Manitoba Transportation and Infrastructure
Lake Manitoba Outlet Channel / Lake St. Martin Outlet Channel

Updated Sediment Transport Assessment During Commissioning with Channel Armouring

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Outlet Channel Content

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For Lake St. Martin
Outlet Channel Content

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Table of Contents

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1. Introduction

Sediment transport modeling during commissioning for the Lake Manitoba Outlet Channel (LMOC) and Lake St. Martin Outlet Channel (LSMOC) was previously undertaken reflecting a channel constructed with a bare till surface (Ref. 1 & 2). Since that time, the designs of the LMOC and LSMOC have advanced and it has been decided that the base and portion of the side slopes of the channels that were to be left as a bare till surface will now be armoured with small stone (crushed limestone) to address concerns over potential degradation or softening of the till over time. Armouring these channels changes the nature of some of the assumptions used in the previous sediment transport analyses. As such, a high-level supplemental assessment has been carried out to estimate the mass of sediment that may be left behind from the construction of the LMOC and LSMOC with an armoured bed. These estimates are compared against those from the previous work that were associated with an assumed 5 mm thick layer of fine particles uniformly distributed over both channels, and an assessment made as to the applicability of the previous modeling results to the revised channel designs. Potential measures that might be able to be implemented to reduce the volume of fine sediment available for mobilization in the channels are also presented.

Information and discussion related to the LMOC presented in this report has been developed by Hatch, while information and discussion related to the LSMOC has been developed by KGS Group.

2. Estimate of Percentage Fines in Armour

With the bed of both the LMOC and LSMOC now being armoured with small stone (crushed limestone), it is expected that some of the fine material present in the armour layer will be resuspended and transported downstream when the gates of the respective Water Control Structures (WCSs) are first opened during commissioning.

Laboratory testing has been conducted to estimate the potential percentage of fine sediment that may be present in the armour layer, which could be available to be resuspended in the water column and transported downstream when the LMOC and LSMOC are commissioned. The testing was undertaken on aggregate samples collected from three different limestone quarries in the Winnipeg area that are representative of the stone sizes and materials currently being considered for the armour layer. The procedure that was used to determine the material gradation of the samples was modified from ASTM (C136) to fully capture the amounts of fines (<80 μm diameter) that may be coating/adhered to the aggregate. These modifications included washing all the aggregate instead of only the proportion of the sample that is 5 mm or less in diameter. To facilitate calculating the fine fraction density, all the wash water was collected, decanted, and oven dried.

The following procedure was undertaken to measure the density of the coarse fraction of the aggregate:

1. The washed aggregate was placed and lightly compacted in a large mold of a known volume (284 mm height, 355 mm diameter) to the top of the mold. Due to size of the material, the top surface could not be made flush with the top of the mold, but individual pieces were visually adjusted to balance the volume of material above the top of the mold with the volume of voids beneath the top of the mold.
2. The material within the mold was then weighed to determine its density.
3. Steps 1 and 2 were repeated three times for each of the three samples and the average density of the material within the mold was calculated.

The following procedure was undertaken to measure the density of the fine fraction of the aggregate:

1. The oven-dried fines were scooped into a graduated beaker up to the 100 ml mark. The sample in the beaker was slightly agitated to lightly compact the fines, and additional fines were added as needed to the 100 ml target.
2. The material within the graduated beaker was then weighed to determine its density.
3. Steps 1 and 2 were repeated three times for each of the three samples and the average density of the fines within the beaker was calculated.

3. Estimate of Fine Sediment in LMOC

It is expected that some of the fine material present in the armour layer that will line the bed of the LMOC will be resuspended and transported downstream into Birch Bay when the gates of the WCS are first opened during commissioning. Furthermore, additional sediment volume left behind from in-the-wet removal of earth plugs that will separate segments of the channel to facilitate construction, as well as excavation of the in-lake portions of the inlet and outlet, will potentially be available to be transported downstream during the commissioning phase.

Estimates for each of these sources are presented below. Note that the sediment estimates associated with inlet/outlet excavation and removal of earth plugs were not accounted for separately in the previous analysis, but rather were considered to be lumped in with the 5 mm thick layer of fine particles uniformly distributed across the channel.

3.1 Mass of Fines within the Armour Layer

As noted in Section 2, laboratory testing indicated that 0.18% to 0.68% (by weight) of the total mass of armour may include fines (consisting of very fine sand, silt and clay) that could be available for resuspension and transport under flowing conditions. The approximate quantities of channel armouring that will be placed along the entire length of the LMOC, based on the current design, are provided below.

Table 3-1: Approximate Channel Armouring Quantities for LMOC

Channel Area	Volume (m^3)	Mass (tonnes)*
Portion permanently under water	289,100	549,290
Portion within ice interaction zone	280,700	533,330
Total	**569,800**	**1,082,620**

* Assuming an in-place density of 1.9 tonnes/m^3

Assuming conservatively that 0.68% of this mass would be available to be resuspended, the estimated total mass of fines within the armour layer would be approximately 7,360 tonnes.

3.2 Mass of Fines from Plug Removal

It is presently envisioned that three inland earth plugs and two shoreline plugs will be used to facilitate construction of the LMOC, which will be removed in-the-wet prior to commissioning. The total volume of the five plugs, which would consist of in-situ native till material, is estimated to be approximately 40,400 m^3 (80,800 tonnes assuming a density of 2.0 tonnes/m^3).

The mass of loose till material that could be leftover in the Channel as a result of earth plug removal in-the-wet has been estimated based on the guidance contained in the 2008 USACE report (Ref. 3) for dredging and removal via excavator (which notes sediment resuspension factors ranging from 0.6% to 5% of the volume removed). Conservatively assuming the 5% resuspension factor, the total mass of loose material remaining from plug removal would be approximately 4,040 tonnes, which would reflect material that consists predominantly medium silt and very fine sand.

3.3 Mass of Fines from In-Lake Portion of Inlet and Outlet Excavations

Excavation of the in-lake portion of the inlet and outlet will also leave behind disturbed sediments. The volume of this sediment will depend on the method of construction. Considering the current design, the estimated excavation volumes are approximately 27,000 m^3 at the inlet and 19,000 m^3 at the outlet, for a total of 46,000 m^3. The estimated mass of sediment would be 92,000 tonnes, assuming a density of 2.0 tonnes/m^3. Using the 5% resuspension factor for dredging and removal via excavator, based on the USACE method (Ref. 3), the estimated mass of fine sediment left behind after in-the-wet excavation of the inlet and outlet, would be approximately 4,600 tonnes.

It is expected, however, that a substantial portion of the fine sediment volume that will be generated from the in-lake excavation of the inlet would not be transported downstream during commissioning or operation of the channel. This is because the inlet has been designed to limit velocities in this area in order to reduce the potential for mobilization of the bed substrate. Based on guidance from the US Department of Agriculture (Ref. 4), fine sand substrate would require depth averaged velocities to remain below a maximum permissible velocity of 0.61 m/s to prevent erosion of the substrate in shallow flow depths (0.9 m). The maximum permissible velocity also increases progressively as the depth of flow increases. Based on numerical modeling completed for inlet channel design, local velocity in the area of excavation during commissioning would be below approximately 0.45 m/s which is associated with depths of flow that are greater than 0.9 m, thus no mobilization is anticipated.

Nevertheless, to be conservative, no reduction has been made to the estimated mass of fine sediment available in the inlet area for resuspension and transport.

The fine sediment volume that will be generated from the Outlet excavation activities would be expected to leave the excavation area and enter the depositional zone identified in the previous modeling (Ref. 1) within Birch Bay.

3.4 Total Mass of Fine Sediment

The estimated mass of fine sediments corresponding to the various sources are summarized below for the LMOC.

Table 3-2: Estimated Mass of Fine Sediments for the LMOC

Sediment Source	Mass of Fines (tonnes)
Armour Stone	7,360
Plug Removal	4,040
In-Lake Inlet Excavation	2,700
In-Lake Outlet Excavation	1,900
Total	**16,000**

Based on the conservative estimates discussed above, the total mass of fine sediment available for resuspension and transport in the LMOC from the armour layer, earth plug removal activities, as well as in-lake inlet and outlet excavations would be approximately 16,000 tonnes. The material would comprise very fine sand, silt and clay.

4. Estimate of Fine Sediment in LSMOC

It is expected that some of the fine material present in the armour layer that will line the bed of the LSMOC will be resuspended and transported downstream into Sturgeon Bay when the gates of the WCS are first opened during commissioning. Furthermore, additional sediment volume left behind from in-the-wet removal of the inlet and outlet cofferdams, as well as some loose material that remains within the footprint of the inlet and outlet, will potentially be available to be transported downstream during the commissioning phase.

Estimates for each of these sources are presented below. Note that the sediment estimates associated with cofferdam removal and inlet/outlet excavation were not accounted for separately in the previous analysis, but rather were considered to be lumped in with the 5 mm thick layer of fine particles uniformly distributed across the channel.

4.1 Mass of Fines within the Armour Layer

As noted in Section 2, laboratory testing indicated that 0.18% to 0.68% (by weight) of the total mass of armour may include fines (consisting of very fine sand, silt and clay) that could be available for resuspension and transport under flowing conditions. The approximate quantities of channel armouring that will be placed along the entire length of the LSMOC, based on the current design, are provided below.

Table 4-1: Approximate Channel Armouring Quantities for LSMOC

Channel Area	Volume (m^3)	Mass (tonnes)*
Channel base and lower side slopes	254,700	483,930
Upper armour zone (ice interaction)	152,000	288,800
Total	**406,700**	**772,730**

* Assuming an in-place density of 1.9 tonnes/m^3

Assuming conservatively that 0.68% of this mass would be available to be resuspended, the estimated total mass of fines within the armour layer would be approximately 5,250 tonnes.

4.2 Mass of Fines from Cofferdam Removal

The method of inlet and outlet construction anticipated for the LSMOC is to isolate the work areas from the lakes with cofferdams and excavate in the dry. Removal of the cofferdams would occur in-the-wet. Based on preliminary design estimates, the portions of the cofferdams that will be removed in-the-wet include approximately 34,000 m^3 and 13,096 m^3 of impervious fill and filter sand at the inlet and outlet, respectively. This corresponds to a mass of 94,192 tonnes (assuming a density of 2.0 tonnes/m^3).

The mass of loose material that could be leftover as a result of cofferdam removal in-the-wet has been estimated based on the guidance contained in the 2008 USACE report (Ref. 3) for dredging and removal via excavator (which notes sediment resuspension factors ranging from 0.6% to 5% of the volume removed). Conservatively assuming the 5% resuspension factor, the cofferdam removal would leave a mass of approximately 4,710 tonnes of fines which would be available to be transported during commissioning of the LSMOC. This estimate is conservative because a portion of the cofferdam would be above the water level and would be removed in the dry.

4.3 Mass of Fines from Inlet and Outlet Excavations

As noted above, the anticipated method of construction of the LSMOC inlet and outlet is dry excavation behind cofferdams. For estimating purposes, it is assumed that a 5 mm thick layer of loose sediment (density of 1.0 tonne/m^3) will remain in the footprint of the inlet and outlet (this is the same assumption that was previously applied for the channel sediment modeling [Ref. 2]). Based on this, the estimated mass of fines for the inlet and outlet are as follows:

Table 4-2: Estimated Mass of Fines for the LSMOC Inlet and Outlet Excavations

Area	Excavation Footprint (m^2)	Estimated Mass of Fine Sediment Remaining (tonnes)
Inlet	269,500	1,350
Outlet	22,700	110

Similar to the LMOC, the inlet of the LSMOC is designed to limit water velocities to prevent erosion of the bare soil excavation area during operation of the channel. Numerical modeling indicates that approximately one third of the inlet excavation area will have local depth-averaged velocities less than 0.61 m/s during commissioning, with flow depths greater than 0.9 m. Thus, only a portion of the fine sediments left over from inlet excavation are expected to be suspended and transported during commissioning of the LSMOC. However, for the purposes of estimating an upper limit of the potential mass of sediment that could be transported during commissioning, this reduction was omitted from the total quantities presented in Section 4.4.

4.4 Total Mass of Fine Sediment

The estimated mass of fine sediments corresponding to the various sources are summarized below for the LSMOC.

Table 4-3: Estimated Mass of Fine Sediments for the LSMOC

Sediment Source	Mass of Fines (tonnes)
Armour Stone	5,250
Cofferdam Removal	4,710
In-Lake Inlet Excavation	1,350
In-Lake Outlet Excavation	110
Total	**11,420**

Based on the conservative estimates discussed above, the total mass of fine sediment available for resuspension and transport in the LSMOC from the armour layer, cofferdam removal activities, as well as in-lake inlet and outlet excavations would be approximately 11,420 tonnes. The material would comprise very fine sand, silt and clay.

5. Comparison with the Previous During Commissioning Sediment Transport Modeling

5.1 Lake Manitoba Outlet Channel

The previous modeling of the LMOC, summarized in Ref. 1, considered a 5 mm thick erodible layer of fine particles uniformly distributed across the channel, which equated to approximately 12,000 tonnes of sediment that might be available for erosion/transport after construction. Under the Base Case gate operation scenario considered, the modeling indicated that approximately 2,700 to 5,500 tonnes of the initial 12,000 tonnes of available loose material would be flushed from the channel within 4 days. Under a Mitigation Case (controlled gate opening) scenario that was simulated in the model to limit the increase in TSS concentrations, it was found that approximately 1,200 to 2,400 tonnes of the initial 12,000 tonnes of available loose material would be flushed from the channel within 11 days. Additional sediment would be mobilized under this scenario as the gates are progressively raised until fully open, which was anticipated to result in an overall total mass of sediment transported into Birch Bay in the order of 5,000 tonnes over a duration of about 1 month from when the gates were initially opened. Thus, while the amount of sediment mobilized was similar, the rate of sediment transport in the Mitigation Case was reduced compared to the Base Case, resulting in lower TSS concentrations at the outlet.

As discussed in the modeling report (Ref. 1), the difference between the total mass of sediment assumed to be available for transport, and that which got transported into Birch Bay based on the model results, is due to the lower velocities present along the upper channel side slopes which were not large enough to mobilize the sediment available in those areas. Additionally, the modeling results showed that some of the material eroded from the channel would deposit progressively along lower portions of the channel side slopes in areas further downstream. Thus, it was anticipated that there would likely be some sediment left within the channel following commissioning. It was noted that this sediment may become remobilized during future channel operation. As such, it was identified that controlled gate operations and monitoring may need to be performed to control TSS concentrations when the channel is put into operation in the future.

The total mass of fine sediment estimated in the supplemental analysis discussed in Section 3 is approximately 33% higher than the total mass of sediment considered in the previous modeling work (Ref. 1). While the updated estimate exceeds the previously modeled volume of 12,000 tonnes and would likely result in some additional deposition downstream in Birch Bay, it is expected that controlled gate operations during commissioning will still be effective in limiting TSS concentrations above background to acceptable levels. Given that the material type of the sediment estimated for the current channel design with an armour layer is similar to that associated with the 5 mm thick layer of erodible sediment considered in the previous analysis, it is reasonable to conclude that the general areas of deposition as estimated and presented in the previous modeling report (Ref. 1) are still applicable to the current channel design, with a corresponding increase in depth of deposition that reflects the percentage increase in total mass of sediment available for resuspension.

5.2 Lake St. Martin Outlet Channel

The previous modeling of the LSMOC, summarized in Ref. 2, considered a 5 mm thick erodible layer of fine particles uniformly distributed across the channel, which equated to approximately 8,500 tonnes of sediment that might be available for erosion/transport after construction. Under both the Base Case (gates opened quickly) and Mitigation Case (controlled gate operations), the modeling indicated that approximately 5,300 tonnes of the initial 8,500 tonnes of available loose material would be flushed from the channel. However, the rate of sediment transport in the Mitigation Case was reduced compared to the Base Case, resulting in lower TSS concentrations at the outlet.

As discussed in the modeling report (Ref. 2), the difference between the total mass of sediment assumed to be available for transport, and that which was actually transported into Lake Winnipeg, is due to the lower velocities present along the upper channel side slopes (i.e., the material did not erode in these areas), and the deposition of some sediment particles upstream of the drop structures and on the lower slopes within the LSMOC. Thus, it was anticipated that there would likely be some sediment left within the channel following commissioning. It was noted that this sediment may become remobilized in during future channel operation. As such, it was identified that controlled gate operations and monitoring may need to be performed to control TSS concentrations when the channel is put into operation in the future.

The total mass of fine sediment estimated in the supplemental analysis discussed in Section 4 is approximately 11,420 tonnes. This is 34% higher than the total mass of sediment assumed in the previous modeling work (Ref. 2). While the updated estimate exceeds the total mass assumed in the previous modeling and would likely result in some additional deposition downstream in Sturgeon Bay, it is expected that controlled gate operations during commissioning would still be effective in limiting TSS concentrations above background to acceptable levels. Given that the material type of the sediment estimated for the current channel design with an armour layer is similar to that associated with the 5 mm thick layer of erodible sediment considered in the previous analysis, it is reasonable to conclude that the general areas of deposition as estimated and presented in the previous modeling report (Ref. 2) are still applicable to the current channel design, with a corresponding increase in depth of deposition that reflects the percentage increase in total mass of sediment available for resuspension.

6. Potential Measures to Reduce Volume of Fine Sediment Available for Mobilization

Some measures may potentially be able to be implemented during construction and commissioning of the LMOC and LSMOC, where appropriate, to reduce the volume of fine sediments available for mobilization and transport. These are primarily related to construction methodologies associated with in-lake excavation and earth plug/cofferdam removal. Note that such measures would need to be further explored during detailed design to assess their suitability with respect to applicability/constructability in the field; environmental suitability; construction schedule implications; and cost to implement.

Measures could potentially include:

- **Remove Deposited Sediment after Plug Removal** - Earth plug removal will be conducted behind turbidity curtains, and following plug removal and settling of suspended fine sediment, the settled material can be collected via pumping into a GeoTube (i.e., filter bag) or a containment cell area within the spoil pile area. Alternatively, a hydrovac could be used to remove the settled sediments rather than by pumping.
- **Use of Alternative Equipment for Earth Plug/Cofferdam Removal and In-Lake Excavation** - Alternative earth removal equipment such as open clamshells, watertight clamshells and bucket dredges, which can result in lower sediment resuspension factors could be considered for in-the-wet excavation instead of a hydraulic excavator. For example, the sediment resuspension factors would range from about 0.3% to 1% for open clamshells, and from about 0.3% to 2% for watertight clamshells as well as for bucket dredges, compared to 0.6% to 5% for hydraulic excavators (Ref. 3).
- **Install Cofferdam Upstream of Inland Earth Plug** - Prior to earth plug removal, a cofferdam, that contains minimal or no earthfill, could be installed upstream of an inland earth plug and the area between the cofferdam and plug dewatered to facilitate plug removal in the dry. Once complete, the area would be rewatered to equalize the pressure and the cofferdam removed. Since the plug would be removed in the dry, this

would be expected to significantly reduce the amount of fine sediment available for mobilization and transport.

- **Use of Chemical Agents for Coagulation and Flocculation of Suspended Sediments** - These could be used at inland plug locations to facilitate faster settlement of suspected fine sediment via the clumping of suspended particles together into larger heavier particles. The settled material would then be removed via pumping or hydrovac. The environmental suitability/acceptability and local soil conditions would need to be considered and pH monitoring would be required when undertaking the work.

7. References

1. Hatch, "Lake Manitoba Outlet Channel - Sediment Transport Modeling to Manage Excess Sediment Concentrations During Commissioning", File No. H358159-1000-228-230-0005, Rev. 0, August 2021.
2. KGS Group, "Lake St. Martin Outlet Channel - Sediment Transport Modelling to Manage Excess Sediment Concentrations During Construction", August 2021.
3. USACE, "Technical Guidelines for Environmental Dredging of Contaminated Sediment", September 2008.
4. US Department of Agriculture, Natural Resources Conservation Service, "Part 654 Stream Restoration Design, National Engineering Handbook, Chapter 8, Threshold Channel Design", August 2007.