MANITOBA INFRASTRUCTURE

Lake Manitoba and Lake St. Martin Outlet Channels Project – System Hydraulic Design Criteria

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TABLE OF CONTENTS

1.0 INTRODUCTION 1

2.0 RATIONALE FOR SELECTION OF DISCHARGE CAPACITIES OF FLOOD RELIEF CHANNELS 2

2.1 Early Background 2

2.2 Review Committee and Task Force 4

2.3 Evolution of the Designs of the Outlet Channels 5

2.3.1 Stage 1 Study 5

2.3.2 Stage 2 Conceptual Design 6

2.3.3 Preliminary and Detailed Design 7

3.0 DISCHARGE CAPACITIES OF OUTLET CHANNELS 8

4.0 HYDROLOGIC ANALYSES 10

4.1 Water Balance Numerical Model 10

4.2 Operation Guidelines 11

4.3 Lake Water Level Frequencies 11

4.4 Discussion of Expected Channel Performance 12

5.0 DAM SAFETY 16

5.1 Lake Manitoba 16

5.2 Lake St. Martin 16

6.0 ANALYSIS OF TRENDS AND CLIMATE CHANGE PROJECTIONS 18

7.0 IMPLICATIONS FOR CHANNEL DESIGN 20

7.1 Erosion Potential 20

7.1.1 Lake Manitoba 20

7.1.2 Lake St. Martin 21

7.2 Freeboard 24

7.2.1 Lake Manitoba 24

7.2.2 Lake St. Martin 26

8.0 SUMMARY 29

9.0 REFERENCES 31

List of Tables

Table 1: Comparison of Predicted Water Levels and Flows for Various Flood Events With and Without the Outlet Channels
Table 2: Percent of Time Lake Levels Below Upper End of Target Range (1981-2017)

List of Figures

Figure 1: Emergency Outlet Channels
Figure 2: Lake Manitoba and Lake St. Martin Outlet Channel Alignments
Figure 3: Water Level vs Discharge Relationship for LMOC (Water Control Structure Fully Open)
Figure 4: Water Level vs Discharge Relationship for LSMOC (Water Control Structure Fully Open)
Figure 5: Lake Manitoba Water Level Hydrographs for Repeat 2011 Flood of Record
Figure 6: Lake St. Martin South Basin Water Level Hydrographs for Repeat 2011 Flood of Record
Figure 7: Duration Curve of Water Levels in Lake Manitoba
Figure 8: Duration Curve of Water Levels in Lake St. Martin (South Basin)
Figure 9: Shear Stress along LMOC for Various Flood Events
Figure 10: Shear Stress along LSMOC for Various Flood Events
Figure 11: Water Surface Profiles in LMOC for Various Flood Events
Figure 12: Minimum Freeboard on LMOC Channel Dikes for Various Flood Events
Figure 13: Water Surface Profiles in LSMOC for Various Flood Events
Figure 14: Minimum Freeboard on LSMOC Channel Dikes for Various Flood Events

STATEMENT OF LIMITATIONS AND CONDITIONS

Limitations

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1.0 INTRODUCTION

The Lake Manitoba Outlet Channel (LMOC) and Lake St. Martin Outlet Channel (LSMOC) will provide flood benefits to communities on Lake Manitoba (LMB) and Lake St. Martin (LSM) by increasing the outflow capacity of the lakes, thereby reducing water levels during flood events. The identification of these outlet channels as the preferred alternative for Lake Manitoba and Lake St. Martin flood mitigation and selection of their capacities was based on several different studies that were initiated following the unprecedented flood of 2011.

The purposes of this document are to:

- Recap the origin and evolution of the design capacities adopted for the proposed outlet channels.
- Summarize the predicted performance of the proposed channels relative to common benchmark floods.
- Summarize potential future changes to the hydrologic regime with respect to climate change trends and projections.
- Provide information on the implications of passing various flood events on the Project design, including:
  - Potential erosion in the outlet channels;
  - Available freeboard on various water retaining structures;
  - Potential erosion and ultimately, potential failure, of the rockfill drop structures in the LSMOC.
- Support responses to information requests on the Project Environmental Impact Statement (EIS).

Within this document, three terms will be used to describe conditions that are considered in the system hydraulic design criteria for the LMOC and LSMOC. These terms are introduced and defined below for clarity:

The **Conveyance Target** refers to the passage of a desired flowrate at a specified reference lake water level. The outlet channels will be capable of delivering discharges both higher and lower than the Conveyance Targets should the lake water levels be above or below the associated reference levels.

The **Design Flood** refers to the flood event that the outlet channels, and components thereof, are designed to withstand without incurring damage. The flowrates in the outlet channels during the Design Flood define the required “level of resiliency” of the various channel design components.

The **IDF** (Inflow Design Flood) is the most severe flood that the outlet channels are designed to accommodate without risk of critical failure of any major Project components. The IDF is determined in accordance with the Canadian Dam Association Dam Safety Guidelines and is typically selected based on the potential consequences of failure. The IDF is more severe than the Design Flood. Some minor (non-critical) damage may be incurred during passage of the IDF (e.g. channel erosion), and is acceptable. To avoid confusion with the Design Flood, the term “IDF” will be used in its shortened form throughout this document.

2.0 RATIONALE FOR SELECTION OF DISCHARGE CAPACITIES OF FLOOD RELIEF CHANNELS

2.1 Early Background

In 2011, record-breaking widespread flooding occurred across much of southern Manitoba resulting in unprecedented high inflows into Lake Manitoba through the Waterhen River, Whitemud River, Portage Diversion, from saturated groundwater storage, and from local ungauged drainage areas. These high inflows extended well into the summer of 2011 and overwhelmed the outflow capacity of the existing hydraulic system between Lake Manitoba and Lake Winnipeg. The result was that the water level on Lake Manitoba crested at El. 249.1 m (817.2 ft), which was 1.43 m (4.7 ft) above the desirable range of El. 247.0 to 247.7 m (810.5 ft to 812.5 ft). Flooding around Lake Manitoba caused significant damage to hundreds of properties around the lake, particularly during a storm in late May when winds reached over 100 km/h (62 mi/h), and wind set-up raised the south end of the lake up to 1.5 m (5 ft), with waves as high as 2.1 m (7 ft).

The inflow to Lake St. Martin from Lake Manitoba was greater than the natural outflow capacity, causing the water level in the south basin of Lake St. Martin to crest at El. 245.6 m (805.5 ft), which was 1.68 m (5.5 ft) above the desirable operating range of El. 242.9 to 243.8 m (797.0 to 800.0 ft). Flooding on Lake St. Martin prompted the emergency construction of dikes up to 2.4 m (8 ft) high with a top elevation of 246.6 m (809 ft). Road access was severely limited to several communities and widespread long-term evacuation from the four First Nations around Lake St. Martin and the Dauphin River was required (i.e. Pinaymootang, Little Saskatchewan, Lake St. Martin, and Dauphin River).

In June 2011, the Province of Manitoba commissioned KGS Group and AECOM to urgently explore options to bring the water levels of Lake St. Martin and Lake Manitoba down to the desirable range on an emergency basis. The Province sought a broad review of potential options to achieve this objective in a timely and cost-effective manner, while also minimizing the potential impact on other areas of the Province. The team recommended the following:

- Begin immediate construction of a 140 m^3/s (5,000 cfs) emergency outlet channel from Lake St. Martin to Buffalo Lake and Creek, en route to Lake Winnipeg through the lower Dauphin River to address the hydraulic limitations at the outlet of Lake St. Martin and to accommodate additional Lake Manitoba outflows over the winter.
- Allow unrestricted outflow of water from Lake Manitoba through the Fairford River Water Control Structure (FRWCS) during the winter of 2011/2012, allowing several times more outflow than past winters.

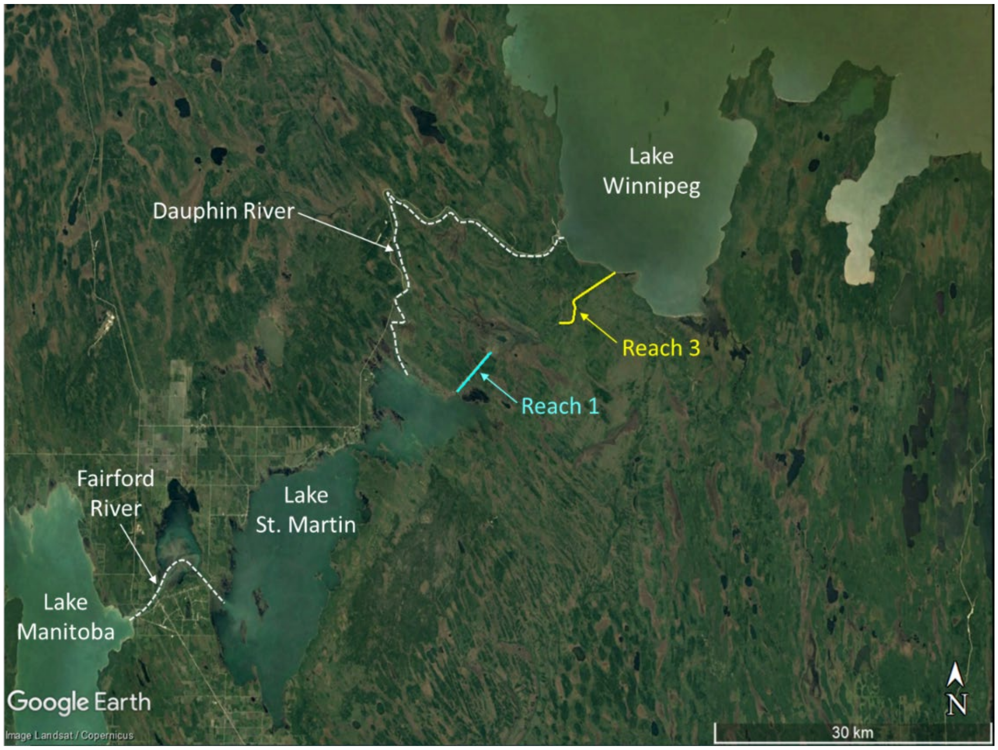
The construction of “Reach 1” of the Lake St. Martin Emergency Outlet Channel (LSMEOC) was completed on November 1, 2011. This was a channel approximately 6 km in length, located at the northern end of Lake St. Martin, which released flow through natural water courses into the Dauphin River (see Figure 1). Reach 1 was originally designed to convey 142 m^3/s (5,015 cfs) at a Lake St. Martin level of El 244.1 m (801 ft). However, due to time constraints and construction challenges, the base width of the original channel design channel was reduced, resulting in a design discharge capacity of approximately 106 m^3/s (3,750 cfs). Ultimately, the actual discharge capacity achieved at El. 244.1 m (801 ft) was 113 m^3/s (4,000 cfs) and a peak discharge in the range of approximately 200 m^3/s (7,000 cfs) was estimated to have occurred in the channel, based on hydrometric data collected during operation of the LSMEOC in 2011 and 2012.

During the urgent studies by KGS/AECOM, the potential for a bypass channel at Lake Manitoba was identified. The studies showed the possibility of constructing an emergency channel to the south of the Fairford River, and releasing supplemental outflow into Lake St. Martin. However, this proposed Fairford River Emergency Outlet Channel (FREOC) was ultimately not constructed, as an expansion of the LSMEOC was not feasible in 2011, and by 2012 the emergency was considered to have passed.

While the Reach 1 project was being constructed, numerical hydraulic modeling of potential water levels at the mouth of the Dauphin River indicated that there was a significant risk of major flooding of the Dauphin River community in the fall of 2011 and spring of 2012 due to potential ice jam formations. This was mostly due to the unprecedented large winter flows with the FRWCS running at full discharge capacity all winter, and the diverted flows that entered the lower Dauphin River from releases of the Reach 1 LSMEOC. It was determined that construction of “Reach 3” of the Lake St. Martin Emergency Outlet Channel would be required to divert flows away from Buffalo Creek and the Dauphin River prior to spring break up and to release them into Lake Winnipeg (see Figure 1). The Reach 3 channel, in combination with dikes being constructed along the banks of the lower Dauphin River, would significantly reduce the risk of flooding for the Dauphin River communities. KGS Group was directed by MI (formally Manitoba Infrastructure and Transportation at the time) to proceed with the development of an appropriate design for Reach 3 in August 2011. Reach 3 was partially constructed between January and March 2012. However, with extremely mild winter conditions, ice jams on the Dauphin River did not develop to the extent that could have occurred under normal winter conditions. This ultimately precluded the need for Reach 3 to be operated in the spring of 2012. The Reach 3 Emergency Channel has never been used and currently remains in an incomplete condition particularly with respect to some hydraulic structures.

Reach 1 was operated from November 2011 to November 2012, and then closed as required under the federal government’s terms and conditions for emergency operations. Another major flood, although not as severe as 2011, occurred in 2014 and again justified the re-opening of Reach 1. Reach 1 was operated from July 2014 to August 2015, when it was again closed. The peak discharge measured in Reach 1 during that period was 112 m^3/s (3,955 cfs). A long-term environmental monitoring program was implemented to document the full impacts of the emergency channel and identify mitigation requirements. Unless required again for emergency operation prior to commissioning of the permanent LSMOC, the LSMEOC will not be re-opened. Reach 1 and the portion of Reach 3 that does not coincide with the LSMOC alignment will be decommissioned once construction and commissioning of the permanent LSMOC is complete. The locations of the emergency outlet channels (Reach 1 and Reach 3) constructed in 2011 are shown in the map of Figure 1.

FIGURE 1: EMERGENCY OUTLET CHANNELS



2.2 Review Committee and Task Force

As a follow-up to the 2011 emergency flood mitigation activities for the Assiniboine River and Lake Manitoba Basins, the Province of Manitoba commissioned two separate groups to independently assess the situation and recommend long-term action:

- The Lake Manitoba and Lake St. Martin Regulation Review Committee (the Committee) chaired by Harold Westdal.
- The Manitoba 2011 Flood Review Task Force (the Task Force) chaired by David Farlinger.

The Committee made the following recommendations in 2013 with respect to LMB and LSM:

- The LSMEOC be made permanent.
- The discharge capacity of that channel should be sufficient such that the water level on Lake St. Martin can be maintained within the desirable range of El. 242.9 to 243.8 m (797 to 800 ft) at least 90 percent of the time.
- Consideration should be given to the inclusion of a control structure at the mouth of the permanent outlet channel to limit outflow at times of low lake levels.
- The current Reach 3 of the LSMEOC should be redirected to release the excess flows south of Willow Point into Lake Winnipeg.

The Task Force, chaired by David Farlinger, made the following broad recommendation with respect to LMB & LSM Outlet Channels:

- Adopt the recommendations of the Lake Manitoba and Lake St. Martin Regulation Review Committee regarding additional requirements for outlet discharge capacity for Lake Manitoba and Lake St. Martin, with due consideration for the engineering studies that were to be conducted.

2.3 Evolution of the Designs of the Outlet Channels

2.3.1 STAGE 1 STUDY

KGS Group was retained by the Province of Manitoba in June 2013 to:

- Identify outlet options for Lake Manitoba and Lake St. Martin.
- Develop screening level drawings and cost estimates for outlets for these lakes.
- Carry out economic analysis and assessments using standard accepted methods of such evaluations, including the development of stage vs damage relationships.
- Conduct open houses to disseminate information and gather input from the public.

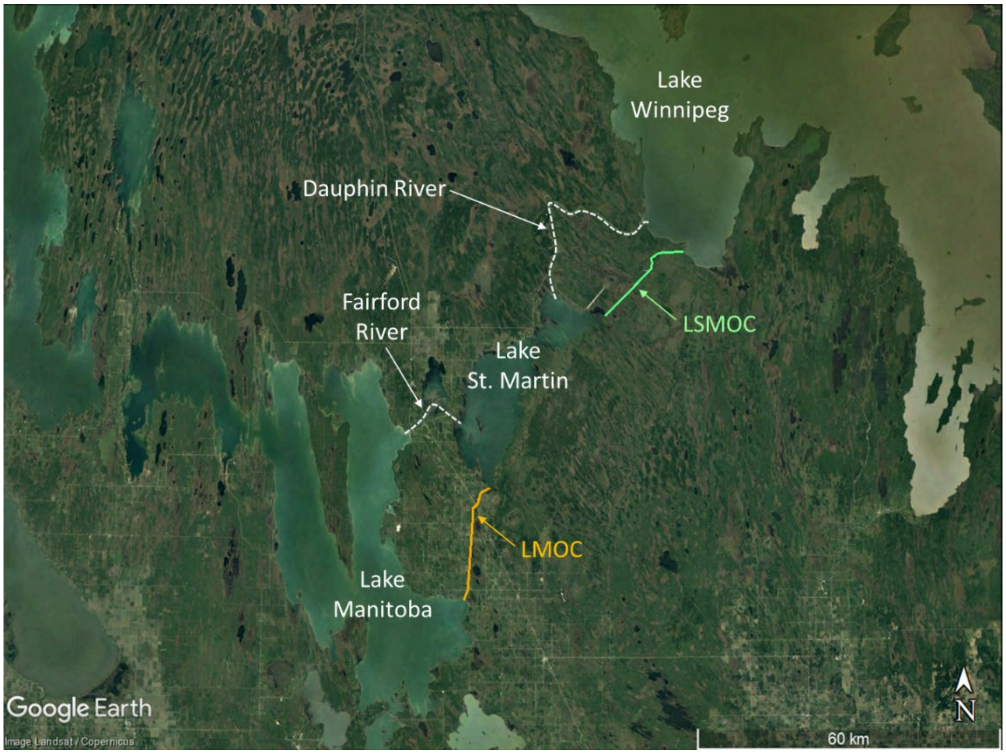
The Stage 1 study was completed and reported in February 2014, including the following points relevant to design discharge capacities:

- The Lake St. Martin Emergency Outlet Channel should be made permanent with a base capacity of 113 m^3/s (4,000 cfs) to control water levels on Lake St. Martin.
- The option with the highest benefit-cost ratio for Lake Manitoba is a channel with a discharge capacity of 142 m^3/s (5,000 cfs).
  - Channel discharge capacities in the range of 142 to 283 m^3/s (5,000 to 10,000 cfs) were recommended to be considered for further review since lesser capacities will not adequately reduce lake levels, and greater capacities are not justifiable due to the high cost.
- The option with the highest benefit-cost ratio for Lake St. Martin was a channel with a discharge capacity of 255 m^3/s (9,000 cfs).
  - Additional discharge capacity from Lake St. Martin in the range of 142 to 283 m^3/s (5,000 to 10,000 cfs) should be considered for further review to match a Lake Manitoba Outlet Channel to ensure that flooding would not be aggravated on Lake St. Martin.
- An economic analysis of all options (including those recommended for further evaluation) determined that the outlet channels would provide substantial flood protection benefits in the order of $100-200 million. The economic analysis included consideration of intangible benefits such as avoided stress and anxiety of populations displaced due to floods. Flood control projects with positive benefit-cost ratios, such as the Red River Floodway Expansion project, are relatively rare, and are typically for protection of large urban communities. It is not uncommon for flood mitigation projects that protect small communities and rural areas to have lower benefit-cost ratios. The Stage 1 study still recommended construction of the Lake Manitoba Outlet Channel and Lake St. Martin Outlet Channel, amongst other projects, to address the significant risk and vulnerabilities in these areas.

2.3.2 STAGE 2 CONCEPTUAL DESIGN

Subsequent to the completion of the Stage 1 Study by KGS Group, the Province publicly announced in November 2014 the intention to construct permanent discharge channels from Lake Manitoba and from Lake St. Martin. The proposed locations are shown in the map in Figure 2.

FIGURE 2: LAKE MANITOBA AND LAKE ST. MARTIN OUTLET CHANNEL ALIGNMENTS



KGS Group was again retained in January 2015 to further refine and provide updated cost estimates for the channels committed to by the Province of Manitoba. As directed by the Province of Manitoba, in the Stage 2 Conceptual Design, the studies focused on Conveyance Targets of 212 m^3/s (7,500 cfs) for the LMOC and 326 m^3/s (11,500 cfs) for the LSMOC. These flows were chosen by the Province to apply at the designated flood stage of 248.11 m (814 ft) on Lake Manitoba and 244.14 m (801 ft) on Lake St. Martin. The selected Conveyance Targets, and the difference between the two, of 113 m^3/s (4,000 cfs), were intended to directly accommodate and compensate on Lake St. Martin the release of the future increases in flood discharges from Lake Manitoba, and in addition provide reduction in flood levels on Lake St. Martin from what had been experienced in the past.

It should be noted that for all studies up to the completion of the Stage 2 report, the potential for significant constrictions to flow through the Narrows between the south and north basins of Lake St. Martin had not been fully assessed. Consequently, the target water level on Lake St. Martin was considered to apply equally to both the north and south basins of the lake. This is a key point that will be addressed later in this document.

Multiple open houses and presentations to stakeholders were conducted during Stage 1 and 2 studies. The Stage 2 Conceptual Design culminated in a report by KGS Group in 2016. Engineering continued after that point to move towards final design.

2.3.3 PRELIMINARY AND DETAILED DESIGN

The Province of Manitoba elected to tender separate design contracts for the two channels. An open competition was held and the engineering contracts were awarded to Hatch (Lake Manitoba) and KGS Group (Lake St. Martin). Both companies were retained for this phase of work in November 2018. Both companies have carried out advanced engineering since that time, working in a coordinated way so that major design philosophies are consistent between each channel and approved by the owner. The Preliminary Designs of the outlet channels were carried out with the primary criteria of meeting the Conveyance Targets specified at the Stage 2 Conceptual Design stage.

In Preliminary Design it was recognized that the outlet channels would be required to pass flows that exceed the Conveyance Targets of 212 m^3/s (7,500 cfs) and 326 m^3/s (11,500 cfs) when lake levels exceed 248.11 m (814 ft) and 244.14 m (801 ft), respectively. Based on input received through the environmental approval process and through public consultation and engagement, the Province has committed to designing the LMOC and LSMOC to safely pass flows that would be associated with a repeat occurrence of the 2011 Flood of Record without exceeding their erosion thresholds, and while maintaining safe freeboard on water retaining components. This flood event approximately corresponds to a flood with annual exceedance probability of 0.33% (i.e. return period of 1 in 300 years) (Luo, 2021) and is the Design Flood adopted for this Project.

The channels are also designed to accommodate the peak flows that would occur in each outlet channel during the designated IDF with some minor damage being acceptable (e.g. potential erosion of the channel and reduced freeboard on water retaining structures). The IDFs and minimum freeboard were selected based on standards and guidelines contained in the Canadian Dam Association Dam Safety Guidelines, as described further in Section 5.0.

Design of the outlet channels is continuing and have evolved to incorporate the various design requirements.

3.0 DISCHARGE CAPACITIES OF OUTLET CHANNELS

The maximum outflow that can be achieved at each of the outlet channels is driven exclusively by the water level in the respective lakes and the frictional effects of the flow of water within the channel. Accordingly, the selected channel geometries will be capable of delivering discharges both higher and lower than the Conveyance Targets should the lake levels be above or below the associated reference levels specified by the Province (i.e. the flood stage on each lake). Figure 3 and Figure 4 show the relationship between lake level and maximum channel discharge for each outlet channel as a function of the prevailing still water levels on Lake Manitoba and Lake St. Martin.

FIGURE 3: WATER LEVEL VS DISCHARGE RELATIONSHIP FOR LMOC (WATER CONTROL STRUCTURE FULLY OPEN)

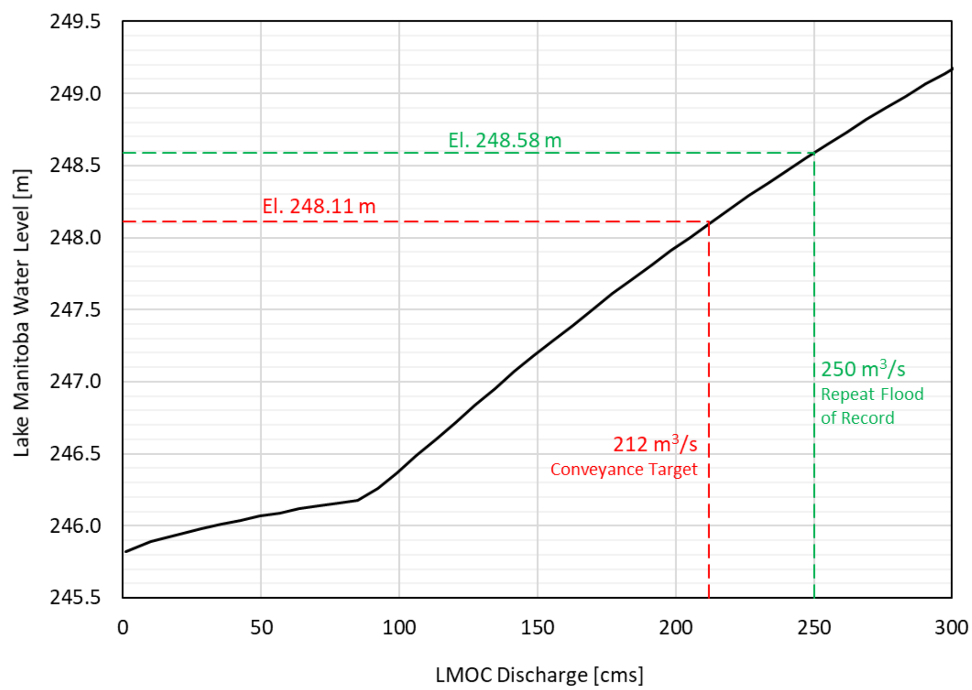
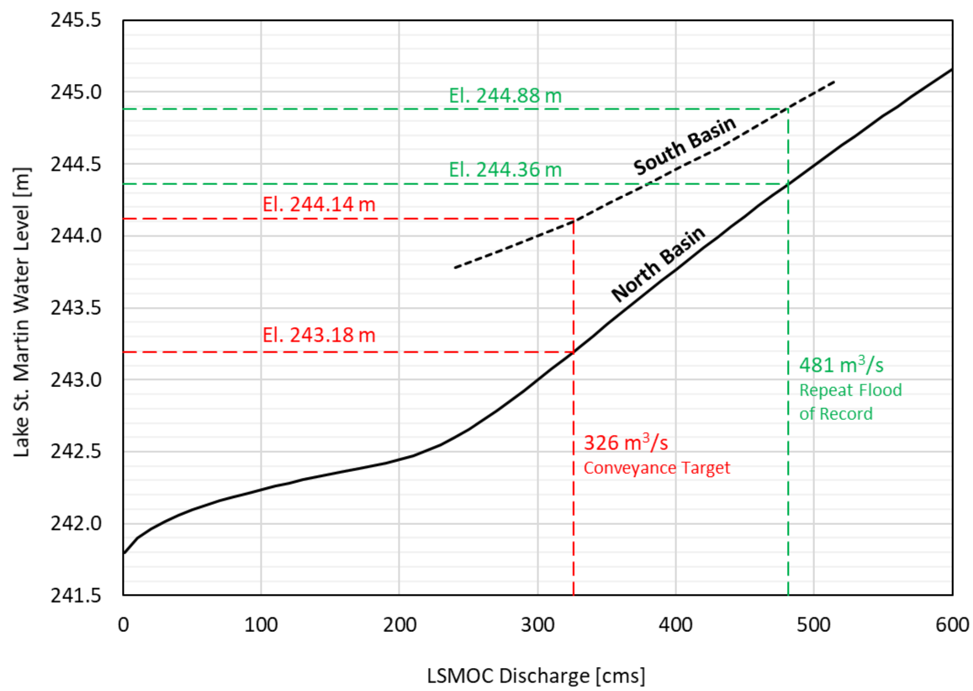


FIGURE 4: WATER LEVEL VS DISCHARGE RELATIONSHIP FOR LSMOC (WATER CONTROL STRUCTURE FULLY OPEN)



As shown, the outlet channels meet their respective Conveyance Targets, but are also capable of passing greater flows at higher lake levels. How well the channels will achieve the other goals of the Review Committee and the Flood Task Force is discussed further in Section 4.0.

Other aspects of the channel design, including freeboard requirements on water retaining structures and protection against erosion in the channels at various flood events are discussed in Section 7.0.

4.0 HYDROLOGIC ANALYSES

4.1 Water Balance Numerical Model

The Province of Manitoba has developed a comprehensive water balance numerical model of Lake Manitoba and Lake St. Martin, using the most accurate hydraulic and hydrologic characteristics available. Details are provided in a report available on the Province of Manitoba website (Propp, 2019). The water balance model was originally developed in Microsoft Excel by Mr. R. Bowering and used extensively during the work of the Review Committee. It has been refined continuously since that time by MI.

Historical daily inflows to Lake Manitoba were estimated for the numerical model for a 103 year period (1915-2017) based on recorded flow and water level data, a stage vs storage relationship for Lake Manitoba (note that "stage" refers to a water level with respect to a defined reference elevation), and precipitation and evaporation data from Environment Canada. The inflows were then routed through the numerical model using accepted hydrologic principles of flood routing to simulate daily water levels and outflows on Lake Manitoba and Lake St. Martin for the period of 1915-2017 under varying operating regimes.

The stage-discharge relationships for the outlet channels in the numerical model were initially based on the information documented in the Assiniboine River & Lake Manitoba Basins Flood Mitigation Study (KGS Group, 2016) and have been continuously updated as the channel designs have advanced. It was also assumed that the fish ladder would be removed from the Fairford River Water Control Structure to increase outflow capacity (and a separate fish passage structure would be constructed). Further refinements of the numerical model were made in 2020 (Johnston, 2020) to address:

- Separation of the north and south basins of Lake St. Martin into two distinct water bodies.
- Representation of head losses at the Narrows between the south and north basins of Lake St. Martin.
- Shortened computational time steps in the numerics to improve the accuracy of simulation.
- Representation of winter ice effects on the outflows from Lake St. Martin into the Dauphin River.

The daily inflows from the Portage Diversion had to be simulated under the assumption of a consistent operating regime for the entire analysis period (1915-2017). It was assumed that the Portage Diversion would be operated according to the rules proposed in the Provincial Flood Control Infrastructure Review of Operating Guidelines Report - August 2015 and that flows released into the lower Assiniboine River would be limited to 510 m^3/s (18,000 cfs). The simulated flows were developed by applying the operating rules to historical daily Assiniboine River flows using algorithms to consider maximum allowable flow on the Assiniboine River, James Avenue water levels in the City of Winnipeg, volume of water to be diverted to Lake Manitoba, and Lake Manitoba forecasted peak water levels. Manual adjustments were made in some years to capture how MI would actually operate in certain situations rather than rigidly applying the operating guidelines.

The model was calibrated and verified against actual field data and found to be suitably accurate for studies of lake control.

4.2 Operation Guidelines

The numerical model of the lakes adopted a set of detailed guidelines that would accurately represent the real-world operation of the control structures and outflow channels. Key features include:

- Any variances in the lake levels outside of the target regulation ranges would be shared between Lake Manitoba and Lake St. Martin insofar as this may be reasonably practicable.
- It is assumed that Lake Manitoba and Lake St. Martin Outlet Channel gate settings will be adjusted when required on a weekly or biweekly basis rather than on a daily basis. This means that gate settings made to match inflows and outflows may not perfectly balance inflows and outflows for the whole period between gate operations.

The operation guidelines for the outlet channels are based on the principles of Lake Manitoba and Lake St. Martin regulation laid out by the 2003 Lake Manitoba Regulation Review Advisory Committee and the 2013 Lake Manitoba, Lake St. Martin Regulation Review Committee.

The current versions of the operating guidelines for the FRWCS, LMOC, and LSMOC can be accessed on the Water Management and Structures Branch page of the Manitoba Infrastructure website.

4.3 Lake Water Level Frequencies

The Province of Manitoba has undertaken a series of analyses using their water balance numerical model that incorporates the operating guidelines referenced in Section 4.2. According to the guidelines, the model allows flows in the outlet channels to exceed the Conveyance Targets of 212 m^3/s (7,500 cfs) and 326 m^3/s (11,500 cfs) when lake levels exceed 248.11 m (814 ft) and 244.14 m (801 ft) on Lake Manitoba and Lake St. Martin, respectively. Frequency analyses were subsequently conducted on Lake Manitoba and Lake St. Martin water levels predicted by the model (Luo, 2021). The results are summarized in Table 1 for cases with and without the proposed channels.

As shown in Table 1, a repeat occurrence of the 2011 Flood of Record in the “With Project” scenario approximately corresponds to a 1:300 year return period. The predicted peak flows in the LMOC and LSMOC for this condition are 250 m^3/s (8,800 cfs) and 481 m^3/s (17,000 cfs), respectively, which represent the peak flowrates in the channels during the Design Flood.

TABLE 1: COMPARISON OF PREDICTED WATER LEVELS AND FLOWS FOR VARIOUS FLOOD EVENTS WITH AND WITHOUT THE OUTLET CHANNELS

Event	Lake Manitoba Water Level[1]		Peak LMOC Discharge	Lake St. Martin South Basin Water Level[1]		Peak LSMOC Discharge
	Without Project	With Project		Without Project	With Project	
1:5 year	247.73 m (812.8 ft)	247.68 m (812.6 ft)	182 cms (6,400 cfs)	244.43 m (802.0 ft)	244.14 m[3] (801.0 ft)	326 cms[3] (11,500 cfs)
1:100 year	248.54 m (815.4 ft)	248.11 m[2] (814.0 ft)	212 cms[2] (7,500 cfs)	245.27 m (804.7 ft)	244.69 m (802.8 ft)	445 cms (15,700 cfs)
1:200 year	248.82 m (816.4 ft)	248.36 m (814.8 ft)	232 cms (8,200 cfs)	245.44 m (805.3 ft)	244.82 m (803.2 ft)	466 cms (16,500 cfs)
1:300 year	249.00 m (816.9 ft)	248.52 m (815.4 ft)	245 cms (8,600 cfs)	245.52 m (805.5 ft)	244.88 m (803.4 ft)	481 cms (17,000 cfs)
1:500 year	249.23 m (817.7 ft)	248.72 m (816.0 ft)	261 cms (9,200 cfs)	245.64 m (805.9 ft)	244.95 m (803.7 ft)	491 cms (17,300 cfs)
1:1,000 year	249.39 m (818.2 ft)	249.07 m (817.2 ft)	290 cms (10,300 cfs)	245.78 m (806.4 ft)	245.06 m (804.0 ft)	513 cms (18,100 cfs)
Repeat of Flood of Record 2011[4,5]	248.99 m (816.9 ft)	248.58 m (815.6 ft)	250 cms (8,800 cfs)	245.52 m (805.5 ft)	244.88 m (803.4 ft)	481 cms (17,000 cfs)
Repeat of Flood of 2014[5]	248.20 m (814.3 ft)	248.05 m (813.8 ft)	209 cms (7,400 cfs)	245.13 m (804.2 ft)	244.60 m (802.7 ft)	437 cms (15,300 cfs)

Notes:
1 Water levels are still water levels (no wind effects)
2 Conveyance target for LMOC
3 Conveyance target for LSMOC
4 Design Flood for LMOC and LSMOC
5 Peak water levels and flows extracted from MI's Water Balance Numerical Model

4.4 Discussion of Expected Channel Performance

The performance of the channels proposed to suit the prescribed Conveyance Targets in the announcement by the Province of Manitoba in 2014 can be judged in broad terms from the array of results presented in Table 1. It is apparent that the water levels of Lake Manitoba and Lake St. Martin would be considerably lower than what would occur without the Projects during a given flood event.

The performance of the outlet channels can also be illustrated by examining specific flood hydrographs produced by MI's water balance numerical model. For example, hydrographs of Lake Manitoba and Lake St. Martin water levels corresponding to a repeat 2011 Flood of Record are shown in Figure 5 and Figure 6, respectively. The hydrographs show the lake levels in the Pre-Project environment (i.e. without operation of the outlet channels) compared to Post-Project (i.e. with operation of the outlet channels).

FIGURE 5: LAKE MANITOBA WATER LEVEL HYDROGRAPHS FOR REPEAT 2011 FLOOD OF RECORD

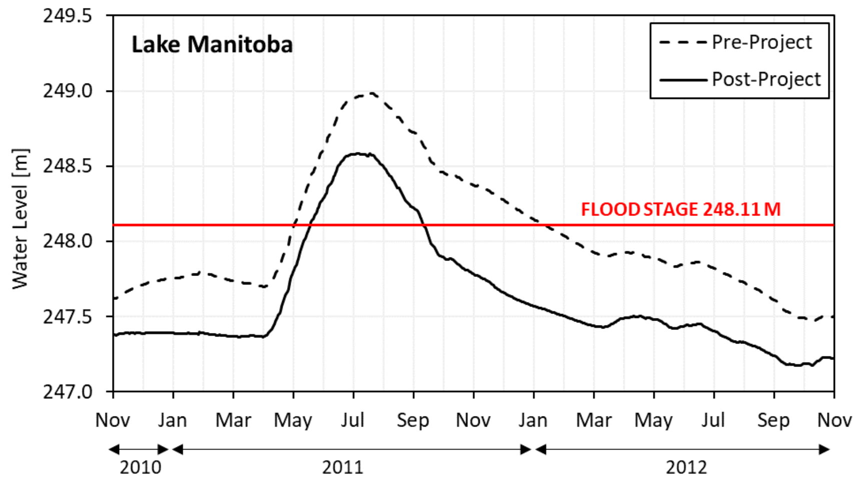
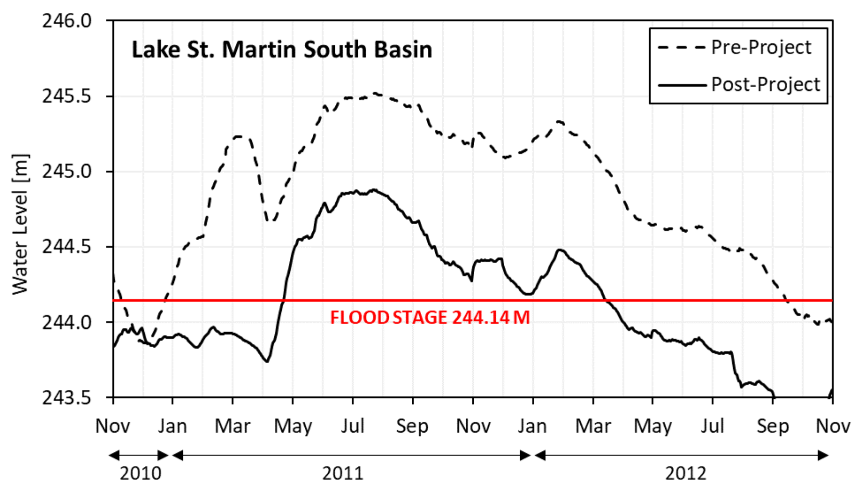


FIGURE 6: LAKE ST. MARTIN SOUTH BASIN WATER LEVEL HYDROGRAPHS FOR REPEAT 2011 FLOOD OF RECORD



The effect of the outlet channels on the flood hydrographs for this scenario are two-fold. First, the outlet channels reduce the peak water levels in each lake. The peak water level in Lake Manitoba is reduced from 248.99 m (816.9 ft) to 248.58 m (815.6 ft), while the peak water level in Lake St. Martin (south basin) is reduced from 245.52 m (805.5 ft) to 244.88 m (803.4 ft).

Second, the durations of time the lake levels are above their respective flood stages are reduced. As noted previously, the Province of Manitoba has defined the flood stage of Lake Manitoba to be 248.11 m (814 ft) and Lake St. Martin (south basin) to be 244.14 m (801 ft). The outlet channels reduce the amount of time the water level is above the flood stage on Lake Manitoba for this scenario from 254 days (Pre-Project) to 115 days (Post-Project). On Lake St. Martin, the Pre-Project hydrograph rises above the flood stage in late 2010 and does not recede to below flood stage until September 2012 (total of 632 days). In contrast, the Post-Project water levels exceed the flood stage in Lake St. Martin for 327 days.

Another metric that can be used to assess the performance of the outlet channels are water level duration curves. Duration curves of water levels simulated with MI's water balance model for the period from 1915-2017 for Lake Manitoba and the south basin of Lake St. Martin are presented in Figure 7 and Figure 8, respectively. The curves indicate the percent of time that the water levels are less than a specified value.

As shown, the percent of time the water level in Lake Manitoba is below the upper end of the target operating range increases from 91% to 97% due to operation of the outlet channels. In Lake St. Martin, the water level in the south basin is below the upper end of the target range 90% of the time in the Post-Project environment, compared to 77% in the Pre-Project environment.

FIGURE 7: DURATION CURVE OF WATER LEVELS IN LAKE MANITOBA

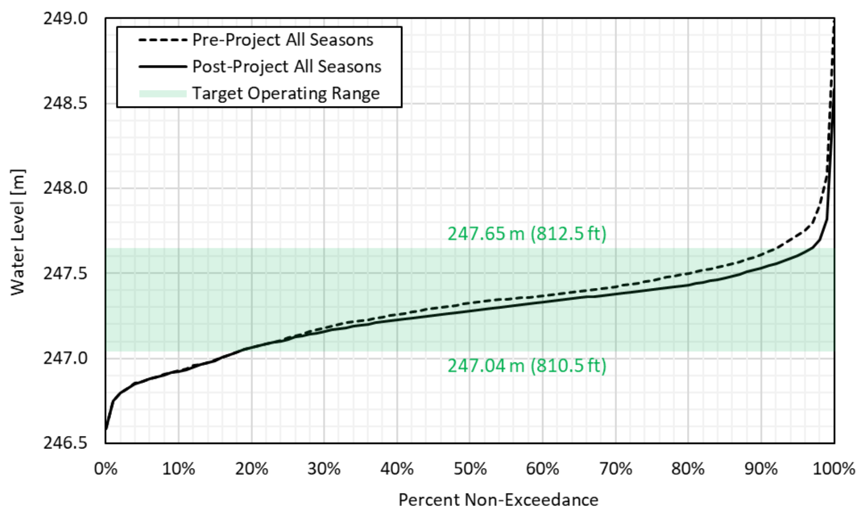
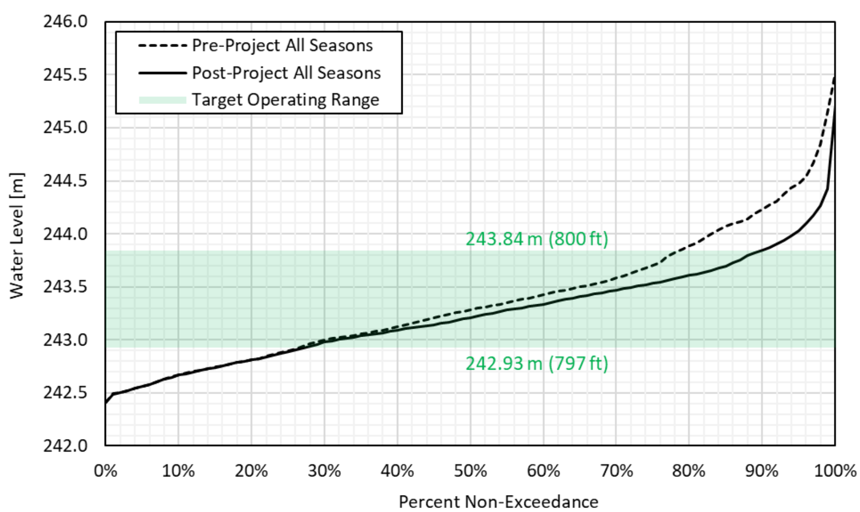


FIGURE 8: DURATION CURVE OF WATER LEVELS IN LAKE ST. MARTIN (SOUTH BASIN)



It should be noted at this juncture that the Projects announced by the Province are flood control projects. They focus on minimizing and controlling water levels during times of excessive flood runoff. They are not intended to address, nor are they capable of, ameliorating drought conditions. Therefore, it is not physically possible with the committed projects to achieve the multi-faceted target stated by the Review Committee to keep the water levels on Lake St. Martin between El. 242.92 m (797 ft) and 243.84 m (800 ft) 90% of the time. Other components besides flood discharge channels would be required for this purpose.

5.0 DAM SAFETY

The designs of the outlet channels consider the standards and guidelines contained in the Canadian Dam Association Dam Safety Guidelines (2013). While the channel geometries are selected based on the stipulated project Conveyance Targets, for dam safety purposes, the CDA Dam Safety Guidelines recommend that water conveyance systems also be capable of performing their function up to an Inflow Design Flood (IDF) capacity. The IDF is the most severe inflow flood for which a water retaining structure installation and its associated facilities are to be designed to accommodate, and by extension, is associated with setting minimum crest elevations of any dikes/dams required to contain the water. The IDF is typically selected on the basis of the potential consequences of failure.

Application of the CDA Dam Safety Guidelines require that the proposed facilities at LMOC and LSMOC be capable of safely managing the respective IDF. This will be achieved by releasing outflow at the maximum possible rate through the outlet channels during the flood event. This would result in the lowest water levels in the lakes (i.e. the greatest flood benefit), but the highest flows through the outlet channels.

Hatch and KGS Group have undertaken extensive evaluations of the Lake Manitoba and Lake St. Martin facilities with respect to the CDA Guidelines. Key aspects of the evaluations are addressed in Sections 5.1 and 5.2 below.

5.1 Lake Manitoba

The proposed facilities for the LMOC were evaluated relative to the requirements of the CDA Dam Safety Guidelines following a risk-based approach. This included an analysis of potential breaches during flood conditions to identify at what point further increasing the IDF for the LMOC would not further reduce the incremental consequences of failure.

The analysis found that an IDF corresponding to the 1:1,000 year event represents a design condition that will dictate (in combination with the freeboard requirements identified in Section 7.2) minimum dike crest elevations above which no additional 3rd party incremental damages would be anticipated to result if the LMOC dikes were to be overtopped.

Based on the frequency analyses summarized in Section 4.3, the 1:1,000 year return period Lake Manitoba water level (with the Project in place) is 249.07 m (817.2 ft), which corresponds to a peak flow in the LMOC of 290 m^3/s (10,300 cfs). This condition has been selected as the IDF capacity for the LMOC.

5.2 Lake St. Martin

The proposed facilities for the Lake St. Martin Outlet Channel were evaluated relative to the requirements of the CDA Dam Safety Guidelines. The analysis included a review of potential breaches of various components of the Project during flood conditions and an assessment of the potential consequences associated with each.

It was determined that a Dam Classification of “Significant” was appropriate for selecting the IDF for the LSMOC. This was based primarily on environmental consequences associated with a breach leading to uncontrolled outflow into the Buffalo Lakes wetland complex.

Following the standards-based approach, the IDF was selected as the 1:1,000 year flood event in accordance with the CDA Dam Safety Guidelines for a “Significant” Dam Classification. Based on the water level frequencies presented in Table 1, the 1:1,000 year return period Lake St. Martin south basin water level (with the Project in place) is 245.06 m (804.0 ft), which corresponds to a peak flow in the LSMOC of 513 m^3/s (18,100 cfs). This condition has been selected as the IDF capacity for the LSMOC.

6.0 ANALYSIS OF TRENDS AND CLIMATE CHANGE PROJECTIONS

It is acknowledged that there is uncertainty as to whether the current observed hydrologic regime will be representative of potential future conditions. To address this uncertainty, MI performed a climate change and trend analysis on runoff records (Propp, 2021). Pertinent conclusions of that study are summarized below.

- Statistically significant trends in historic runoff volumes were calculated for the Assiniboine River and Lake Manitoba watersheds.
- The magnitude of the trend was dependent on the range of historical record used. Higher magnitude trends were observed using the last 50 years of data compared to the full historic dataset (105 years).
- The projected increase in mean annual runoff depth 50 years into the future based on the trend analysis for the Lake Manitoba watershed ranged from 15-37 mm, while the projected increase for the Assiniboine River watershed ranged from 3-10 mm.
- Ensemble simulation runs of General Circulation Models (GCMs)show a wide range of projected changes in mean annual runoff in the future due to climate change, with an approximate 50/50 split of models showing a decrease or an increase in mean annual runoff.
- The 75th percentile and bias-corrected maximum increases were used as a conservative range of the potential effects of climate change.
- For the Lake Manitoba basin, the climate change projections into the 2050s and 2080s indicate an increase in mean annual runoff depth in the range of 16.7-38.7 mm using the 75th percentile and bias corrected maximum GCM projections.
- For the Assiniboine River basin, the climate change projections into the 2050s and 2080s indicate an increase in mean annual runoff depth in the range of 9.6-37.7 mm using the 75th percentile and bias corrected maximum GCM projections.
- In a repeat 2011 Flood of Record event with the Project in place, with the additional runoff volumes estimated with the climate change projections, the peak water levels in Lake Manitoba and Lake St. Martin were found to increase by 0.15-0.37 m (0.5-1.2 ft) and 0.12-0.30 m (0.4-1.0 ft), respectively.
- Without the channels in place, the peak levels in a repeat 2011 Flood of Record with additional runoff volumes due to climate change would be approximately 0.46 m (1.5 ft) higher on Lake Manitoba and 0.72 m (2.4 ft) higher on Lake St. Martin compared to the same climate change projection scenario with the outlet channels in place.

The projected increases to runoff volumes were applied to the water balance model for the period from 1981-2017 to assess the change to the percent of time the lake water levels were below the top of their respective target operating ranges (247.65 m (812.5 ft) for Lake Manitoba and 243.84 m (800 ft) for Lake St. Martin). Results are summarized in Table 2.

TABLE 2: PERCENT OF TIME LAKE LEVELS BELOW UPPER END OF TARGET RANGE (1981-2017)

	Historic Hydrologic Regime (Base Case)		Hydrologic Regime with Climate Change Projections	
	Without Project	**With Project**	**Without Project**	**With Project**
Lake Manitoba	86%	95%	58-78%	83-93%
Lake St. Martin	65%	83%	31-51%	56-73%

The return period of the 2011 Flood of Record has been estimated to be approximately 1:300 years. Runoff trend analysis and climate change projections indicate that the return period of this flood may slowly decline over time, becoming more probable in the future. The peak flows in the LMOC and LSMOC associated with passage of the Design Flood event, with the impacts of climate change included, will be greater than at present, but still less than the magnitude of the estimated present day 1:1,000 year flood event (i.e., the IDF). Accordingly, the LMOC and LSMOC will be capable of passing such a future flood event without risk of failure of major Project components, albeit with potentially some reduction in freeboard and factors of safety.

There remains uncertainty as to how the hydrologic regime will be affected by climate change and which climate change scenario will be realized. However, projections generally indicate that there will be more water moving through the system in the future. This reinforces the need and benefit of the outlet channels, as without this infrastructure in place, flood damages could be more severe and more frequent in the future.

7.0 IMPLICATIONS FOR CHANNEL DESIGN

All channels and structures must be designed for some limiting condition that is acceptably infrequent and improbable, such that damage to the facilities would be unlikely (but not impossible) to occur over their lifetime. The following sections describe the design philosophy of the LMOC and LSMOC with consideration of the various hydraulic criteria. As discussed above, the three main flow conditions to be considered for each channel are:

- Conveyance target
- Design Flood (Repeat 2011 Flood of Record)
- IDF

7.1 Erosion Potential

Erosion in the channel and at the various structures should not be tolerated for flood magnitudes that are common and occur frequently.

The design of the water control structures for the LMOC and LSMOC have been developed so that all flows, whether at exceptional flood conditions or routine flood releases with partial gate openings, can be passed without risk of significant erosion that could jeopardize the stability and integrity of the structure. Both structures have been planned to be equipped with an energy dissipating stilling basin with adequate riprap protection immediately downstream. It is not anticipated that there would be a significant risk of serious erosion at the water control structures at any of the flood conditions summarized in Table 1.

The following sections describe the specific channel erosion criteria adopted for the LMOC and LSMOC.

7.1.1 LAKE MANITOBA

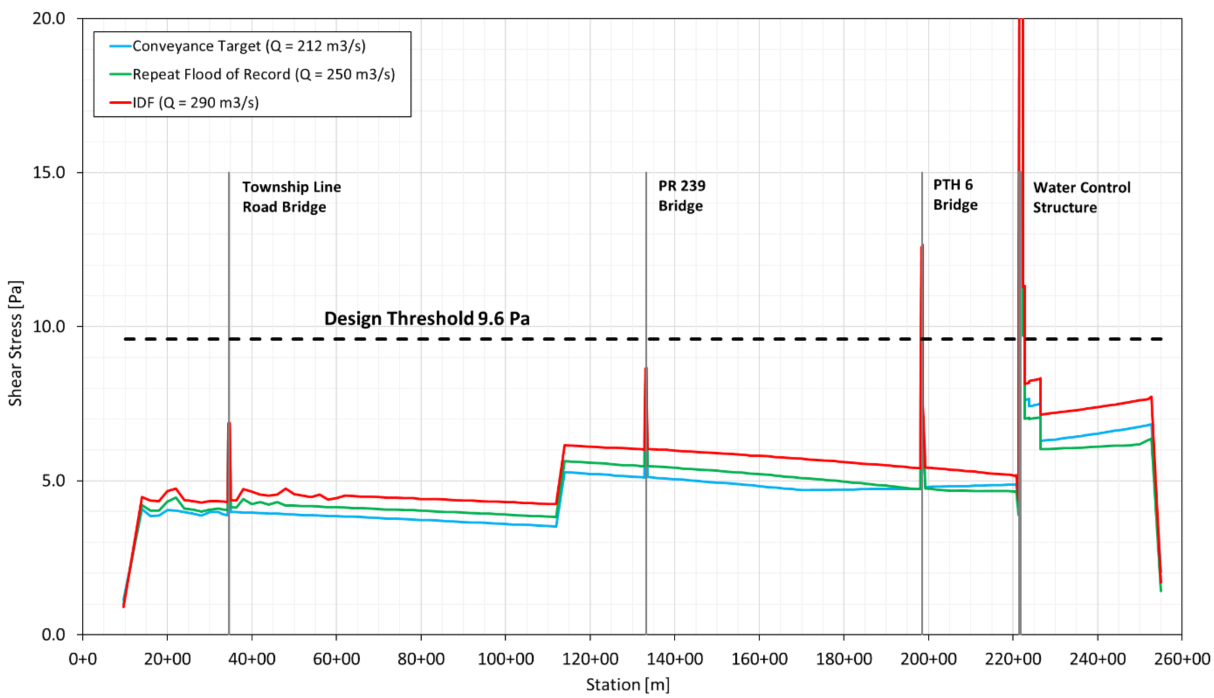
Channel

The base of the channel is primarily incised in glacial till ("till"), in which the channel base and side slopes predominantly intersect dense to very dense till. The erosion threshold of the material has been selected based on available literature and engineering judgement, taking into consideration available geotechnical soil property data.

The LMOC channel geometry is designed to limit the shear stress in the channel to not exceed the erosion threshold of the bed material, so as to minimize potential erosion. For passage of flows up to the Design Flood, a maximum allowable bed shear stress of 9.6 Pa was selected for straight sections of the channel, along with a maximum permissible velocity of 1.35 m/s. For more severe flood conditions, during which the occurrence of minor damage is acceptable, a maximum allowable shear stress of 14.3 Pa can be considered, along with a maximum permissible velocity of 1.5 m/s.

The channel cross section design and gradients were found to be governed by the requirement to meet the stipulated Conveyance Target, rather than the erosion threshold requirement during passage of the Design Flood. As such, the resulting shear stresses along the LMOC are below the maximum allowable limits noted above for flowrates associated with passage of flood events up to the IDF. The anticipated shear stresses at various flood conditions are summarized in Figure 9. Note that the channel will be protected with riprap in the vicinity of the bridges and water control structure, and therefore can tolerate the higher shear stresses that are expected to be present in these locations.

FIGURE 9: SHEAR STRESS ALONG LMOC FOR VARIOUS FLOOD EVENTS



The process of till softening has been identified as a potential risk that could reduce the erosion resistance of the bed material over time, and thus lower the maximum shear stress that it can tolerate prior to eroding. The complications of this phenomenon are uncertain and are currently being investigated to better understand the potential variability in the till shear resistance that may occur over the life of the LMOC. Should this investigation confirm that till softening is a reasonable concern, then armouring of the channel will be incorporated in strategic areas where the shear stresses in the channel are anticipated to exceed the shear resistance of the softened till.

7.1.2 LAKE ST. MARTIN

Channel

The base of the LSMOC is primarily incised in glacial till ("till"), with some zones of bedrock limestone. Upstream of the first drop structure (approximately 10 km of channel length), the channel base and side slopes primarily intersect dense, cemented silt till. Further downstream, portions of the channel invert intersect clay till and clay. Determining erosion thresholds for till can be complex given the presence of both cohesive fine and non-cohesive coarse particles (up to the size of boulders). In the absence of site-specific erosion tests (which have been planned but put on hold due to site access constraints), the erosion thresholds of the different materials have been selected based on available literature and engineering judgement.

The designs of the channel gradients, cross section, side slopes, and other geometries are selected to limit the maximum shear stress on the base of the channel to the adopted permissible limit of the bed material, beyond which erosion occurs. Upstream of the first drop structure (channel mainly in silt till), a critical shear stress of 10 Pa was selected, while 6 Pa was selected in the downstream reaches where clay is exposed (which is less dense and cemented than the silt till).

The process of till softening has been identified as a potential risk that could affect the erosion resistance of the bed material over time, which could affect the critical shear stress. The complications of this phenomenon are uncertain and are currently being investigated.

At the Preliminary Design stage, the channel geometry was selected such that the shear stresses along the LSMOC were below the critical erosion limits at the Conveyance Target flow of 326 m^3/s (11,500 cfs). The shear stresses at that flow condition and other potential flood conditions are summarized in Figure 10.

FIGURE 10: SHEAR STRESS ALONG LSMOC FOR VARIOUS FLOOD EVENTS

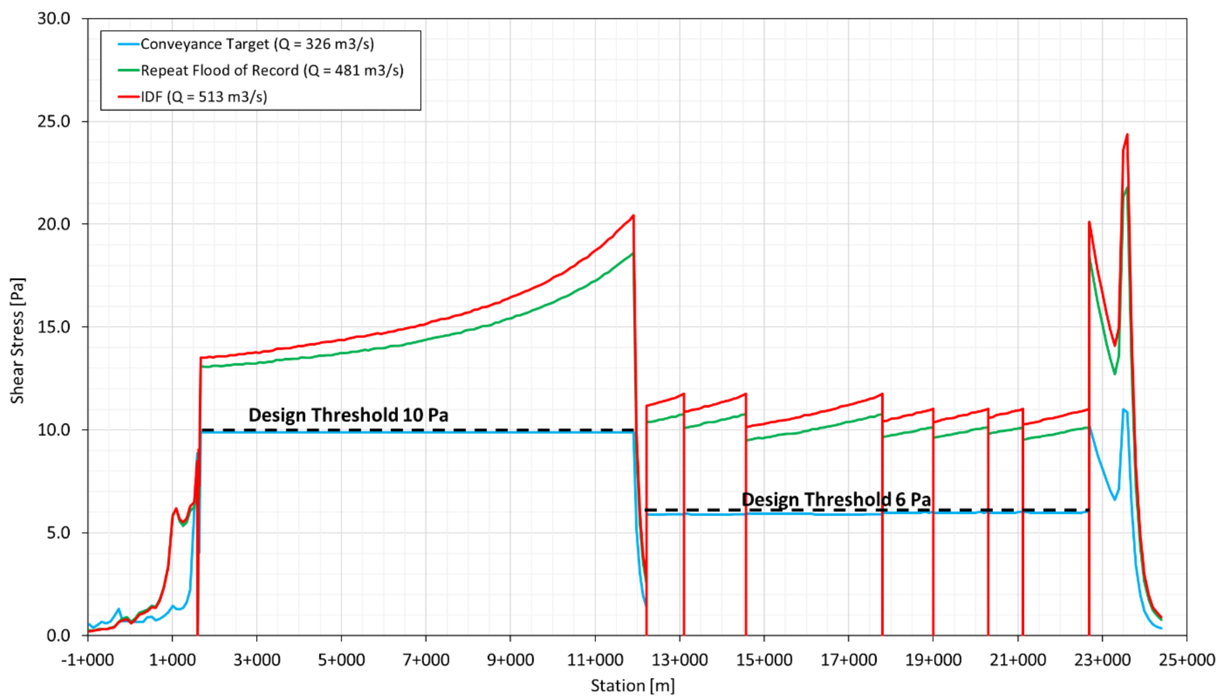


Figure 10 demonstrates that for flows in excess of the Conveyance Target, there would be an increasing risk of erosion of the channel bed. This process of erosion would be self-limiting due to the potential for self-armouring (i.e. as fine particles within the till are eroded, coarser gravels and rocks are left behind), which is expected to cap the depth of erosion at approximately 40 cm. That is, however, a very approximate figure and would be expected to vary widely over the length of the channel, depending on the distribution of stones within the body of the till that could serve as suitably resistant armour.

The risk of channel erosion at flows exceeding the Conveyance Target was identified at the Preliminary Design stage. The expected extent of channel erosion did not present an engineering risk, but it was acknowledged that environmental input was required on the acceptability of potential sediment transport and release into Lake Winnipeg. It was recognized that design changes could be incorporated to further minimize the potential for erosion.

Based on environmental input on the risks and impacts associated with erosion of the channel and transport of sediment to Lake Winnipeg, the design of the LSMOC has been modified to include a layer of armouring on the channel base and lower side slopes. The armour consists of coarse stones that are of sufficient size to withstand the range of shear stresses that could occur. The armour layer will be designed to withstand the flows experienced at the Design Flood, at a minimum. The armour will also be designed to accommodate the IDF flow with a reduced safety factor commensurate with the likelihood of the event. The armour layer will significantly reduce the risk of sediment transport from the LSMOC into Lake Winnipeg. Modifications to the channel geometry are ongoing to optimize the design with the armouring detail.

Drop Structures

The steep gradient along the channel route from Lake St. Martin to Lake Winnipeg, especially near the downstream end, requires a series of drop structures that can dissipate energy without serious risk of erosion.

It should be noted here that the lower end of the Dauphin River is also exposed to this risk but over the millennia of its existence, it has developed a resistant layer of armouring by natural cobbles. Erosion of that protective material is only possible at severely high river flows.

The drop structures were studied by KGS Group in the Stage 1 Engineering and the concept of construction with rockfill was adopted. Since the drop structures are critical in controlling water velocities and shear stresses in the channel, it is important that they do not fail during a severe flood event. The sudden failure of a structure would lead to a ripple effect of potentially serious erosion of the channel, which could compromise dike stability and subsequently lead to a breach. The loss of hydraulic control would also lead to increased shear stresses and velocities upstream, which could cause down-cutting of the channel base. The failure of a drop structure could also create the risk of a cascade failure of downstream drop structures. It is difficult to precisely identify the flow that would be required to cause serious collapse and failures of the rockfill. However, the best indicators are guidelines provided by C.D. Smith (1995).

Two stages of failure are described by C.D. Smith. First, “initial failure” of the rock slope would occur at a flow of approximately 125% of the design discharge. Initial failure is characterized by significant downslope movement of rock on the chute, but the structure remains intact and functional.

Second, “ultimate failure” of the rock slope can occur at flows ranging from approximately 150-200% of the design discharge or higher. Ultimate failure is characterized by complete failure of the rock slope and washout of the structure. The structure would not be functional in maintaining hydraulic control to water levels following ultimate failure.

At the Preliminary Design stage, the adopted philosophy was to design the drop structures for the repeat 2011 Flood of Record, and ensure that ultimate failure was not a risk at the IDF. Note that the LSMOC flows corresponding to the repeat 2011 Flood of Record and IDF quoted in the Preliminary Design report have evolved due to design modifications since that time (to account for head loss through Lake St. Martin Narrows). With the updated flows, the drop structures will be designed for a flow of 481 m^3/s. Based on the guidance provided in C.D. Smith, the drop structures would not be at risk of ultimate failure at the IDF flow.

7.2 Freeboard

7.2.1 LAKE MANITOBA

Water retaining dikes are required along portions of the LMOC where existing ground elevations are low, in order to contain the flow within the channel and prevent water from spilling overland into the low-lying wetland areas. The minimum crest elevation of these dikes will be set to the greater of the following criteria, which reflect both Project specific requirements and the intent of the CDA Dam Safety Guidelines:

- 1:1,000 wind setup event applied to the maximum normal water level in the LMOC when the channel is not in operation, which is taken as the maximum normal operating level of Lake Manitoba and Lake St. Martin (i.e., el. 247.65 m, (812.5 ft) on Lake Manitoba and el. 243.84 m (800.0 ft) on the south basin of Lake St. Martin).
- The predicted water surface in the LMOC associated with passage of the IDF in combination with a 1:10 year wind setup event on Lake Manitoba.
- 1 m above the predicted water surface in the LMOC associated with the Conveyance Target flow condition.
- The water surface elevation of any naturally inundated areas that may be present immediately adjacent to the LMOC dikes, outside of the channel, that are associated with the above conditions.

Predicted water surface profiles within the LMOC for a range of flood events are shown in Figure 11, along with the proposed minimum channel dike elevations based on the above criteria. The associated freeboard available to the top of the proposed channel dikes along the length of the LMOC for these flood events is shown in Figure 12.

FIGURE 11: WATER SURFACE PROFILES IN LMOC FOR VARIOUS FLOOD EVENTS

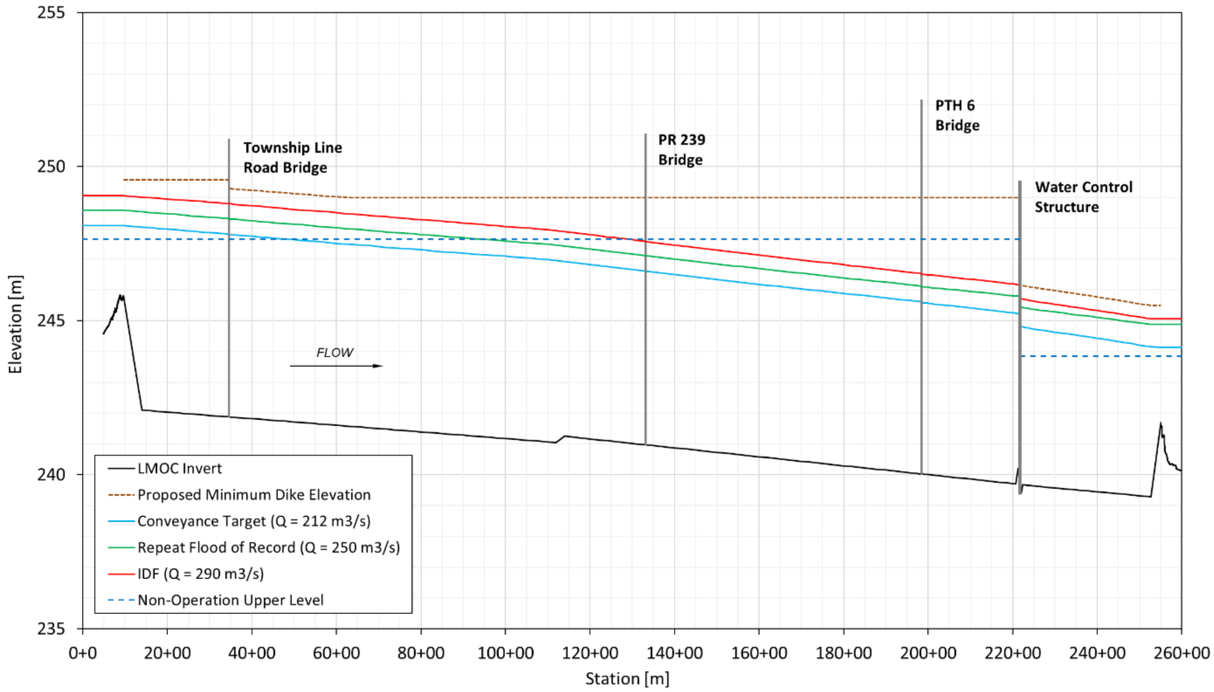
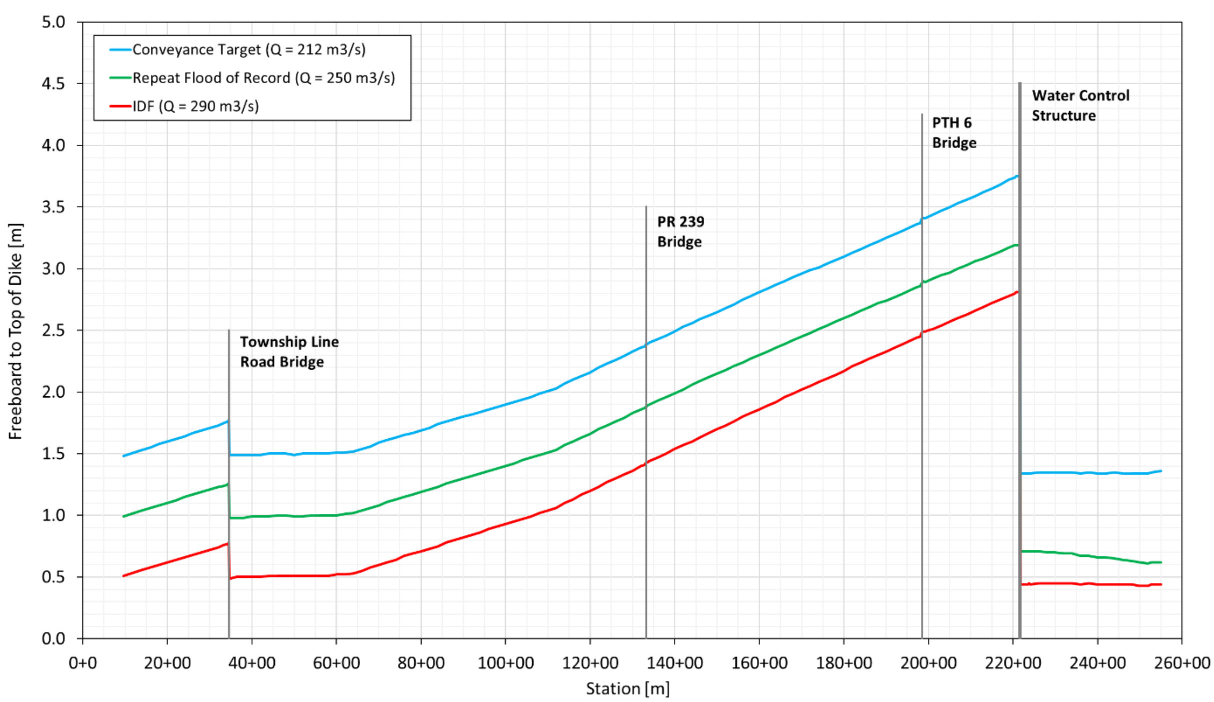


FIGURE 12: MINIMUM FREEBOARD ON LMOC CHANNEL DIKES FOR VARIOUS FLOOD EVENTS



7.2.2 LAKE ST. MARTIN

Channel Dikes

Water retaining dikes are required along the majority of the LSMOC to contain flow in the channel and prevent water from spilling overland to the Buffalo Creek drainage area and thereby incurring damages of the type that were experienced in 2011 and 2014. At the Preliminary Design stage, the crest elevations of these dikes were based on the water surface profile in the channel at the Conveyance Target of 326 m^3/s (11,500 cfs), with 1 m of freeboard. This Project-specific criteria was stipulated in the Terms of Reference.

As discussed previously, the LSMOC will pass flows exceeding its Conveyance Target over its lifetime. To accommodate the range in flow conditions and minimize the likelihood of overtopping, the channel dike crest elevations will be set to the following criteria, at a minimum:

- 1.0 m freeboard at the Conveyance Target flow condition
- 0.6 m freeboard at the Design Flood (repeat occurrence of 2011 Flood of Record)
- 0.3 m freeboard at the IDF

Freeboard on the dikes provides a safety margin against various uncertainties in the design process (e.g. actual bed roughness versus assumed roughness in hydraulic models, stage-discharge relationship of control structure, etc.). The freeboard will also be checked at each flow condition to ensure it is adequate to accommodate any flow surcharge from wind setup on Lake St. Martin. If required, MI will have the ability to raise the dikes in the future on an emergency basis using excess spoil materials that will be stockpiled within the Project Right-of-Way.

Water surface profiles for a range of flood events, as computed with a 1D HEC-RAS model, are shown in Figure 13. The minimum freeboard on the channel dikes (elevations selected based on the criteria above) along the length of the LSMOC at the different events are shown in Figure 14. As shown, the freeboard criteria for the Flood of Record governs the dike heights along the majority of the LSMOC.

FIGURE 13: WATER SURFACE PROFILES IN LSMOC FOR VARIOUS FLOOD EVENTS

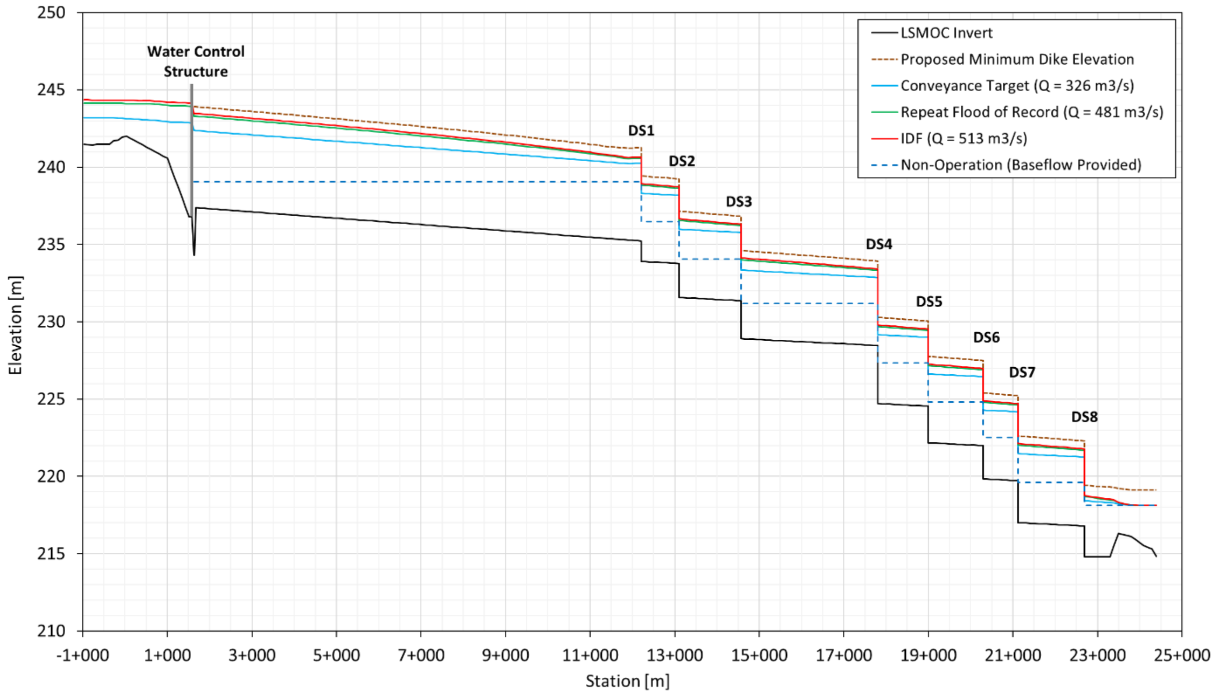
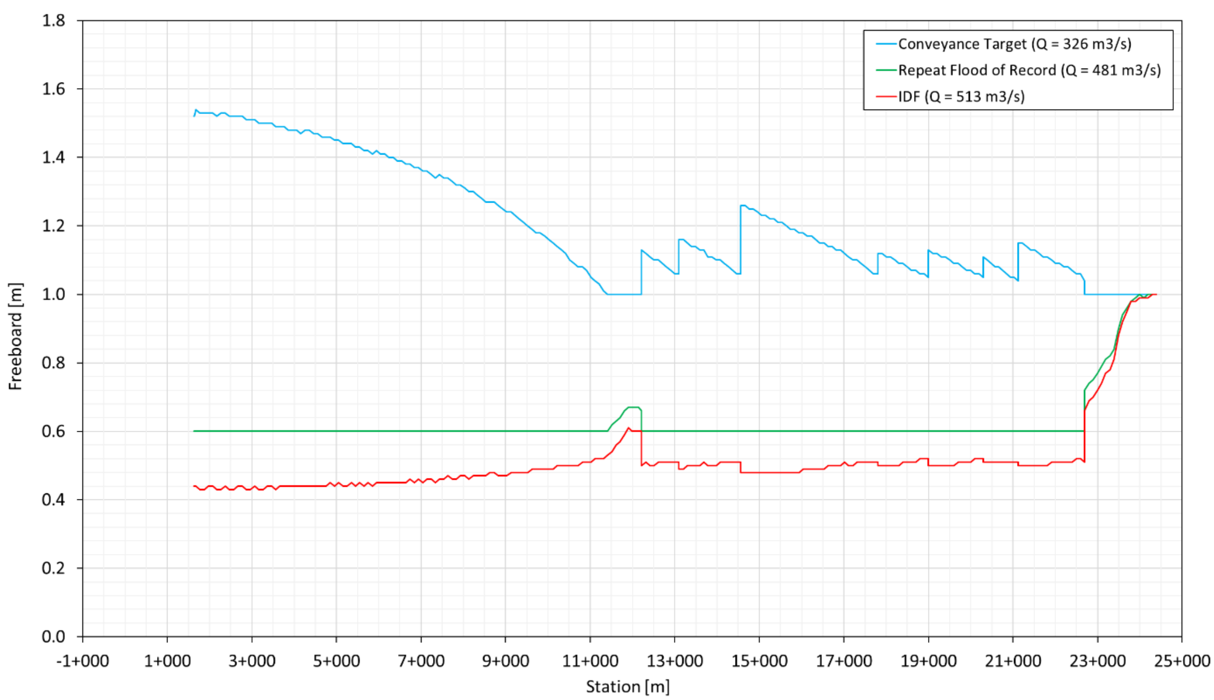


FIGURE 14: MINIMUM FREEBOARD ON LSMOC CHANNEL DIKES FOR VARIOUS FLOOD EVENTS



Access Road Between Control Structure and Reach 1 Channel

The Project includes a permanent all-season road to the LSMOC to provide access to the channel for inspections, maintenance, and operations. MI requested that the access road be extended across the LSMOC to Reach 1 of the Emergency Outlet Channel. It is critical that the access road not be overtopped during a severe flood event to maintain safe access to the LSMOC.

The road has been planned to have a crest elevation of 246.5 m (808.7 ft). This elevation is high enough to provide a freeboard of approximately 1.9 m at the IDF water level in the north basin of Lake St. Martin. The road elevation is adequate to protect against wave action and wind setup that could be expected during passage of the IDF, in accordance with the CDA Guidelines.

8.0 SUMMARY

This document summarizes the origins and evolution of the various hydraulic design criteria that are associated with the current designs for the LMOC and the LSMOC. The design criteria are summarized as follows:

Conveyance Targets

The channels are sized to meet the Conveyance Targets committed to by the Province of Manitoba in 2014:

- LMOC: Passage of 212 m^3/s (7,500 cfs) at a Lake Manitoba water level of El. 248.11 m (814 ft) and a Lake St. Martin south basin water level of El. 244.14 m (801 ft)
- LSMOC: Passage of 326 m^3/s (11,500 cfs) at a Lake St. Martin south basin water level of El. 244.14 m (801 ft)

Design Flood (Repeat Occurrence of 2011 Flood of Record)

The channels are designed to accommodate the peak flow that will occur in each outlet channel associated with passage of a repeat of the 2011 Flood of Record through the Lake Manitoba/Lake St. Martin system, with the permanent outlet channels in place, without exceeding erosion thresholds and while maintaining safe freeboard and factors of safety on Project components (i.e. drop structures, bridges, WCS, channel dikes). This event reflects the adopted Design Flood condition for the LMOC and LSMOC.

The peak flows in the outlet channels are driven by the peak water levels in the respective upstream lakes. Based on the current design of the outlet channels, the peak flows for this condition are estimated to be approximately:

- LMOC: Passage of 250 m^3/s (8,800 cfs)
- LSMOC: Passage of 481 m^3/s (17,000 cfs)

IDF

The channels are designed to accommodate the peak flows that would occur in each outlet channel during associated with passage of the 1:1,000 year flood event through the Lake Manitoba/Lake St. Martin system, with the permanent outlet channels in place, without risk of failure of major Project components (i.e. drop structure, WCS, channel dikes). This event reflects the IDF for the LMOC and the LSMOC, which was selected on the basis of the potential consequences of failure following the methodology outlined in the Canadian Dam Association Dam Safety Guidelines. Reduced freeboard and factors of safety are considered for this scenario.Based on the current design of the outlet channels, the peak flows for this condition are estimated to be approximately:

- LMOC: Passage of 290 m^3/s (10,300 cfs)
- LSMOC: Passage of 513 m^3/s (18,100 cfs)

Additional points regarding the design and estimated performance of the outlet channels are summarized below:

- With the outlet channels designed to achieve the Conveyance Targets established in the Terms of Reference, the estimated peak water levels during a repeat of the 2011 Flood of Record in Lake Manitoba and Lake St. Martin (south basin) are 248.58 m (815.6 ft) and 244.88 m (803.4 ft), respectively. This reflects a reduction in the expected peak water levels by 0.41 m (1.3 ft) on Lake Manitoba and 0.64 m (2.1 ft) on Lake St. Martin for this event compared to the scenario without the Project in place. The channels also reduce the duration of time each lake is above its respective flood stage.
- The LMOC and LSMOC will be designed to mitigate the potential for erosion and sediment transport to downstream lakes when passing flows associated with a repeat of the 2011 Flood of Record (at a minimum).
  - For the LMOC, this is achieved by designing the channel geometry to limit water velocities and associated shear stresses to be less than the maximum allowable shear stress of the till. Strategic armouring of the channel will be incorporated into the design where this is not possible.
  - For the LSMOC, this is achieved by armouring the channel base with rock and incorporating robust rockfill drop structures. Some minor damage may be incurred at the IDF, but significant erosion is not anticipated.
- The return period of the 2011 Flood of Record has been estimated to be approximately 1:300 years. Runoff trend analysis and climate change projections indicate that the return period of this flood may slowly decline over time, becoming more probable in the future. The peak flows in the LMOC and LSMOC associated with passage of the Design Flood event, with the impacts of climate change included, will be greater than at present, but still less than the magnitude of the estimated present day 1:1,000 year flood event (i.e., the IDF). Accordingly, the LMOC and LSMOC will be capable of passing such a future flood event without risk of failure of major Project components, albeit with potentially some reduction in freeboard and factors of safety. The dike crests can be raised, if required, to account for increased flows if the climate change trends are realized.

9.0 REFERENCES

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