MANITOBA INFRASTRUCTURE

Lake St. Martin Outlet Channel Dissolved Oxygen Analysis Report

Revision:

Final / Rev 0

KGS Group Project:

18-0300-005

Date:

July 30, 2021

PREPARED BY:

Melissa Haresign, P.Eng.
Water Resources Engineer

PROVINCE OF MANITOBA
P.A.G. LECLERCQ
Member
24531
REGISTERED PROFESSIONAL ENGINEER

REVIEWED BY:

Patrice Leclercq, P.Eng.
Water Resources Engineer

APPROVED BY:

Dave MacMillan, P.Eng.
Project Manager / Principal

TABLE OF CONTENTS

List of Tables

List of Figures

STATEMENT OF LIMITATIONS AND CONDITIONS

Limitations

This report has been prepared for Manitoba Infrastructure (“MI”) in accordance with the agreement between KGS Group and MI (the “Agreement”). This report represents KGS Group’s professional judgment and exercising due care consistent with the preparation of similar reports. The information, data, recommendations and conclusions in this report are subject to the constraints and limitations in the Agreement and the qualifications in this report. This report must be read as a whole, and sections or parts should not be read out of context.

This report is based on information made available to KGS Group by MI. Unless stated otherwise, KGS Group has not verified the accuracy, completeness or validity of such information, makes no representation regarding its accuracy and hereby disclaims any liability in connection therewith. KGS Group shall not be responsible for conditions/issues it was not authorized or able to investigate or which were beyond the scope of its work. The information and conclusions provided in this report apply only as they existed at the time of KGS Group’s work.

Third Party Use of Report

Any use a third party makes of this report or any reliance on or decisions made based on it, are the responsibility of such third parties. KGS Group accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions undertaken based on this report.

1.0 INTRODUCTION

1.1 Background

The LSMOC includes eight drop structures to safely dissipate energy of flow along the LSMOC. This allows for the excavated channels between the drop structures to have suitably mild slopes. The objective is to avoid high velocities and thereby prevent erosion of the channel bed. When the channel is not in operation, there will be a pool of water upstream of each structure, with water depths ranging between 1.0 and 2.7 meters. Amongst other reasons, the pools have been included to provide habitat for any fish that do not migrate downstream to Lake Winnipeg after an operation of the channel. An ice cover is expected to form on the surface of each pool in winter. However, the minimum depths for the pools have been designed to provide adequate conditions for the fish beneath the ice.

The design assumes that a baseflow of approximately 1.4 m^3/s will be provided to the channel by discharging water from Lake St. Martin through the Water Control Structure (WCS). The baseflow is intended to provide sufficient dissolved oxygen (DO) to support aquatic life in the channel, and an opportunity for fish to migrate downstream towards Lake Winnipeg.

KGS Group has completed an analysis of the effectiveness of the proposed baseflow to maintain sufficient levels of DO. The analysis has focussed on a range of magnitudes of baseflow as well as other relevant parameters. Results of predictions of levels of DO were compared to threshold values required to support aquatic life. The development of the numerical model of potential variations of DO, assumptions, controlling parameters and results of the analysis are described in this report.

The reporting is organized in the following three sections. Section 2 describes the numerical model development that was used for the bulk of the analyses. Section 3 summarizes the key results, sensitivity analyses, and findings. Section 4 lists the various conclusions from this work.

1.2 Standards for Dissolved Oxygen

In consideration of the Canadian Council of Ministers of the Environment (CCME 1999a) and the Manitoba Water Quality, Standards and Guidelines (MWI 2011), the DO results were analyzed in the context of a 5.5 mg/L limit for the protection of aquatic life (warm water, non-early life stages). In addition, a lower 3 mg/L DO threshold was used to evaluate the results for potential lethal effects in fish. Mortality and loss of equilibrium have been reported to occur at DO levels between 1 and 3 mg/L, with some species, such as northern pike, tolerating lower than 1 mg/L DO concentration (CCME 1999b and citations therein).

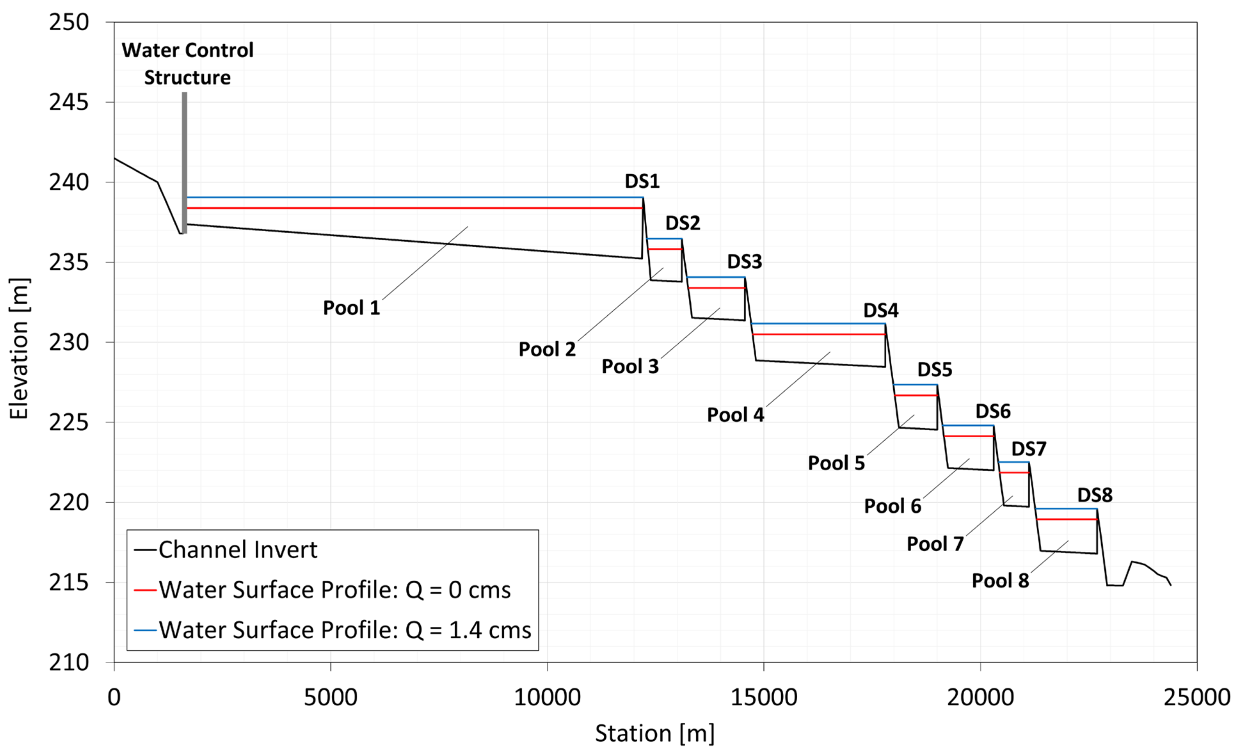
2.0 MODEL DEVELOPMENT

2.1 Modelling Approach

A mathematical model of mass-balance was developed in Microsoft Excel to assess the effectiveness of the proposed baseflow to maintain adequate DO levels in the channel. The model considered the relevant DO sources and sinks to the channel using an hourly time step. During prolonged periods of ice cover on the water surface of the channel, the water is almost entirely sealed off from the atmosphere and cannot be recharged with oxygenated air. Furthermore, ice and snow reduce the amount of sunlight reaching aquatic plants, thereby further reducing photosynthesis and production of oxygen. Consequently, the analysis of mass-balance was carried out over the winter period only, as that is anticipated to represent the worst-case scenario.

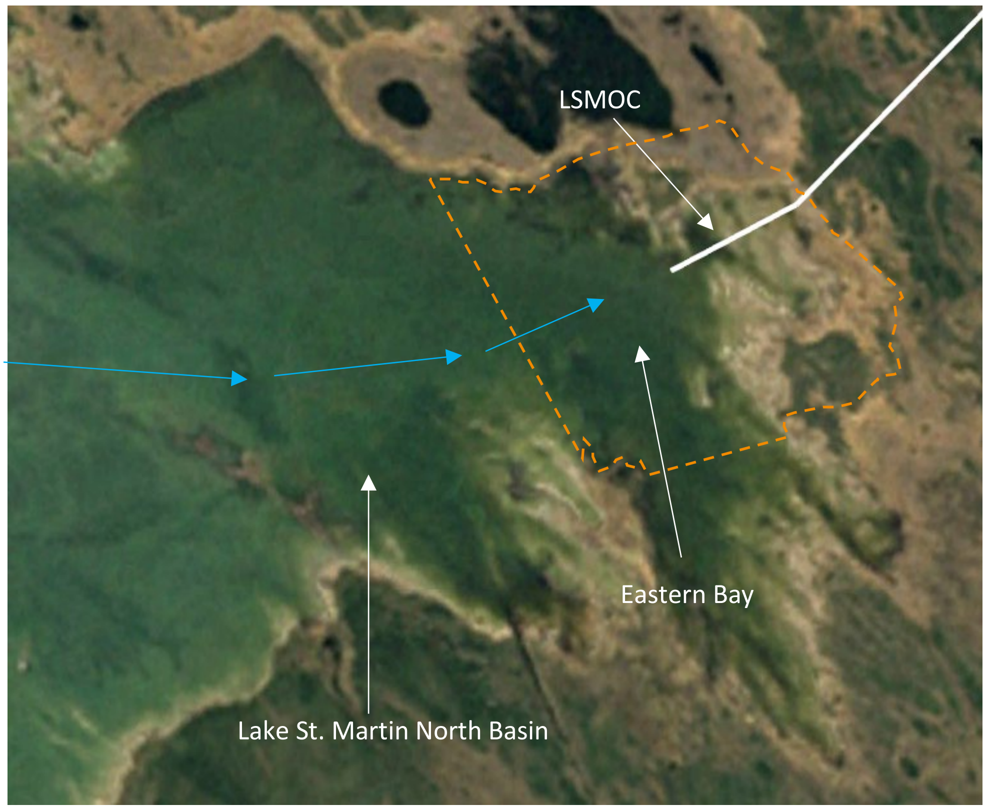
A profile of the LSMOC showing the location of the eight drop structures and their upstream pools is provided on Figure 1. As shown on the figure, the depth and volume of each of the pools are dependent on the flow being conveyed by the channel.

FIGURE 1: PROFILE OF LSMOC



The inlet to the LSMOC is at the eastern side of the Lake St. Martin north basin. Figure 2 shows its location and the general flow path of the water towards the inlet. Measurements of DO taken by North South Consultants during the winter of 2021 have indicated that DO concentrations in the eastern bay depleted notably more throughout the winter than at the center of the north basin. This may be attributed to the shallow, marshy nature of the eastern bay. It contains a relatively small volume of water with potentially a relatively high demand for oxygen compared to the main areas of the lake. This area was included in the model to ensure that the properties of the bay are captured in the analysis. The approximate area of the eastern bay is shown outlined in orange and was used to calculate the wetted area and volume for use in the model.

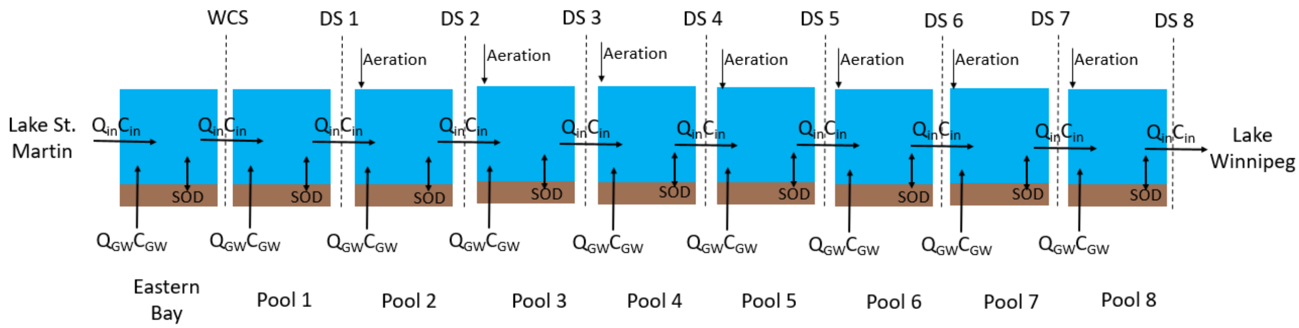
FIGURE 2: LOCATION MAP



Downstream of drop structure 8 (channel outlet) the reach of channel is very short (600 m) and is directly connected to Lake Winnipeg. Therefore, the water level in the channel will be the same as Lake Winnipeg and DO from the lake may also diffuse into the outlet. Furthermore, although an ice cover will form in the outlet, pathways with sufficient depths of water under the ice are expected to allow fish to egress into Lake Winnipeg when there is base flow in the channel. For these reasons, the channel outlet was not included in the DO model.

Each of the pools in the LSMOC, as well as the eastern bay, has several sources and sinks of DO. These are shown schematically on Figure 3. The DO sinks include the sediment oxygen demand (SOD) and outflows from the pool. The DO sources include the influx of DO from the inflows to the pool, which includes the baseflow from Lake St. Martin that passes through the LSMOC gates and groundwater inflow, as well as reaeration from contact of the water surface with the air.

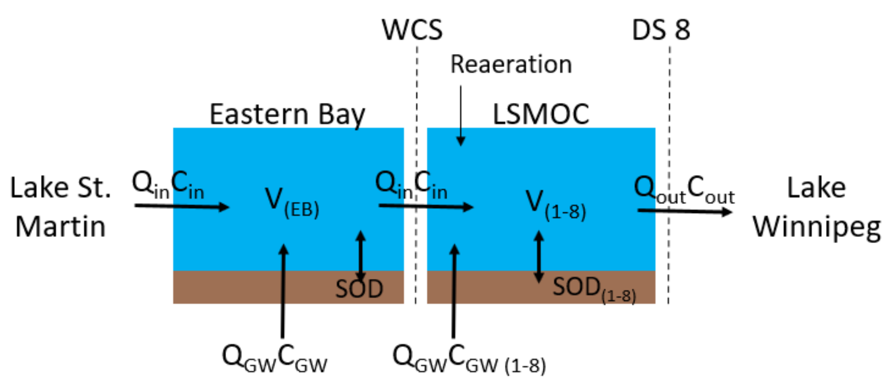
FIGURE 3: SCHEMATIC OF LSMOC



Based on this set-up, Pool 1 of the LSMOC would always be receiving oxygenated water from the north basin in Lake St. Martin (via the eastern bay pool). Consequently, it would generally have the highest DO concentration of all the LSMOC pools. The DO in each subsequent pool in the LSMOC would decrease as DO is consumed by the SOD and as dilution occurs. Though there would be oxygen recharge from the air at the drop structures, it was conservatively assumed to be negligible. As a result, the lowest and worst case DO concentrations would be found in Pool 8.

Since the analysis was focused on estimating the lowest DO concentration along the length of the channel, calculating DO in each LSMOC pool was not necessary. A simplified model was developed to calculate the DO at the outlet of Pool 8. This was achieved by combining the system of eight pools into a single pool system, with a volume and wetted area equal to that of the sum of all eight pools. Modelling the channel in this manner results in the DO estimates to be generally equal to those calculated in Pool 8 if all pools were modelled in series. It is therefore representative of the lowest concentrations throughout the channel. The eastern bay was not combined with the rest of the channel pools so as to appropriately represent the lake conditions at the inlet. This set-up is shown schematically on Figure 4.

FIGURE 4: SIMPLIFIED SCHEMATIC OF DO IN THE LSMOC



2.2 Estimation of Key Parameters in Analysis

The key parameters used in the analysis are described below. The estimated range of values used for these parameters was selected by consultation with the project environmental team, including North South Consultants and Stantec, and from available literature. Due to the uncertainty associated with the selection of many of the values of the parameters, some ranges were estimated and subsequently tested in the sensitivity analysis (described in Section 3.2).

2.2.1 POOL VOLUME, ICE THICKNESS AND BASEFLOW

The volume of the various pools is related to the channel geometry, the ice thickness generated by the winter conditions, and the amount of baseflow that is being conveyed by the channel. Pool volume was calculated using an existing HEC-RAS model of the channel and completing simulations with varying estimated ice thicknesses and baseflows.

A range of scenarios of baseflow were considered, from 0 m^3/s (no baseflow) to 1.4 m^3/s (assumed baseflow by MI in their chosen scenarios for studies of flood routing). The corresponding water level in the pools were based on either the bottom elevation of the V-notch at the drop structures (no baseflow) or the crest elevation of the drop structure to represent conditions when the V-notch is flowing full (releasing an estimated 1.4 m^3/s). In addition, ice covers ranging from 0.6 m to 1.2 m thick were considered. These were selected based on local experience and estimated to reflect ice with thicknesses below and above average, respectively.

The estimated pool volumes for the range of baseflow and ice thickness conditions are shown in Table 1.

TABLE 1: ESTIMATED VOLUMES OF LSMOC POOLS

	Pool Volume (m^3)							
	Baseflow = 1.4 m^3/s				Baseflow = 0 m^3/s			
Pool	no ice cover	0.6 m cover	1.0 m cover	1.2 m cover	no ice cover	0.6 m cover	1.0 m cover	1.2 m cover
1	1,366,519	1,043,943	844,802	749,605	978,798	690,082	512,149	428,389
2	134,094	100,248	80,098	70,399	93,696	64,392	46,219	37,634
3	221,645	166,672	132,932	116,718	155,637	106,615	76,076	61,536
4	498,417	373,265	294,919	257,112	347,700	233,298	161,663	127,092
5	173,783	132,010	106,125	93,776	123,474	86,009	62,911	51,923
6	206,163	156,070	125,280	110,531	146,009	101,460	74,063	61,083
7	119,506	90,428	72,545	64,017	84,520	58,655	42,930	35,427
8	251,237	190,245	152,773	134,961	178,024	123,793	90,170	74,189
All Pools	2,971,364	2,252,881	1,809,474	1,597,119	2,107,858	1,464,304	1,066,181	877,273

2.2.2 GROUNDWATER FLOW AND CONCENTRATION

The potential range of inflow from groundwater was estimated by analyzing data from preliminary design studies by KGS Group, past investigations, and ongoing tasks supporting environmental assessment of groundwater. This analysis determined that groundwater inflow could range from approximately 0.025 m^3/s to 0.042 m^3/s.

The DO concentration in the groundwater was estimated from numerous field measurements collected between 2019 and 2020. This data indicated that the average DO concentration was 3.05 mg/L and the minimum measurement 0.3 mg/L. As a result, the analysis considered a range of groundwater DO concentrations between 0.3 mg/L and 3.05 mg/L. Higher DO concentrations were not considered, so as to maintain a conservative upper limit of potential impacts.

2.2.3 DO CONCENTRATION IN LAKE ST. MARTIN

North Basin

A dissolved oxygen measurement was taken in Lake St. Martin at the inlet to the LSMOC on October 28, 2020 which indicated a DO concentration of 12.5 mg/L. This measurement was not taken under an ice cover however, it was taken at a point in time that was close to freeze-up. It was therefore deemed to be a reasonable representation of the DO concentration in the lake at the beginning of the winter period. Subsequent measurements taken in late March 2021 largely indicated that there had been little dissolved oxygen depletion in the lake over the winter. As a result, the concentration in LSM was estimated to be constant at 12.5 mg/L over the entire winter.

Eastern Bay

Most of the DO measurements taken in the north basin of LSM were constant over the winter period. However, the measurement in March 2021 in the eastern bay indicated a DO concentration of 1.83 mg/L which is substantially lower than measurements for the remainder of the north basin. That low DO concentration is likely attributable to shallow depths and the marshy environment in this area. The DO depletion in this area was taken into account by modelling the eastern bay area as a separate pool, as described in Section 2.1.

LSMOC

Although the channel receives baseflow from the lake, the SOD, inflow of groundwater and aeration would impact the levels of DO. During the open water season, aeration at the water surface, including in the turbulence at the drop structures, would be expected to recharge the DO concentration to near saturation and possibly even exceed the levels of DO in Lake St. Martin. It was therefore considered, for simplicity, that the initial DO concentration in the channel was equal to that in Lake St. Martin at the beginning of the winter period (12.5 mg/L).

2.2.4 OXYGEN DEMAND FROM SEDIMENT AND BIOCHEMICAL SOURCES

The sediment oxygen demand (SOD) is the rate at which dissolved oxygen is removed from the water column during the decomposition of organic matter in the sediments in the streambed or lakebed. For this project, the rate of SOD was determined by first back-calculating the rate of SOD in the eastern bay of LSM based on field measurements from the 2020-2021 winter season, and then applying that SOD rate to the LSMOC.

Available DO measurements in the eastern bay indicated that the DO concentration at the beginning of winter was 12.5 mg/L and declined to 1.83 mg/L by March 17, 2021. This information was used to develop a DO model of the eastern bay under pre-project conditions for the winter season of 2020-2021. The wetted area and pool volume in the eastern bay at the start (November 1) and end (March 17) of the simulation were estimated by overlaying the estimated water levels occurring on those days with the digital elevation model of LSM. It was estimated that these variables would decrease linearly throughout the winter season between the estimated values at the start and end of the winter. Once the conditions in the eastern bay over winter were established, the SOD rate was back-calculated by simulating the measured DO depletion from 12.5 mg/L to 1.83 mg/L. The resulting SOD rate of 0.07 g/m^2/day was found to be in good agreement with the comparable SOD values derived from a limited literature review, including:

- from 0.07 to 0.5 g/m^2/day for mineral to sandy bottoms (Bowie et. al, 1985).
- from 0.5 g/m^2/day for mineral soils to 6 g/m^3/day for flooded peat land (Manitoba Hydro, 2012).
- from 0.01 to 0.5 g/m^2/day downstream of a pulp mill (Casey, 1990).

The SOD rate of 0.07 g/m^2/day was applied to the entire wetted area of the channel. These areas were estimated by the existing HEC-RAS model and are summarized in Table 2.

Biochemical oxygen demand (BOD) represents the amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter. It is believed that organic matter would settle to the channel bed and would become part of the SOD. For this reason, the BOD was considered negligible.

TABLE 2: ESTIMATED WETTED AREAS OF POOLS

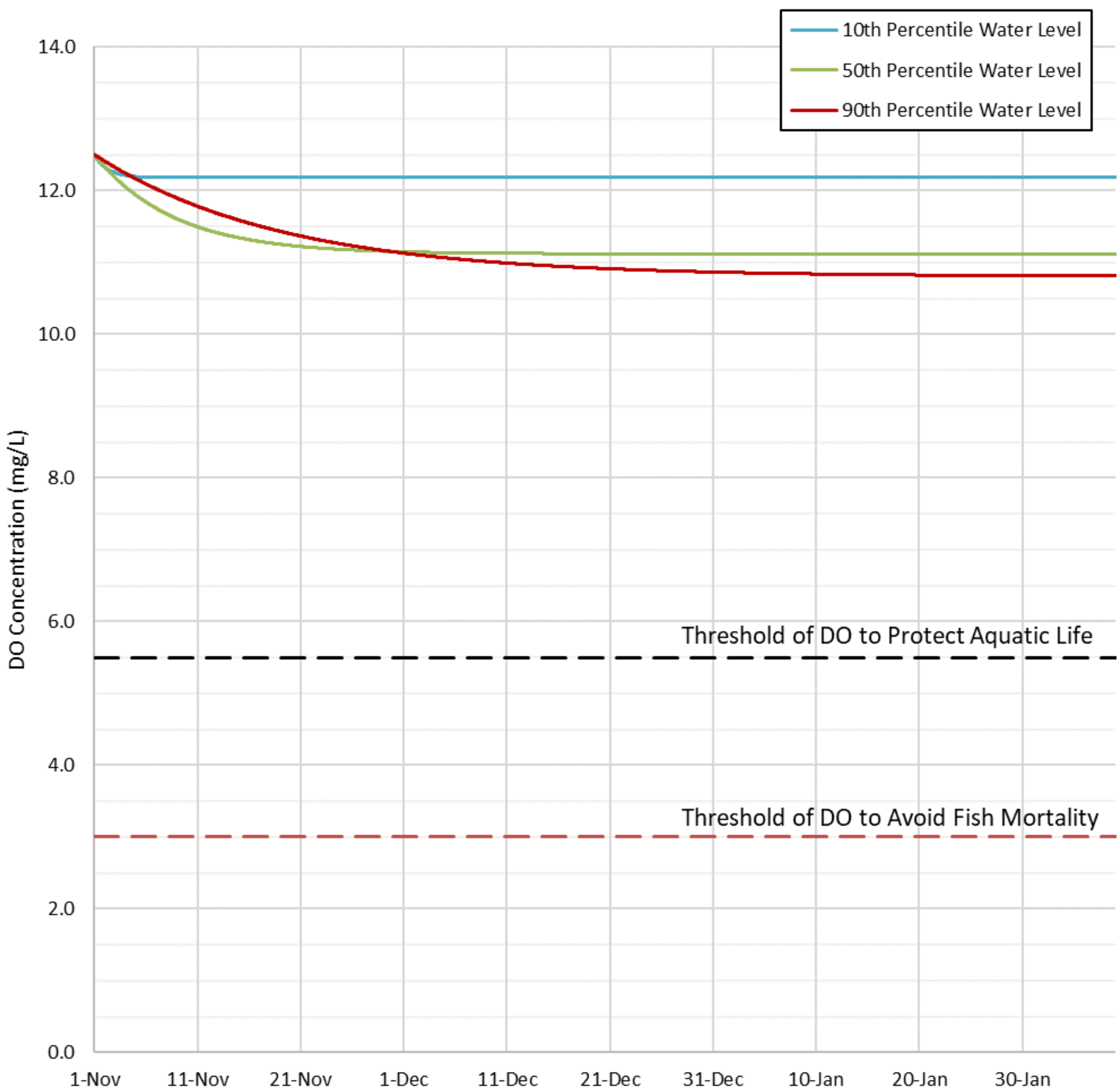
	Wetted Area (m^2)							
	Baseflow = 1.4 m^3/s				Baseflow = 0 m^3/s			
Pool	no ice cover	0.6 m cover	1.0 m cover	1.2 m cover	no ice cover	0.6 m cover	1.0 m cover	1.2 m cover
1	620,436	563,016	529,976	513,680	552,312	503,425	470,834	438,045
2	68,512	56,263	53,939	51,537	55,518	50,808	47,385	46,275
3	106,134	96,606	89,992	86,685	93,024	85,448	80,248	78,357
4	240,539	219,536	208,872	204,270	216,560	201,319	190,764	186,200
5	82,512	73,300	68,261	66,655	72,236	65,626	60,700	59,149
6	97,563	87,482	81,851	77,929	84,760	76,626	72,887	69,668
7	57,371	50,731	47,138	46,026	49,992	43,980	41,837	39,445
8	119,649	105,110	99,631	95,836	103,344	94,357	88,283	86,021
All Pools	1,392,716	1,252,044	1,179,660	1,142,618	1,227,746	1,121,589	1,052,938	1,003,160

2.2.5 BASEFLOW CONCENTRATION

The baseflow to the LSMOC is supplied from LSM via the eastern bay. As a result, it was considered that at each time step, the DO concentration in the outflow from the eastern bay pool would be equal to the DO concentration in the LSMOC baseflow.

The model of the eastern bay pool was simulated for a range of water levels in the north basin between the 10th percentile level (242.24 m) and 90th percentile level (243.62 m). This would establish an appropriate time series of DO concentrations in the baseflow to the LSMOC. In all cases, the volume and wetted area of the eastern bay pool were estimated in conjunction with an ice cover of 1.2 m in thickness on the surface of the lake. The resulting DO concentrations of the eastern bay outflow are shown in Figure 5.

FIGURE 5: DO CONCENTRATION IN OUTFLOW OF EASTERN BAY



Based on the results of this analysis, it was determined that high lake levels would generally result in conservatively low DO concentrations in the eastern bay. This results from the dilution of the DO from the large volume in the pool and the large consumption of the DO of the relatively high wetted area. As a result, the series of DO concentrations associated with the water level at the 90th percentile (i.e. exceeded by 10% of the water levels) was adopted as input to the model of the LSMOC pool. The volume of the pool and the wetted area at the water level at the 90th percentile were 2,238,711 m^3 and 2,608,321 m^2, respectively.

2.2.6 RECHARGE OF DISSOLVED OXYGEN

Recharge of dissolved oxygen occurs when water comes into contact with the air. Although a competent ice cover will form on much of the LSMOC, small portions of the channel downstream of the drop structures will likely remain open due to the turbulence of the water as it passes over each structure. As a result, it is anticipated that even during the winter season, there would be recharge of DO at each structure. However, to estimate conservatively low levels of DO, this analysis considered that there would be no DO recharge along the entire length of the channel.

3.0 RESULTS OF SIMULATIONS

3.1 Base Case

A base case was defined to establish a DO baseline under reasonably adverse conditions. The parameters selected for this base case are summarized in Table 3. The values selected were considered "best guesses" and could turn out to be better or worse in the field. A sensitivity analysis was completed to address the effects of this potential variability, as discussed in Section 3.2.

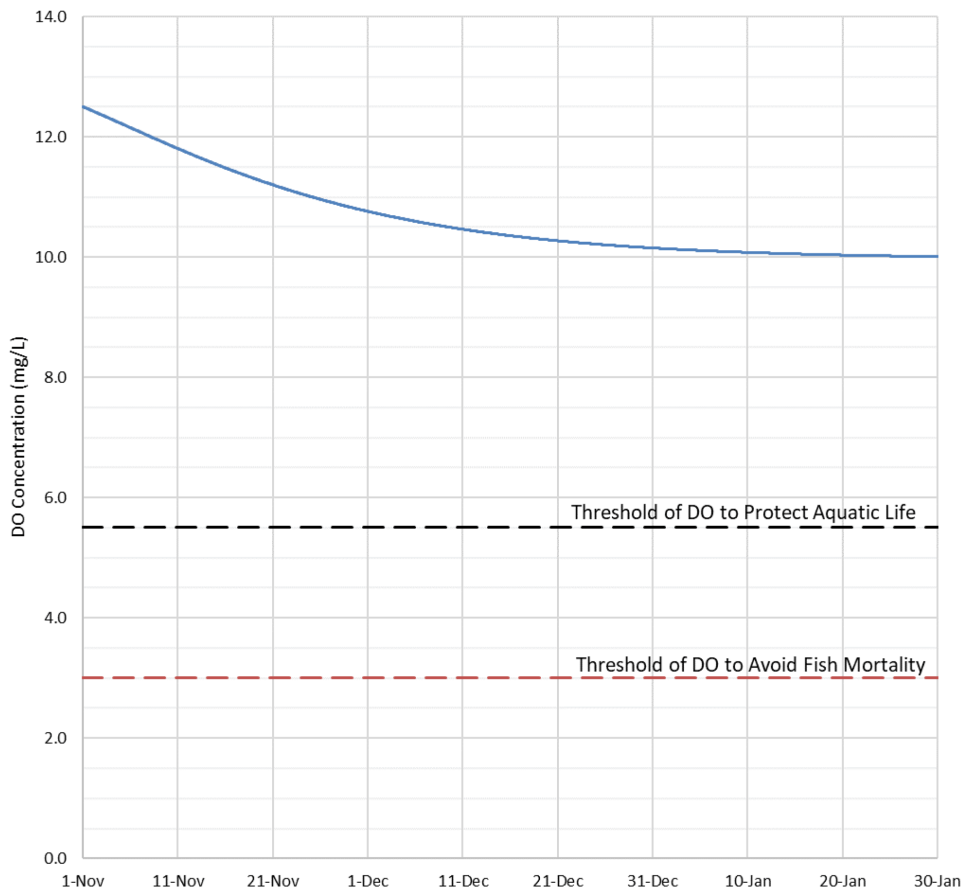
TABLE 3: PARAMETERS FOR BASE CASE

Parameter	Adopted Value
Ice Thickness	1.2 m
Winter Duration	5 months
Pool Volume	1,597,119 m^3
Baseflow	1.4 m^3/s
Baseflow Concentration	12.5 mg/L – 10.2 mg/L
Groundwater Flow	0.025 m^3/s
Groundwater Concentration	0.3 mg/L
SOD	0.07 $g/m^2/day$
DO Recharge	None Assumed

As described in Section 2.1, the base case assumed that all eight pools would act as a single pool and no DO recharge would occur. It is anticipated that the results of the analysis would be approximately equal to the DO concentration in Pool 8 if all pools were modelled together in series.

The results for the base case are shown on Figure 6. They indicate that the DO concentration in the channel will slowly decrease until an equilibrium point is reached approximately 4.5 months into the simulation. The resulting DO concentration is estimated to be 10 mg/L, which is well above the threshold for fish mortality.

FIGURE 6: LSMOC DO CONCENTRATION – BASE CASE



3.2 Sensitivity Analysis

A sensitivity analysis was undertaken to obtain a better understanding of the effect of varying the magnitude of each parameter on the DO concentration in the channel. The magnitudes of the parameters were adjusted to a reasonable upper or lower limit and the resulting simulations were compared to the original base case. The findings of this analysis are described in the remainder of Section 3.

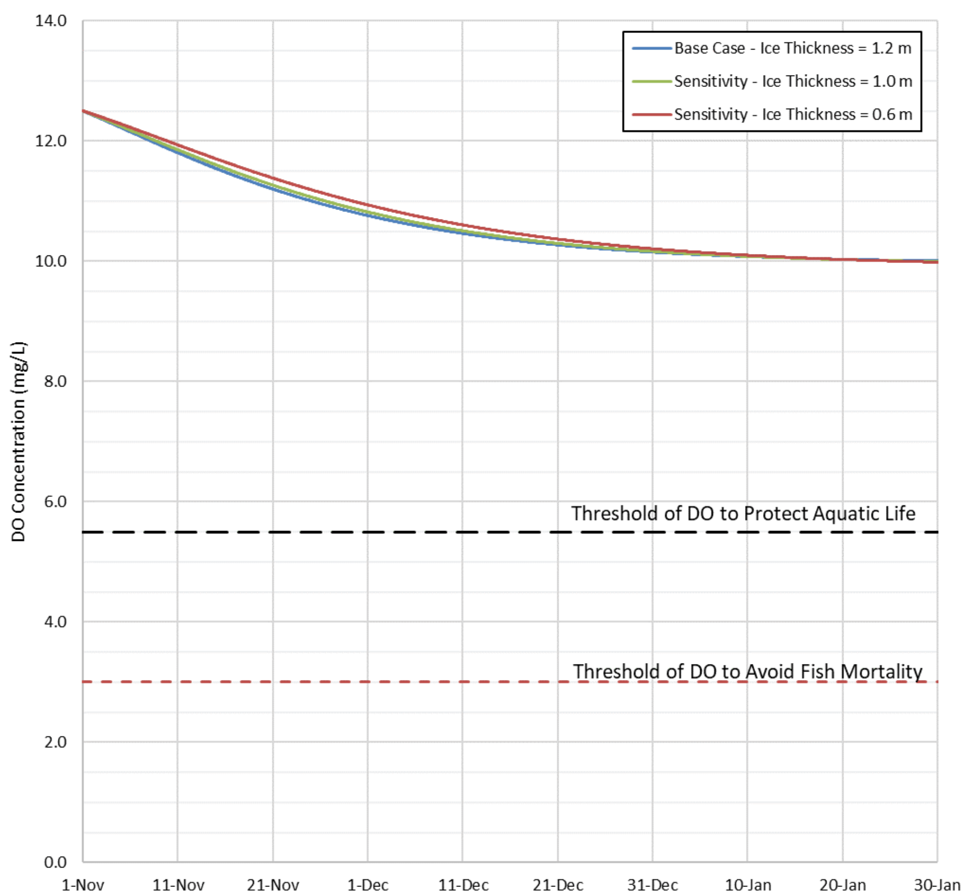
3.2.1 ICE THICKNESS

The thickness of the ice on the channel affects the volume of pooled water, as well as the wetted area of the channel. Thick ice results in a reduction in both the volume of the pools and the wetted areas for the SOD. However, these differences are considered to be small relative to the overall volumes and wetted areas of the pools.

DO simulations with ice thicknesses of 1.0 m and 0.6 m were compared to the base case which considered a conservative ice thickness of 1.2 m.

The results, shown on Figure 7, indicated that during the initial weeks of simulation, the thick ice estimated for the base case resulted in a relatively rapid decline in DO concentration over time. This is due to the relatively small volume of water under the thick ice. The low volume has a similarly low quantity of stored oxygen which therefore depletes relatively quickly. Subsequently, the DO stabilized as a result the benefits of a reduced wetted area for the SOD. If the inflow were reduced, the impacts of an ice cover on DO concentration would become more evident. However, the design acknowledges that there would be a baseflow, and the differences in all DO concentrations between these cases were small. Consequently, it has been concluded that the magnitude of ice thickness in the channel is not expected to have a significant effect on DO concentrations in the channel.

FIGURE 7: SENSITIVITY OF DO CONCENTRATION TO ICE THICKNESS IN LSMOC

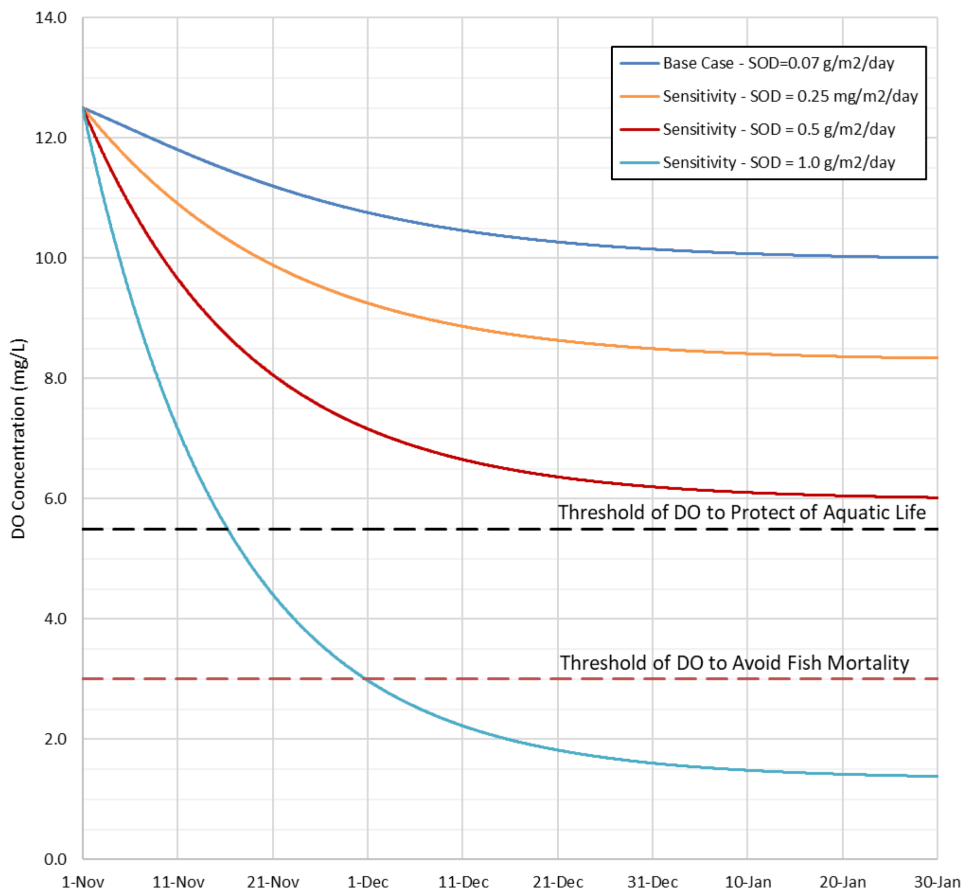


3.2.2 SEDIMENT OXYGEN DEMAND

The Sediment Oxygen Demand (SOD) affects the rate at which dissolved oxygen is removed from the water column during the decomposition of organic matter in the sediments of the streambed or lakebed. The larger the SOD, the more oxygen is depleted daily. The base case assumed an SOD of 0.07 $g/m^2/day$. However, SOD rates can be highly variable and difficult to define precisely. As a result, three additional rates were considered, based on ranges documented in the literature: 0.25 g/m^2/day (moderate), 0.5 g/m^2/day (high), and 1.0 g/m^2/day (extreme). Simulations using these SOD rates were carried out and the results are compared to the base case on Figure 8.

The results indicate that the DO in the LSMOC is sensitive to the SOD rate. But even at a high SOD rate, the DO concentration remains above the aquatic life protection DO threshold. At an extreme SOD rate, it only falls slightly below the threshold of DO for fish mortality. Considering that the model results are sensitive to the assumed SOD, it is recommended that a monitoring program be implemented following construction to measure DO in the channel and to confirm the rate of SOD.

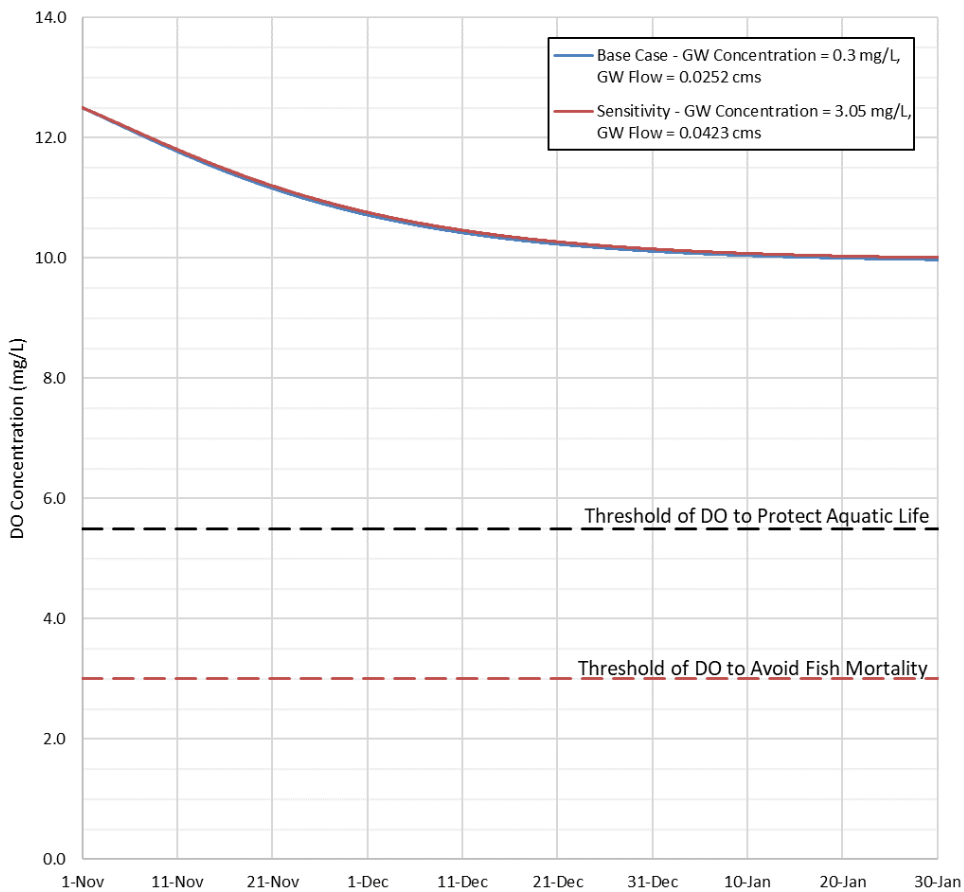
FIGURE 8: SENSITIVITY OF DO CONCENTRATION TO SOD RATE IN LSMOC



3.2.3 DO CONCENTRATION AND FLOW IN GROUNDWATER

Groundwater inflow to the LSMOC can dilute DO in the channel due to the relatively low DO concentration in the groundwater. The base case assumed a groundwater flow of 0.025 m^3/s with a DO concentration of 0.3 mg/L. Both of these values were considered to be minimum values in the range of potential values, as identified by field measurements. A sensitivity test was defined using the upper bound on expected flow rate, 0.042 m^3/s, and the average of the field measurements of DO concentration, 3.05 mg/L. These results, shown on Figure 9, indicate that changes in the assumptions of the groundwater flow and DO concentration have little effect on the overall DO concentration in the channel. This is largely due to the fact that the groundwater inflow is so small, relative to other components of flow in the channel.

FIGURE 9: SENSITIVITY OF DO CONCENTRATION TO GROUNDWATER IN LSMOC

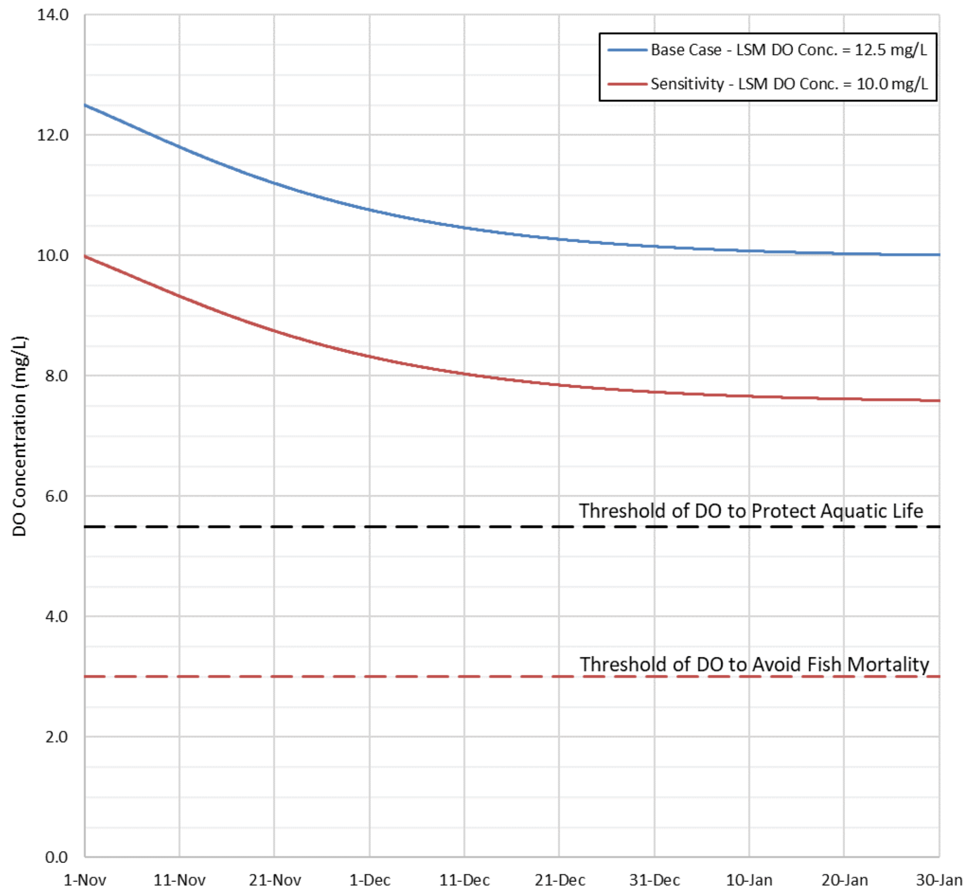


3.2.4 DO CONCENTRATION IN LAKE ST. MARTIN

The selection of the starting DO concentration in LSM was based on a field measurement taken on October 28, 2020 in the north basin. The measurement showed that the DO concentration in the lake was 12.5 mg/L. However, it is possible that in some years the DO concentration may be lower than that value due to variations in water levels, inflows, and other factors.

A sensitivity analysis was completed to determine the effects of adopting an initial DO concentration (10.0 mg/L) in LSM that is lower than in the base case. The results of that analysis, with a comparison to the base case, are shown on Figure 10. The results indicate that the assumed initial concentration can significantly affect the ultimate DO concentration in the channel. However, even a reasonably low initial DO concentration in LSM would not reduce the DO in the LSMOC below the threshold for protection of aquatic life.

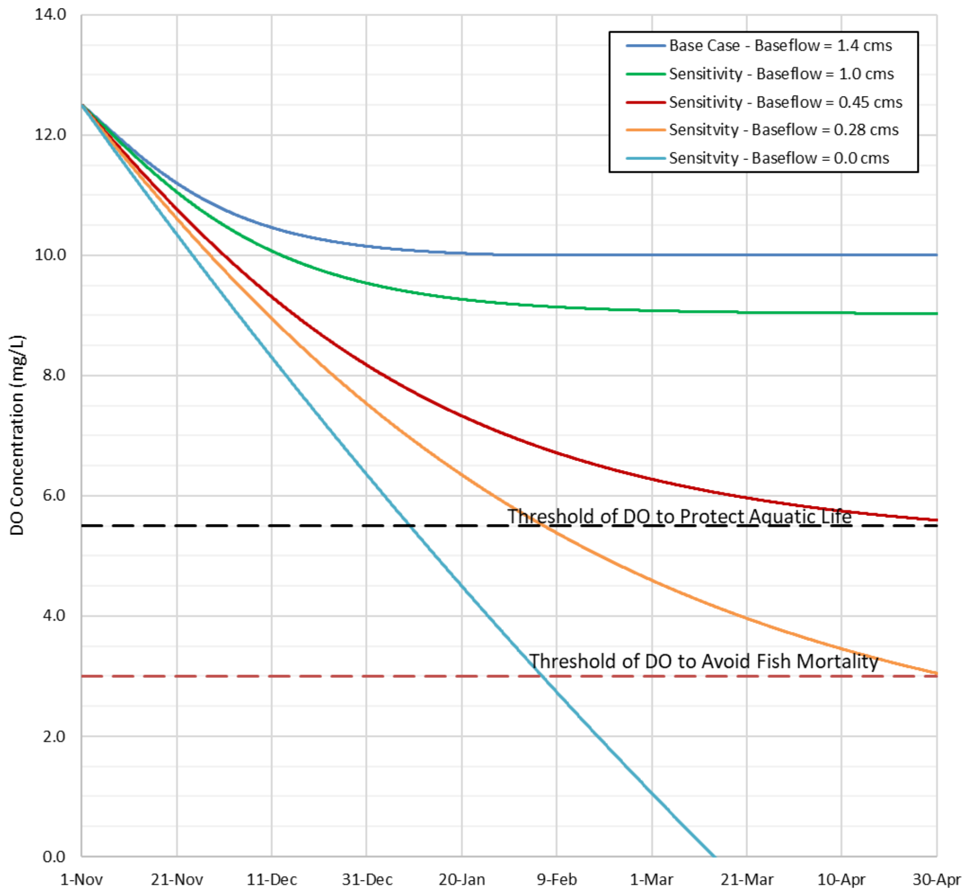
FIGURE 10: EFFECTS OF DO IN LSM ON DO CONCENTRATION IN LSMOC



3.2.5 BASEFLOW

The current design of the LSMOC specifies that a baseflow of approximately 1.4 m^3/s (assumed baseflow by MI in their chosen scenarios for studies of flood routing) will be provided when the channel is not in flood operation. However, under prolonged periods of drought, and depending on flow conditions in the Dauphin River, there may be times where it may not be desirable to provide the full baseflow of 1.4m^3/s in the LSMOC. A sensitivity analysis was therefore carried out to determine the effects of a range of baseflows on the DO concentration in the channel. The results of this analysis are shown on Figure 11. That figure indicates that a baseflow of at least 0.28 m^3/s is required to maintain a DO concentration above 3.0 mg/L. Furthermore, a baseflow of at least 0.45 m^3/s is required to maintain a DO concentration above 5.5 mg/L over the entire winter period. If no baseflow is provided, results show that the channel may become anoxic in about 4.5 months. This would take longer if a thinner, more gradual ice formation would be assumed in the model.

FIGURE 11: EFFECT OF BASEFLOW ON DO CONCENTRATION IN LSMOC



4.0 CONCLUSIONS AND RECOMMENDATIONS

An analysis of DO concentration was completed for the LSMOC. The conclusions from this work are as follow:

- Analysis of the base case indicated that the DO concentration at the end of winter in the LSMOC near the outlet would be approximately 10 mg/L. This far exceeds the threshold of DO for fish mortality of 3 mg/L and 5.5 mg/L for protection of aquatic life.
- The base case was considered to be a reasonably pessimistic portrayal of the conditions in the LSMOC. For example, the base case did not consider oxygen recharge at drop structures, which is certain to occur to some extent. Had recharge been considered, the DO concentration in the channel would have been greater than shown in the analysis.
- The DO calculations were not sensitive to the ice thickness on the surface of the LSMOC when there is a baseflow of at least 1.4 m^3/s.
- A SOD rate was calculated using available data on DO concentration recorded in the eastern bay. However, even if the SOD rate would be increased significantly to be pessimistically higher than previously measured, the estimated DO concentration in the LSMOC would still clearly exceed the minimum threshold for aquatic life protection (5.5 mg/L).
- Given the minimal flow of groundwater into the channel, the DO concentration in the LSMOC is not believed to be sensitive to either the magnitude of the groundwater inflow or its DO concentration.
- The concentration of DO in Lake St. Martin affects the resulting DO concentration downstream in the LSMOC. However, a reasonably low concentration of DO in LSM during winter will still not result in DO concentrations in the LSMOC to be lower than the threshold for protection of aquatic life (5.5 mg/L).
- The baseflow of 1.4 m^3/s has been adopted for a design condition. It is considered sufficient to maintain DO concentrations in the channel above the minimum threshold for protection of aquatic life (5.5 mg/L). The minimum baseflow required to achieve DO concentrations above this threshold is 0.45 m^3/s. If no baseflow is provided, the channel may become anoxic within approximately 4.5 months.
- It is recommended that a monitoring program be implemented following construction to measure DO in the channel and confirm the rate of SOD, as well as the predictions from this study.

5.0 REFERENCES

- Bowie. (1985). *Rates, Constants and Kinetics in Surface Water Quality Modeling.* Athens, Georgia: United States Environmental Protection Agency, Environmental Reserarch Lab.
- CCME (Canadian Council of Ministers of the Environment). 1999a (Updated to 2018). Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg.
- CCME. 1999b. Canadian Water Quality Guidelines for the Protection of Aquatic Life – Dissolved Oxygen (Freshwater) Factsheet. Available at https://ccme.ca/en/res/dissolved-oxygen-freshwater-en-canadian-water-quality-guidelines-for-the-protection-of-aquatic-life.pdf
- Casey, R. (June 1990). *Sediment oxygen demand during the winter in the Athabasca River and the Wapiti-Smokey Rvier system.* Alberta Environment Standards and Approvals Divsiion and Evironmental Assessment Division.
- Manitoba Hydro. (June 2012). *Keeyask Generation project Environmental Impact Statement Response to EIS Guidelines. Supporting Volume.* . Keeyask Hydropower Limited Partnership.
- Manitoba Water Stewardship (MWS). 2011. Manitoba Water Quality Standards, Objectives and Guidelines. Water Science and Management Branch, Manitoba Water Stewardship. Report 2011-01.

KGS GROUP

Experience in Action