MANITOBA INFRASTRUCTURE

Lake Manitoba and Lake St. Martin Outlet Channels
Analysis of Physical Impacts to Lakes within the Hydraulic System

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Limitations

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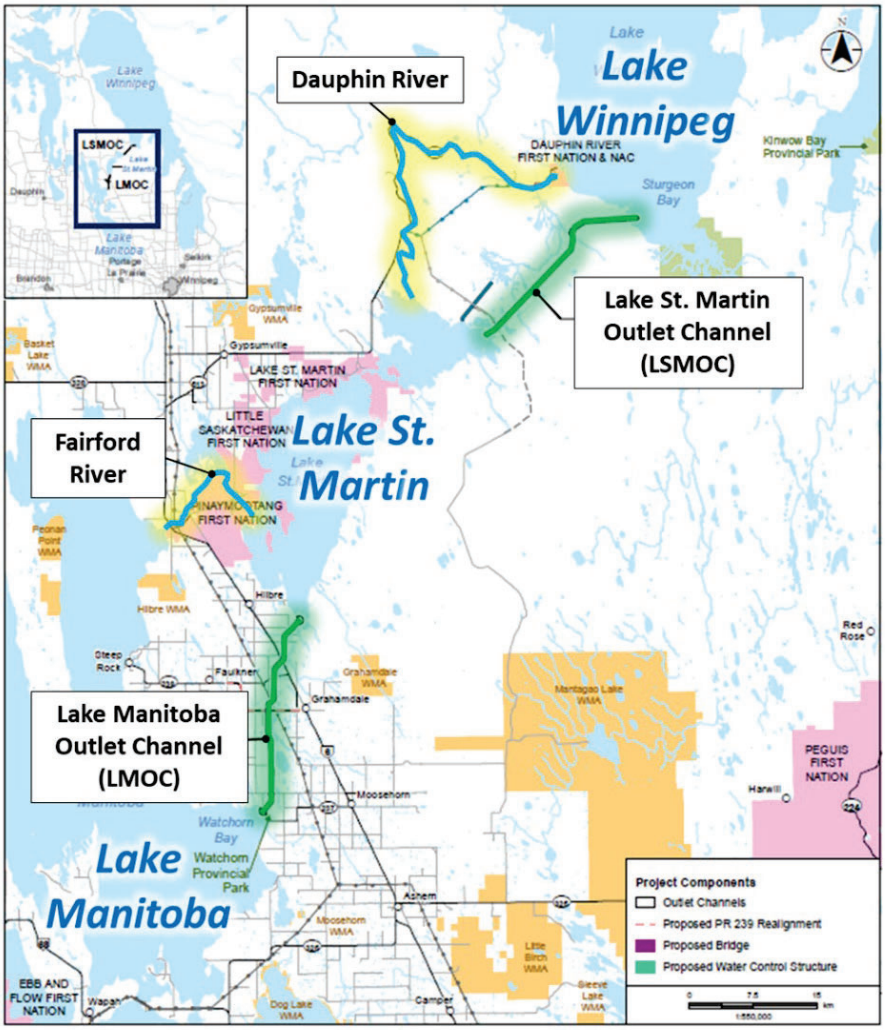
1.0 INTRODUCTION

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. The Project will provide additional pathways to convey water from Lake Manitoba (LM) to Lake St. Martin (LSM), and from LSM to Lake Winnipeg. Outflows from LM and LSM are currently conveyed solely by the Fairford River and Dauphin River, respectively. The LMOC runs from Watchorn Bay in LM to Birch Bay in LSM, while the LSMOC conveys water from the north basin of LSM to a location south of Willow Point in Sturgeon Bay. A map of the Project is shown in Figure 1.

FIGURE 1: MAP OF PROJECT AREA



The outlet channels will effectively reduce the frequency of high water levels in LM and LSM. They will also provide additional flexibility in the system to regulate the lake levels within the desired target ranges.

Operation of the LSMOC and LMOC will alter the local flow patterns in the lakes in the vicinity of the channel inlets and outlets. This could potentially influence lake morphology and ice processes.

1.2 Objective and Structure of Report

The objective of this study is to evaluate the impacts of the Project on flow patterns, and physical processes pertaining thereto, in LM, LSM, and Lake Winnipeg. The variation in flows and water levels in the lakes 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. The “Post-Project” environment refers to the flow system with the addition of the LMOC and LSMOC. The purpose of the level of assessment documented in this report was to analyze the effects of the Project on a system-scale, and to assist in identifying potential areas of further study. Effects on specific regions of the lakes and/or shorelines would require a more refined and targeted modeling approach.

Changes to lake water levels and broad-scale flow patterns at the 10th, 50th, and 90th percentiles were quantified via numerical modeling. Potential impacts on lake shoreline morphology and on ice processes are discussed qualitatively. Travel times of water moving along the primary flow paths through LM and LSM were also estimated for the Pre- and Post-Project scenarios. While the work was ongoing, the LSM Narrows was identified as a key area of concern to stakeholders. A scope item was added to assess the impacts of the Project on water velocities and erosion potential through the Narrows. This was achieved by leveraging the hydrodynamic model results from completed simulations.

Shoreline geomorphological studies in the vicinities of the inlets and outlets of the LMOC and LSMOC were undertaken as part of the engineering design for the outlet channels. They are documented in separate reports (Zuzek Inc., 2020, 2021; JDMA, 2019). The study described herein supplements those studies. It considers the broader scale flow patterns in the lakes and the associated potential effects on shoreline morphology. A separate study, conducted in parallel with this study, addresses impacts of the Project on flows and hydraulics within the Fairford River and Dauphin River (KGS Group, 2021).

Percentiles of water levels for LM and LSM in the Pre-Project and Post-Project environments are presented in Section 2.0. Two-dimensional modeling of the flow patterns in each lake at the 10th, 50th, and 90th percentile conditions are included in Section 3.0. In Section 4.0, results of the numerical model are analyzed and a qualitative assessment of potential changes to shoreline morphological processes and ice processes is presented. Sophisticated sediment transport modeling and ice modeling were not included in the scope of this study. The potential impacts of the Project on lake morphology and ice processes are inferred primarily from the results of the hydrodynamic model (i.e. velocity vectors and water levels). Major conclusions of the study and recommended future work are summarized in Section 5.0.

2.0 EFFECTS OF THE PROJECT ON LAKE WATER LEVELS

Manitoba Infrastructure (MI) developed an Excel-based water balance model to compute historical 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 is described in a memorandum titled “Lake Manitoba and Lake St. Martin Outlet Channels Impacts on Lake Manitoba and Lake St. Martin” (MI, 2019). The model has gone through several iterations as the designs of the LMOC and LSMOC have advanced, and to evaluate the effects of various operating strategies and assumptions (e.g. winter flow restrictions, type of water control structure, and frequency of gate adjustments).

Recent revisions to the Excel model take into consideration the impact of the Narrows on water levels in the south and north basins of LSM. 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 revisions are 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 adopted in the water balance model (as of November 2020) that forms the basis of the analysis is presented as follows:

- Revised stage-discharge curves for the LSMOC and LMOC reflecting the advanced designs of the outlet channels. The LSMOC Water Control Structure (WCS) is a 4-bay structure and the stage-discharge 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 LSM.
- 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.
- Maximum flow restrictions in winter of 90 m^3/s for the LMOC and 150 m^3/s for the LSMOC are imposed.
- Ice-affected stage-discharge relationships 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 is required during periods of non-operation, with a provision to reduce or eliminate the riparian flow during periods of drought to maximize flows in the Dauphin River.
- Representation of LSM as two separate basins, with differential water levels between the two caused by head loss through the Narrows.

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

The daily water levels were processed to create duration curves for each lake. A duration curve is a cumulative frequency curve that shows the percent of time that lake levels were less than or equal to a specified elevation over the simulation period. Water levels corresponding to different percentiles, as described in the following paragraphs, were used as inputs to the numerical models presented in Section 3.0.

The duration curves of water levels in LM and the south and north basins of LSM are shown in Figure 2, Figure 3, and Figure 4, respectively. The 10th, 50th, and 90th percentile levels are tabulated in Table 1, Table 2, and Table 3. 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). As shown, the Project generally reduces the frequency of high water levels, with a small effect on the frequency of low lake levels. The water levels on the south basin of LSM are more affected by the Project than the levels on LM. For example, the water level at the 90th percentile in the Post-Project environment is reduced by approximately 0.37 m in LSM, while the water level at the 90th percentile in LM is only reduced by 0.08 m.

FIGURE 2: DURATION CURVE OF WATER LEVELS IN LAKE MANITOBA

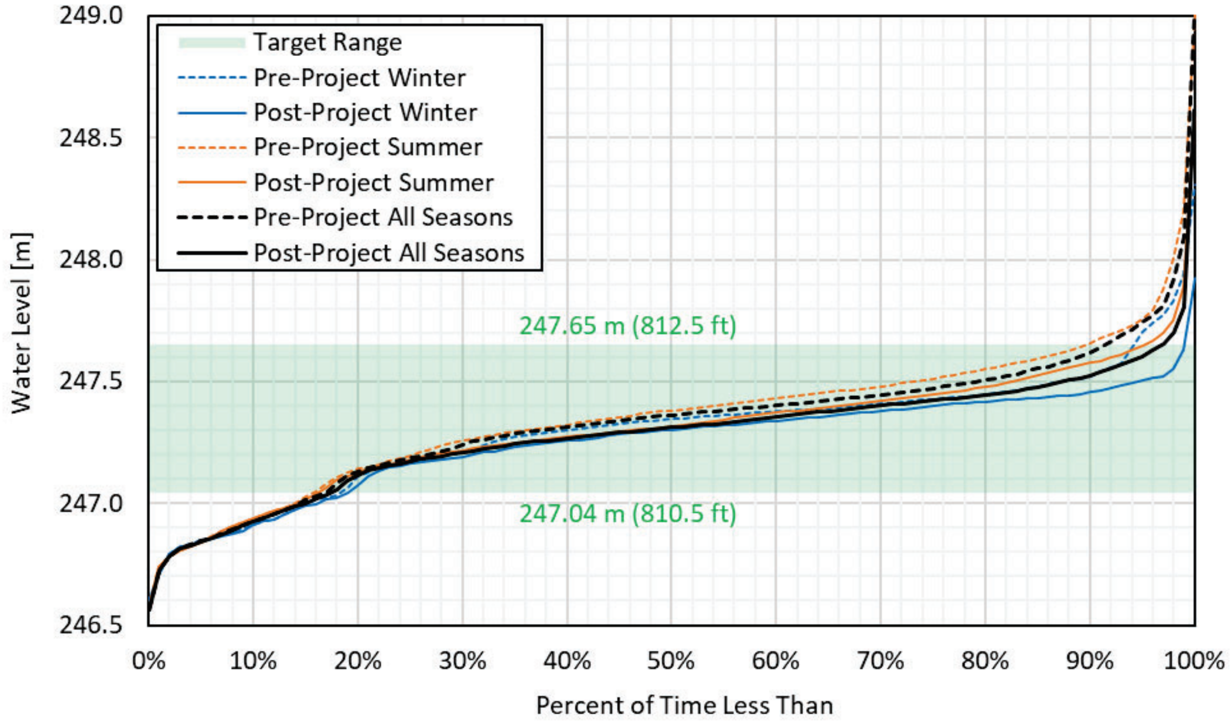


TABLE 1: WATER LEVELS IN LAKE MANITOBA

	Water Level in LM [m]								
	All Seasons			Summer (Open Water)			Winter (Ice Covered)		
Percentile	10th	50th	90th	10th	50th	90th	10th	50th	90th
Pre-Project	246.93	247.36	247.62	246.94	247.38	247.66	246.91	247.35	247.52
Post-Project	246.93	247.31	247.52	246.94	247.32	247.58	246.91	247.30	247.46
Change	-	-0.05	-0.10	-	-0.06	-0.08	-	-0.05	-0.06

FIGURE 3: DURATION CURVE OF WATER LEVELS IN SOUTH BASIN OF LAKE ST. MARTIN

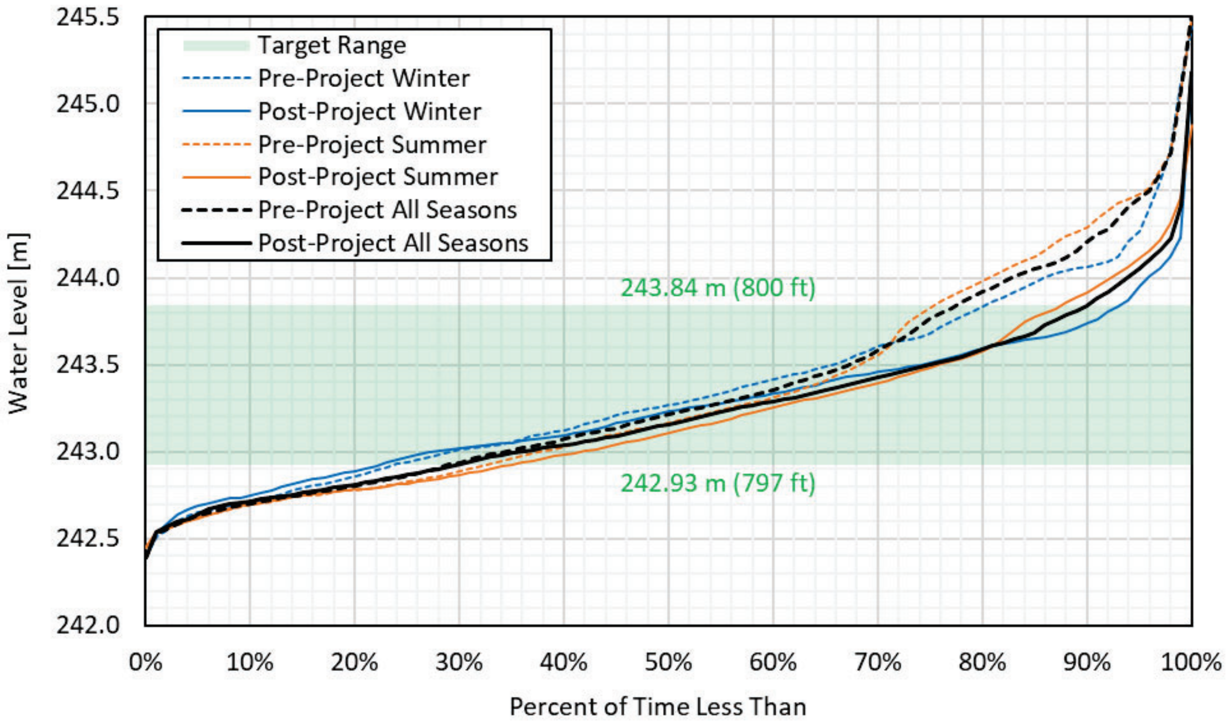


TABLE 2: WATER LEVELS IN SOUTH BASIN OF LAKE ST. MARTIN

Water Level in the South Basin of LSM [m]									
	All Seasons			Summer (Open Water)			Winter (Ice Covered)		
Percentile	10th	50th	90th	10th	50th	90th	10th	50th	90th
Pre-Project	242.70	243.21	244.21	242.69	243.17	244.29	242.71	243.27	244.06
Post-Project	242.72	243.16	243.84	242.70	243.11	243.92	242.74	243.23	243.74
Change	+0.02	-0.05	-0.37	+0.01	-0.06	-0.37	+0.03	-0.04	-0.32

FIGURE 4: DURATION CURVE OF WATER LEVELS IN NORTH BASIN OF LAKE ST. MARTIN

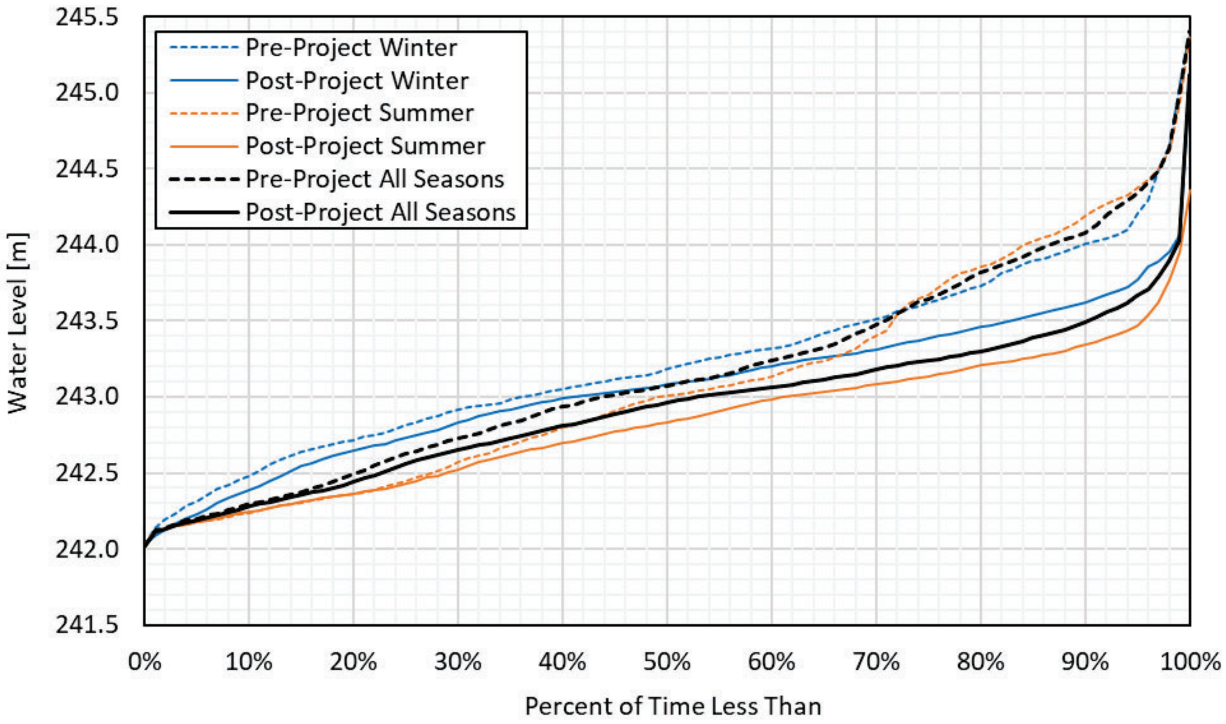


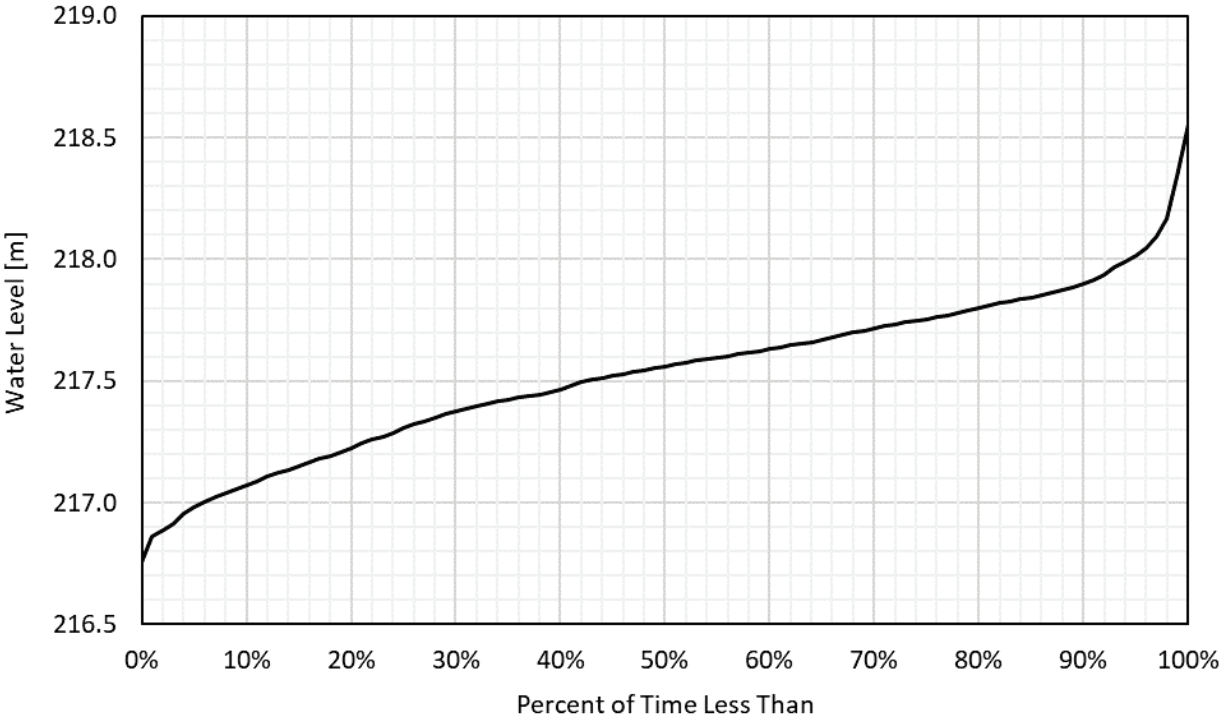
TABLE 3: WATER LEVELS IN NORTH BASIN OF LAKE ST. MARTIN

Water Level in North Basin of LSM [m]									
	All Seasons			Summer (Open Water)			Winter (Ice Covered)		
Percentile	10th	50th	90th	10th	50th	90th	10th	50th	90th
Pre-Project	242.30	243.07	244.08	242.24	243.01	244.19	242.48	243.18	244.01
Post-Project	242.28	242.96	243.49	242.24	242.83	243.34	242.39	243.08	243.62
Change	-0.02	-0.11	-0.59	-	-0.18	-0.85	-0.09	-0.10	-0.39

MI's flood routing model does not include Lake Winnipeg. A study conducted by Manitoba Hydro (2019) found that minor increases (0.07 m) in Lake Winnipeg water levels during peak flows from the outlet channels are possible if no alteration to their existing management protocols for outflows are implemented. However, Manitoba Hydro also acknowledged that they may alter the operation of outflows during flood events when the outlet channels are in operation. Consequently, the computed change in peak water levels of 0.07 m is likely overestimated. Manitoba Hydro therefore concluded that the outlet channels will not have a discernable impact on water levels in Lake Winnipeg within the context of the variabilities in the existing system (see Appendix 6I in the Project Environmental Impact Statement).

Figure 5 shows a duration curve of average water levels recorded in the north basin of Lake Winnipeg after the 1976 regulation rules came into effect. The water levels at the 10th, 50th, and 90th percentiles on Lake Winnipeg are 217.09 m, 217.58 m, and 217.93 m, respectively.

FIGURE 5: DURATION CURVE OF AVERAGE WATER LEVELS IN NORTH BASIN OF LAKE WINNIPEG



3.0 EFFECTS OF PROJECT ON LAKE FLOW PATTERNS

3.1 Development of Numerical Model

3.1.1 SELECTION OF SOFTWARE

MIKE 21, a commercially available software developed and marketed by the Danish Hydraulic Institute (DHI), was adopted to develop the two-dimensional models of Lake Winnipeg, LSM, and LM. MIKE 21 is a numerical model for the two-dimensional simulation of free surface flows. It solves the depth-averaged 2D Navier-Stokes equations using a cell-centered finite volume solution technique to simulate water level variations and flow patterns. The models were run without any wind forces for simplicity. Flow patterns at the LSMOC outlet under the influence of wind effects are included in Zuzek Inc. (2020, 2021).

3.1.2 MESH DESIGN

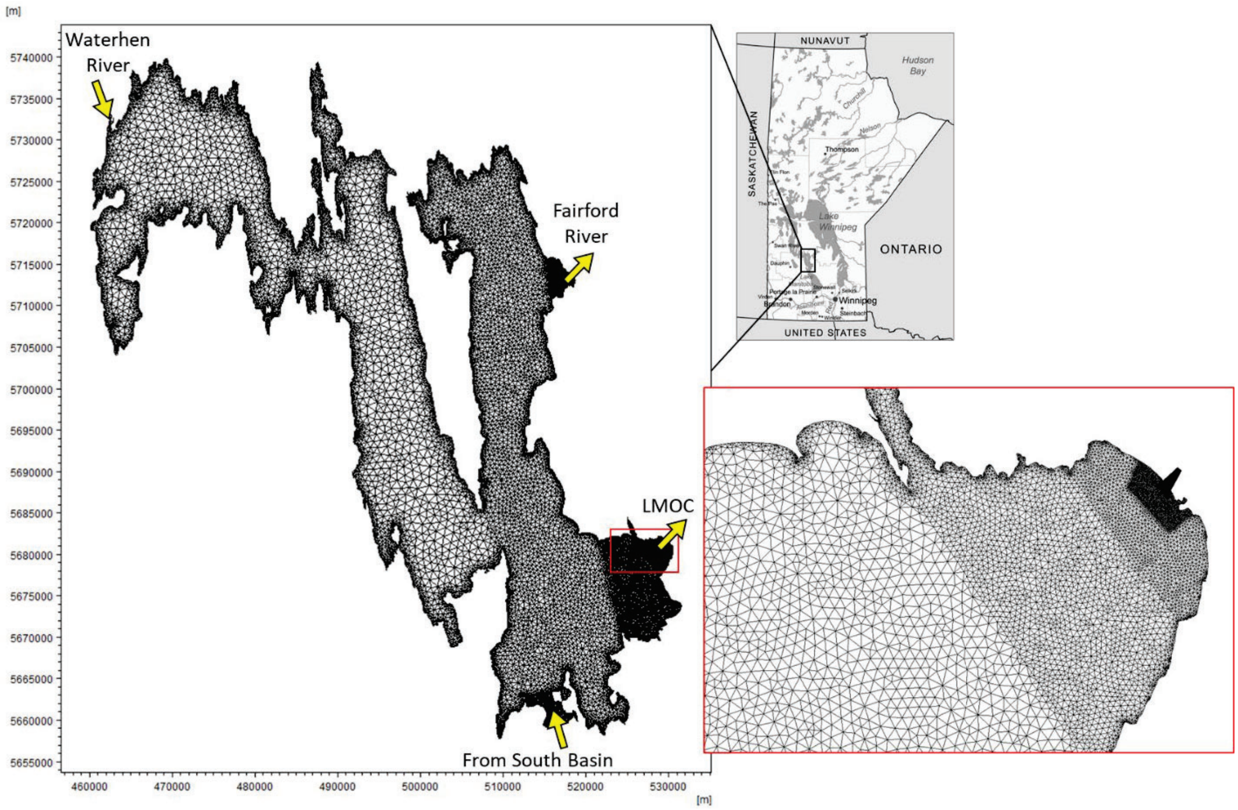
The MIKE 21 software supports two types of mesh cells, triangular mesh (three sided) or quadrangular mesh (four sided). For this study, only triangular mesh elements were used in order to best represent the geometry of the lakes. It would be less computationally intensive to use quadrangular elements, but triangular elements were more desirable for the lake models. They conform well to the lake shore boundaries and features such as expansions and contractions, sand bars, and high points in the lake bed. In addition, quadrangular elements were less desirable as their main benefits are realized in areas with a predominant flow direction, or for modeling linear structures such as roads or dikes. The lake models are subject to changing flow directions and have natural non-linear shore boundaries.

The mesh for each lake model was designed such that the resolution throughout the model domain was variable. A high mesh resolution was assigned to areas of interest, including model inflow and outflow locations, areas of notable change in lake bed elevation, and any flow constrictions. Mesh resolution was decreased as distance from regions of interest increased, in order to reduce computational time.

3.1.3 LAKE MANITOBA MODEL

The domain for the LM model was limited to the north basin of the lake for computational efficiency. A fine mesh resolution was applied on the east side of the north basin, with very fine resolution near the inlet to the LMOC. The numerical model of LM consists of a mesh with approximately 100,000 elements, as shown in Figure 6.

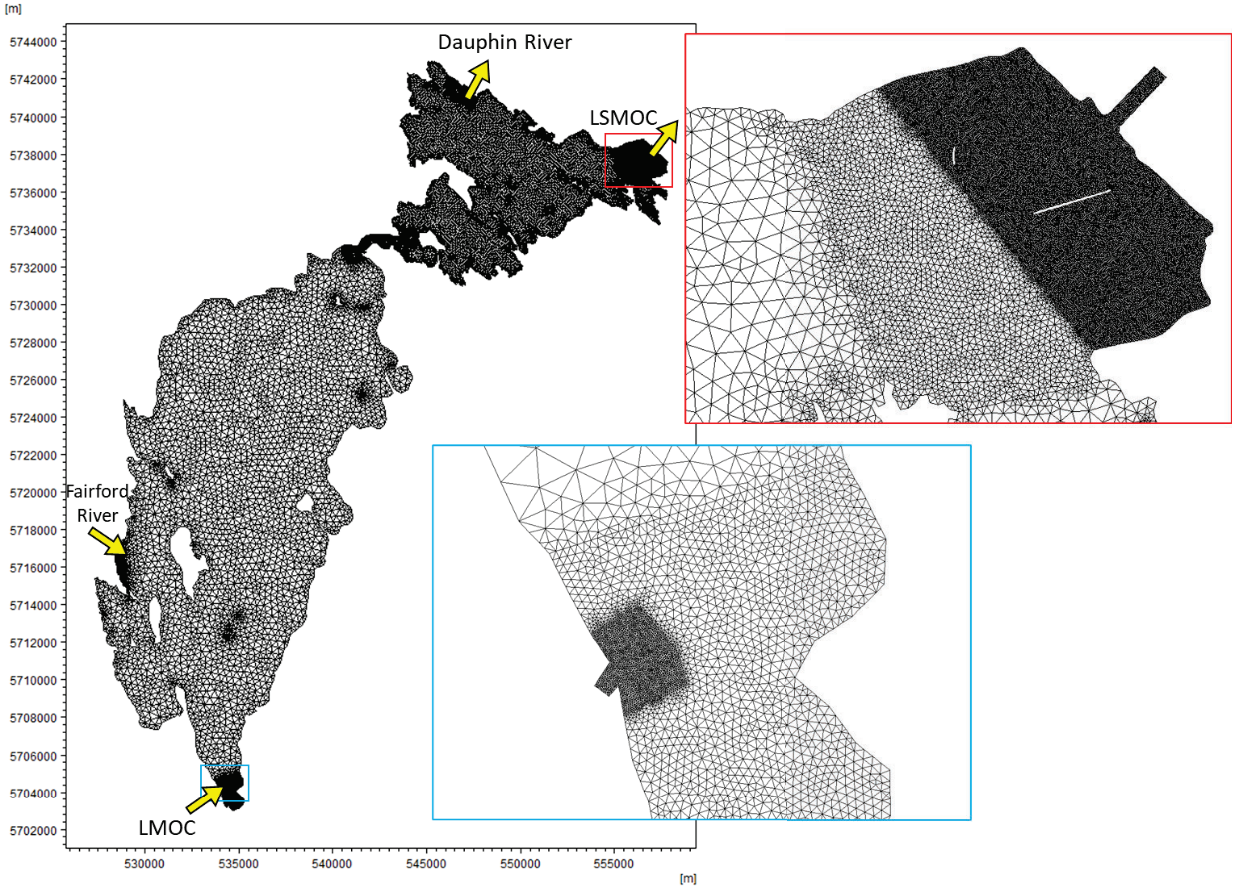
FIGURE 6: MODEL MESH FOR LAKE MANITOBA



3.1.4 LAKE ST. MARTIN MODEL

The domain for the LSM model includes the full area of the lake. The mesh resolution in the south basin is coarser than in the north basin. Areas of very fine mesh resolution were applied near the Fairford River outlet, Dauphin River inlet, LSMOC inlet, and in the narrow constriction between the basins. The LSM mesh consists of approximately 70,000 elements, shown in Figure 7. Additional details of the setup for the LSM model, including calibration of head losses, are provided in the Lake St. Martin Head Loss Analysis Report (KGS Group, 2021).

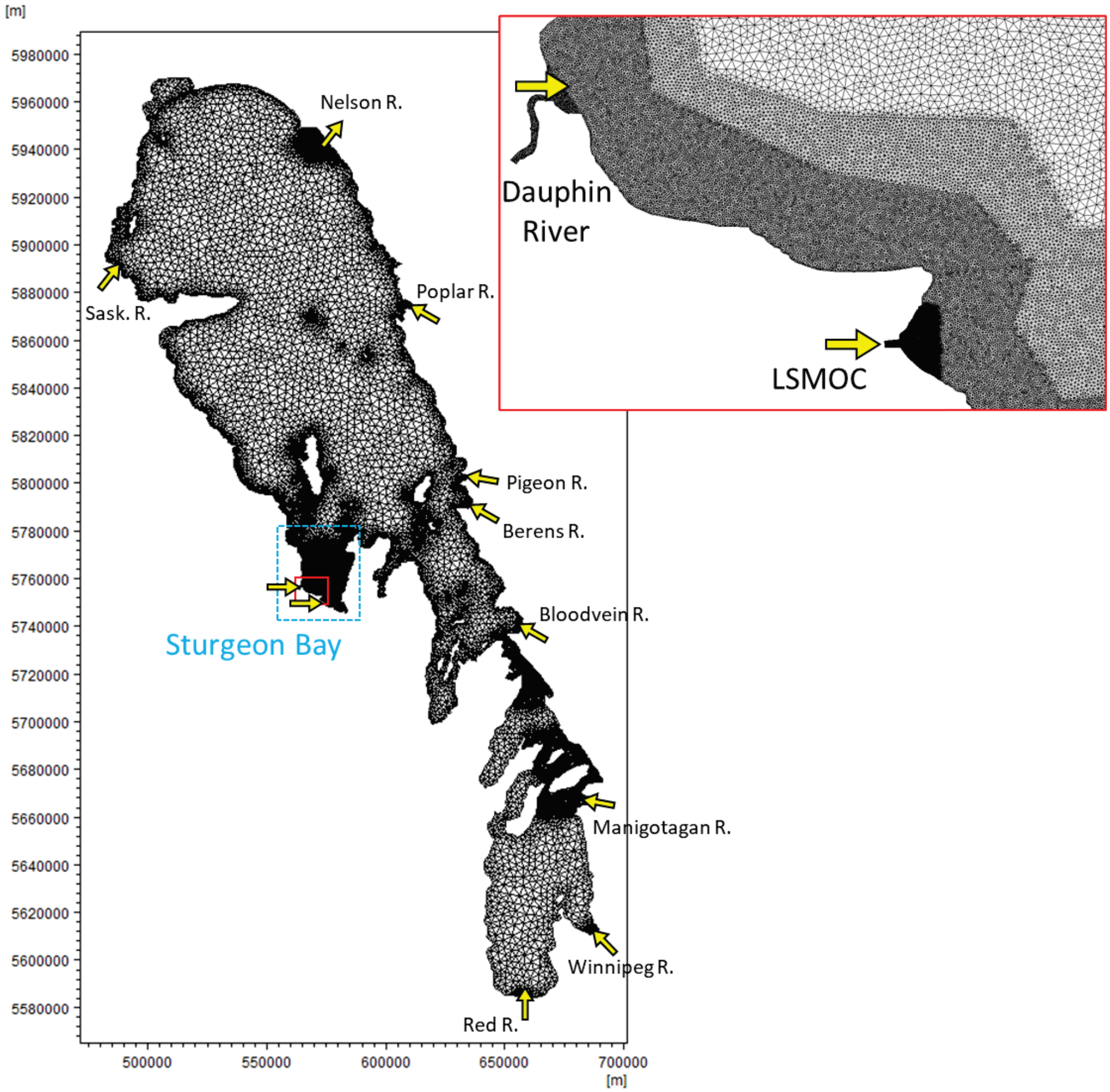
FIGURE 7: MODEL MESH FOR LAKE ST. MARTIN



3.1.5 LAKE WINNIPEG MODEL

The model of Lake Winnipeg was previously developed as part of the Baseline Shoreline Morphology Assessment for the Preliminary Design of the LSMOC. The model domain includes the full area of Lake Winnipeg. The mesh resolution was optimized to achieve a high level of model accuracy while minimizing computational time. The final model mesh has a high resolution in Sturgeon Bay and in the Lake Winnipeg Narrows, with reduced resolution in the interior portions of the lake. The final Lake Winnipeg mesh consists of 125,000 elements, as shown in Figure 8.

FIGURE 8: MODEL MESH FOR LAKE WINNIPEG



3.2 Simulation Setup

Each lake model was run to simulate steady state conditions representative of the 10th, 50th, and 90th percentiles in the Pre- and Post-Project environments. Judgement was applied in selecting the flow and water level conditions for the various model runs, as percentiles calculated for flows and water levels do not necessarily coincide. The following subsections summarize the boundary conditions applied to each lake model.

3.2.1 LAKE MANITOBA MODEL

Boundary conditions for the LM model were selected based on the analysis of flows and water levels simulated by MI's flood routing model. A water level boundary condition was specified at the outlet to the Fairford River and was set equal to the target water level on LM (i.e. the water level at the 10th, 50th or 90th percentile). Outflows from the Fairford River and LMOC were set equal to their respective flow at the 10th, 50th, or 90th percentile, while the inflow to the north basin of LM was set equal to the sum of the Fairford River and LMOC outflows to achieve steady state conditions. The resulting flow conditions for the LM scenarios are summarized in Table 4.

TABLE 4: FLOW AND WATER LEVEL CONDITIONS FOR LAKE MANITOBA MODEL

	10th Percentile		50th Percentile		90th Percentile	
	Pre	Post	Pre	Post	Pre	Post
Fairford River Flow [m^3/s]	14.0	14.0	55.0	41.4	217.1	123.2
LMOC Flow [m^3/s]	0	0	0	0	0	157.6
Inflow [m^3/s]	14.0	14.0	55.0	41.4	217.1	280.8
Lake Manitoba Level [m]	246.93	246.93	247.36	247.31	247.62	247.52

3.2.2 LAKE ST. MARTIN MODEL

The results of MI's flood routing model (duration curves) were used to select the boundary conditions for the LSM simulations. The inflows, outflows, and water levels in LSM are interrelated. However, the percentiles calculated for flows and water levels do not necessarily coincide. Therefore, judgement was applied to develop scenarios representative of the 10th, 50th, and 90th percentile events in LSM.

Boundary conditions consisting of flow and water level were set up to allow the water level in the south basin of the lake to match the open water levels corresponding to the 10th, 50th, and 90th percentiles. This also considered the head loss through the Narrows. The run setups are summarized in Table 5. For the Post-Project runs at the 10th and 50th percentiles, the inflow from the Fairford River was set to equal the total outflow from the Dauphin River and riparian flow through the LSMOC. For the Post-Project run at the 90th percentile, the LSMOC was assumed to be operating at a partial gate setting. This allowed the water levels in the south and north basins to match their respective 90th percentiles. For this run it was assumed that the LMOC discharge was equal to the LMOC discharge (167.2 m^3/s) at the 90th percentile. The Fairford River flow contributed the difference (153.8 m^3/s) to ensure that total inflow was equal to total outflow.

TABLE 5: FLOW AND WATER LEVEL CONDITIONS FOR LAKE ST. MARTIN MODEL

	10th Percentile		50th Percentile		90th Percentile	
	Pre	Post	Pre	Post	Pre	Post
Fairford River Flow [m^3/s]	16.7	18.1	68.3	61.9	236.0	153.8
LMOC Flow [m^3/s]	0	0	0	0	0	167.2
Dauphin River Flow [m^3/s]	16.7	16.7	68.3	60.5	236.0	111.0
LSMOC [m^3/s]	0	1.4	0	1.4	0	210.0
Lake St. Martin South Basin Water Level [m]	242.69	242.70	243.17	243.11	244.29	243.92
Lake St. Martin North Basin Water Level [m]	242.25	242.25	242.96	242.88	244.19	243.34

3.2.3 LAKE WINNIPEG MODEL

The flow and water level conditions applied to the Lake Winnipeg model runs are shown in Table 6. The inflows from the Dauphin River and LSMOC were prescribed as the flow percentiles calculated directly from the flood routing model results (considering all seasons). The water levels in Lake Winnipeg (initial conditions) represent the recorded average north basin lake levels, post-1976 regulation (as shown in Figure 5).

Inflows from eight other rivers to Lake Winnipeg were also included in the model, including the Winnipeg, Saskatchewan, Red, Pigeon, Bloodvein, Berens, Poplar, and Manigotagan Rivers. The Nelson River is the only major outflow from Lake Winnipeg. The flow boundary conditions were set up such that total inflow and outflows were equal. A water level boundary condition was applied at the Nelson River outlet, equal to the Lake Winnipeg water level noted in Table 6.

TABLE 6: FLOW AND WATER LEVEL CONDITIONS FOR LAKE WINNIPEG MODEL

	10th Percentile		50th Percentile		90th Percentile	
	Pre	Post	Pre	Post	Pre	Post
Dauphin River Flow [m^3/s]	10.1	9.5	55.9	45.3	202.6	100.9
LSMOC Flow [m^3/s]	0	1.4	0	1.4	0	118.9
Lake Winnipeg Level [m]	217.09	217.09	217.58	217.58	217.93	217.93

3.3 Simulated Velocities and Flow Patterns

This section includes results of the two-dimensional modeling of each lake. Flow patterns are illustrated as contours and directional vectors of depth-averaged velocity. They are compared in the Pre-Project and Post-Project conditions at the 10th, 50th, and 90th percentiles. This information is used subsequently in Section 4.0 to qualitatively assess potential impacts of the Project on shoreline morphology and on ice processes within the lakes. Project effects on water velocity through the LSM Narrows and potential implications on erosion are presented in Sections 3.4 and 4.0.

3.3.1 LAKE MANITOBA

Simulated water velocities and flow patterns in the north basin of LM for the flow conditions at the 10th, 50th, and 90th percentiles are shown in Figure 9, Figure 10, and Figure 11, respectively. At the conditions for the 10th and 50th percentiles (Figure 9 and Figure 10), there are no discernible changes between the Pre- and Post-Project scenarios. For these runs it was assumed that all inflow to LM would come from the Waterhen River.

At the 90th percentile condition (Figure 11), operation of the LMOC has some effect on the flow patterns within the north basin of LM. Inflow from the Waterhen River was set equal to its 90th percentile (189 m^3/s), as computed from historical flows recorded at Water Survey of Canada Station 05LH005. The rest of the inflow was input from the south basin such that the total inflow matched the total outflow from the Fairford River and LMOC.

Velocity patterns from the Waterhen River to the location marked “LMB1” remain nearly identical between the Pre- and Post-Project scenarios, with some small increases in velocity at the constriction points due to the increased outflow capacity of the lake afforded by the LMOC. Velocities at the LM Narrows (LMB2) are also slightly greater in the Post-Project environment. In the Post-Project scenario, flow coming from the west portion of the lake (i.e. from the Waterhen River) splits at LMB1, with portions directed north to the Fairford River, and south to the LMOC. In the immediate vicinity of the LMOC inlet, velocities in the Post-Project scenario reflect the operation of the LMOC, with aligned vectors and greater flow speeds. The same area is comparatively stagnant in the Pre-Project environment, with negligible water velocities. Velocity patterns at location LMB3 and near the inlet to the Fairford River are also similar between the Pre- and Post-Project scenarios, with differences only due to the difference in flows discharged by the Fairford River.

FIGURE 9: LAKE MANITOBA FLOW PATTERNS – 10TH PERCENTILE CONDITION

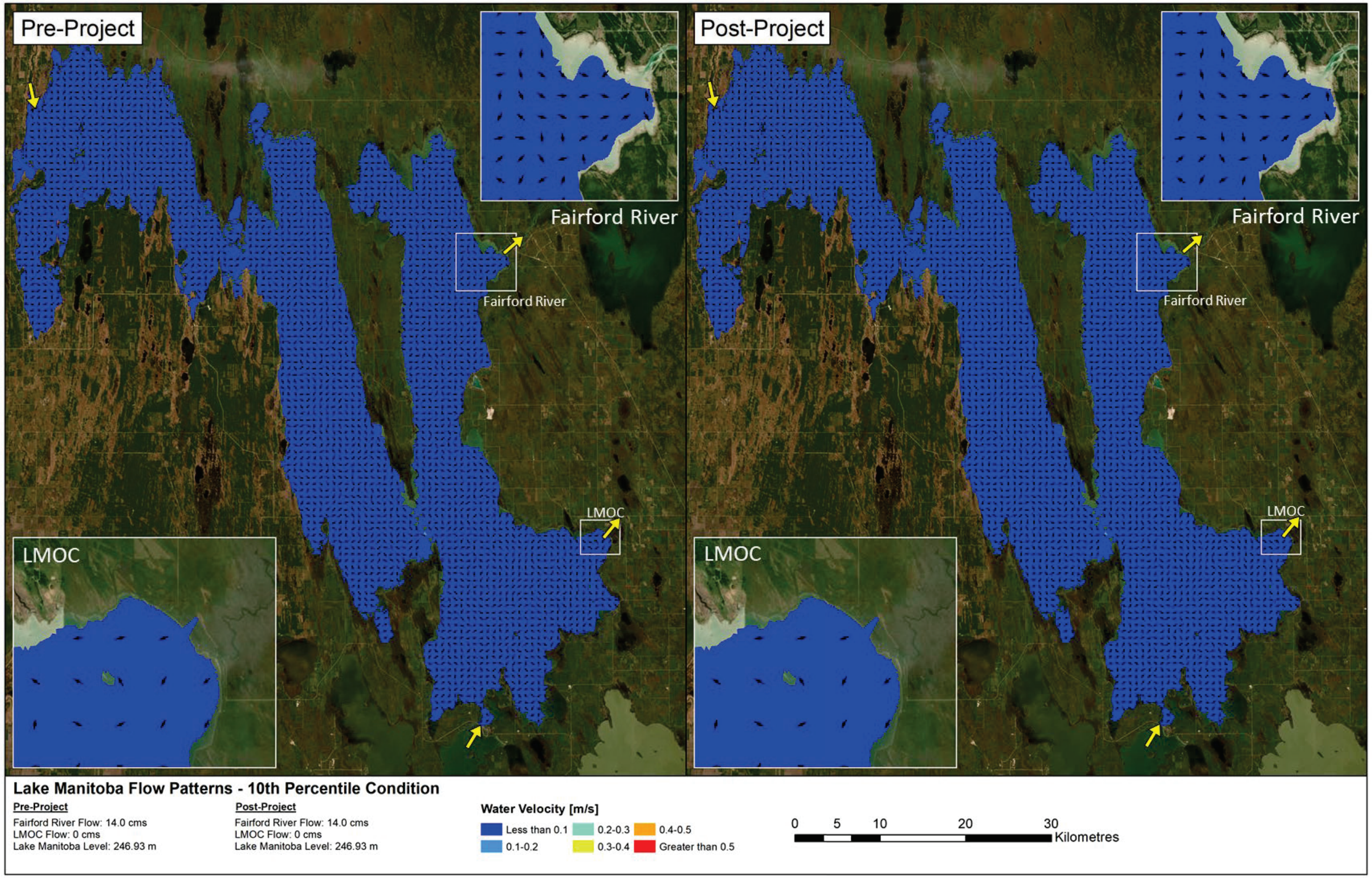


FIGURE 10: LAKE MANITOBA FLOW PATTERNS – 50TH PERCENTILE CONDITION

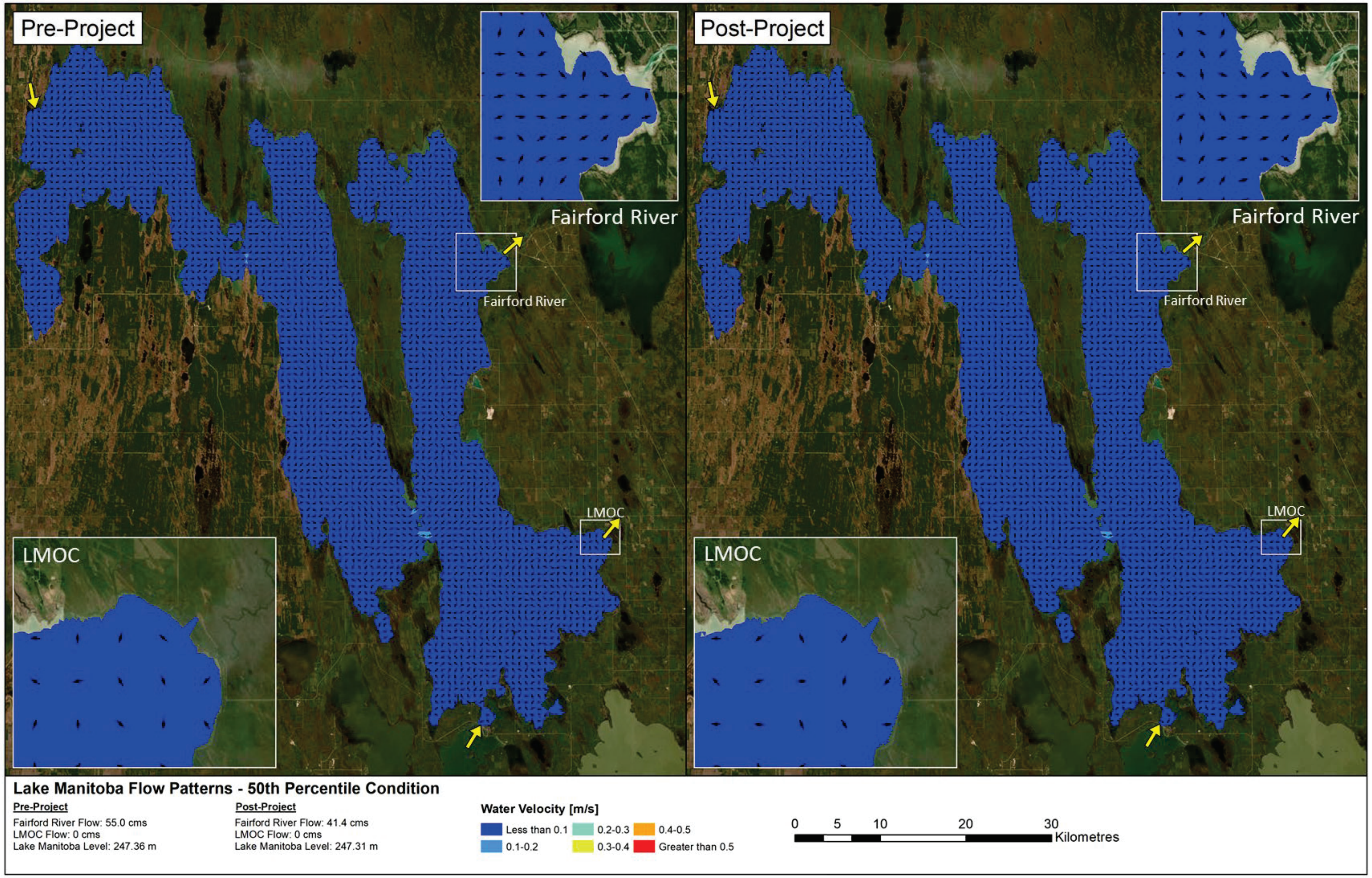
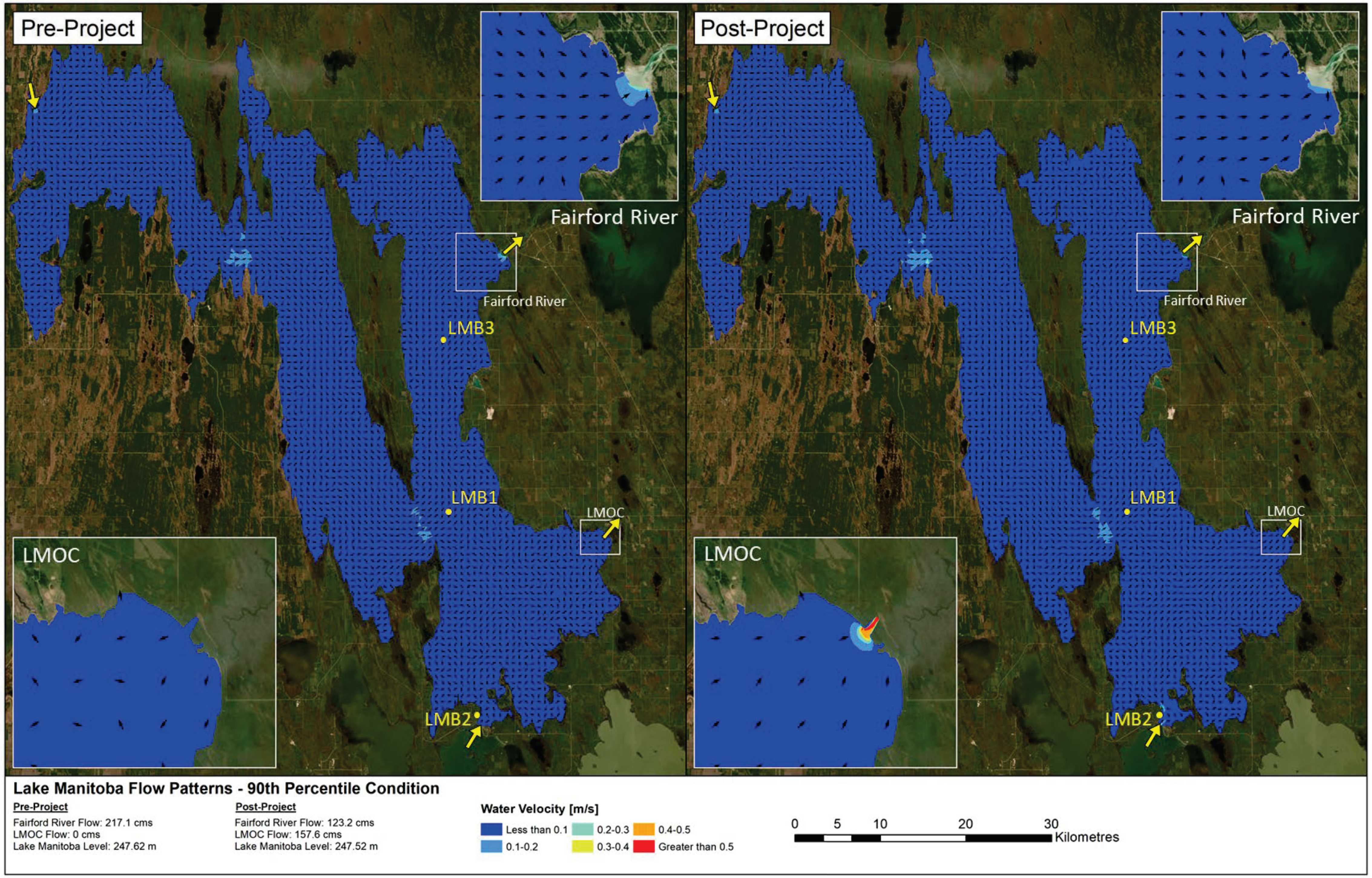


FIGURE 11: LAKE MANITOBA FLOW PATTERNS – 90TH PERCENTILE CONDITION



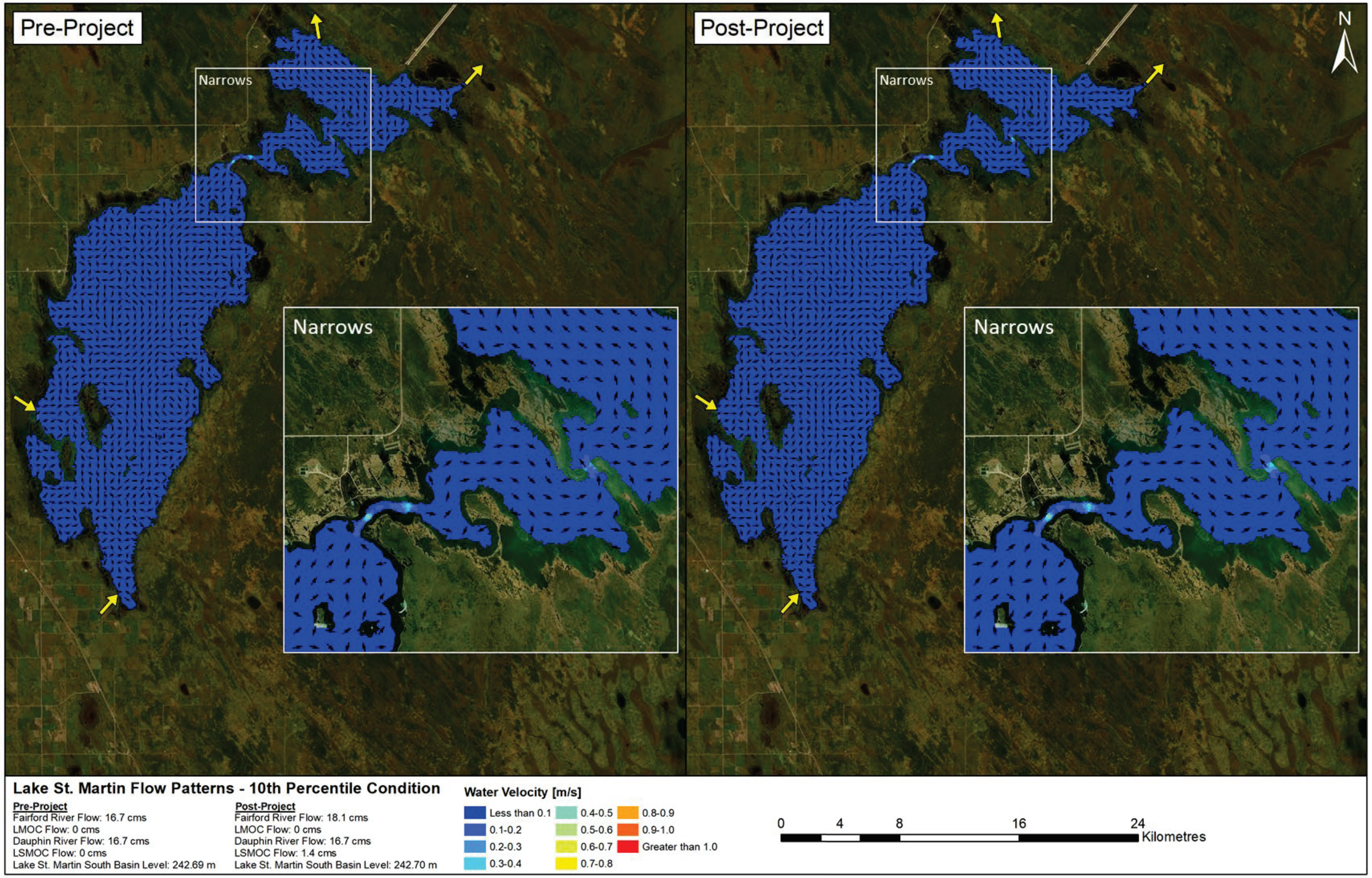
3.3.2 LAKE ST. MARTIN

Simulated water velocities and flow patterns in LSM for the flow conditions at the 10th, 50th, and 90th percentiles are shown in Figure 12, Figure 13, and Figure 14, respectively.

At the 10th and 50th percentile conditions (Figure 12 and Figure 13), the inflows and outflows are very similar between the Pre- and Post-Project scenarios. The changes in flow patterns and velocities in the lake are negligible.

At the 90th percentile condition (Figure 14), the introduction of flow from the LMOC results in a change in the flow patterns in the southern portion of the lake. The velocity vectors are more aligned in the Post-Project environment (LSM1) in this area. In the middle of the south basin (LSM2), the flow pattern is similar in the Pre- and Post-Project scenarios, with the water primarily flowing in the northeast direction toward the Narrows. The velocity through the LSM Narrows (LSM3) is higher in the Post-Project simulation due to the higher flow through the lake. In the north basin (LSM4), the flow pattern in the Pre-Project scenario is fully directed northwest to the Dauphin River, while in the Post-Project scenario a portion of the flow is directed east to the LSMOC.

FIGURE 12: LAKE ST. MARTIN FLOW PATTERNS – 10TH PERCENTILE CONDITION



Pre-Project
Fairford River Flow: 16.7 cms
LMOC Flow: 0 cms
Dauphin River Flow: 16.7 cms
LSMOC Flow: 0 cms
Lake St. Martin South Basin Level: 242.69 m

Post-Project
Fairford River Flow: 18.1 cms
LMOC Flow: 0 cms
Dauphin River Flow: 16.7 cms
LSMOC Flow: 1.4 cms
Lake St. Martin South Basin Level: 242.70 m

FIGURE 13: LAKE ST. MARTIN FLOW PATTERNS – 50TH PERCENTILE CONDITION

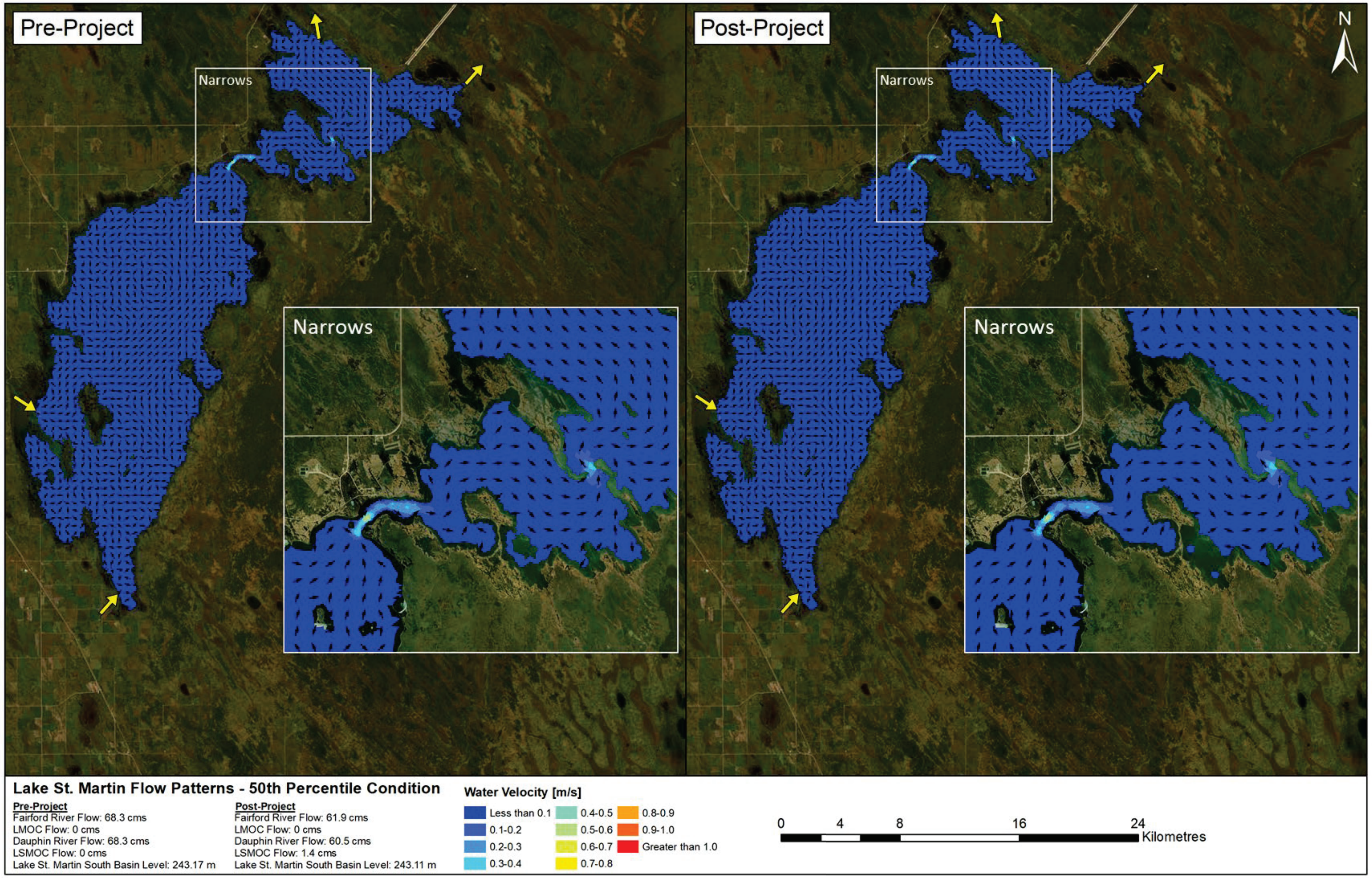
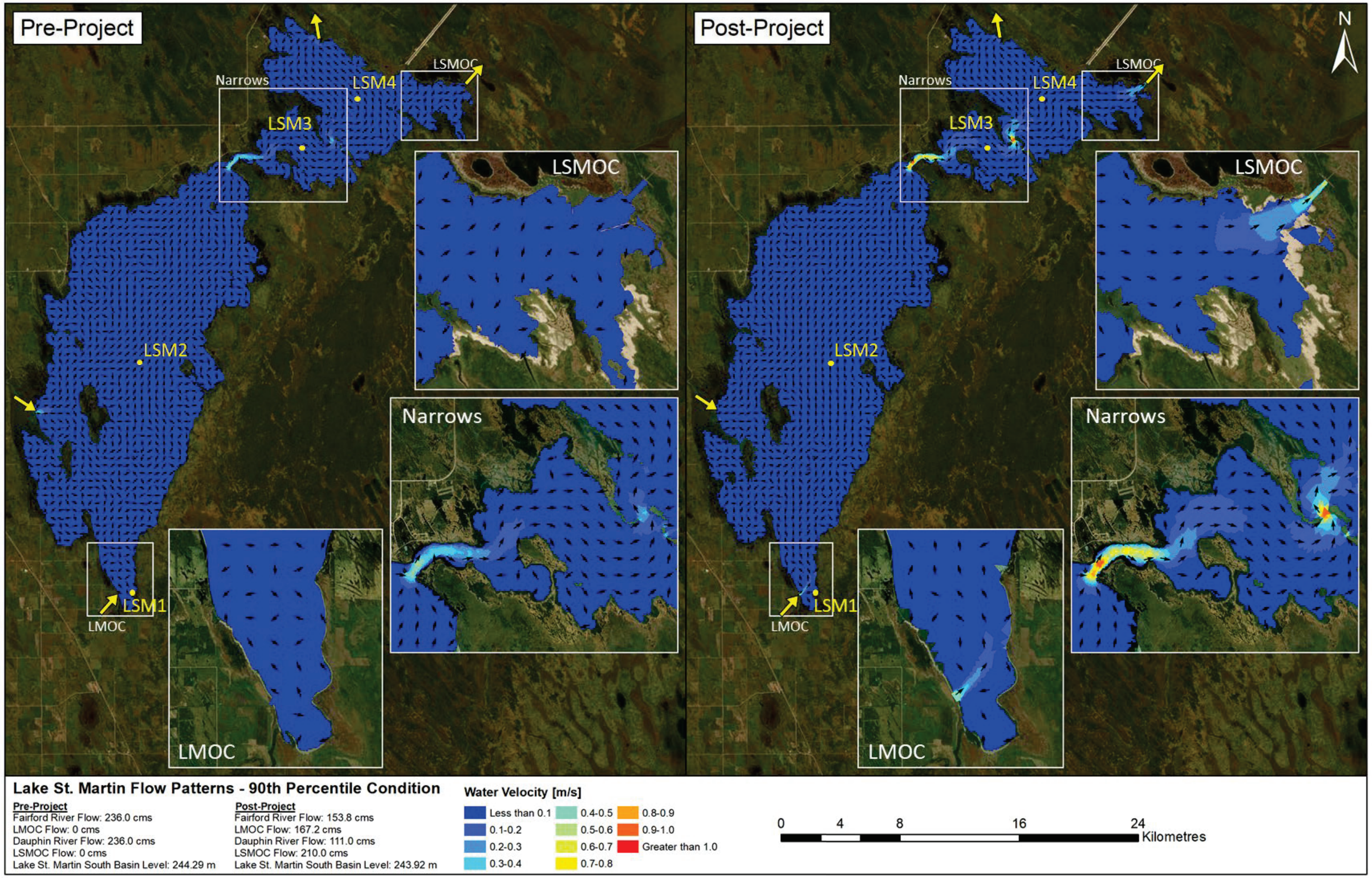


FIGURE 14: LAKE ST. MARTIN FLOW PATTERNS – 90TH PERCENTILE CONDITION



3.3.3 LAKE WINNIPEG

While the entirety of Lake Winnipeg was modeled, the effects of the Project were found to be limited to local areas within Sturgeon Bay. Consequently, the maps presented in this section focus only on Sturgeon Bay.

Simulated water velocities and flow patterns in the vicinity of the LSMOC outlet in Sturgeon Bay for the flow conditions at the 10th, 50th, and 90th percentiles are shown in Figure 15, Figure 16, and Figure 17, respectively.

At the 10th percentile condition (Figure 15), the low flow from the Dauphin River in both the Pre- and Post-Project scenarios does not result in a discernible flow pattern in Sturgeon Bay. The LSMOC is not operated, and only supplies a base flow of 1.4 m^3/s. The differences between the Pre- and Post-Project flow patterns are negligible.

At the 50th percentile condition (Figure 16), outflows from the Dauphin River are greater and a flow pattern is more pronounced in Sturgeon Bay. Velocity vectors indicate that flow exiting the Dauphin River moves east within Sturgeon Bay, then is directed north near the east shoreline of the bay. Due to the small differences in Dauphin River flow and nominal base flow of 1.4 m^3/s supplied by the LSMOC, there are no discernible differences in the flow patterns in Sturgeon Bay flow in the Pre- and Post-Project environments at the 50th percentile flow condition.

At the 90th percentile condition (Figure 17), the flow introduced by the LSMOC alters the flow patterns in the southern portion of Sturgeon Bay compared to the Pre-Project scenario (SB1). The flow pattern near the Dauphin River outlet (SB2) is not changed substantially. However, the current in the Pre-Project scenario is stronger due to the greater flow from the Dauphin River. Further east toward the middle of Sturgeon Bay (SB3), the flow pattern in the Pre-Project environment tends to be directed northeast, as the flow from the Dauphin River turns to move north through the lake. In the Post-Project environment, the flow pattern at this location is oriented north due to the flow from the LSMOC outlet.

FIGURE 15: LAKE WINNIPEG FLOW PATTERNS – 10TH PERCENTILE CONDITION

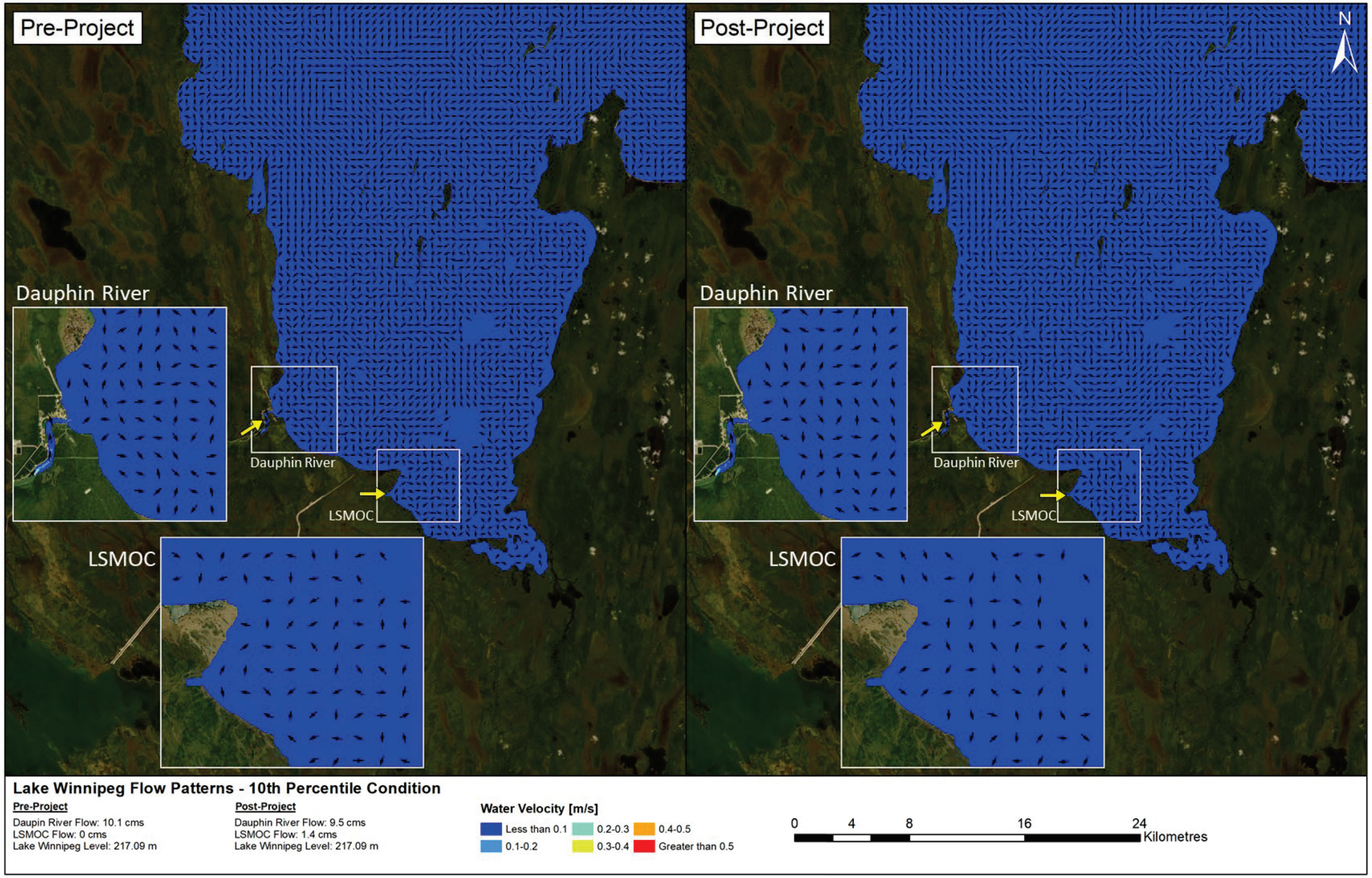
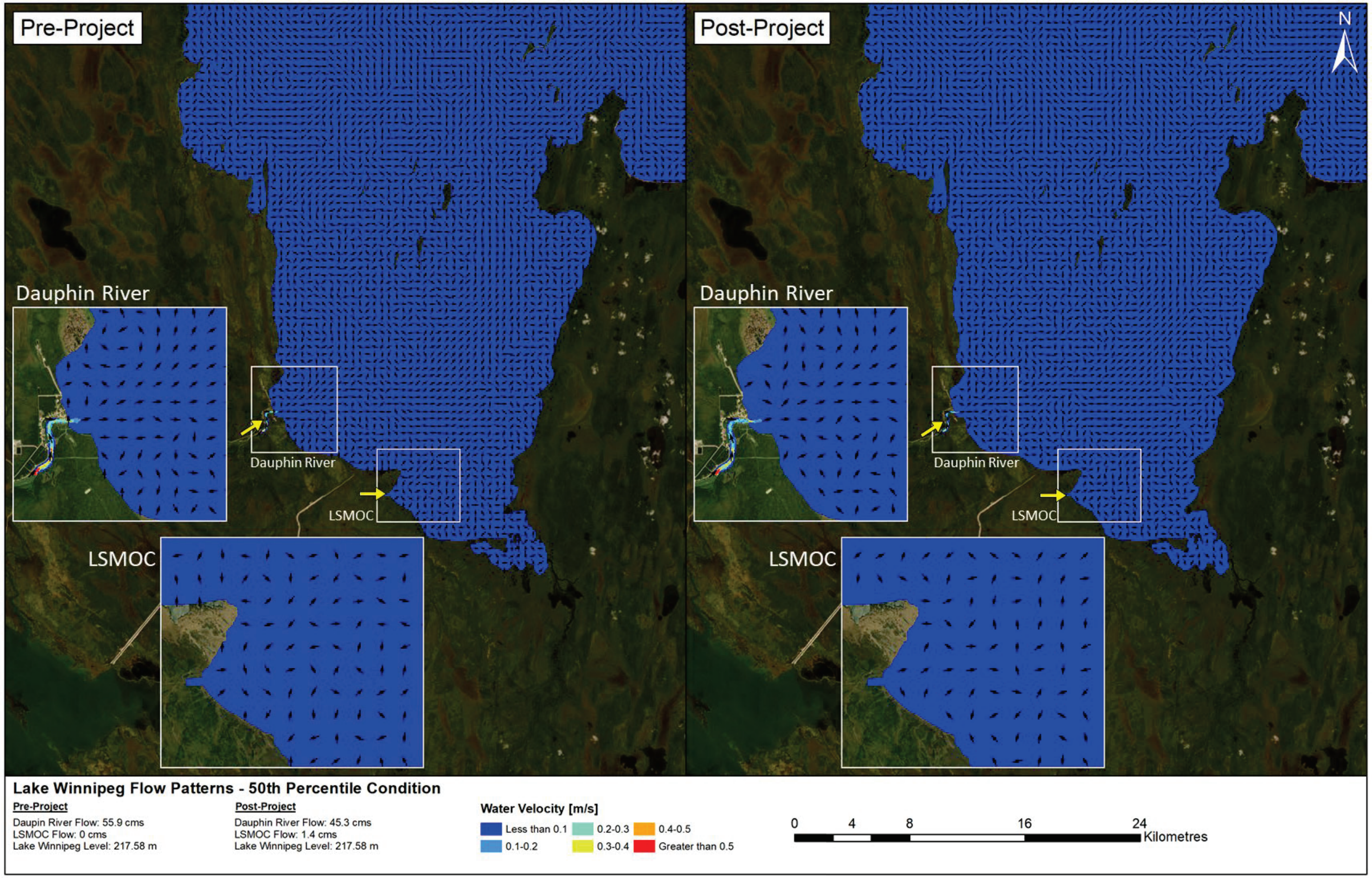


FIGURE 16: LAKE WINNIPEG FLOW PATTERNS – 50TH PERCENTILE CONDITION

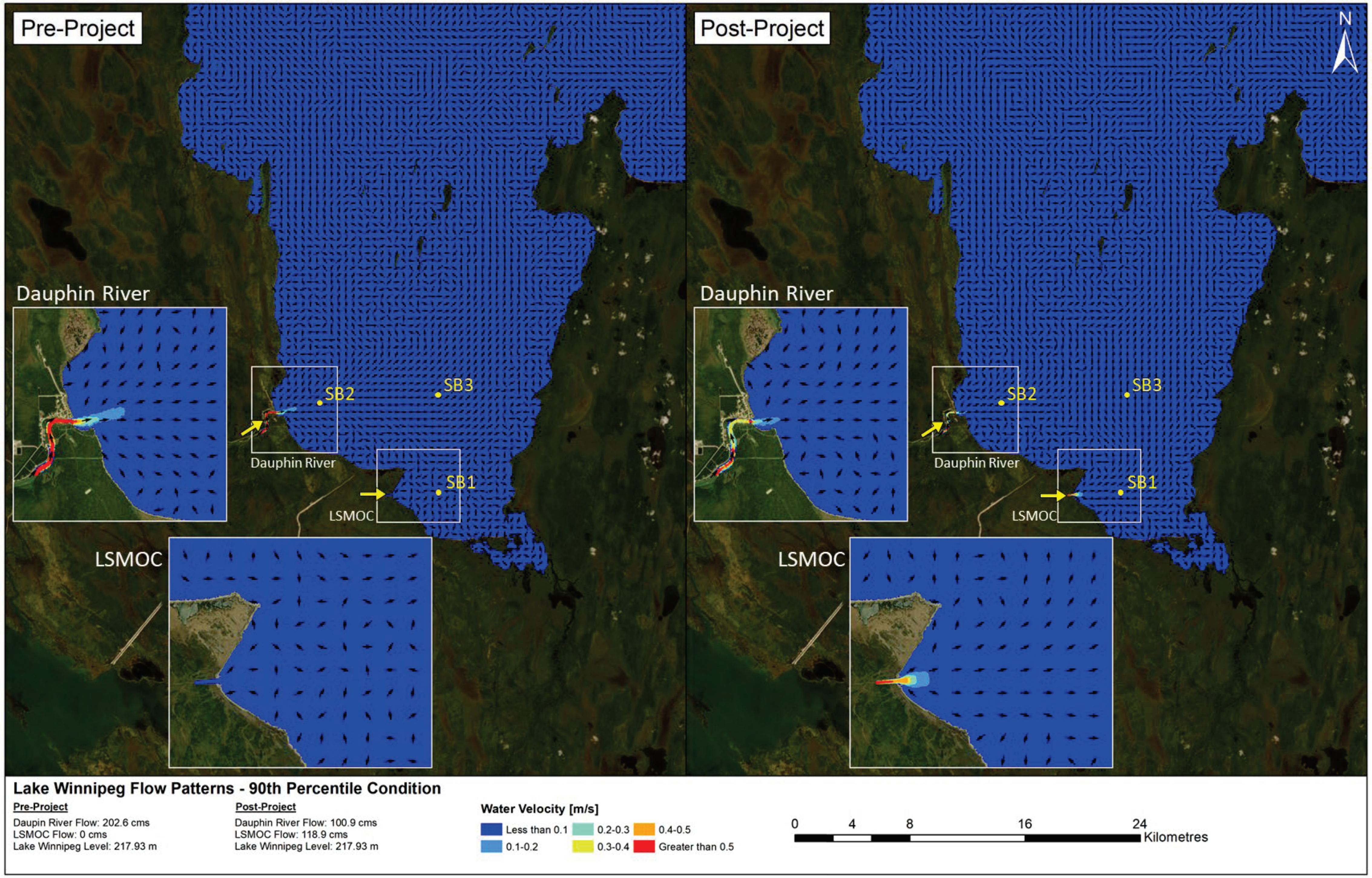


Lake Winnipeg Flow Patterns - 50th Percentile Condition

Pre-Project
Daupin River Flow: 55.9 cms
LSMOC Flow: 0 cms
Lake Winnipeg Level: 217.58 m

Post-Project
Dauphin River Flow: 45.3 cms
LSMOC Flow: 1.4 cms
Lake Winnipeg Level: 217.58 m

FIGURE 17: LAKE WINNIPEG FLOW PATTERNS – 90TH PERCENTILE CONDITION



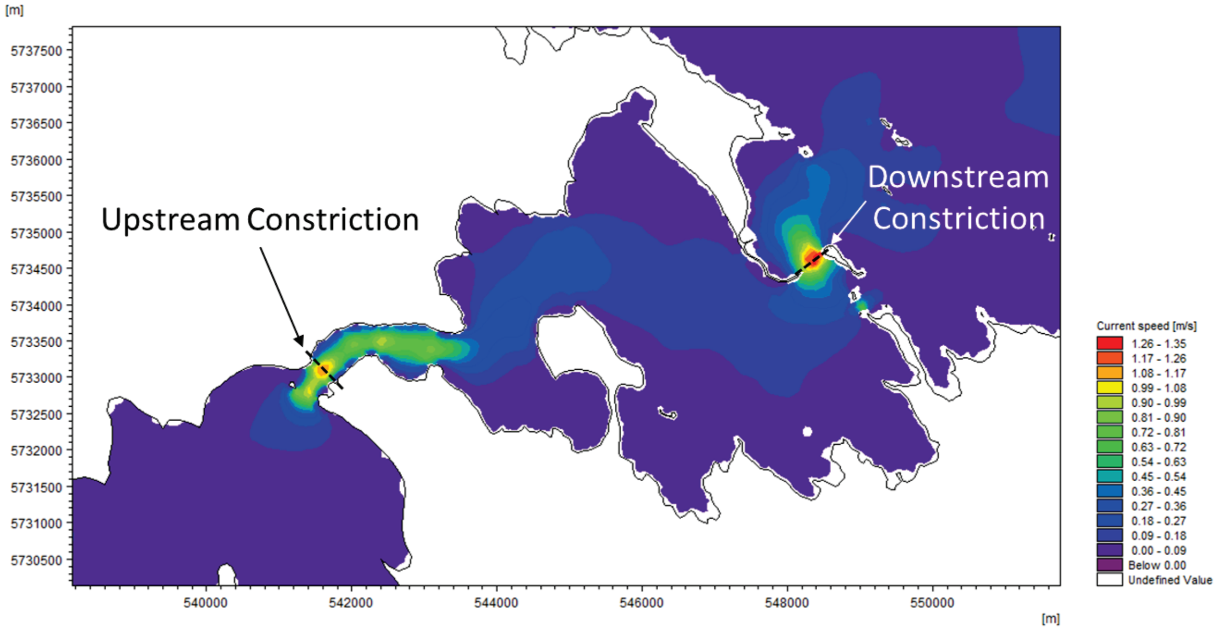
3.4 Flow Conditions Through Lake St. Martin Narrows

The Project will increase the outflow capacities of LM and LSM, resulting in greater flows through the system while maintaining lower lake levels during flood events. Since water velocity through the Narrows is influenced by discharge and flow depth, velocities will be greater when the outlet channels are in operation as compared to the Pre-Project environment.

3.4.1 LOCATIONS OF INTEREST

Upon review of model results and aerial imagery, two constriction points were identified where changes to discharge and lake levels have the greatest influence on water velocity (and therefore the greatest potential impacts to the physical system). The constriction points on LSM were named as the “upstream constriction” and “downstream constriction” and are shown in Figure 18. Note that the “Narrows” refers to the general area between the south and north basins of LSM, and includes both constriction points shown in Figure 18.

FIGURE 18: LOCATIONS OF INTEREST

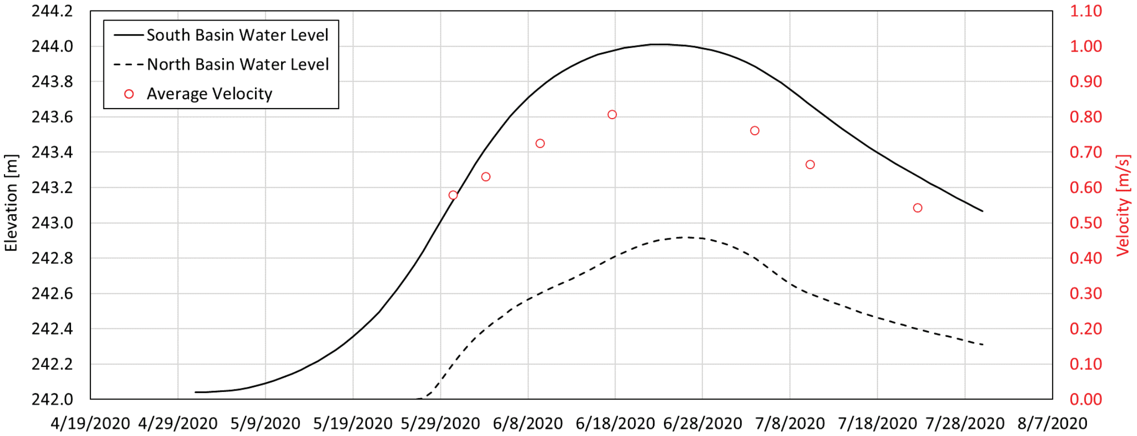


3.4.2 FAMILY OF NARROWS VELOCITY AND WATER DEPTH CURVES

An ensemble of model runs previously completed for the LSM Narrows head loss assessment (KGS Group, 2021) covered a range of lake water levels and discharges. Those runs permitted the development of a family of velocity and water depth curves for each constriction point. Results were extracted along each cross section (shown in Figure 18) for the simulation period. They were then post-processed to extract the average velocity and water depths at discrete pairs of water levels in the north and south basins.

An example hydrograph from a model simulation is presented in Figure 19. As shown, the water level in the south basin rises from approximately El. 242 m to 244 m over the course of the flood, while the water level in the north basin peaks at El. 242.9 m. Near the peak of the hypothetical flood (on 6/8/2020), when the water level in the north basin was El. 242.8 m and the water level in the south basin was El. 244.0 m, the average velocity was calculated to be 0.8 m/s at the upstream constriction.

FIGURE 19: EXAMPLE HYDROGRAPH AND AVERAGE VELOCITY AT THE UPSTREAM CONSTRICTION



This process was repeated for the ensemble of model simulations to develop several data points of water velocity and depth through the constrictions corresponding to specific combinations of water levels in the south and north basins. Trend lines were fit to the data points to develop equations that could be used to predict the water velocity and depth if the south and north basin water levels are known.

The family of velocity curves for the upstream and downstream constrictions are presented in Figure 20 and Figure 21, respectively. Note that “NB” in the figure legends indicates the north basin of Lake St. Martin. Each series of data points corresponding to a constant water level in the north basin was fit with a trend line to obtain an equation characterizing the change in velocity with change in south basin water level. In general, for a given north basin water level, the velocity through the constrictions increases as the water level in the south basin increases. A similar set of curves was developed for the water depths through the constriction points (not shown).

FIGURE 20: FAMILY OF VELOCITY CURVES – UPSTREAM CONSTRICTION

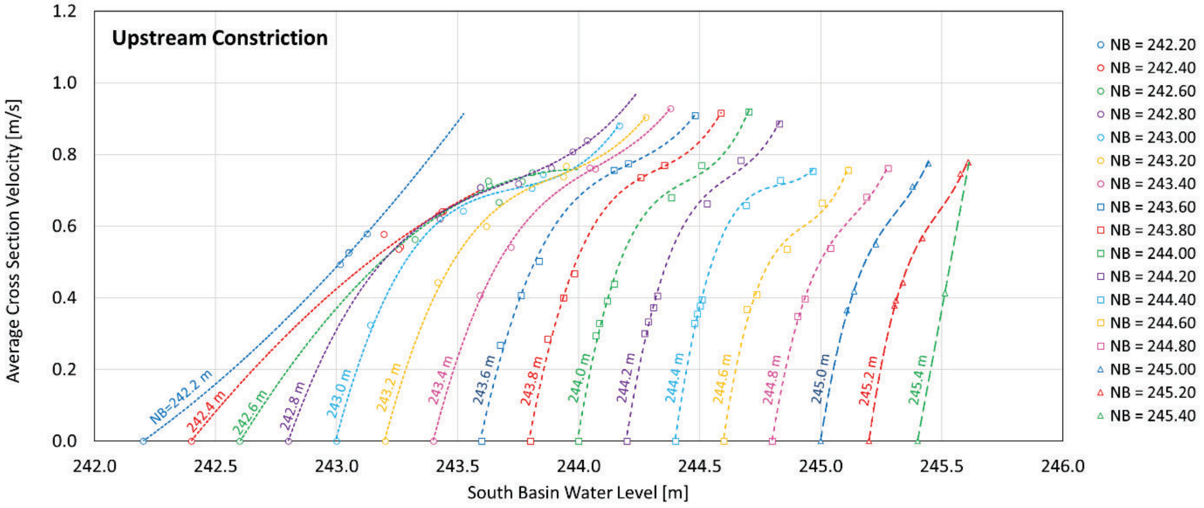
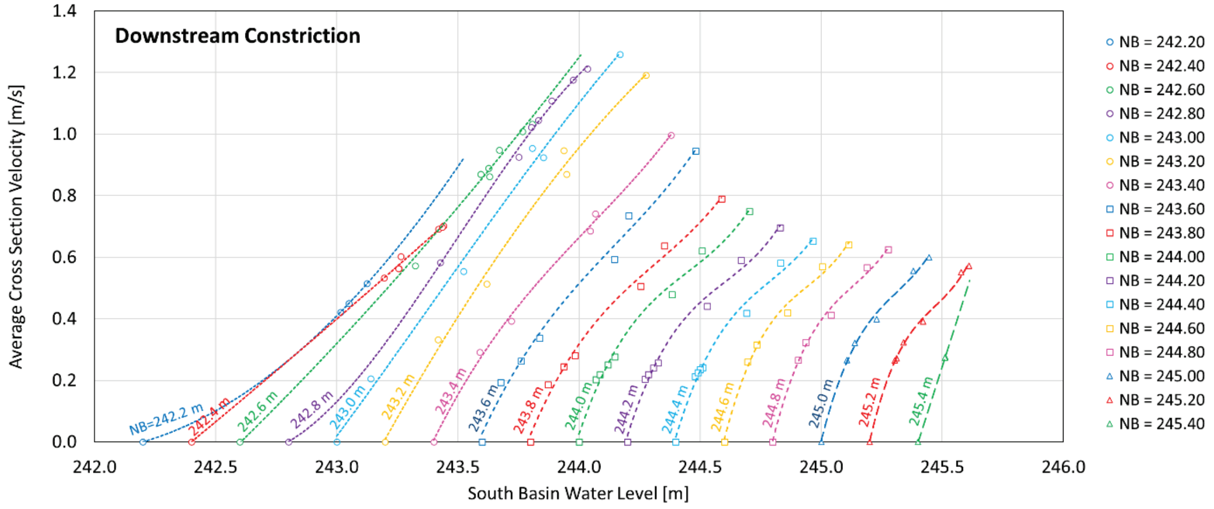


FIGURE 21: FAMILY OF VELOCITY CURVES – DOWNSTREAM CONSTRICTION



3.4.3 PROJECT IMPACTS

The trend line equations were applied to the results of MI's water balance model to develop a time series of estimated water velocities and depths through the LSM Narrows for the simulation period of 1915-2017, both with and without the Project in place. Results are shown in Figure 22 to Figure 24.

FIGURE 22: SIMULATED TIME SERIES OF LAKE LEVELS, WATER DEPTHS, AND VELOCITIES THROUGH NARROWS WITH AND WITHOUT THE PROJECT (1915-1950)

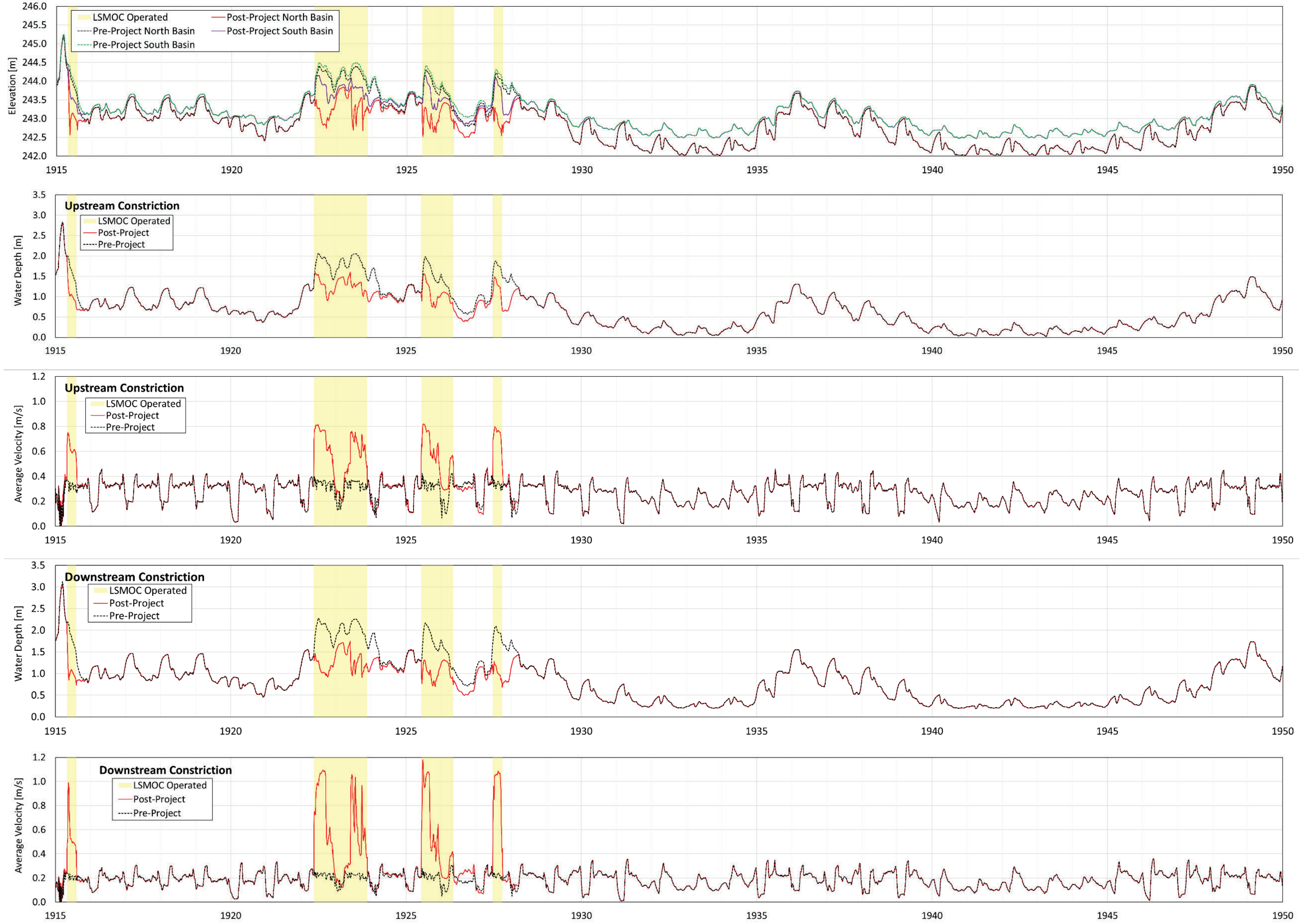


FIGURE 23: SIMULATED TIME SERIES OF LAKE LEVELS, WATER DEPTHS, AND VELOCITIES THROUGH NARROWS WITH AND WITHOUT THE PROJECT (1950-1985)

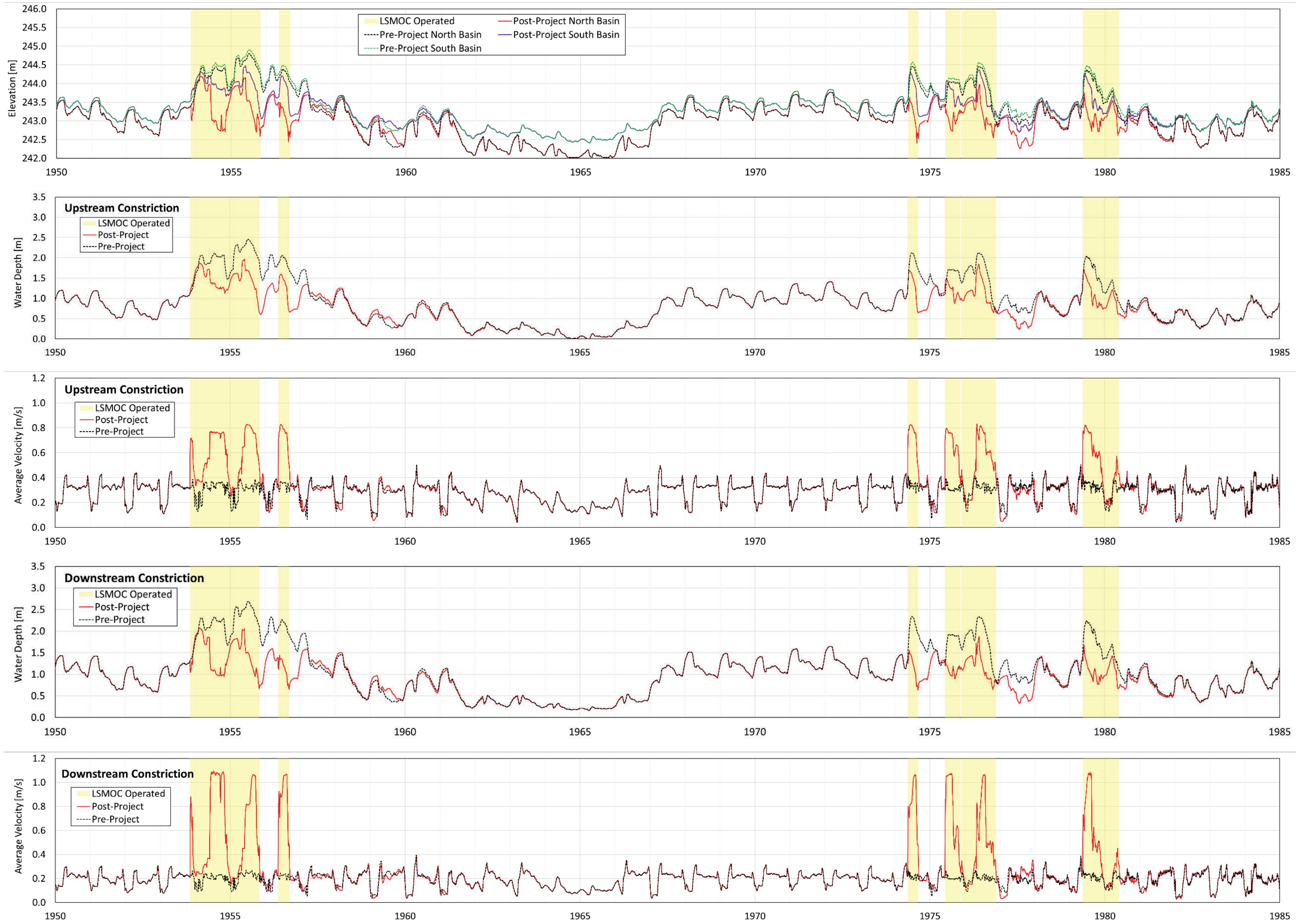
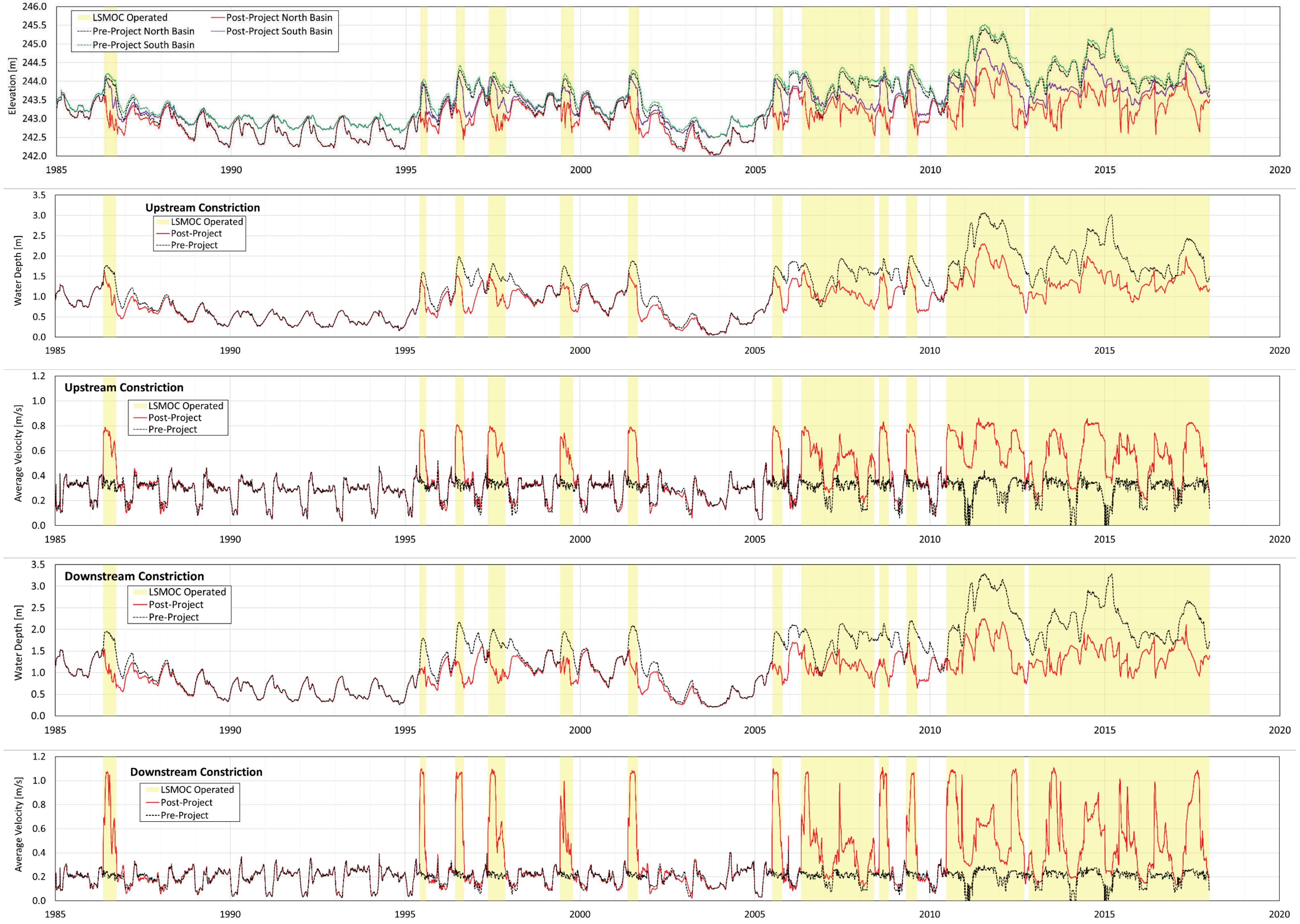


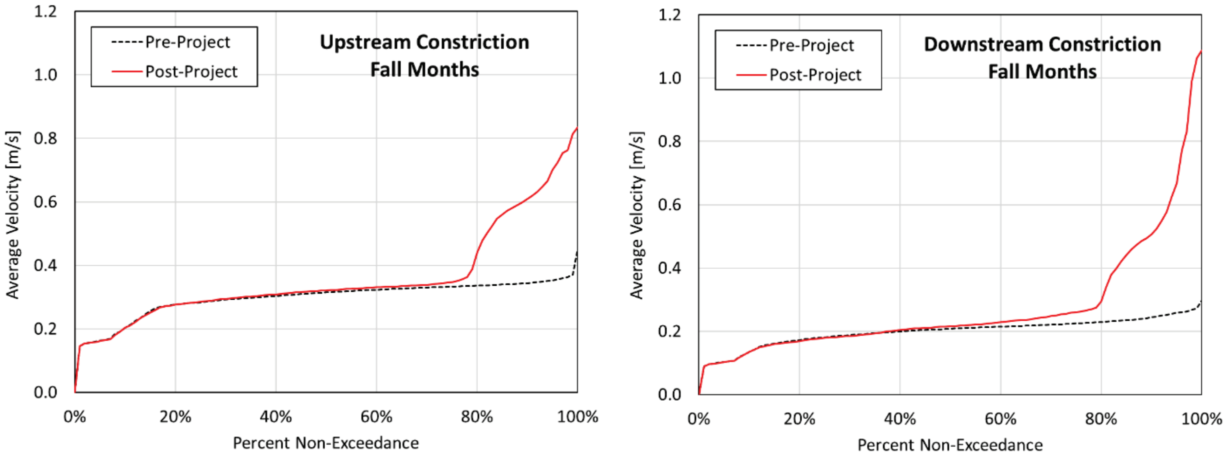
FIGURE 24: SIMULATED TIME SERIES OF LAKE LEVELS, WATER DEPTHS, AND VELOCITIES THROUGH NARROWS WITH AND WITHOUT THE PROJECT (1985-2020)



As shown, operation of the LSMOC (periods highlighted in yellow) causes a reduction in lake levels (top panel of each figure). During operation, the water depths through the constriction points decrease, while velocities increase. During the periods of non-operation, lake levels and water velocities through the Narrows are identical in the Pre-Project and Post-Project scenarios. Also evident in Figure 24 is the greater frequency of Project operation with the historical water supplies for the last few decades compared to 1915 to 1985.

Velocity through the Narrows during the months of September, October, and November are of particular interest because of the documented migration of whitefish through the Narrows for spawning. Duration curves of average water velocity at the upstream and downstream constrictions for the Pre- and Post-Project conditions, during the fall months of September through November, are shown in Figure 25. Average water velocity in Figure 25 is shown at the cross section where a maximum velocity is achieved. The average water velocity represents the average across the cross section at that location. It would be expected that the velocity would vary above and below that average, with the greatest velocity typically near the location of greatest depth.

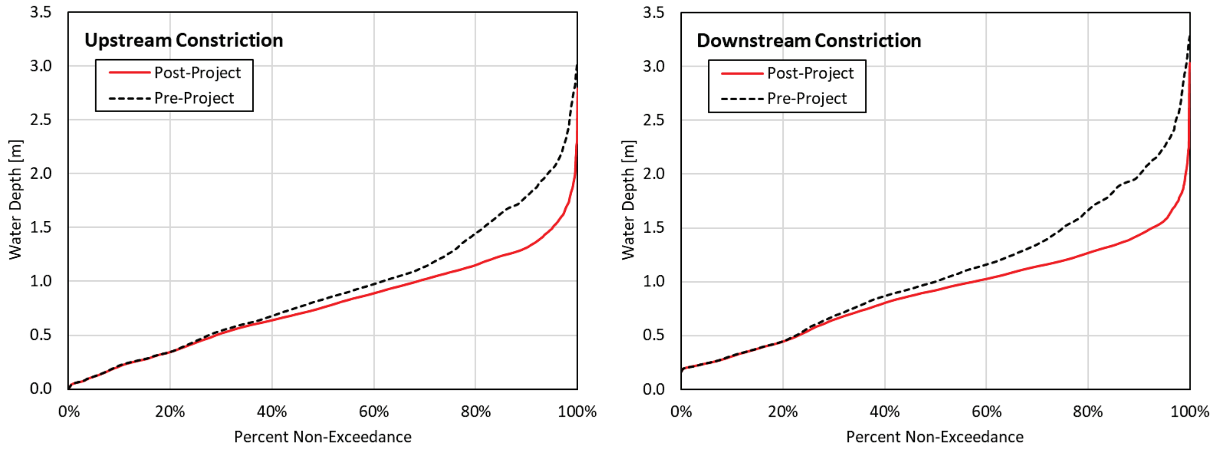
FIGURE 25: DURATION CURVES OF NARROWS WATER VELOCITY DURING FALL MONTHS



The effect of the Project on water velocities below approximately the 80th percentile is small. This corresponds to the approximate duration of time that the LSMOC would be in operation. At the 90th percentile, the average velocity at the upstream constriction increases from approximately 0.34 m/s to 0.61 m/s. At the downstream constriction, the 90th percentile average velocity increases from approximately 0.24 m/s to 0.51 m/s. The maximum average water velocities at the upstream and downstream constrictions in the Post-Project simulation are approximately 0.8 m/s and 1.1 m/s, respectively.

Duration curves of water depths through the Narrows are presented in Figure 26. In general, the Project will reduce water depths through the Narrows, with a greater impact at the higher percentiles (i.e. above the 80th percentile).

FIGURE 26: DURATION CURVES OF WATER DEPTHS THROUGH THE NARROWS



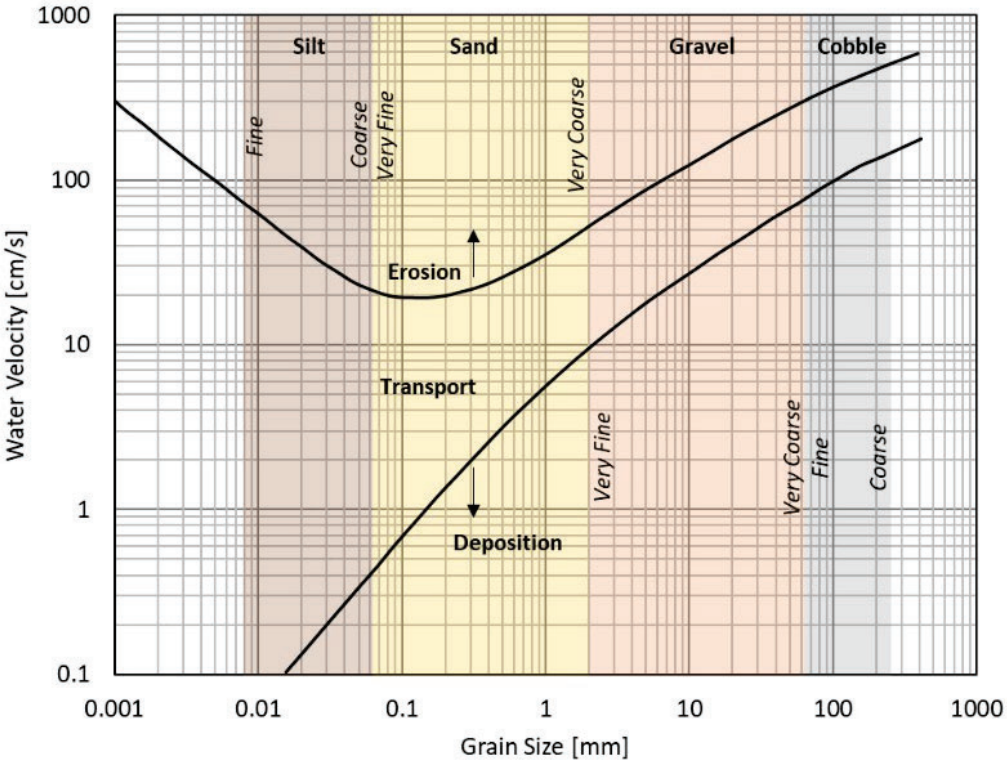
4.0 ASSESSMENT OF PROJECT EFFECTS

4.1 Erosion Potential Through Lake St. Martin Narrows

As demonstrated in Section 3.4, water velocities through the LSM Narrows will increase during operation of the outlet channels. The associated change in erosion potential is discussed in this section.

The potential for erosion and deposition of sediments is commonly defined in terms of thresholds of water velocities above which erosion would be expected to initiate. The Hjulström curve, shown in Figure 27, illustrates the threshold velocities for erosion and deposition for particle sizes ranging from fine silt to coarse cobbles. For example, a particle with a diameter of 2 mm (very coarse sand) will commence to erode at a threshold velocity of approximately 0.5 m/s. Once in suspension, it will continue to be transported until the velocity decreases to approximately 0.1 m/s, at which point it will be deposited on the bed. It should be noted that these are approximate values.

FIGURE 27: HJULSTRÖM CURVE



There is limited information on substrate types through the Narrows. North South Consultants conducted a coarse bathymetric survey of LSM in 2017. Sparse substrate sampling was also conducted; substrate samples just north of Pine Island (in the lower velocity area between the two constriction locations) comprised gravel with silt/clay and trace sand.

A satellite image from Google Earth shows the area surrounding the LSM Narrows in Figure 28. Photographs of the shoreline are presented in Figure 29 (locations of photos are indicated in Figure 28).

FIGURE 28: SATELLITE IMAGE OF LAKE ST. MARTIN NARROWS

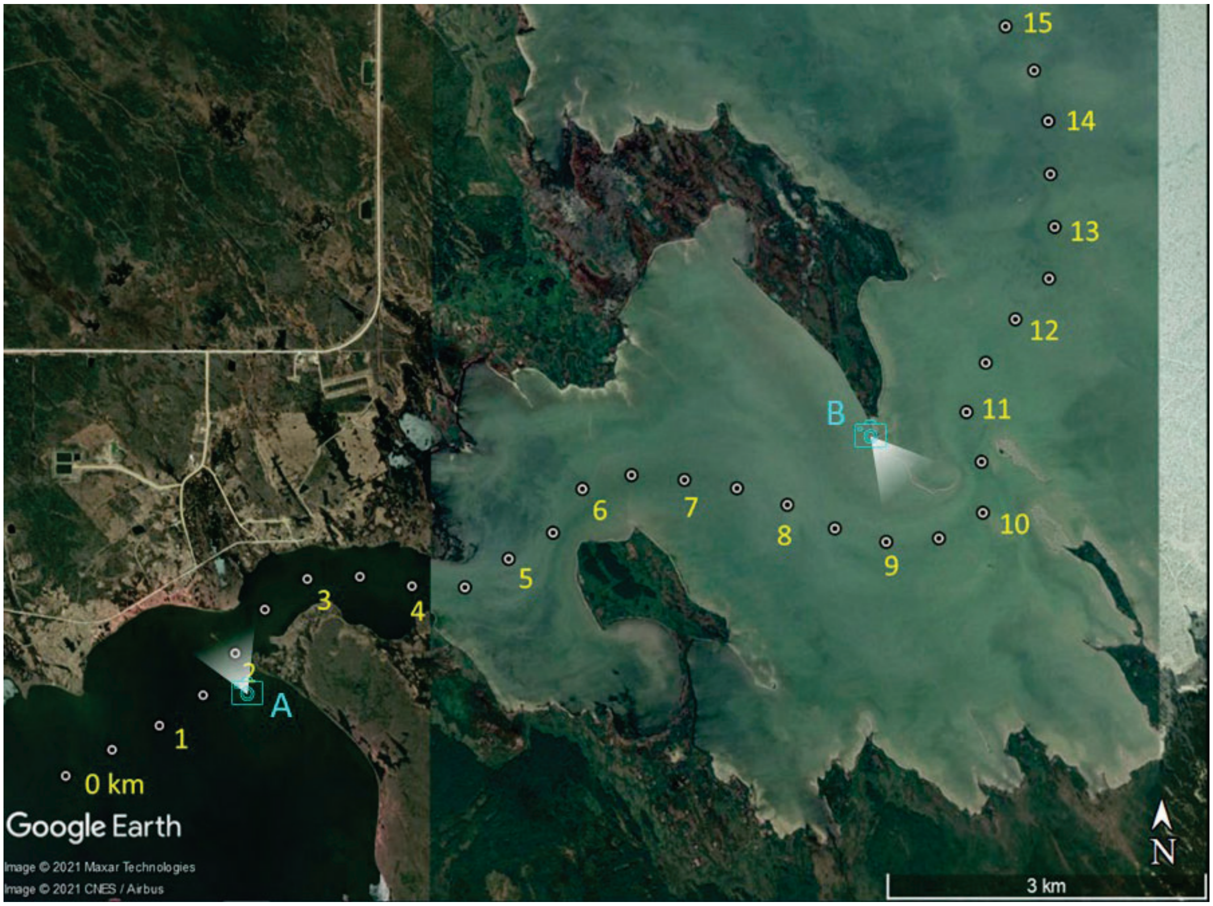


FIGURE 29: PHOTOS OF SHORELINE IN LAKE ST. MARTIN NARROWS

There are several distinct shoreline features that create the flow constrictions, possibly anchored by bedrock or hard glacial till armoured with cobble-boulder lag deposits. Based on a preliminary review of historical aerial images dating back to the 1980s, the shoreline morphology has been stable. The oblique aerial images of the northern constriction (as depicted in Figure 29) show ridges of large boulders have accumulated, possibly due to ice-push. These boulder ridges have resisted erosion during periods of high flow velocities through the Narrows. Finer material (e.g. sand and gravel) exists further down the slope and while this material could be re-worked by waves and current, the aerial photographs reviewed suggest the shoreline has been stable, even following fluctuations between low and high water levels. Additional surveys of substrate and shoreline composition are planned by Manitoba Infrastructure to more accurately classify the material types in the area and the potential for erosion.

Water elevations and velocities along the centreline through the Narrows (shown at points in Figure 28) are presented in Figure 30, Figure 31, and Figure 32. They represent the Pre- and Post-Project conditions at the 10th, 50th, and 90th percentiles, respectively. Overlaid on the figures is the range in velocities at which gravel and sand begin to erode (from the Hjulström curve).

At the 10th and 50th percentiles, water levels and velocities are very similar in the Pre- and Post-Project environments. Water velocities at the centreline of the constrictions indicate that sand and fine gravel could be eroded at these conditions, if present.

FIGURE 30: PROFILES OF WATER SURFACE AND VELOCITIES AT CENTRELINE THROUGH NARROWS – 10TH PERCENTILE

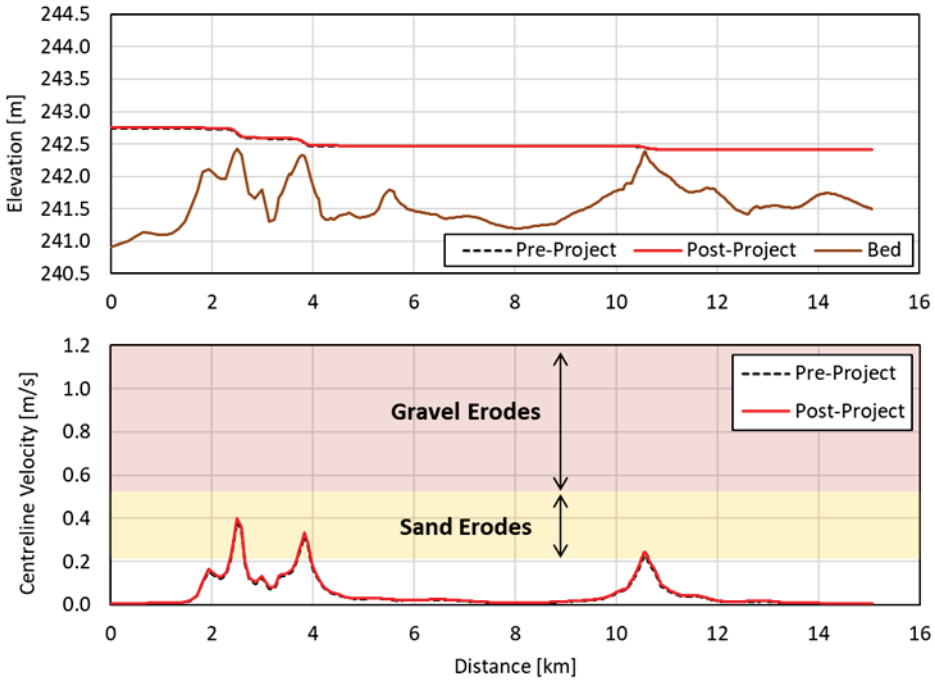


FIGURE 31: PROFILES OF WATER SURFACE AND VELOCITIES AT CENTRELINE THROUGH NARROWS – 50TH PERCENTILE

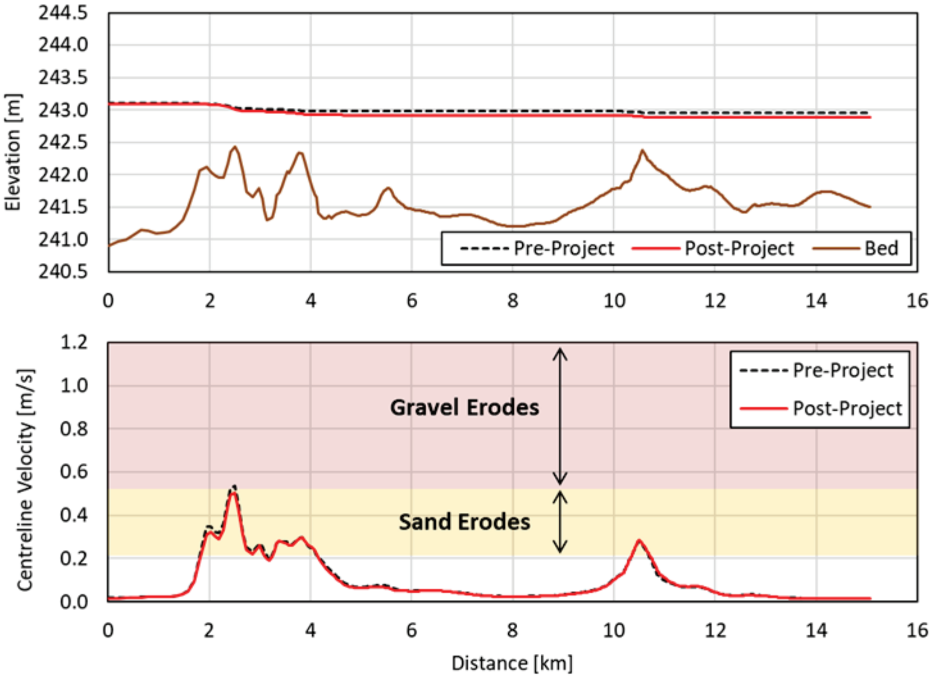
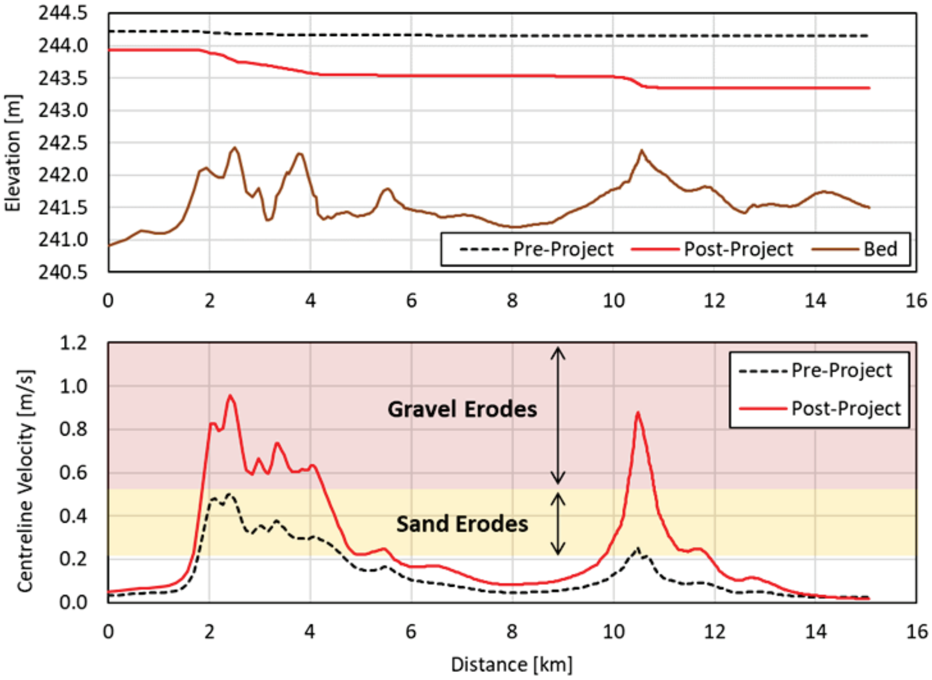


FIGURE 32: PROFILES OF WATER SURFACE AND VELOCITIES AT CENTRELINE THROUGH NARROWS – 90TH PERCENTILE



At the 90th percentile condition, the effect of the additional outflow from the north basin of LSM results in shallower flow depth and higher velocities compared to the Pre-Project condition. At the upstream constriction, velocities in the Pre-Project environment indicate that medium to coarse sand could be eroded, while in the Post-Project environment, fine to medium gravel could be eroded.

Similarly, at the downstream constriction, velocities in the Pre-Project environment might cause erosion of fine sand, while in the Post-Project environment the increased velocities are capable of eroding medium gravel. Velocities in the Post-Project environment remain below the critical thresholds of coarse gravel and cobbles at both constriction points through the Narrows.

As noted previously, planned field surveys will further refine the characterization of the substrate and potential for erosion during Post-Project flows.

4.2 Shoreline Morphology

This section describes the anticipated Post-Project impacts on shoreline morphology for LM, LSM, and Lake Winnipeg. The descriptions are largely based on studies conducted by Zuzek Inc. (2020, 2021) and JDMA (2019), which focused on the areas near the Project inlets and outlets. The flow patterns simulated by the numerical model runs in the present study supplement those findings and consider potential impacts of the Project on flow patterns on a broader scale which could affect shoreline morphology.

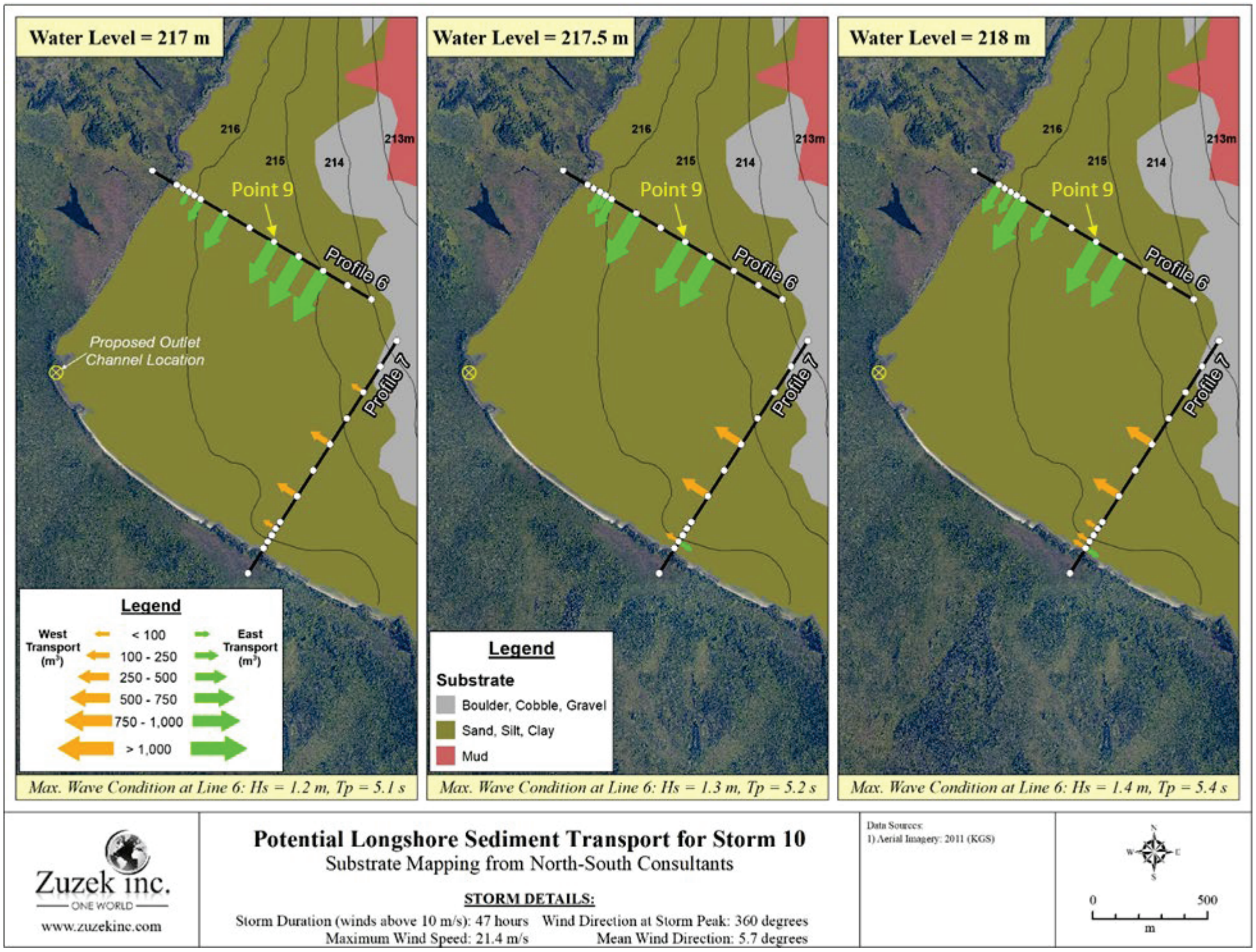
4.2.1 INFLUENCE OF WATER LEVELS ON WAVE ACTION DURING STORMS

Lake levels influence the size of waves in the nearshore zone of lakes and the extent of wave breaking and runup that reaches the shoreline. For example, when lake levels are high, a 2.0 m deep water wave can propagate closer to shore, break on the beach, and erode the backshore. Conversely, when lake levels are low, the same 2.0 m deep water wave interacts with the lake bottom sooner and the breaking and shoaling processes start further offshore, leading to smaller wave heights at the shoreline and less erosion potential.

This process was documented in the report by Zuzek Inc. (2021) on Post-Project morphology, where the nearshore waves and potential for sediment transport in Sturgeon Bay were evaluated for three different lake levels (217 m, 217.5 m, and 218 m). Refer to Figure 33. The green arrows indicate the magnitude of potential for sediment transport. When lake levels are low (217 m), the majority of the wave breaking and potential for sediment transport happens around the 215 m contour. For high lake levels (218 m), wave breaking and sediment transport happens closer to shore (around the 216 m contour).

This process, whereby the lake water level influences the zone of wave breaking and sediment transport potential, is referenced in Sections 4.2.2 to 4.2.4 to assess potential impacts of the Project on shoreline morphology.

FIGURE 33: INFLUENCE OF WATER LEVEL ON SEDIMENT TRANSPORT POTENTIAL NEAR THE LSMOC OUTLET IN STURGEON BAY



4.2.2 LAKE MANITOBA

The Project effects on future LM water levels were summarized in Section 2.0. With the additional discharge capacity of the proposed LMOC, there will be a small reduction in the lake levels at the 50th and 90th percentiles. With lower lake levels in the future, storm waves will break further offshore and the potential for shoreline and bank erosion will decrease. If longshore currents develop during storm conditions, the zone of longshore sediment transport will occur further offshore than for the Pre-Project conditions.

The report on the Lake Manitoba Outlet Channel Shoreline Morphology (JDMA, 2019) concluded that the shoreline in Watchorn Bay around the proposed outlet of the LMOC has been stable for 70 years. Waves transport sediment onshore and offshore, while ice shoves can push larger boulders onshore (JDMA, 2019). The small reduction in the future water levels will not materially alter these processes.

With the projected reduction in the 90th percentile flows into the Fairford River (271.1 m^3/s to 123.2 m^3/s; KGS Group, 2021), the potential for currents to erode the nearshore and river banks during peak flow events will decrease in the future, likely leading to more shoreline stability.

4.2.3 LAKE ST. MARTIN

The Birch Bay shoreline in the southern portion of Lake St. Martin is low lying and frequently inundated during periods of high lake levels, yet it has been stable in the long term (JDMA, 2019). The future water level projections for the south basin of Lake St. Martin include a small reduction in the 50th percentile water level (5 cm) but a greater reduction for the 90th percentile (37 cm). This reduction in lake levels will result in less inundation in the future and will not impact the shoreline stability, as breaking waves that have the potential to erode sediment during periods of high lake levels will occur further offshore.

The north shoreline of Lake St. Martin at the proposed inlet of the LSMOC was characterized as stable in the Baseline Shoreline Assessment (Zuzek Inc., 2020). Cobble-boulder headlands and stable embayments characterize the shoreline. A picture of a stable cobble shoreline is presented in Figure 34. While the shoreline position is altered by fluctuating water levels, shoreline erosion due to waves or sediment transport is not a governing physical process in the northern basin of Lake St. Martin. Therefore, the 0.59 m reduction in the water level in the north basin at the 90th percentile will result in less flooding/inundation in the future. This should lead to enhanced stability of the shoreline.

FIGURE 34: STABLE COBBLE SHORELINE NEAR LSMOC INLET LOCATION

It is interesting to note that both the report by JDMA (2019) for the south basin of Lake St. Martin, and the report by Zuzek Inc. (2020) for the north basin of the lake identify large boulder piles and ridges in the shallow nearshore that have been stable for many decades. These stable boulder features reinforce the finding that the nearshore and shoreline are stable and the Post-Project scenario will further enhance this stability by directing the zone of breaking waves further offshore.

With a modest reduction in the 50th percentile flows in the Fairford River and further reductions in the 90th percentile flows (236.0 m^3/s to 153.8 m^3/s), the potential for erosive river currents to alter the mouth of the Fairford River will decrease once the Project has been constructed. This section of the Fairford River has historically been stable (KGS Group, 2021) and no changes in this trend Post-Project are anticipated.

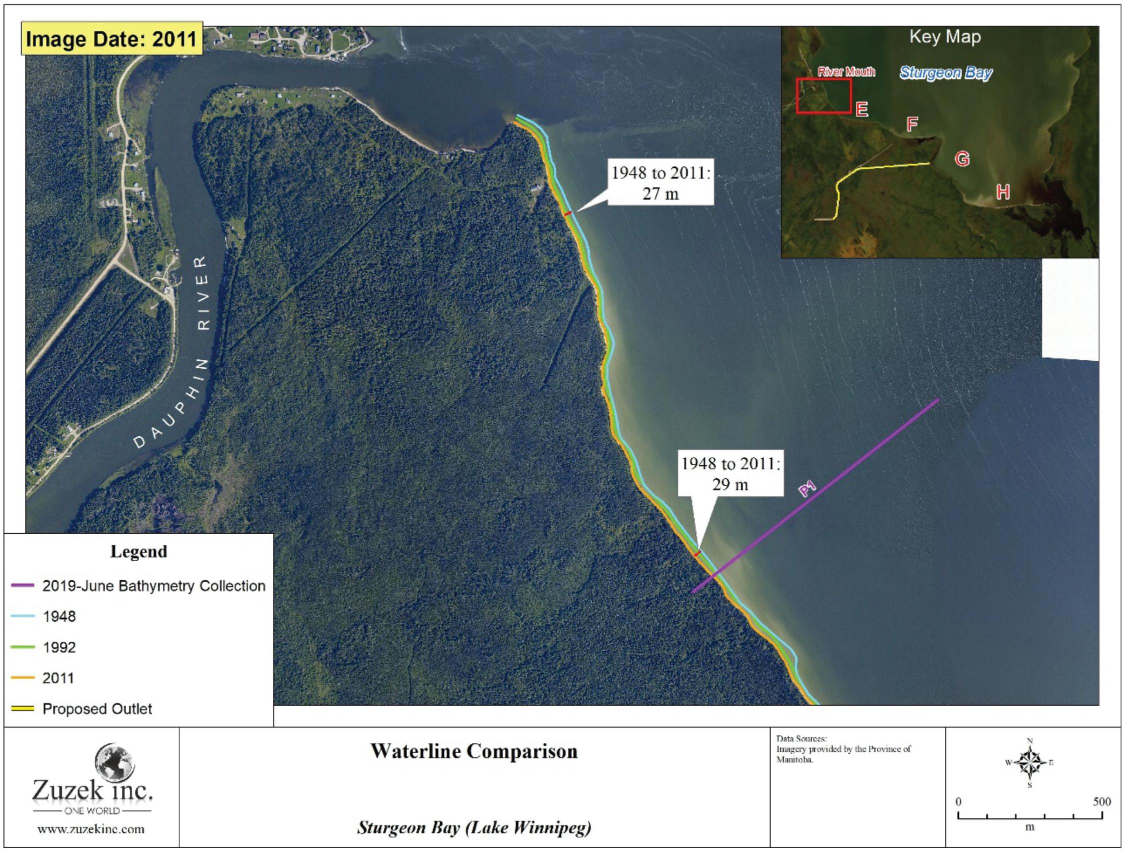
For the Post-Project scenario at the Dauphin River mouth, a substantial reduction in the 90th percentile flow (i.e., more than a 50% reduction in flow) and a 0.85 m reduction in the water level will reduce the threat of riverbank erosion from currents and lake waves. The existing stable conditions are seen in Figure 35.

FIGURE 35: TYPICAL CONDITION OF THE DAUPHIN RIVER BANKS AT THE MOUTH IN LAKE ST. MARTIN

4.2.4 LAKE WINNIPEG

Data on rates of change in historical shorelines near the mouth of the Dauphin River was presented in the report on the rivers flow system (KGS Group, 2021). While the banks of the river have generally been stable, the lake shoreline north of the river mouth featured a long-term recession rate of approximately 0.2 m/yr from 1963 to 2011. An additional aerial photograph from 1948 was registered for the lake shoreline south of the river mouth, as seen in Figure 36. The long-term recession rate south of the river mouth is estimated to be 0.44 m/yr.

FIGURE 36: SHORELINE RECESSION FROM 1948 TO 2011 SOUTH OF THE DAUPHIN RIVER MOUTH

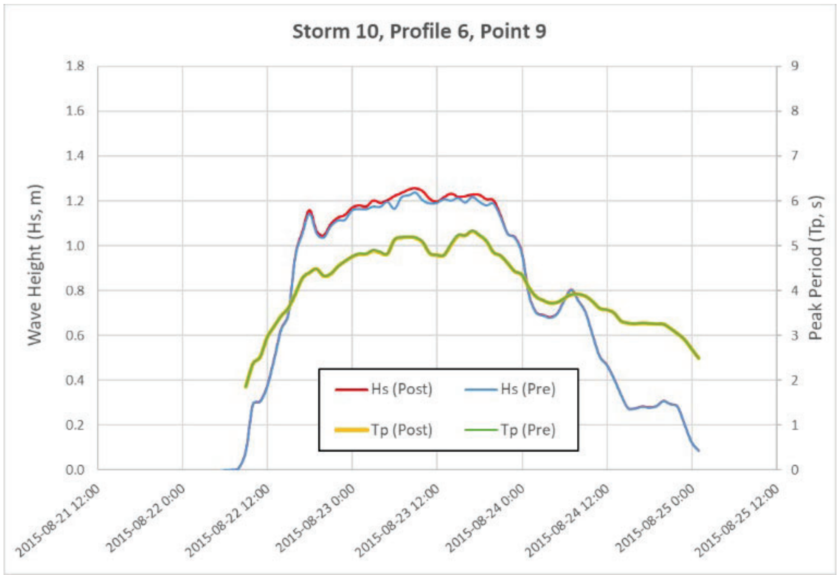


For the Post-Project condition, no significant changes are anticipated for the Lake Winnipeg water levels (as indicated in the analysis conducted by Manitoba Hydro (2019), discussed in Section 2.0). However, the 90th percentile flows at the river mouth are projected to decrease by 50% relative to Pre-Project conditions. This reduction in peak flows will reduce the rate of down cutting of the riverbed at the mouth, which may benefit adjacent shoreline stability in the long-term.

The baseline assessment of the shoreline for the Lake St. Martin Outlet Channel (Zuzek Inc., 2020) and the Post-Project Shoreline Morphology Assessment (Zuzek Inc., 2021) both highlighted the influence of longshore sediment transport on the redistribution of sand and ultimately shoreline evolution from the Dauphin River Mouth to the Sturgeon Bay Park Reserve. However, if there is no significant change in the water level (as indicated by the analyses conducted by Manitoba Hydro (2019)), the future wave conditions (wave height, period, and direction) during storms will not be measurably influenced or moderated by the Project. Therefore, the Project will not significantly influence this key physical process that impacts shoreline evolution.

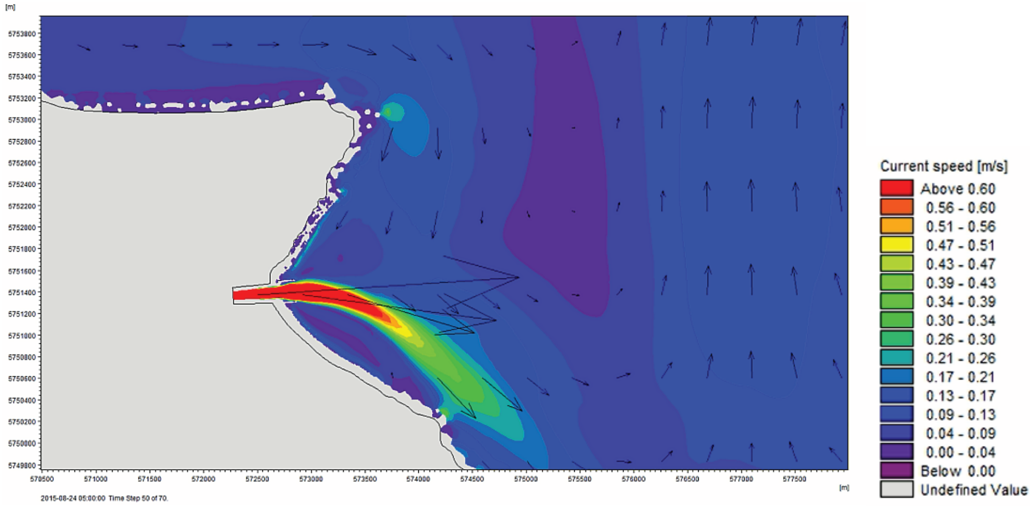
The localized influence of the outlet channel in Sturgeon Bay on water levels and wave climate was investigated in Zuzek Inc. (2021). In that study, a number of windstorms on Lake Winnipeg (George Island) were reviewed, and a few were selected to assess wave action and potential sediment transport in Sturgeon Bay. “Storm 10” was the wind event selected to be representative of a north-northwest wind direction. The maximum wind speed during Storm 10 is 21.4 m/s. The predicted wave heights for Storm 10 for the Pre- and Post-Project conditions at “Point 9” along “Profile 6” (adjacent to the LSMOC outlet, see Figure 33) are shown in Figure 37. The significant wave heights and peak wave periods are denoted by “Hs” and “Tp”, respectively. The wave height is almost identical throughout the storm at that location. Therefore, with negligible changes in the future wave climate, it is unlikely that any measurable changes in the potential sediment transport rates would occur in the Post-Project era.

FIGURE 37: COMPARISON OF WAVE HEIGHT AND PERIOD FOR STORM 10 AT PROFILE 6 (POINT 9)



Simulations of the Post-Project condition in Sturgeon Bay with the LSMOC operating at the design discharge of 326 m^3/s were completed for the report on Post-Project Morphology (Zuzek Inc., 2021). A sample of the model output for Storm 10 at hour 50 is presented in Figure 38. The current velocities exceed 0.5 m/s and may result in localized transport of lake bottom material (sands) beyond background rates. Substrate monitoring will be conducted by Manitoba Infrastructure at selected sites in Sturgeon Bay to determine whether long term changes in substrate composition occur in key aquatic habitat locations.

FIGURE 38: VELOCITY CONTOURS FOR THE POST-PROJECT CONDITIONS IN STURGEON BAY DURING STORM 10 (HOUR 50)



In summary, the analysis of future lake levels and flows in the connecting channels from LM to Lake Winnipeg has not identified any changes to the key physical processes that would accelerate shoreline erosion and/or sedimentation rates. In fact, in many locations lower water levels and flows may increase the stability of the shoreline for the Post-Project scenario.

4.3 Ice Cover Formation

The following sections present a qualitative assessment of potential changes in ice processes in the lakes caused by the Project. The effect on ice processes is inferred from the changes in winter flows and water levels (Section 2.0) and the velocity patterns simulated by the 2D model (Section 3.3).

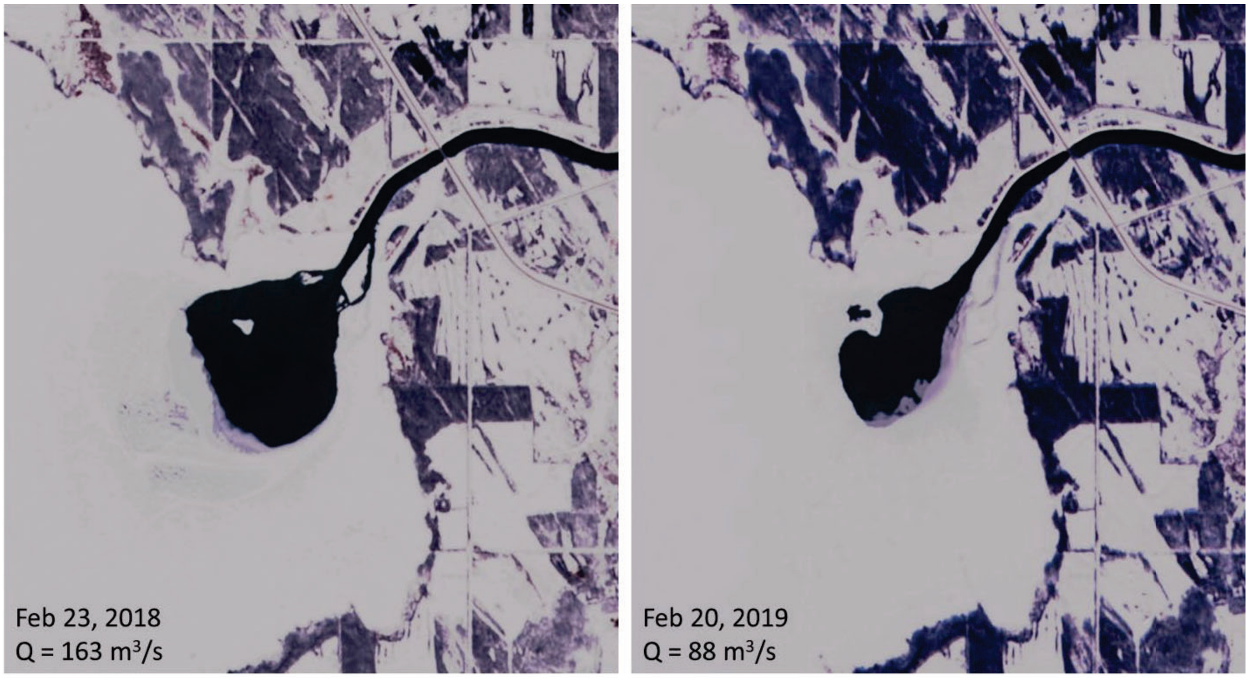
4.3.1 LAKE MANITOBA

The main areas in LM that could potentially see changes to ice processes as a result of the Project are the inlets to the Fairford River and LMOC.

When a lake forms an ice cover in the winter, the ice cover shields the water surface from wind action, allowing the water beneath the ice cover to develop a vertical temperature gradient. Since freshwater is most dense at 4°C, warmer water will occupy greater depths. The ice cover also has an insulating effect on the lake water, slowing the rate of heat loss to the atmosphere. The geothermal heat flux causes the lake water to remain slightly above 0°C through the winter. At lake outlets, the combination of higher water velocities and the upwelling of the warm lake water often limits the extent of lake ice formation, leaving a zone of open water that can remain for the entire winter. The depth of water in a lake also affects this process, with deeper lakes having greater reserves of warm water at depth through the winter.

This phenomenon occurs upstream of the Fairford River. The extent of the open water zone is influenced by water velocities (which are related to flow through the river) as well as air temperature. As an example, Figure 39 shows ice conditions near the inlet of the Fairford River at flows of 163 m^3/s and 88 m^3/s. The effect of the higher river flow on ice formation upstream of the control structure is evident by the greater area of open water and the absence of an ice cover in the secondary outflow channel.

FIGURE 39: SENTINEL SATELLITE IMAGERY OF OPEN WATER AREA UPSTREAM OF FAIRFORD RIVER



At the 10th and 50th percentiles, flows in Fairford River the Pre- and Post-Project environments are similar. Consequently, it is expected that there would not be a notable change in ice conditions at either the inlet to the Fairford River or the LM Narrows. The LMOC is not in operation, and thus there would be no changes to ice formation near the inlet (Watchorn Bay).

At the 90th percentile flow condition, the LMOC would be operated, which would reduce the magnitude of the flow through the Fairford River compared to the Pre-Project environment. Thus, it is expected that the inlet area of the Fairford River would more easily develop an ice cover. It would consequently have less open water area, and there would be less potential for lake bottom erosion during storms. The LMOC inlet area would have increased velocities due to flow conveyed into the outlet channel. This would cause an open water area to develop and persist through the winter due to the same process of warm water being drawn up from depth in the lake and through the outlet. The velocity contours in the vicinity of the LMOC inlet in Figure 11 provide an indication of the approximate extent of the affected area, which would likely be localized to within a few hundred metres to a kilometre of the inlet. The effect of the Project on ice conditions further away from the inlet are anticipated to be small (the ice thickness in those areas would be governed by air temperatures, snow cover, and wind as they are currently in the Pre-Project environment).

4.3.2 LAKE ST. MARTIN

The areas in Lake St. Martin that could potentially undergo changes to ice processes as a result of the Project are the Fairford River outlet, LMOC outlet (Birch Bay), Dauphin River inlet, LSMOC inlet, and Lake St. Martin Narrows.

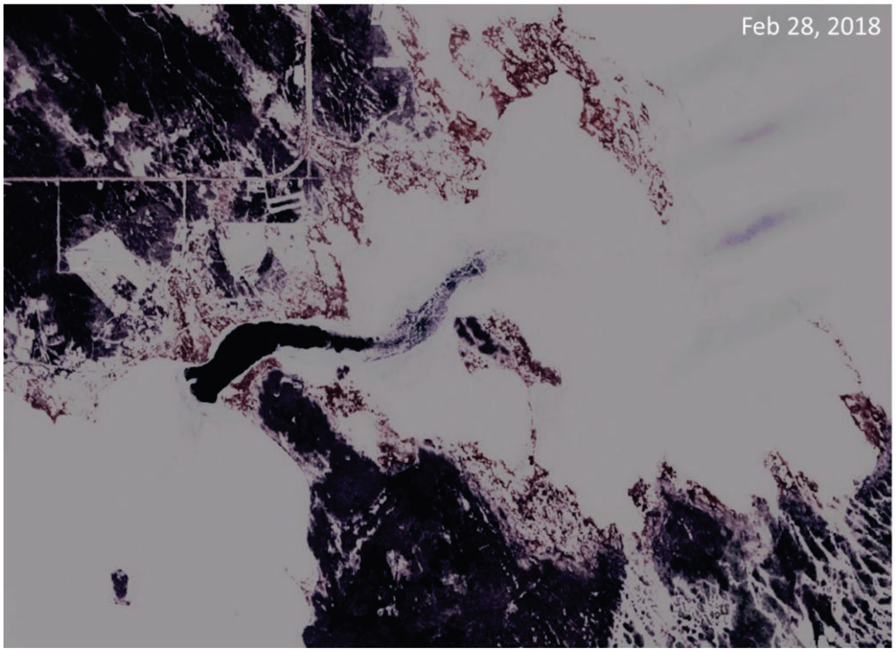
At the 10th and 50th percentiles, the outlet channels are not in operation and the changes to river flows is small. Thus, the effect on ice processes within the lakes will be negligible. The base flow in non-operating conditions of 1.4 m^3/s through the LSMOC will not change the velocity patterns enough to create a notable change to ice conditions near the inlet.

At the 90th percentile condition, operation of the outlet channels will reduce flows through the adjacent rivers and increase the total flow through the lake, while maintaining lower water levels. The reduction in flow in the Fairford River would result in lower velocities and more uniform and smooth thermal ice cover at the outlet. Meanwhile, the addition of flow from the LMOC would result in a localized zone of ice cover with reduced thickness in Birch Bay in the vicinity of the outlet. Figure 14 shows velocity contours at the LMOC outlet at a flow of 163 m^3/s, which provides some information for the area of lake ice that could be affected by winter operation of the LMOC. The maximum winter flow restriction in the LMOC is proposed to be 90 m^3/s, so the extent of increased velocity and reduced ice thickness would be less than what is shown in Figure 14.

Currently, in winters with relatively high flows, open water persists in the Dauphin River inlet area throughout the winter. In those high flow years, operation of the LSMOC would reduce the amount of flow through the Dauphin River and allow a more extensive and uniform ice cover to develop in the area. This would be expected to increase the protection of the lake and river bottom from the erosive action of waves. Operation of the LSMOC would increase velocities in the vicinity of the inlet, resulting in thinner ice covers and/or open water areas (similar to those that occur at the inlet of the Fairford River shown in Figure 39).

Open water areas and/or zones of rough ice cover occur through the Lake St. Martin Narrows currently, as shown by the example of a satellite image in Figure 40. Operation of the outlet channels in the winter will increase the total flow through the lake, resulting in greater water velocities through the Narrows. Thus, it is expected that the extent of the open water area through the Narrows would be greater in the Post-Project environment than in the Pre-Project condition in years when the outlet channels are operated. In the areas where an ice cover does develop, the higher velocities could produce a rough, mechanically thickened ice cover in some areas as compared to the Pre-Project environment.

FIGURE 40: SENTINEL SATELLITE IMAGE SHOWING OPEN WATER AREA THROUGH LAKE ST. MARTIN NARROWS



4.3.3 LAKE WINNIPEG (STURGEON BAY)

The areas in Lake Winnipeg that could potentially undergo changes to ice processes as a result of the Project are at the mouth of the Dauphin River and at the outlet of the LSMOC.

At the 10th and 50th percentile conditions, the Project would not be operated, and flows in the Dauphin River would be very similar to the Pre-Project condition. Ice conditions at the mouth of the Dauphin River would be the same as they are currently. Lake Winnipeg would form a thermal ice cover at freeze-up, which would initiate the progression of an ice cover up the lower Dauphin River. The magnitude of Dauphin River flows at the 10th and 50th percentile condition would allow the ice cover to progress upstream from the lake ice cover without the formation of a severe hanging ice dam. The riparian discharge of 1.4 m^3/s released by the LSMOC would not cause any discernable variation in lake ice formation at the LSMOC outlet.

At the 90th percentile condition, the Dauphin River winter flow is reduced in the Post-Project environment, from approximately 139 m^3/s to 97 m^3/s (see Analysis of Rivers Flow System; KGS Group, 2021). At flows of this magnitude, the lake ice cover in the vicinity of the mouth of the Dauphin River typically forms through surface packing of ice pans discharged from the river. Ice pans may also be swept under the lake ice cover and deposited to create an ice formation called a “hanging ice dam”. The severity of ice accumulations at the mouth of the Dauphin River and increases in water level required to enable the advancement of the ice cover up the river are influenced by discharge. In general, the reduction in the magnitude of Dauphin River flow during flood events due to operation of the LSMOC will result in less severe ice conditions at the mouth compared to the Pre-Project condition, and thus reduce the likelihood of excessive ice-affected staging and potential flooding. The potential for ice to scour the lake bottom at the river mouth would also be reduced.

The winter outflow from the LSMOC will change the flow velocity in the vicinity of the outlet, which could influence ice formation processes. It is anticipated the LSMOC would be operated at low flows in the winter, with a maximum flow of 150 m^3/s imposed in the operating guidelines to promote the formation of a stable ice cover in the channel. Since the channel will form a solid ice cover, the volume of ice transported into Lake Winnipeg will be small. Thus, the potential for a severe hanging ice dam similar to that which forms at the mouth of the Dauphin River will be small. Changes to ice formation processes in the lake will therefore be affected mainly by the change in water velocity, which could result in thinner ice covers and/or open water leads within a few hundred meters of the shoreline (see Figure 17 for velocity contours at a LSMOC flow of 123.5 m^3/s).

The effect of the Project on ice processes further out in Sturgeon Bay and in the rest of Lake Winnipeg are expected to be negligible, as thermal ice growth and ridging from wind events are the dominant processes in these areas.

4.4 Travel Time of Water Through Lakes

Operation of the outlet channels will move water more quickly through the lakes. The potential change in travel time was computed as input to environmental assessments.

The travel times of water particles moving through the lakes along the preferential flow paths were computed from the two-dimensional model results presented in Section 3.3. These travel times are sensitive to the flow path selected, and represent very approximate lower bounds to the expected residence times of water particles in the lakes. The actual residence times would be affected by wind-induced currents, and advection of water through stagnant regions in the lakes. Thus, the residence times shown in the following tables are presented for comparative purposes only.

Travel times for water particles moving from the Waterhen River to the Fairford River, and from the LM Narrows to the LMOC inlet, are shown in Table 7. As shown, the differences at the 10th and 50th percentiles are relatively small or negligible. At the 90th percentile, the travel time from the Waterhen River to the Fairford River would increase from 132 days to 159 days because of the reduced flow through the Fairford River.

TABLE 7: TRAVEL TIMES IN LAKE MANITOBA

		Travel Time [days]	
Flow Path	**Condition**	**Pre-Project**	**Post-Project**
Waterhen River to Fairford River	10th percentile	682	682
Waterhen River to Fairford River	50th percentile	392	472
Waterhen River to Fairford River	90th percentile	132	159
LMB Narrows to LMOC	90th percentile	NA	57

Travel times for water particles moving from Fairford River to the Dauphin River and from the LMOC outlet to the LSMOC inlet are shown in Table 8. The Project has the effect of slightly reducing the travel times at the 50th and 90th percentiles due to the increased magnitude of flow through the lake.

TABLE 8: TRAVEL TIMES IN LAKE ST. MARTIN

		Travel Time [days]	
Flow Path	**Condition**	**Pre-Project**	**Post-Project**
Fairford River to Dauphin River	10th percentile	100	100
Fairford River to Dauphin River	50th percentile	57	50
Fairford River to Dauphin River	90th percentile	24	21
LMOC to LSMOC	90th percentile	NA	27

5.0 SUMMARY OF KEY ASSUMPTIONS

A number of assumptions were stated in the preceding sections, which were adopted to simplify the methodology to a level commensurate with the objectives of this study. The key assumptions are reiterated below, along with other sources of uncertainty which provide context to potential areas of future work.

- The wide range of possible flood and non-flood flow scenarios that could be experienced was simplified by considering the 10th, 50th, and 90th percentile conditions as simulated by MI's water balance model from the historical basin hydrology. In reality, each flood event that triggers operation of the outlet channels would have a slightly different system response compared to the Pre-Project scenario, depending on the shape of the inflow hydrograph, preceding conditions, and operation of the outlet channels.
- Wind forcing was excluded from the numerical modeling. This was adopted as a simplifying assumption to isolate the advection currents originating from the Project without alteration from wind effects. In reality, wind effects could change velocity patterns within the lakes and shift the zones of higher velocities emanating from the outlet channels. This was examined at the LSMOC outlet in Zuzek Inc. (2021) for a selection of storm events.
- There is some uncertainty in the model results stemming from a lack of data for calibration and verification of the numerical models, along with relatively sparse bathymetry in certain areas. One notable area where this is of particular interest is the Lake St. Martin Narrows, where model bathymetry is interpolated from limited survey data. Because of the flow constriction, hydraulic properties such as velocity and head loss are more sensitive to changes in bathymetry than other parts of the lake. Although the water levels in the south and north basins were calibrated to measured data from past flood events (see KGS Group, 2021), there remains some uncertainty in the simulated water velocities particularly in the Post-Project environment when the flow through the Narrows would exceed the historical range.
- The assessment of Project effects on lake ice processes were inferred from the velocity patterns simulated by the hydrodynamic model in a limited number of runs. Ice processes are dependent on complex interactions between hydraulic and meteorological conditions and require sophisticated models to capture the various processes at play. The present assessment is therefore qualitative and relatively general in its description of how changes in flow patterns might affect the lake ice.
- Effects of the Project on shoreline morphology in the vicinities of the inlets and outlets were largely extracted from other studies and reports (e.g. Zuzek Inc., 2020, 2021; JDMA, 2019). This study utilized findings of those studies, along with the broader scale flow patterns in the lakes, to qualitatively summarize potential impacts of the Project on shoreline morphology.
- Lake residence times were roughly estimated based on a simplified calculation of the travel time of water through the lakes. In reality, a wide range of residence times is possible; stagnant water in back bays will take more time to exit the system than water along the main flow path. More detailed analyses involving particle tracking in the numerical models could be used to obtain more precise predictions.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been made based on the analyses presented in this report:

- Operation of the outlet channels will occur during flood conditions and will reduce water levels in LM and Lake St. Martin. There is a greater reduction in water levels at the high percentiles compared to the lower percentiles.
- During operation of the outlet channels, the additional inflow and outflow locations will cause local changes to the flow patterns and velocities within the lakes. The effect of the Project on broad scale flow patterns within the lakes would be negligible.
- During non-operation of the outlet channels, the flow patterns in the Post-Project environment are very similar to the Pre-Project environment. Residual effects of operation of the outlet channels would result in slightly lower lake levels and river flows.
- During operation of the LSMOC, the water level differential between the south and north basins of Lake St. Martin would be increased, as would be the average velocity through the Narrows connecting the two basins. The changes to water velocity during flood events are expected to increase the size of sediment that can be eroded by the flow (from fine to coarse sand in the Pre-Project environment to medium gravel in the Post-Project environment). Simulated water velocities in the Post-Project environment remain below the erosion thresholds of coarse gravel, cobbles, and boulders.
- During storm events on LM and Lake St. Martin, the lower water levels for the Post-Project 90th percentile would transfer the zone of breaking waves further offshore and reduce the potential for beach and bank erosion. This would increase shoreline stability.
- With the construction of the LMOC, the water levels and flows in the Fairford River would decrease. Therefore, shoreline stability should increase at the Fairford River inlet and mouth.
- For the Dauphin River, future reductions in the Lake St. Martin water levels and flows at the 90th percentile would reduce erosion potential at the river inlet and increase shoreline stability.
- Negligible changes in the wave climate in Sturgeon Bay are expected for the Post-Project scenario and thus no measurable changes to erosion induced by waves and sediment transport are expected. Therefore, the LSMOC is not anticipated to affect the shoreline in Sturgeon Bay, other than trapping sand in small fillet beaches along the jetties of the outlet.
- Some localized scour of the lake bottom attributed to the increased water velocities near the LSMOC outlet may occur in the future, as current velocities during the peak channel discharge conditions exceed localized background rates during storms.
- Operation of the Project may cause local changes to ice formation processes. The changes will be limited primarily to the vicinities of the inlets and outlets of the rivers and outlet channels and the Lake St. Martin Narrows. The extent of open water areas is influenced by the stratification of lake water temperatures that enables the water at depth to remain above 0°C through the winter. In general, higher velocities at the Project inlets and outlets during winter operation would likely result in open water areas that last through the winter, or areas of reduced ice thickness. The corresponding reduction in flow through the Fairford and Dauphin Rivers will result in more uniform formation of the lake ice cover at the river inlets and outlets. The extent of open water areas and areas with reduced ice

thickness which currently occur at the constriction points in Lake St. Martin Narrows will likely increase in size during operation of the Project.

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