents intersecting the toe of the riverbank that is currently eroding. However, the WSE would be 0.41 m lower than the Pre-Project WSE, which would reduce the existing potential for erosion of the riverbank.

TABLE 23: SUMMARY OF RESULTS AT DETAILED OBSERVATION SITES ON THE FAIRFORD RIVER

		Modeled Change Due to Project		
Flow Condition	**Site**	**WSE [m]**	**Velocity [m/s]**	**Shear Stress [Pa]**
10th Percentile	F - FR3	-	-	-
	G - FR6	-	-	-
	H - FR12	-	-	-
	I - FR17			
	J - FR20	-	-	-
	K - FR22			
50th Percentile	F - FR3	-0.15	-0.11	-0.27
	G - FR6	-0.18	-0.07	-0.30
	H - FR12	-0.17	-0.03	-0.01
	I - FR17	-0.20	-0.08	-0.28
	J - FR20	-0.17	-0.11	-0.48
	K - FR22	-0.20	-0.08	-0.38
90th Percentile	F - FR3	-0.46	-0.15	-0.67
	G - FR6	-0.37	-0.12	-0.61
	H - FR12	-0.36	-0.08	-0.33
	I - FR17	-0.40	-0.15	-1.04
	J - FR20	-0.39	-0.22	-1.60
	K - FR22	-0.44	-0.18	-1.35

The bank conditions just downstream of Site J are presented in Figure 56 for June 11, 2019. The riverbank is actively eroding, but under the flows that day the riverbank was not threatened by erosion. At the Post-Project flows for the 50th percentile, the water surface elevation would be even lower than the conditions observed on June 11, 2019. This would indicate that the erosion potential due to the hydraulic conditions in the river would be low. During the Post-Project flows at the 90th percentile, the WSE would be roughly 0.6 m higher than the June 11, 2019 conditions, likely encroaching on the toe of the bank. But the WSE, currents, and bed shear stress would all be lower than under Pre-Project conditions, so there should be a reduction in the potential erosion of the face of the riverbank.

FIGURE 56: ERODING RIVERBANK IN FRONT OF HOME (DOWNSTREAM OF SITE J), JUNE 11, 2019

5.0 CONCLUSIONS

The following conclusions are based on the analyses presented in this report:

- Since the outlet channels would be operated only during flood events, the effect of the Project on the flow regimes of the Dauphin and Fairford Rivers would be a reduction at the high flow percentiles, with smaller effects on the mid flow percentiles, and negligible effect on the low flow percentiles.
- No changes are expected to the geomorphic evolution of the rivers in the future for the flow conditions at the 10th percentile. At the conditions associated with the 50th and 90th percentiles, the reduced water levels, velocities, and shear stresses are expected to result in slower rates of erosion where the existing riverbanks are vulnerable and currently experience erosion. This is considered a potential positive benefit of the Project, as the volume of sediment released into the downstream lakes will be reduced. Depositional processes are not expected to change significantly, as the change in the flow regime would be most pronounced at the high flow percentiles where the potential for deposition is already low. Portions of the riverbanks that have been stable over the last several decades (e.g. Sites F to H in the delta region in Lake Pineimuta) are expected to remain stable in the Post-Project environment.
- Ice processes are not expected to be impacted significantly by the Project on either river. The diverse processes of ice cover formation would still occur in the Post-Project environment as they do in the existing environment (i.e. thermal growth of border and skim ice in low velocity areas, fragmented ice covers in high velocity areas). The reduction in flows at the high percentiles in both rivers will reduce the severity of ice jams and reduce the likelihood of flooding due to ice jam formations (e.g. flooding of PR 513 along the Dauphin River that has occurred in recent years). This is considered a potential net benefit of the Project.

6.0 REFERENCES

- JD Mollard and Associates, 2019. Lake Manitoba Outlet Channel Shoreline Morphology Review – Final Report. November 2019.
- Lake Manitoba Lake St. Martin Regulation Review Committee (LM&LSMRRC), 2013. Finding the Right Balance: A Report to the Minister of Infrastructure and Transportation. Volume 1: Main Report. January 2013.
- Lake Manitoba Regulation Review Advisory Committee (LMRRC), 2003. Regulation of Water Levels on Lake Manitoba and Along the Fairford River, Pineimuta Lake, Lake St. Martin and Dauphin River and Related Issues. A Report to the Manitoba Minister of Conservation Volume 2: Main Report. July 2003.
- KGS Group, 2016. Assiniboine River and Lake Manitoba Basins – Flood Mitigation Study LMB & LSM Outlet Channels Conceptual Design – Stage 2. KGS Group Project 12-0300-011. Final Report. January 2016.
- Manitoba Hydro, 2019. Impacts of Lake Manitoba and Lake St. Martin Outlet Channels Project on Downstream Water Levels. May 2019.
- Zuzek Inc., 2020a. Lake St. Martin Outlet Channel Baseline Shoreline Assessment. Prepared for KGS Group.
- Zuzek Inc., 2020b. Lake St. Martin Outlet Channel Post-Project Shoreline Morphology Assessment. Prepared for KGS Group.

APPENDIX A

Photo Logs

Photo Location DR0: Mouth of Dauphin River

Photo Location DR1: Right (east) bank across from power line crossing about 1.5 km from outlet, looking downstream

Photo Location DR2: Right (east) bank approximately 2.1 km from lake. View looking upstream.

Photo Location DR3: Left (west) bank approximately 2.5 km from lake. View looking upstream.

Photo Location DR4: Left bank looking downstream, across from Buffalo Creek outlet. Approximately 3.7 km from Lake Winnipeg.

Photo Location DR4: Left bank looking upstream, across from Buffalo Creek outlet. Approximately 3.7 km from Lake Winnipeg.

Photo Location DR5: Left bank looking downstream, approximately 8.7 km from Lake Winnipeg.

Photo Location DR5: Left bank looking downstream, approximately 8.7 km from Lake Winnipeg.

Photo Location DR6: Left bank looking downstream, approximately 13.0 km from Lake Winnipeg.

Photo Location DR6: Left bank looking upstream, approximately 13.0 km from Lake Winnipeg.

Photo Location DR7: Left bank looking downstream, approximately 16.5 km from Lake Winnipeg.

Photo Location DR7: Left bank looking upstream, approximately 16.5 km from Lake Winnipeg.

Photo Location DR8: Left bank looking downstream, approximately 23.2 km from Lake Winnipeg.

Photo Location DR8: Left bank looking upstream, approximately 23.2 km from Lake Winnipeg.

Photo Location DR9: Aerial image of Big Bend looking upstream. Approximately 25.0 km from Lake Winnipeg.

Photo Location DR9: Aerial image of Big Bend looking downstream (near WSC gauge). Approximately 25.0 km from Lake Winnipeg.

Photo Location DR10: looking downstream

Photo Location DR10: looking upstream

Photo Location DR10-11: Aerial image approximately 35.3 km upstream of Lake Winnipeg, looking downstream.

Photo Location DR10-11: Aerial image approximately 35.3 km upstream of Lake Winnipeg, looking upstream.

Photo Location DR12: looking downstream

Photo Location DR12: looking upstream

Photo Location FR1

Photo Location FR2

Photo Location FR3

Photo Location FR4

Photo Location FR5

Photo Location FR6

Photo Location FR7

Photo Location FR8

Photo Location FR9

Photo Location FR10

Photo Location FR11

Photo Location FR12

Photo Location FR13

Photo Location FR14

Photo Location FR15

Photo Location FR16

Photo Location FR17

Photo Location FR18

Photo Location FR19

Photo Location FR20

Photo Location FR21

Photo Location FR22

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