MANITOBA INFRASTRUCTURE

Lake St. Martin Head Loss Analysis Report

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Limitations

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1.0 INTRODUCTION

In support of the design of the Lake St. Martin Outlet Channel (LSMOC), KGS Group carried out an analysis of water surface profiles in Lake St. Martin using a two-dimensional hydrodynamic numerical model. The purpose of this analysis was to quantify the gradient of the water surface that occurs between the north and south basins of Lake St. Martin. This gradient (i.e. difference in water levels between the two basins) has been referred herein as the “head loss” between basins. The area where the head loss occurs has been named the Lake St. Martin Narrows. This area comprises of the entire portion of the lake that spans between the two basins.

Impacts of the estimated gradient through the lake on the hydraulic design of the LSMOC were identified and quantified. Various outputs from the numerical model, including velocities of flow between the two basins, were generated to support environmental assessments. This report summarizes the modelling completed and results of the analysis.

2.0 AVAILABLE DATA

The hydrometric data used for this analysis consisted of flows and water levels recorded by Water Survey of Canada (WSC) as well as data provided by MI. The following data was available:

- North basin water levels for 1995 and 2011 floods (provided by MI).
- North basin water levels from newly installed gauge 05LM803 from June 1, 2020 to August 11, 2020 (provided by MI).
- South basin water levels from 1966 to 2018 (from WSC gauge 05LM005).
- Fairford River flow from 1912 - 2018 (from WSC gauge 05LM001).
- Dauphin River flow from 1977 – 2018 (from WSC gauge 05LM006).

In addition to the hydrometric data listed above, MI also provided the results from their Excel-based flood routing numerical models:

- the initial model that represented Lake St. Martin as one contiguous water body (Feb 2020);
- a subsequent, more refined simulation with two separate basins (Nov 2020).

3.0 MODEL DEVELOPMENT

3.1 Numerical Model Software

The analysis was based on the application of the MIKE 21 software. This is a commercially available two-dimensional hydrodynamic modelling software package developed and marketed by the Danish Hydraulic Institute (DHI). MIKE 21 solves the depth-averaged 2D Navier-Stokes equations using a cell-centered finite volume solution technique in order to simulate flows in rivers, lakes, estuaries, bays, coastal areas, and overland flooding. MIKE 21 is adaptable for both small micro-type problems to large regional areas such as complete watersheds.

3.2 Digital Elevation Model

The Digital Elevation Model (DEM) that represents the lakebed and shoreline elevations of Lake St. Martin was developed using a combination of LiDAR data, sonar surveys and shoreline linework data. Specifically, the following data was used:

- Shoreline linework (including islands) at elevation 245.4 m (805.1 ft).
- Shoreline toe (offset at 15 m) at elevation 244.0 m (800.5 ft).
- North / South Consultants sonar survey (2017/2018).
- LiDAR (2011/2017)

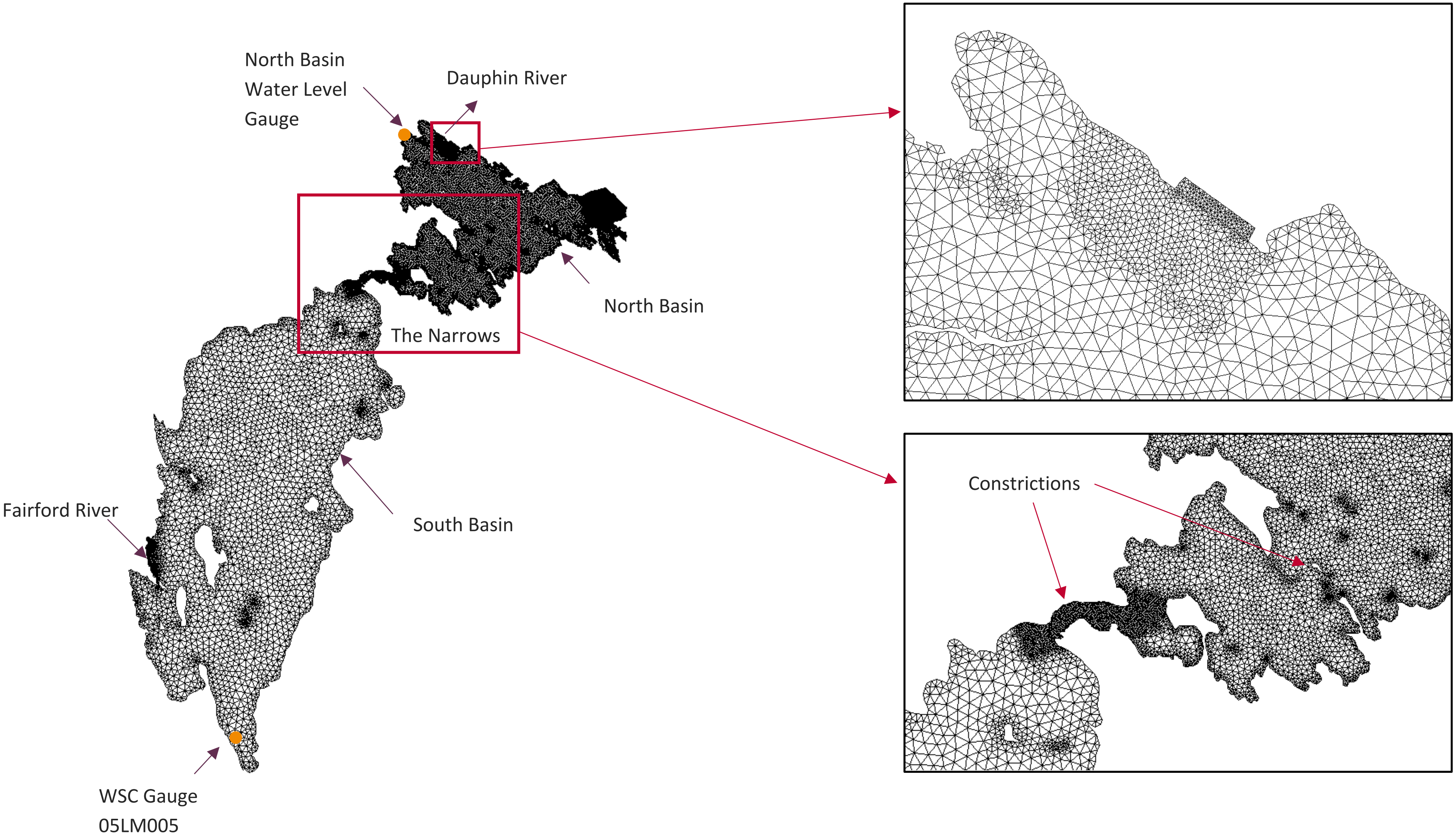
The shoreline for Lake St. Martin, including islands, was developed from available linework data and formed the basis for the outer boundary of the DEM. Once the shoreline boundary was established, bathymetric data from sonar surveys performed by North / South Consultants was added to establish the geometry for the lake bed and LiDAR data was added to establish lake shore elevations above the normal water level. This data was then interpolated to a 5 m grid to create a uniform DEM of the entire lake.

3.3 Development of Finite Element Mesh

A finite element mesh was developed for the entire extent of Lake St. Martin. The mesh was composed of triangular elements to best represent the irregular geometry of the lake. The mesh was designed such that the resolution throughout the model domain was variable. A finer mesh resolution was assigned to areas of interest, model inflow and outflow locations, areas of notable change in lake bed elevation, and any constrictions in the model domain, such as the Lake St. Martin Narrows. Mesh resolution was decreased as distance from regions of interest increased, so as to reduce computational time. The resulting mesh is shown on Figure 1. It should be noted that the Lake St. Martin Narrows refers to the entire portion of the lake that spans between the north and south basins. This area is shown on Figure 1 and includes two distinct constrictions.

Once the appropriate mesh sizing was established, the digital elevation data from the DEM was imported into the MIKE 21 model and interpolated into the mesh elements using the "natural neighbour interpolation technique".

FIGURE 1: FINITE ELEMENT MESH

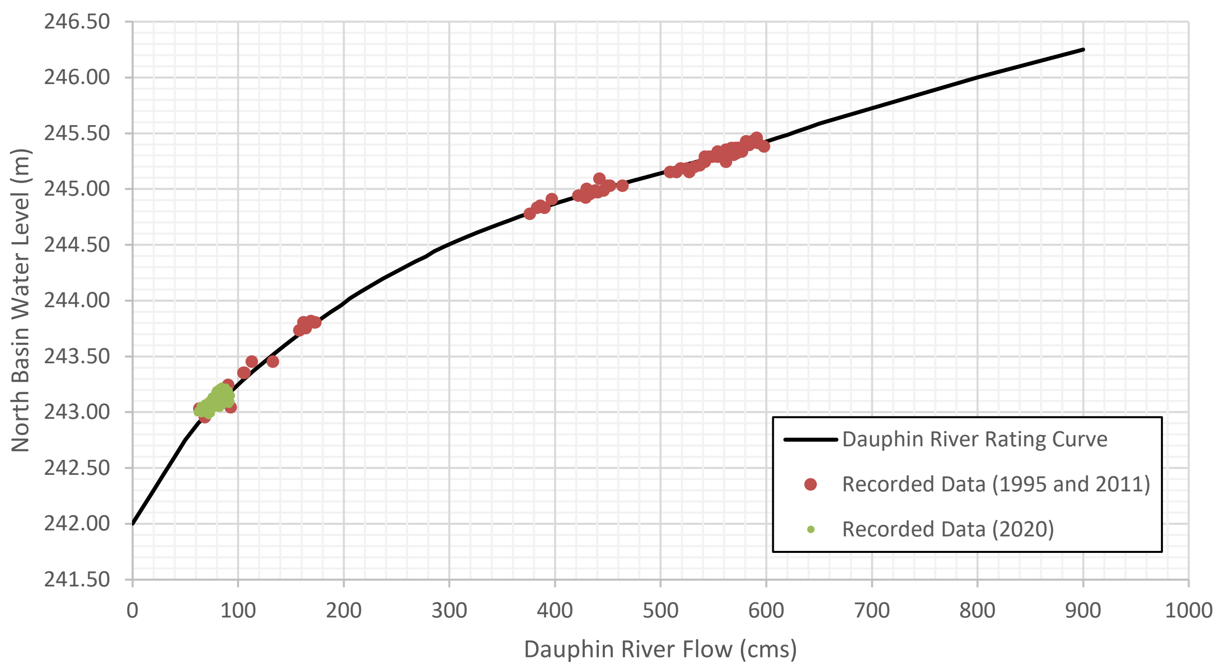


3.4 Boundary Conditions

The model had one inflow boundary, which was the Fairford River. Data for this boundary condition was taken from recorded hydrometric data at WSC gauge 05LM001.

The model had one outflow boundary, the Dauphin River, which was defined as a rating curve in the model. This rating curve for the Dauphin River at the Lake St. Martin outlet was developed from north basin observed water levels (provided by MI) and corresponding recorded flows in the Dauphin River (from WSC gauge 05LM006). This rating curve is shown on Figure 2.

FIGURE 2: DAUPHIN RIVER RATING CURVE



Since data for flows less than 60 m^3/s (2,100 cfs) was not available, the portion of the rating curve below this point was based on limited bathymetric data at the mouth of the river. That information was taken from a survey completed in June 2019 to support the analysis of the flow system comprising Lake Manitoba and Lake St. Martin. Based on the data, it was estimated that the elevation of the lake bottom at the mouth entering the Dauphin River is approximately El 242.0 m (794.0 ft). This elevation is lower than what had been previously assumed at the early stages of the study and will allow the model to represent the release of more flow into the Dauphin River when water levels in the north basin of Lake St. Martin are relatively low.

In June 2020, MI installed a water level gauge in the north basin of Lake St. Martin. To date, water levels measured between June 1, 2020 and August 11, 2020 have been extracted from that gauge. The recorded water levels, shown on Figure 2, were in good agreement with the estimated rating curve. Continued monitoring of water levels in the north basin of Lake St. Martin will provide additional data to verify the rating curve.

4.0 CALIBRATION AND VERIFICATION OF NUMERICAL MODEL

The model was calibrated using data from the 1995 and 2011 floods events. The key data included the following:

- The 1995 flood had a peak outflow of 190 m^3/s (6,700 cfs) to the Dauphin River and peak water levels of El 243.98 m (800.46 ft) and El 243.82 m (799.93 ft) in the South and North Basin, respectively.
- In the 2011 flood event, there was a peak outflow to the Dauphin River of 600 m^3/s (21,200 cfs) and peak water levels of El 245.53 m (805.54 ft) and El 245.40 m (805.12 ft) in the South and North Basin, respectively.

A number of simplifying assumptions were made during the calibration process. These assumptions are summarized below:

- Simulations were limited to the open water season, which was assumed to occur between April 15 and October 31 in any given year.
- Wind effects were not considered, although wind set up and set down may affect results. Instead, wind data from surrounding wind gauges and judgement was used to estimate wind eliminated water levels on the north and south basins.
- Precipitation and evaporation on the lake surface was not included, although could have a notable effect on water levels, particularly during large rainstorms such as the one that occurred in May 2011.
- Local runoff is estimated to be relatively small and was considered negligible.
- Manning's n-value is assumed to be constant throughout the model domain and was set to a value of 0.02, based on judgment.
- The model was started using steady state flow conditions that correspond to the first day of the simulation (April 15). The corresponding starting water levels for the north and south basins were computed by the model.

Simulated water levels and outflows were compared to observed values. Preliminary results indicated that the computed water levels were too high because the assumed inflow to the lake overly exceeded the recorded outflow. It was found that reducing the Fairford River inflow by 2% resulted in substantially better agreement between the simulated and recorded water levels. The Fairford River flow gauge is located upstream of Lake Pineimuta. As a result, it is believed that there would be a modest attenuation due to storage effects in Lake Pinemuta, and the reduction of 2% in the peak outflow from that lake is entirely reasonable.

The Manning's n-value in the Lake St. Martin Narrows was also adjusted in order to achieve good agreement between recorded and simulated water levels in the south basin, as well as good agreement between recorded and simulated head loss between the north and south basins. The Manning's n-value was increased to 0.025 in that area. The n-value rest of the domain remained at 0.020.

Model results for each of the two floods are summarized in the following sub-sections.

4.1 Results of Calibration for the Flood of 1995

Comparison of simulated and observed data for the north basin, south basin, and Dauphin River for the flood of 1995 are shown on Figures 3 to 5. Overall, there is good agreement between the observed and simulated data. It is apparent from the results that water levels and flows on the falling limb of the flood hydrograph are slightly underestimated. This is due to the fact that the observed outflow rating curve is slightly higher on the falling limb than the rising limb. In the model, the same outflow rating curve was used for the entire duration of the simulation and thus, levels and flows on the falling limb are slightly underestimated. The average differential in water level between the north and south basins (herein referred as the "head loss") for this flood was computed to be approximately 10 cm.

FIGURE 3: COMPARISON OF SIMULATED AND OBSERVED WATER LEVELS IN NORTH BASIN – 1995 FLOOD

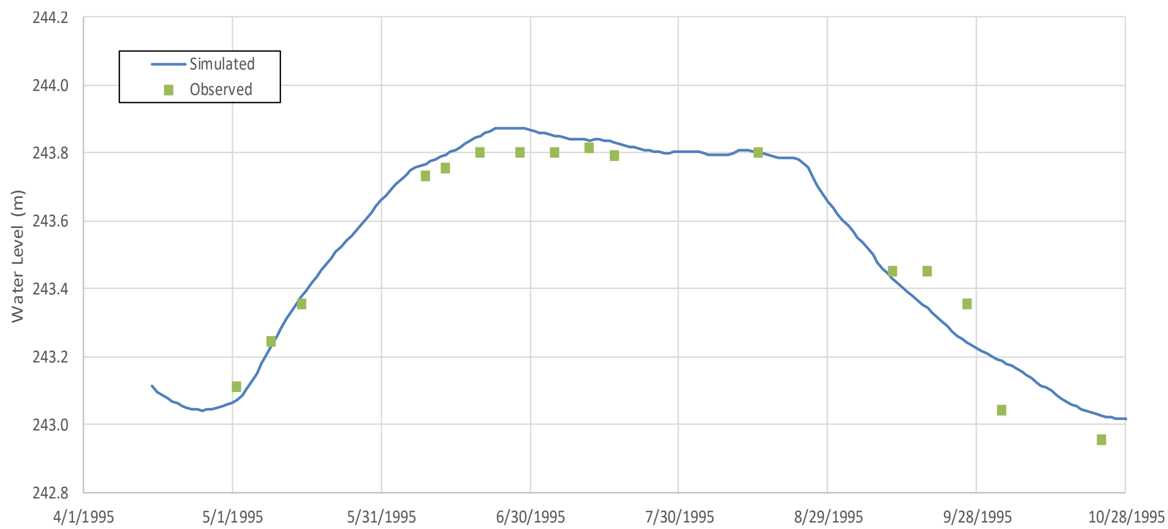


FIGURE 4: COMPARISON OF SIMULATED AND OBSERVED WATER LEVELS IN SOUTH BASIN – 1995 FLOOD

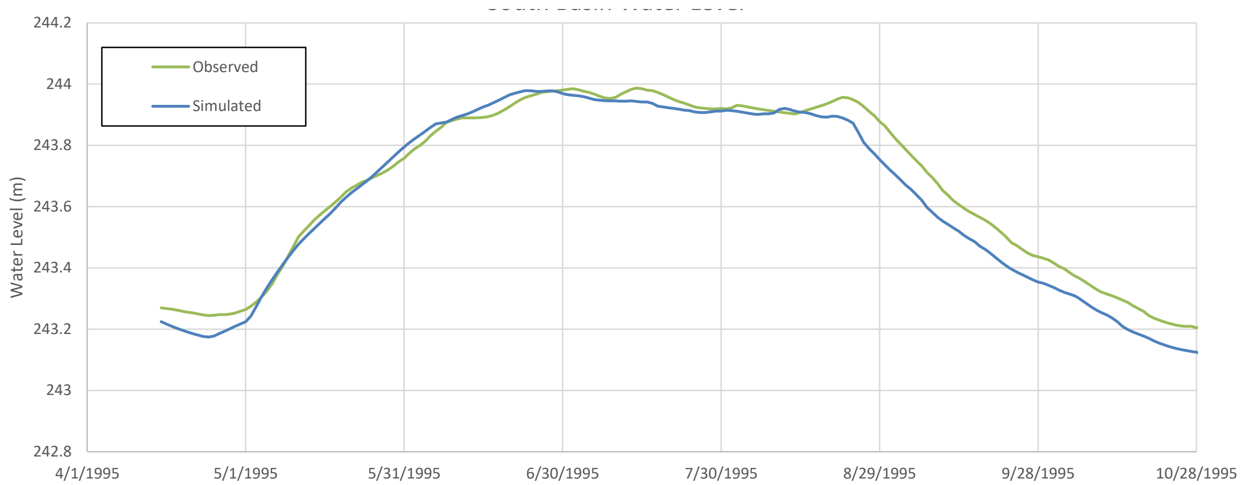
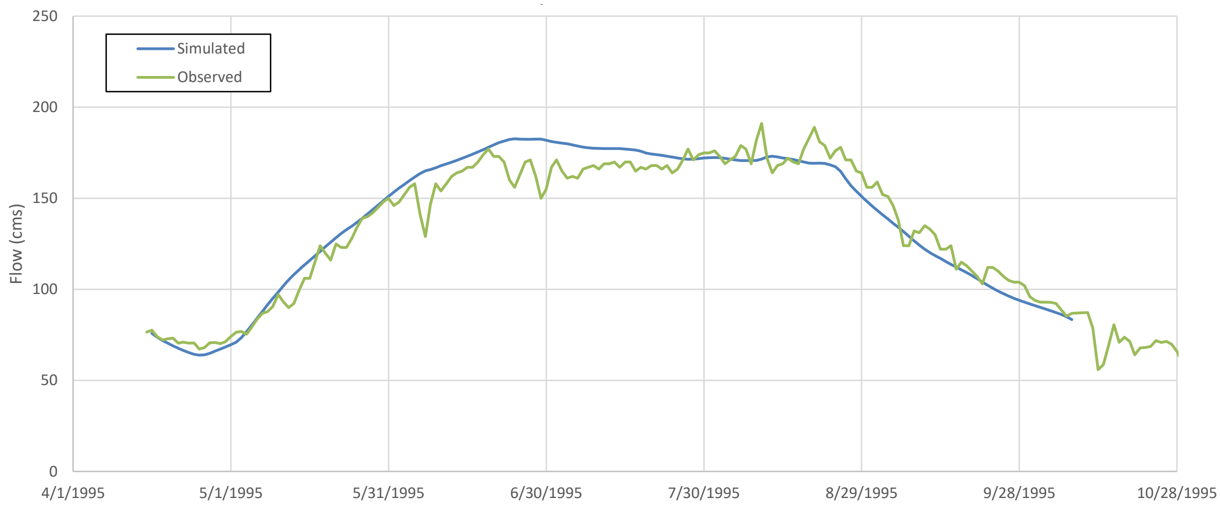


FIGURE 5: COMPARISON OF SIMULATED AND OBSERVED FLOWS IN DAUPHIN RIVER – 1995 FLOOD



4.2 Results of Calibration for Flood of 2011

Comparison of simulated and observed data for the north basin, south basin, and Dauphin River for the 2011 flood evant are shown on Figures 6 to 8. Overall, there is good agreement between the observed and simulated data. It is apparent from the results that water levels and flows on the rising limb of the hydrograph are being underestimated by the model. This is most likely attributed to the fact that large rainstorms occurred in May 2011, with approximately 10 cm of precipitation. Since the model does not consider precipitation directly on the lake nor runoff from the local catchment, it would be expected to underestimate water levels and flows during this time. The average head loss between the north and south basins for this flood was approximately 11 cm, and could be explained by the precipitation.

FIGURE 6: COMPARISON OF SIMULATED AND OBSERVED WATER LEVELS IN NORTH BASIN – 2011 FLOOD

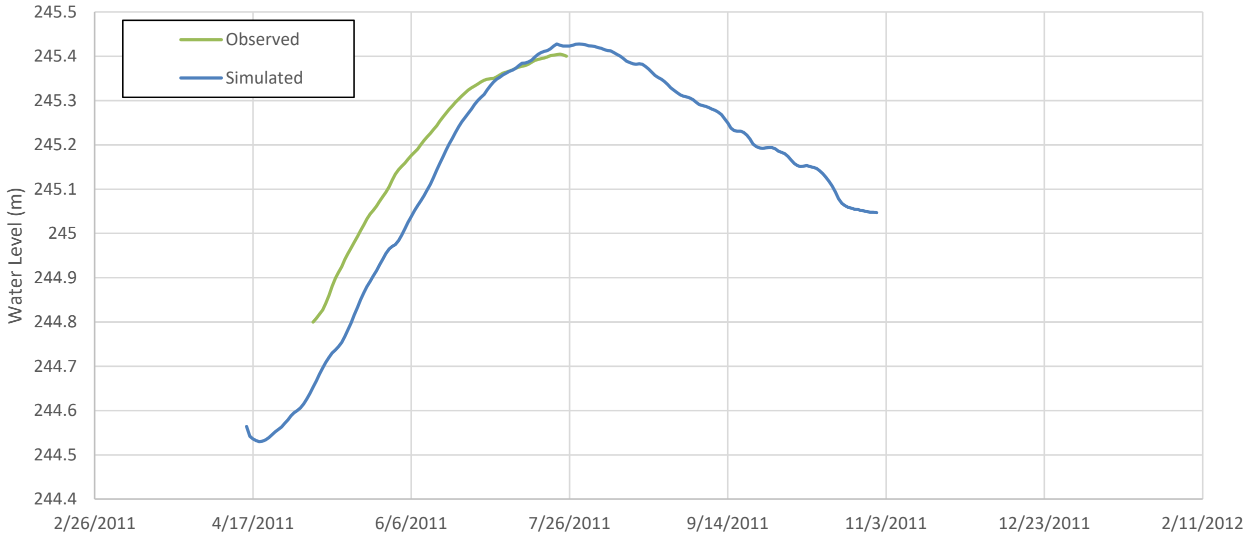


FIGURE 7: COMPARISON OF SIMULATED AND OBSERVED WATER LEVELS IN SOUTH BASIN – 2011 FLOOD

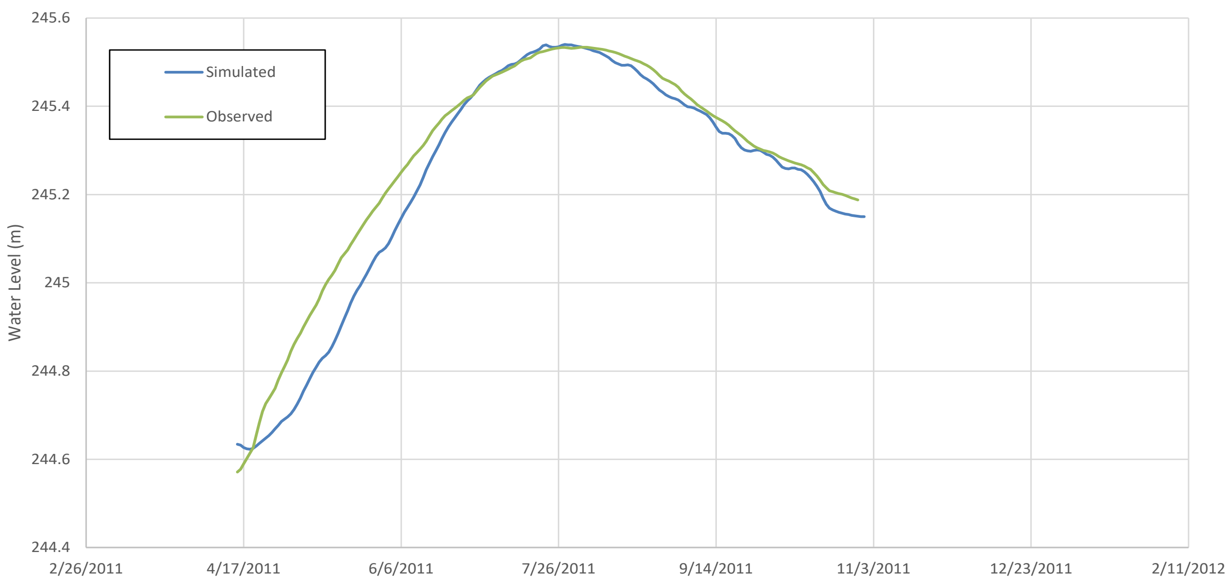
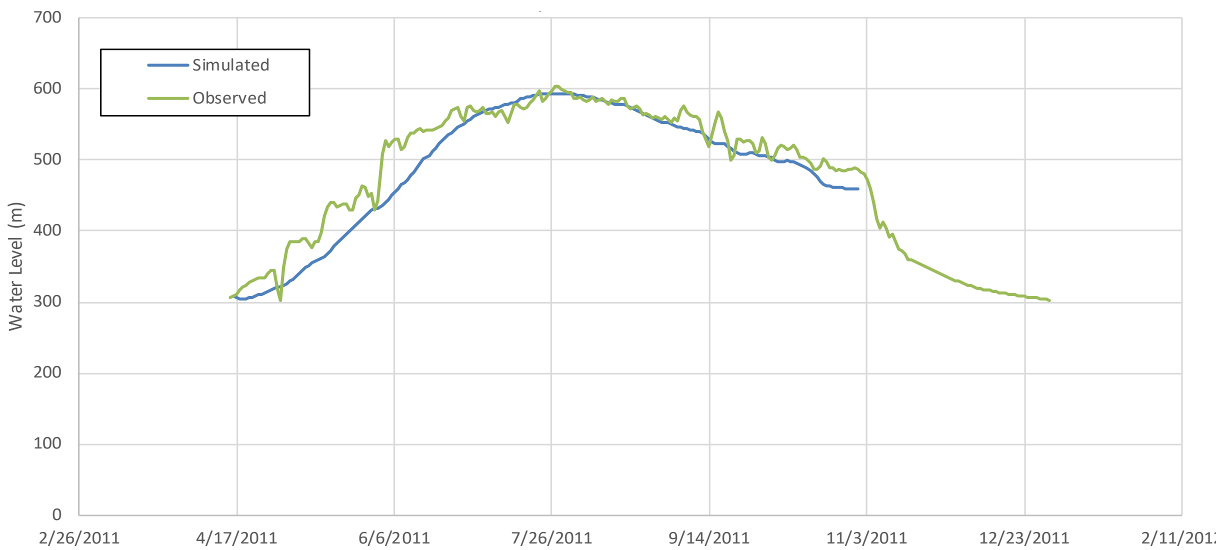


FIGURE 8: COMPARISON OF SIMULATED AND OBSERVED FLOWS IN DAUPHIN RIVER – 2011 FLOOD



4.3 Model Verification

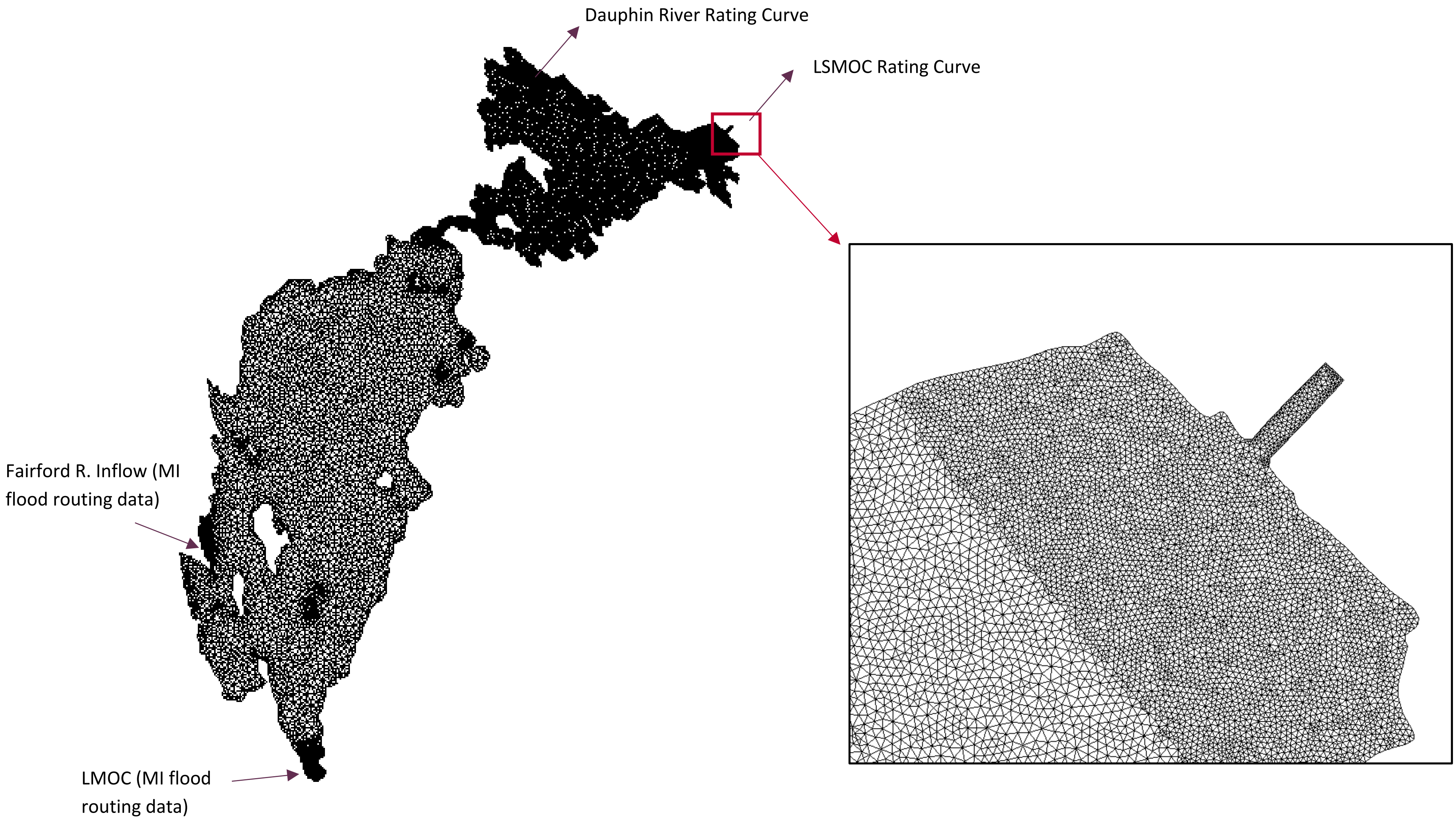
The results of the calibration for the flood events of 1995 and 2011 demonstrate that the numerical model has been verified and is suitable for estimating water levels and water surface gradients for other flood events.

5.0 SIMULATION OF OPERATIONAL SCENARIOS

Subsequent to the calibration and verification of the numerical model, simulations were undertaken to estimate water levels and head losses for the post-construction operational scenarios. The lakebed geometry in the calibrated model was first adjusted to represent post-construction conditions. This included the addition of the LSMOC inlet geometry and a small portion of the proposed Lake St. Martin Outlet Channel (LSMOC), as well as adding an additional inflow boundary condition for the LMOC and an outflow boundary for the LSMOC. A schematic for the post construction condition is shown on Figure 9.

A 1 m DEM for the channel and inlet area was developed using the proposed channel geometry and incorporated into the existing DEM.

FIGURE 9: POST CONSTRUCTION MODEL SET UP



The post construction model was then used to simulate a typical operation scenario that occurs approximately 1 in every 7 years. This scenario requires that the LSMOC channel conveys a flow of 326 m^3/s (11,500 cfs) when the south basin water level is 244.14 m (801.0 ft). An operational scenario that represents the 2011 flood of record was also simulated. The 2011 flood was estimated to have a return period of approximately 1:300 years. This event corresponds to the design condition for the Lake Manitoba and Lake St. Martin system that must be accommodated by the outlet channels, in accordance with Manitoba's flood protection commitments. Model inflows for the Fairford River and the LMOC were taken from MI's flood routing model (Feb 2020). Rating curves were used to define outflows for the Dauphin River and LSMOC, which vary depending on the water levels in the south and north basins of Lake St. Martin.

The model was simulated using the Preliminary Design geometry and channel rating curve for the LSMOC. However, model results indicated that when the channel outflow reached 326 m^3/s (11,500 cfs), the water level in the south basin was computed to be El 244.43 m (801.94 ft) which exceeded the target lake level of El 244.14 m (801.0 ft). As a result, additional simulations were completed with iterative adjustments to the LSMOC inlet geometry and outflow rating curve until the target lake level was met. Five simulations were completed, and the results of each simulation are summarized in Table 1.

Based on the runs completed, it is estimated that when the LSMOC would be conveying the typical operation flow of 326 m^3/s (11,500 cfs) and the water level in the south basin would be at its target water level of El 244.14 m (801.0 ft), the water level in the north basin would be at El 243.18 m (797.84 ft), resulting in 0.96 m of head loss between the two. It should be noted there was not a simulation within the five runs that resulted in an exact match to the target lake level and the true simulation lies between Run 4 and Run 5. Results shown for the most accurate simulation were therefore estimated by linearly interpolating between the results of Run 4 and Run 5.

TABLE 1: SUMMARY OF POST CONSTRUCTION SIMULATIONS

Run	Description	LSM Water Level when LSMOC Outflow = 326 m^3/s (11,500 cfs)		Head Loss
		North Basin	South Basin	
1	Preliminary Design LSMOC geometry and rating curve	243.88 m (800.13 ft)	244.43 m (801.94 ft)	0.56 m (1.81 ft)
2	Preliminary design geometry. Preliminary design rating curve was lowered by 0.45 m	243.69 m (799.51 ft)	244.33 m (801.61 ft)	0.65 m (2.10 ft)
3	Preliminary design geometry. Preliminary design rating curve was lowered by 1.85 m	243.61 m (799.25 ft)	244.29 m (801.48 ft)	0.68 m (2.23ft)
4	Revised geometry and revised geometry rating curve	243.42 m (798.62 ft)	244.24 m (801.31 ft)	0.82 m (2.69 ft)
5	Revised geometry. Revised rating curve lowered by an additional 0.5 m	243.04 m (797.38 ft)	244.08 m (800.79 ft)	1.04 m (3.41 ft)
Final Adjusted Condition	Linear interpolation of simulation between Runs 4 and 5	243.18 m (797.84 ft)	244.14 m (801.0 ft)	0.96 m (3.41 ft)

The results for Run 5 described above were compared to MI's initial flood routing model results (Feb 2020) and are shown on Figures 10 to 12. This comparison indicated that the outflows in the Dauphin River estimated by the MIKE 21 model were notably lower than those estimated by the initial flood routing model. This was attributed to the fact that the initial flood routing model did not account for head loss between the north and south basins of Lake St. Martin and therefore overestimated water levels in the north basin. Since Dauphin River outflows were calculated based on a rating curve, an overestimation of water levels in the north basin would also lead to an overestimation of outflows into the Dauphin River.

Another notable difference between the two models was the implementation of an operating regime for the Lake St. Martin Outlet Channel. The operating regime affects the water level in the north basin, as well as the outflow split between the Dauphin River and the Lake St. Martin Outlet Channel. The MIKE 21 model assumed that Lake St. Martin water control structure was fully open for the entire simulation. The proportion of flow discharged through the LSMOC was increased due to the revision of the channel geometry and outflow rating curve to acknowledge and replicate the head loss through the Lake St. Martin Narrows.

Given that MI's flood routing model was not able to accurately predict water levels in the north basin, KGS Group recommended that the model be updated to a 2-basin model that considers head loss between the north and south basins. This recommendation was carried out by MI and is further described in Section 6.0.

FIGURE 10: COMPARISON OF MIKE 21 AND INITIAL FLOOD ROUTING MODELS – DAUPHIN RIVER OUTFLOW

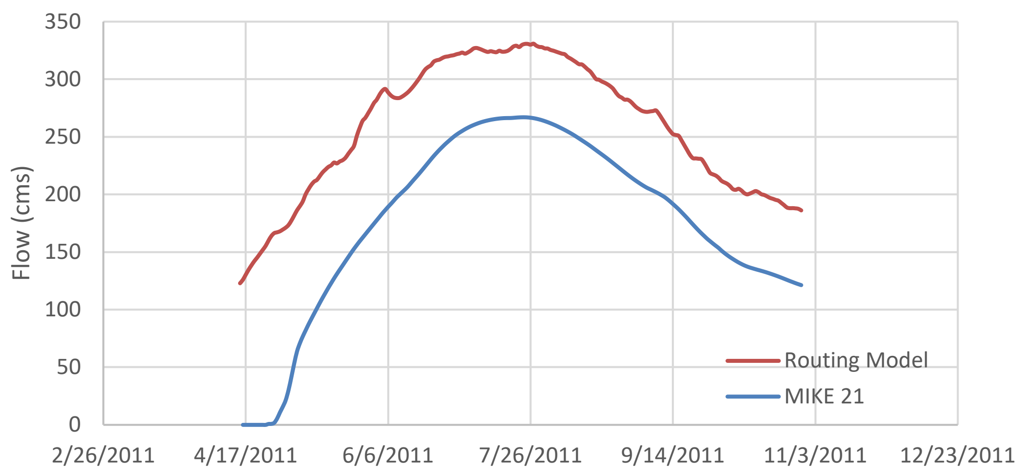


FIGURE 11: COMPARISON OF MIKE 21 AND INITIAL FLOOD ROUTING MODELS – LAKE ST. MARTIN OUTLET CHANEL OUTFLOW

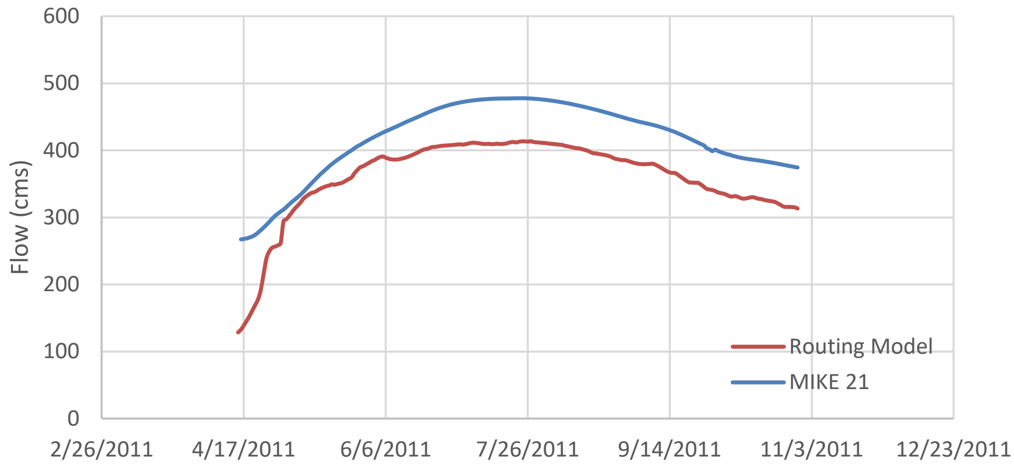
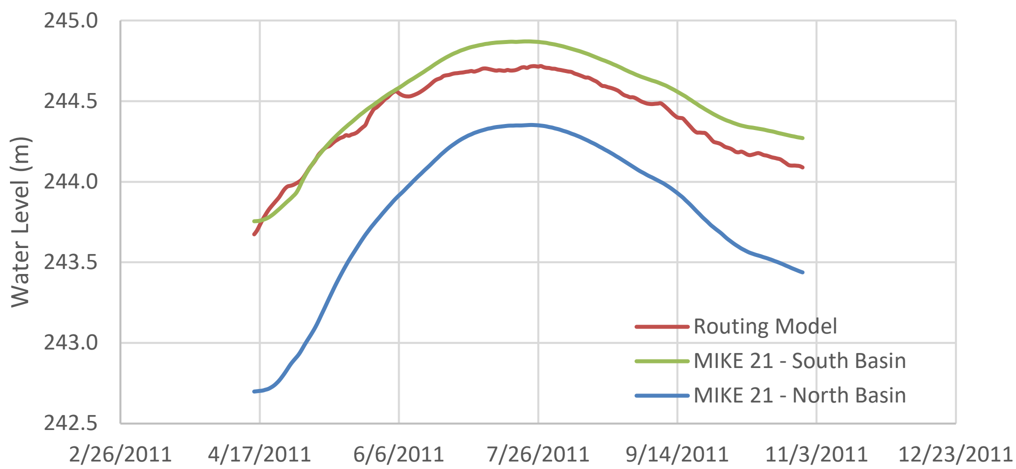


FIGURE 12: COMPARISON OF MIKE 21 AND INITIAL FLOOD ROUTING MODELS – LAKE ST. MARTIN WATER LEVELS



The changes to the rating curve of the LSMOC that were found to be required to suit the operational scenarios for Lake St. Martin are further described in Section 6. Necessary modifications to the geometry of the LSMOC to correspond to these revised rating curves are summarized in Section 8.

6.0 UPDATES TO FLOOD ROUTING MODEL

As discussed in Section 5.0, MI's one basin flood routing model was not able to accurately predict water levels in the north basin and outflows from the lake because it did not take into account the head loss between the north and south basins. As a result, MI updated their flood routing model to a two-basin model that estimated the head loss between the two basins using a family of rating curves and incorporated the most recent estimate of the LSMOC rating curves.

6.1 Family of Rating Curves for North and South Basins of Lake St. Martin

6.1.1 DEVELOPMENT OF RATING CURVES

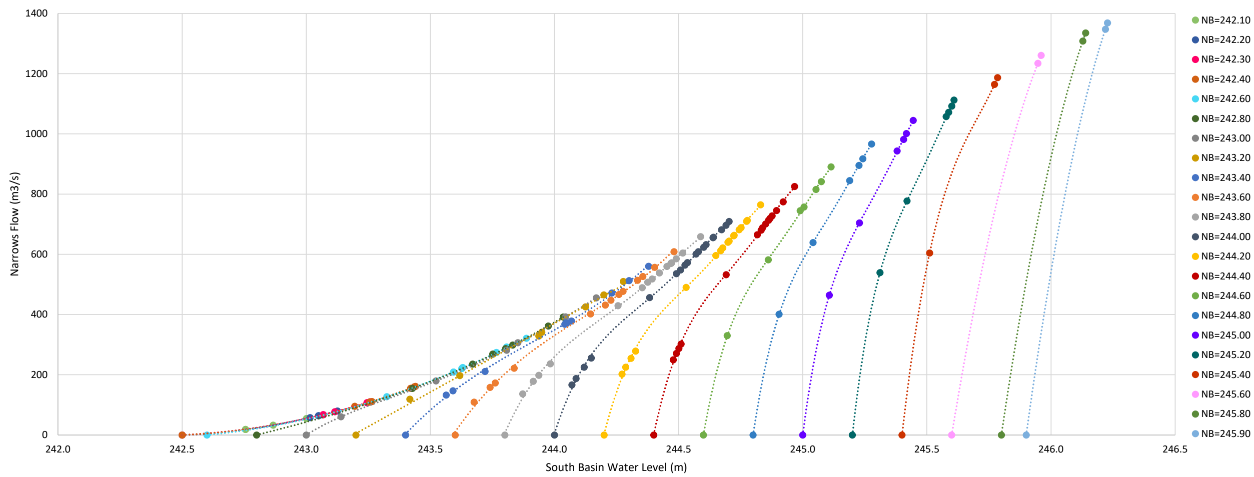
The family of rating curves for the north and south basins of Lake St. Martin was derived from the results of hydrodynamic simulations performed using the MIKE 21 model of Lake St. Martin. A range of flows from 1 m^3/s up to approximately 1350 m^3/s were simulated at the Narrows using various inflow hydrographs. These hydrographs were a combination of data from recorded floods, as well as fabricated hydrographs developed to fill in any remaining flow ranges. The model uses these flow inputs, along with the rating curves developed for the Dauphin River and LSMOC, to compute water levels in the north basin and south basin. These levels ranged between El 242.4-245.9 m and El 242.5-246.2 m, for the north and south basin, respectively.

The data collected from each simulation was compiled and rating curves were developed to formulate a relationship between the flow through the Narrows and the corresponding south basin water level for the range of north basin water levels noted above. Trendlines were fit to the rating curve data, as shown on Figure 13. "NB" in the legend of this figure indicates "north basin". These equations corresponding to these trendlines were then used to interpolate values to populate a look-up table that MI programmed into their flood routing model. The look-up table is included in Appendix A.

Data from both the rising and falling limb of the simulated hydrographs were used to generate the trendlines, although it is expected that there would be slightly different rating curves for the rising and falling limbs. Generally, the trendlines fit the data very well and suggest that the difference between the rising and falling limbs is negligible.

It should be noted that the lowest point on the curve for the south basin was based on available bathymetric data through the Narrows. The data suggests that the controlling invert elevation in the shallowest part of the Narrows is approximately El 242.5 m (795.6 ft). Continued monitoring of water levels in the south and north basins of Lake St. Martin will provide additional data to verify the family of rating curves.

FIGURE 13: FAMILY OF RATING CURVES



6.1.2 EXTRAPOLATION OF RATING CURVES

The trendlines shown in Figure 13 have been based on discrete data points and flows and water levels beyond these points have not been defined with certainty. Consequently, extrapolation of the trendlines shown on Figure 13 is not recommended.

6.1.3 WINTER RATING CURVES

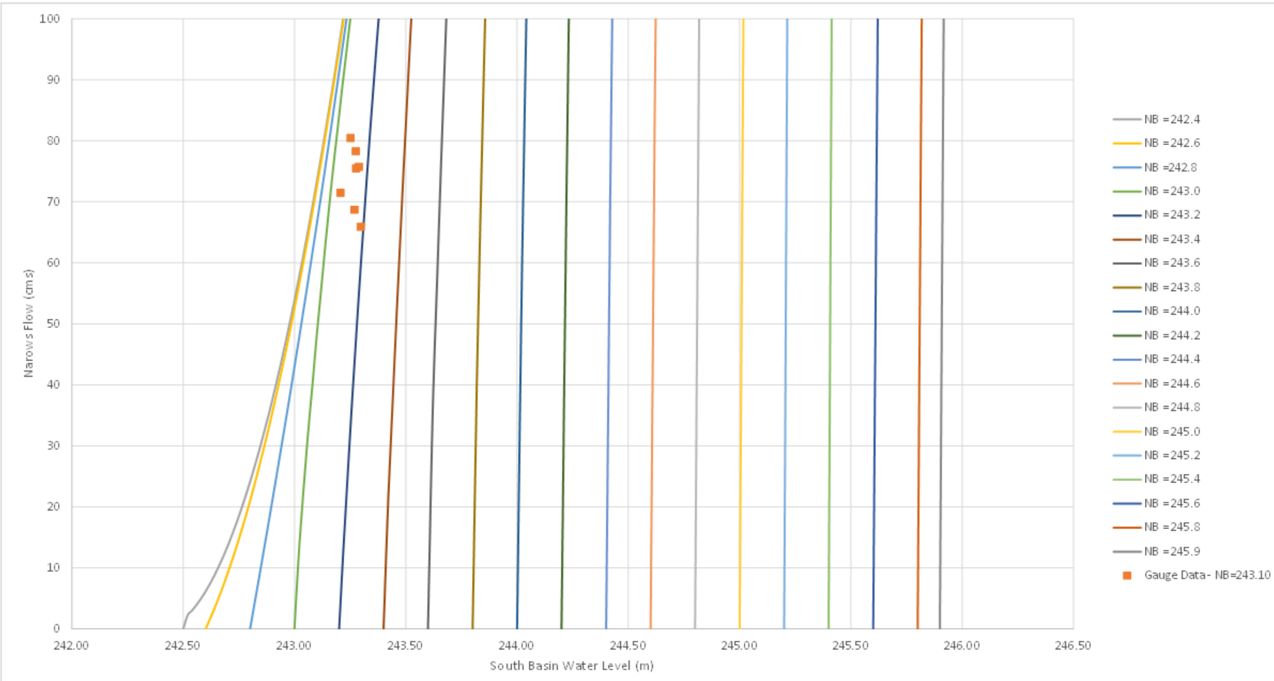
During winter, natural formation of ice in the Dauphin River as well as anticipated ice formations in the LMOC and LSMOC will reduce how much flow is conveyed through the system. Similar flow reductions are also expected through the Lake St. Martin Narrows.

KGS Group has not carried out analyses on the effects of winter conditions on the rating curves through the Narrows. To represent the impact of ice on the flow through the Narrows, MI has applied a flow reduction in winter to the summer rating curves. This adjustment was estimated through the model calibration process. The simulated results in winter fit the historic data relatively well during the periods addressed through the calibration. It is considered unlikely that different assumptions on winter effects would change the potential impacts of the LSMOC project on the Dauphin River, or affect the design of the LSMOC. Therefore, based on discussions with MI, further analyses to refine estimates of the effects of winter conditions at the Narrows were not undertaken at this time.

6.1.4 COMPARISON OF GAUGE DATA TO FAMILY OF RATING CURVES

As stated in Section 2.0, MI has installed a water level gauge in the north basin of Lake St. Martin. Water levels from this gauge between June 1, 2020 and August 11, 2020 was compared to the family of rating curves shown on Figure 13. The gauge data during this period indicated that water levels in the north basin ranged from El 243.0 m (797.2 ft) to El 243.2 m (797.9 ft). The corresponding flow through the Narrows was approximated by averaging the Dauphin River Flow and Fairford River flow on a given day. On Figure 14 (which is a copy of Figure 13, but with a truncated y-axis scale), points corresponding to north basin = El 243.1 m (797.6 ft) have been inserted on the family of rating curves. It is evident that all of these points fall between the lines between NB=El 243.0 m (797.2 ft) and NB=El 243.2 m (797.9 ft). This indicates good agreement between the measured data and the family of rating curves that was developed. It should be noted that these points do not fall in a defined line. This is likely due to various sources of error, such as approximating the flows through the Narrows and not accounting for environmental factors such as precipitation, local runoff, and wind effects. As detailed design of the channels progress, this analysis will be expanded as a larger range of data becomes available to further verify modeling results.

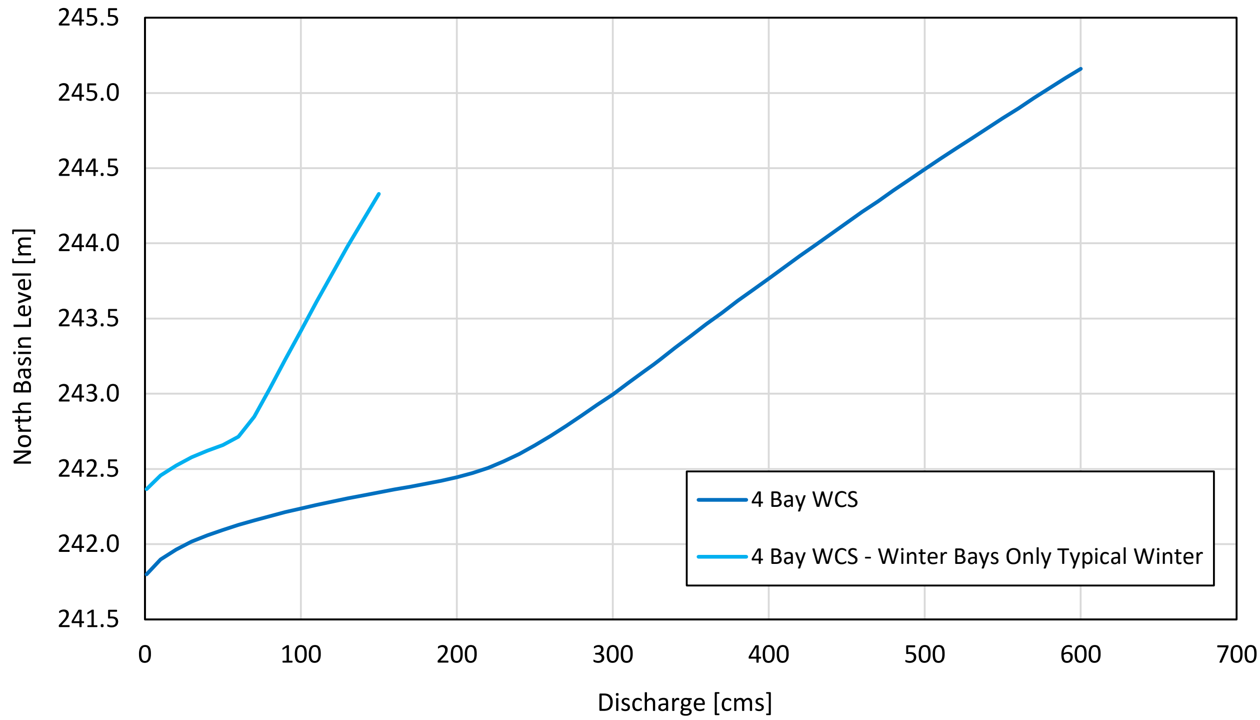
FIGURE 14: COMPARISON OF GAUGE DATA TO FAMILY OF RATING CURVES



6.2 Updates to the LSMOC Rating Curves

Based on the preliminary findings of the head loss assessment, as described in Section 5.0, and considering the various modifications for the LSMOC design, as described in Section 6.0 (elaboration on these changes is further described in Section 8), updated LSMOC rating curves were developed for input into the flood routing model. These are shown on Figure 15.

FIGURE 15: LSMOC RATING CURVE – 4 BAY WATER CONTROL STRUCTURE



6.3 Refinements to Operating Guidelines

As described in Section 5.0, preliminary flood routing results with the 1-basin model indicated that when water levels in the north basin of Lake St. Martin were low and the LSMOC was in operation, most of the discharge was simulated to be conveyed by the LSMOC, resulting in a Dauphin River outflow approaching zero. To mitigate this risk, MI proposed a change to the operating guidelines in their 2-basin flood routing model to allow for a gradual increase in discharge at initial operation of the LSMOC. This change moderates the sudden drawdown of the north basin, which would be highly responsive to changes in flow. It would ultimately minimize the occurrence of low flows in the Dauphin River that were first estimated.

The proposed change to the operating guidelines was tested with the updated two-basin flood routing model for the period of 1915 - 2017. In summary, the results indicated that the risk of low Dauphin River flows could be successfully managed with the operating guidelines while maintaining the flood reduction benefits of the project. Further optimization of the operating guidelines should consider final design of the outlet channels, stakeholder input and the environment. Details of MI's hydrological analysis that incorporate the effects of the Narrows on Lake St. Martin are available in a separate technical memorandum (MI, Nov 2020).

6.4 Updated Simulation Results from MI's Routing Model

MI updated their single basin routing model to reflect the changes described in the previous section of this report, including:

- Transitioning from a single basin model to a two-basin model so that the north and south basins could be modelled independently. The family of rating curves was used to estimate water level difference between the two basins.
- Updates to the winter rating curves.
- Updates to the operational procedures.

Similar to the initial routing model, the results computed by the updated routing model were compared to the MIKE 21 results for Run 5 (the details of the Run 5 simulation are described in Section 5.0). These comparisons are shown on Figures 16-18. Overall, the results show that the updated routing model is good agreement with the MIKE 21 results. However, there is a notable difference in the computed water levels and flows during the rising limb of the hydrographs. This can be attributed to differences in assumptions made regarding the operation of the channel. As mentioned previously, The MIKE 21 model assumed that Lake St. Martin water control structure was fully open for the entire simulation. When lake levels are very low, this resulted in essentially all lake outflows being discharged through the Lake St. Martin Outlet Channel and Dauphin River outflows were nearly zero. This was an appropriate assumption based on the intended use of this model, which was to confirm head loss between the north and south basins and evaluate the capacity of the channel. Conversely, the routing model incorporates the various operating procedures and therefore considered partial gate openings at the beginning of the freshet period.

Another factor that contributes to the large discrepancies in the first two weeks of the simulation is the use of winter rating curves. The routing model incorporates winter rating curves from December 1 to April 30, which affect the outflows from the model. The MIKE 21 model was not developed to consider winter conditions and therefore assumes an open water rating curve for the entire simulation.

FIGURE 16: COMPARISON OF MIKE 21 AND UPDATED FLOOD ROUTING MODELS – DAUPHIN RIVER OUTFLOW

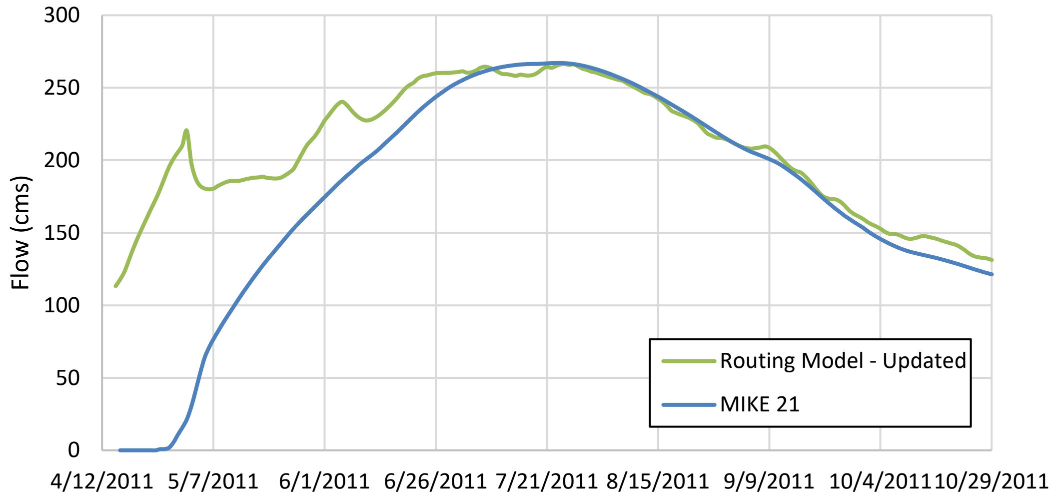


FIGURE 17: COMPARISON OF MIKE 21 AND UPDATED FLOOD ROUTING MODELS – LAKE ST. MARTIN OUTLET CHANEL OUTFLOW

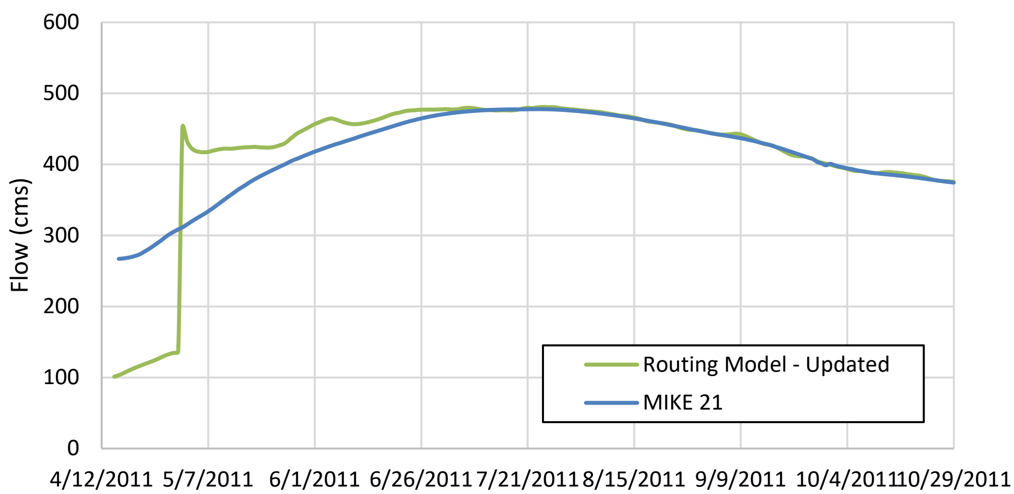
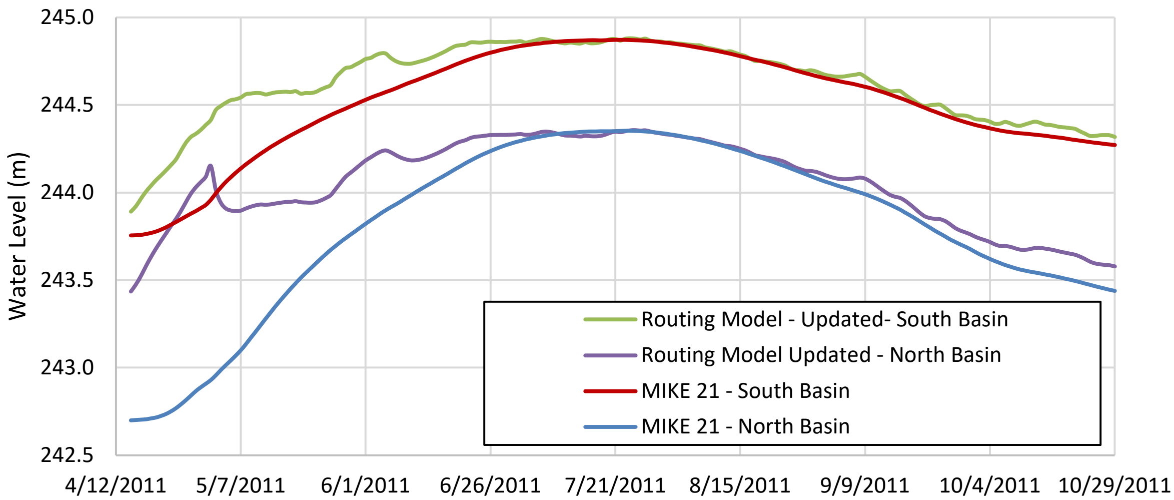


FIGURE 18: COMPARISON OF MIKE 21 AND UPDATED FLOOD ROUTING MODELS – LAKE ST. MARTIN WATER LEVELS



7.0 SELECT MODEL RESULTS TO SUPPORT INFORMATION REQUESTS

MI has requested outputs from model results of various flow conditions. Their objective is to support responses to various Information Requests regarding velocities of flow through the Lake St. Martin Narrows. These scenarios are as follows:

- ***Scenario 1*** – 2011 maxium flow through the Narrows under existing conditions
    - Flow through the Narrows = 595 m^3/s (21,00 cfs)
    - South Basin Water Level = 245.50 m (805.45 ft)
    - North Basin Water Level = 245.39 m (805.09 ft)
- ***Scenario 2*** – 2011 maxium flow through the Narrows under post construction conditions
    - Flow through the Narrows = 745 m^3/s (26,300 cfs)
    - South Basin Water Level = 244.87 m (803.38 ft)
    - North Basin Water Level = 244.35 m (801.67 ft)
- ***Scenario 3*** – Typical Operational Scenario under existing conditions
    - Flow through the Narrows = 213 m^3/s (7,500 cfs)
    - South Basin Water Level = 244.14 m (801.0 ft)
    - North Basin Water Level = 244.04 m (800.66 ft)
- ***Scenario 4*** – Typical Operational Scenario under post construction conditions
    - Flow through the Narrows = 435 m^3/s (15,400 cfs)
    - South Basin Water Level = 244.14 m (801.0 ft)
    - North Basin Water Level = 243.10 m (797.57 ft)

Each of the scenarios is shown graphically on Figures 19 to 22. Velocities shown are vertically averaged values at each location.

FIGURE 19: FLOW VELOCITY THROUGH NARROWS – SCENARIO 1

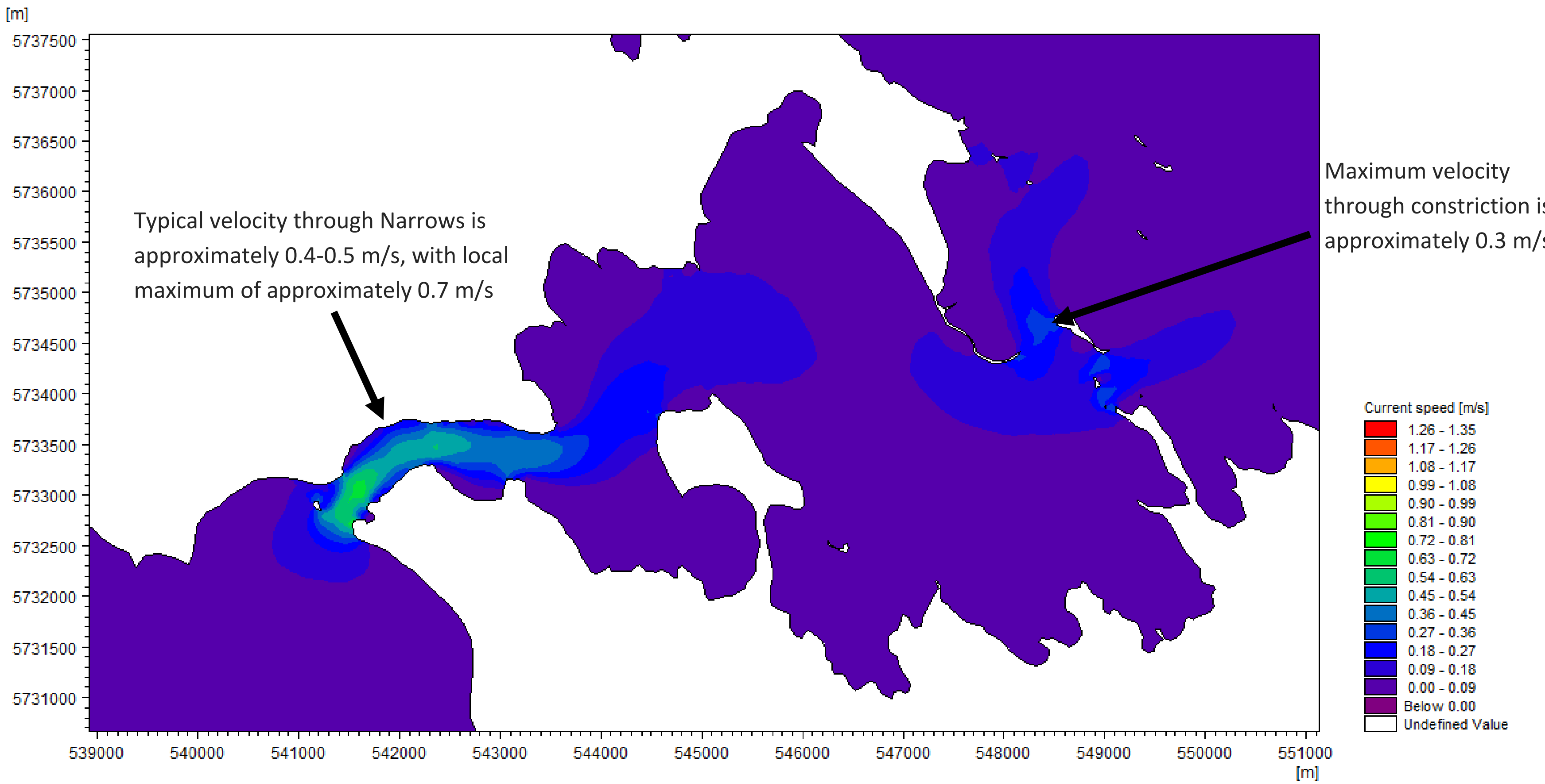


FIGURE 20: FLOW VELOCITY THROUGH NARROWS – SCENARIO 2

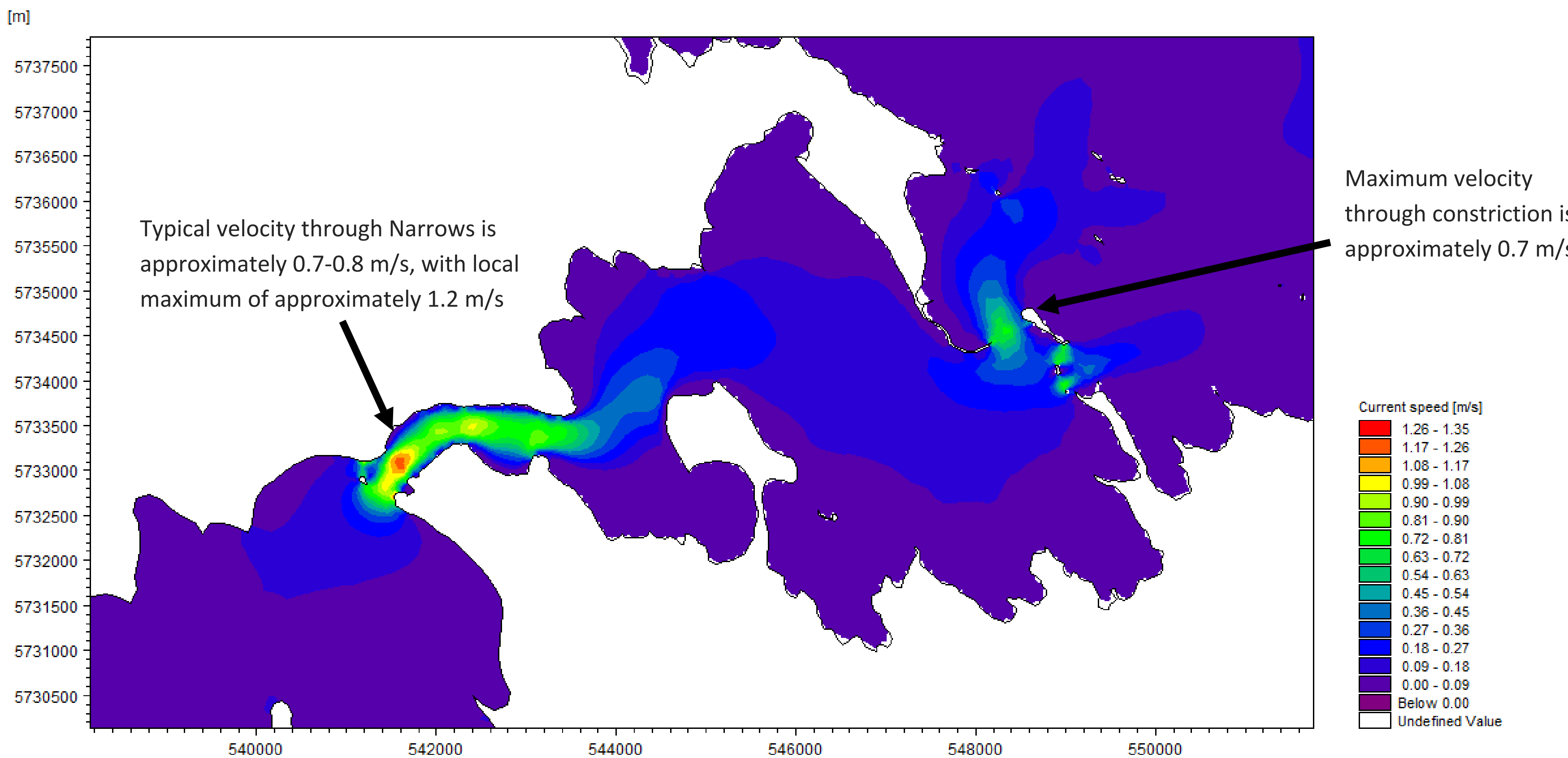


FIGURE 21: FLOW VELOCITY THROUGH NARROWS – SCENARIO 3

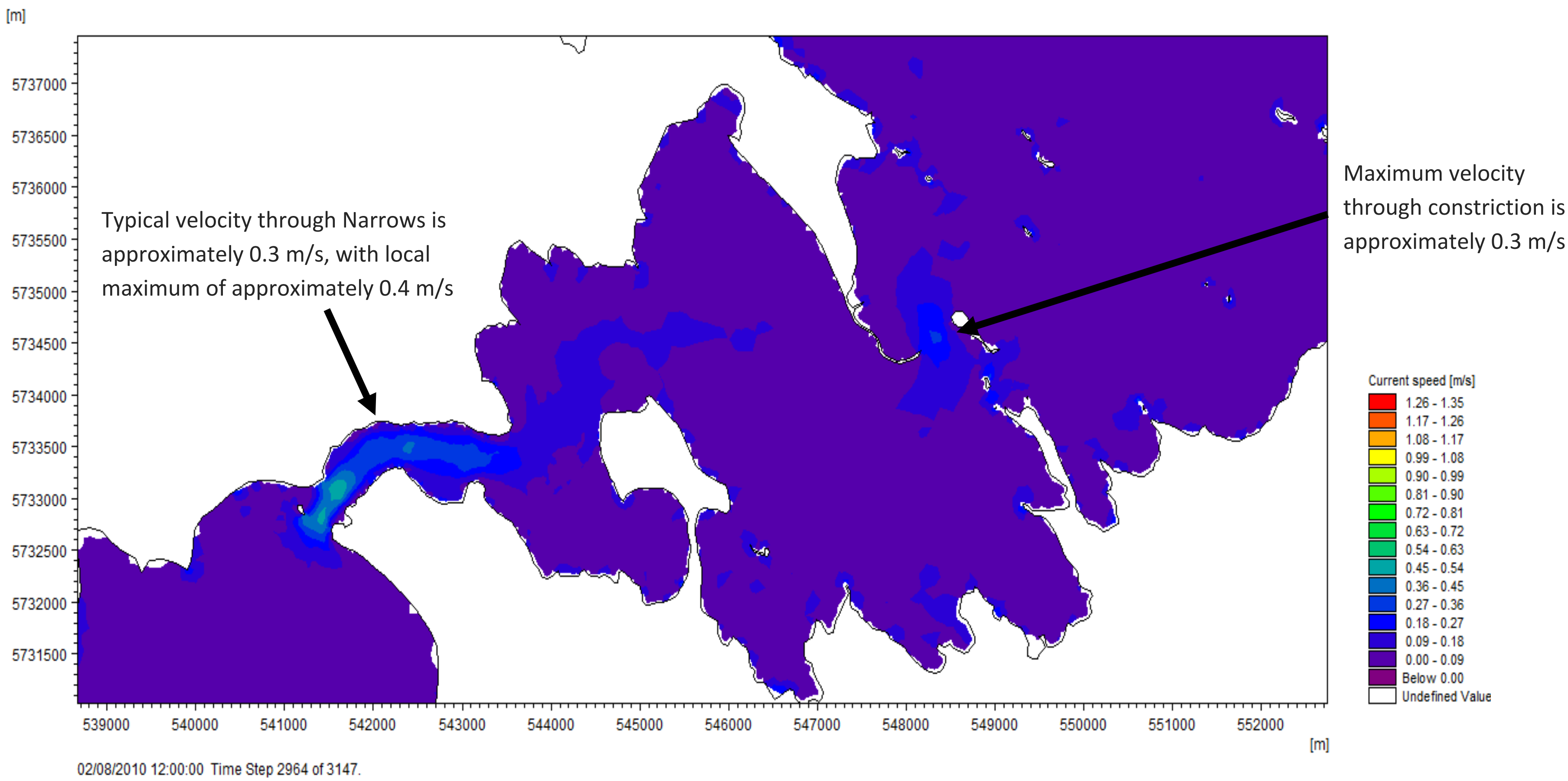
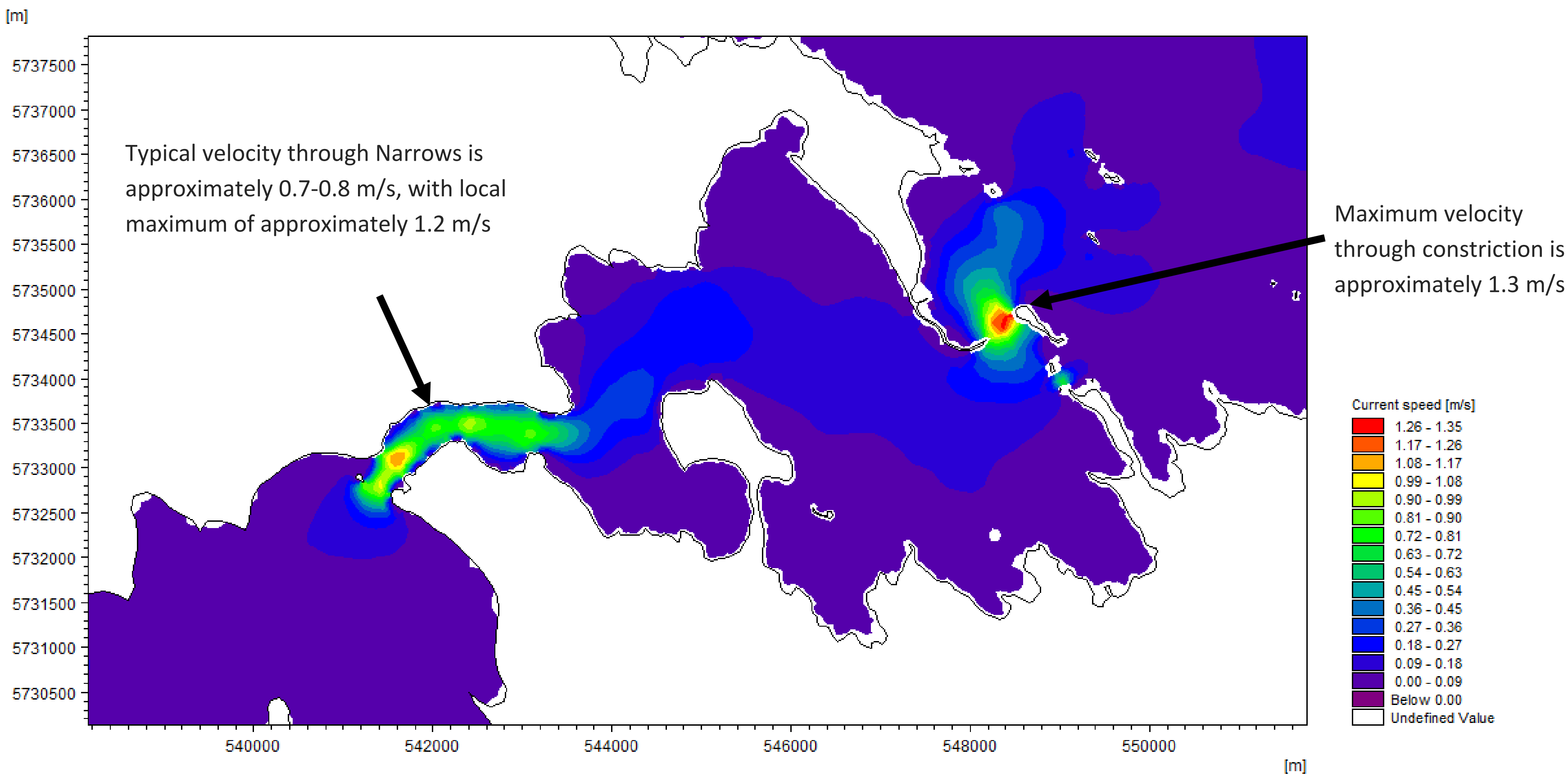


FIGURE 22: FLOW VELOCITY THROUGH NARROWS – SCENARIO 4



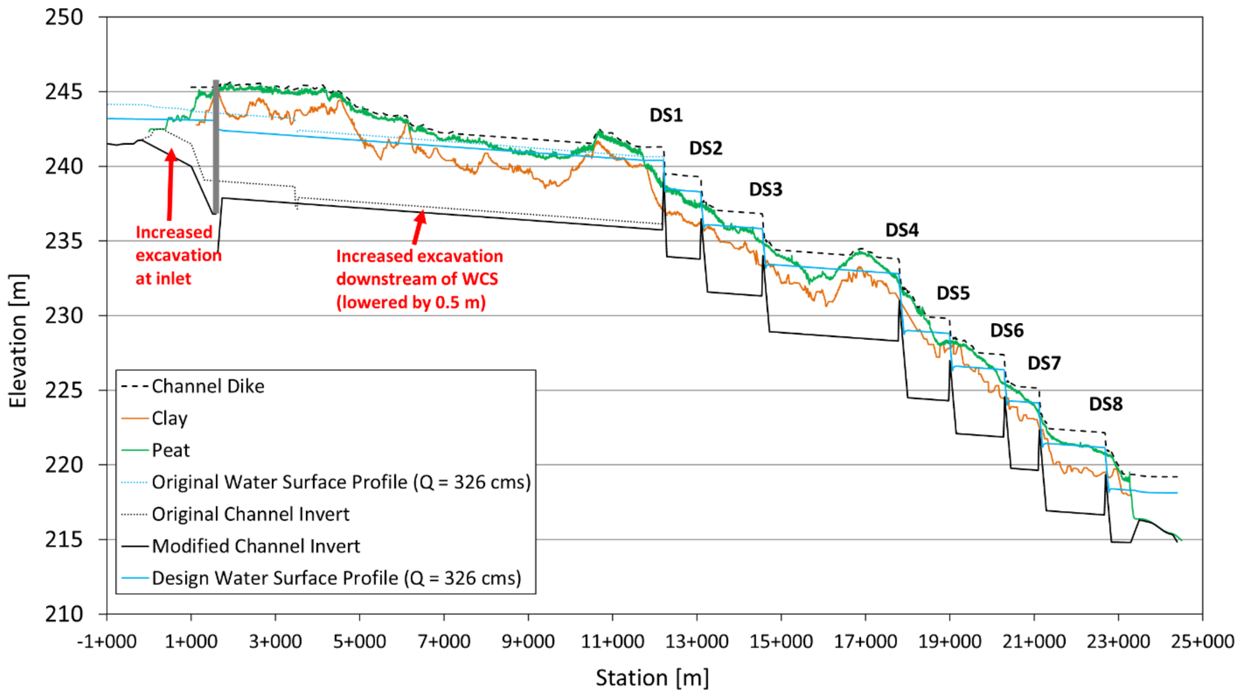
8.0 PRELIMINARY COST AND DESIGN IMPLICATIONS

Modifications to the preliminary geometry of the LSMOC were found to be required to accommodate the water surface gradient through the Lake St. Martin Narrows. This gradient had not been originally included in preliminary studies. The modifications were required to ensure that the LSMOC can convey a discharge of 326 m^3/s at a south basin water level of El 244.14 m. The channel modifications are shown graphically in Figure 23. They include:

- Increasing excavation downstream of the Lake St. Martin Water Control Structure (WCS) by lowering the channel invert by 0.5 m.
- Increasing excavation in the inlet area upstream of the WCS. The inlet elevation was reduced and consequently the point at which the channel invert “daylights” extends further upstream into Lake St. Martin than in the original preliminary design. The expanded inlet will require longer cofferdams to allow excavation further into the lake.
- No modifications were made to the WCS directly as a result of the assessment described herein. However, the structure was modified from a 2 bay structure (9 m wide bays) to a 4 bay structure (6 m wide bays) to reduce the risk of ice buffeting on the backs of the control gates during winter operation at partial gate openings.

In total, it is estimated that the channel modifications result in an additional cost of approximately $8-10 million. The cost may be reduced through optimization of channel modifications, which may be completed at the detailed design stage.

FIGURE 23: CHANNEL MODIFICATIONS TO INCORPORATE RESULTS OF HEAD LOSS ASSESSMENT



9.0 CONCLUSIONS AND RECOMMENDATIONS

The analysis described above has led to the following conclusions and recommendations:

- The water surface gradient (head loss) through the Narrows when the LSMOC conveys 326 m^3/s (11,500 cfs) and the south basin water level is El 244.14 m (801.0 ft) is estimated to be 0.96 m (3.1ft). The resultant water level in the north basin is El 243.18 m (El 797.84 ft).
- The water surface gradient (head loss) through the Narrows during repeat of the 2011 flood with the LSMOC in operation is 0.52 m (1.7 ft). The corresponding water levels in the south basin is El 244.87 m (803.4 ft) and in the north basin is El 244.35 m (El 801.7 ft).
- It is estimated that there is a $8-10 million cost to increase the discharge capacity of the LSMOC to accommodate the head losses in Lake St. Martin.
- MI installed a water level logger in the north basin of Lake St. Martin. The logger should be maintained long-term and the data extracted from this logger should be used to refine the Dauphin River and Narrows rating curves and to confirm model results.
- MI’s flood routing model was updated to reflect the head loss between the north and south basins of Lake St. Martin. The head loss was estimated via a family of rating curves for the Narrows.
- Operating guidelines for the LSMOC were updated to gradually phase in the initial operation of the channel to reduce sudden draw-down of the north basin water levels and potential impacts to Dauphin River flows. Further optimization of the operating guildelines should consider final design of the outlet channels, stakeholder input and the environment.
- Hydrometric data from the north basin should continue to be monitored and utilized as it becomes available.

10.0 REFERENCES

1. Integration of Modified Lake St. Martin Permanent Outlet Channel Design Configuration and Lake St. Martin Narrows into Lake Manitoba and Lake St. Martin Hydrologic Water Balance Model, Manitoba Infrastructure, November 3, 2020 (MI, Nov 2020).

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