Manitoba Infrastructure
Lake Manitoba Outlet Channel

Winter Dissolved Oxygen Analysis

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1. Overview

A concern has been raised that Dissolved Oxygen (DO) concentrations in the Lake Manitoba Outlet Channel (LMOC) during the winter months when the Water Control Structure (WCS) gates are closed may be problematic for fish present in the Channel. During low water years, the lake ice cover on Lake Manitoba and/or Lake St. Martin may freeze to the bottom near where the Inlet/Outlet excavations daylight. If this were to occur, then blockage of the LMOC Inlet/Outlet could result, isolating the Channel from DO replenishment via exposure to the lakes while also restricting fish egress from the Channel should they wish to leave due to potentially low DO concentrations. There could also be limited reaeration ability during the winter in the absence of riparian flows through the WCS with an ice cover present over the Channel water surface.

This report examines the risk that the lake ice cover may freeze to the lake bottom, isolating the Channel at the Inlet and Outlet locations, and further analyzes DO concentrations in the LMOC under such conditions over the course of a given winter season.

This report has been prepared jointly by Hatch Ltd. (Hatch) and Stantec Consulting Ltd. (Stantec), as part of the overall Hatch Team for the design of the LMOC.

This report was prepared using the metric system, as it is the adopted system of units used in Canada. However, the Province of Manitoba and other stakeholders have historically used the imperial system of units when reporting lake levels and flows in the region. Accordingly, for ease of reference, this report presents lake levels and flows in both metric and imperial units, while all other quantities are presented solely in metric units.

2. Isolation Analysis

There is a concern that the lake ice cover on Lake Manitoba and/or Lake St. Martin may freeze to the lake bed near where the LMOC Inlet and Outlet excavations daylight during low water years when the Channel is not in operation. If the ice thickness were large enough to result in blockage of the LMOC Inlet/Outlet, this could isolate the Channel from DO replenishment via exposure to the lakes while also restricting fish egress from the Channel. An assessment of ice thicknesses in Lake Manitoba and Lake St. Martin, and the resulting clearance above the lake bed at the location where the Inlet and Outlet excavations daylight was undertaken to assess the risk of this occurring.

2.1 Ice Thickness Assessment

Lake ice thicknesses on Lake Manitoba and Lake St. Martin were estimated for a number of years based on the standard static ice growth formula (Stefan equation) that relates the resulting ice thickness to the number of degree days of freezing experienced and a representative ice growth coefficient (Ashton, 1986).

The degree days of freezing were determined by processing available average daily air temperature data. Nearby Environment Canada climatic stations were reviewed to identify candidate stations that: 1) were located in proximity to the LMOC and within the Interlake region; 2) had a reasonably long climatic record length; and 3) included observations within the last decade. Based on this review, the Environment Canada station at Arborg (Climate ID: 5030080; ECCC 2021) was selected. Fifty-three years of air temperature data is available at this station, covering the period between 1961 to 2016 (note that the years 1964 and 1966 were excluded from the analysis due to large gaps in the data).

Based on this data, ice thicknesses over the course of each winter were estimated. An envelope of ice thicknesses was prepared to reflect the suggested ice growth coefficient range for “average lake conditions with snow”, which vary between 17 mm/(°C·d)$^{1/2}$ to 24 mm/(°C·d)$^{1/2}$. Separate duration curves for each winter month (reflecting the mid-month ice thicknesses) were computed for the months of November, December, January, February and March to provide a sense of the potential ice thickness variability, which are shown on Figure 1.

As illustrated on Figure 1, ice thicknesses would be expected to range between 0.8 m and 1.2 m by end of winter assuming a high ice growth coefficient of 24 mm/(°C·d)$^{1/2}$.

2.2 Winter Lake Levels

Manitoba Infrastructure’s (MI’s) 103 year routing simulation results for Lake Manitoba and Lake St. Martin, post permanent outlet channels, were analyzed to estimate the range and frequency of anticipated water levels during the winter months. These simulations, and the assumptions that went into performing them, were documented in a February 2019 Manitoba Infrastructure memorandum from Chris Propp to Eugene Kozera (MI, 2019).

Spaghetti plots of the simulated daily lake levels between the beginning of October and the end of April for each of the simulation years are provided on Figures 2 and 3, along with the calculated average daily water levels.

The water level data for both lakes were processed and representative levels for November, December, January, February, and March of each year were determined based on the mid-month 15 day average water level. This was done to remove potential noise in the data set. Separate duration curves for these representative water levels were then developed for each of these months for each lake, as shown on Figures 4 and 5.

It is noted that the desirable operation range of Lake Manitoba is el. 247.04 m to 247.65 m (810.5 ft to 812.5 ft), and el. 242.93 m to 243.84 m (797 ft to 800 ft) on Lake St. Martin. In reviewing Figures 2 to 5, the following notable observations can be made:

- The extreme low winter lake level on Lake Manitoba is el. 246.5 m (808.7 ft), which is 0.46 m (1.5 ft) below the low end of the desirable operating range.
- Winter lake levels on Lake Manitoba do not change significantly from month to month over the winter.

- Winter lake levels less than el. 247.04 m (810.5 ft) – the low end of Lake Manitoba's desirable operating range – occur between the months of November to March in approximately 20% of the years over the 103 year simulation period.
- The extreme low winter lake level on Lake St. Martin is el. 242.4 (795.2 ft), which is 0.55 m (1.8 ft) below the low end of the desirable operating range.
- Winter lake levels on Lake St. Martin typically rise over the course of the winter.
- Winter lake levels less than el. 242.93 (797 ft) – the low end of Lake St. Martin's desirable operating range – occur in approximately 40% of the years over the 103 year simulation period in November, decreasing to approximately 11% of the years in March.

2.3 Clearance Assessment

The clearance available between the underside of the ice cover and the lake bottom was calculated based on the duration curves of lake levels and ice thicknesses described above. A density of ice corresponding to 92% of water was used when computing the underside of ice elevation (i.e., 92% of the ice thickness is submerged).

A lake bottom of el. 245.8 m was used for Lake Manitoba and el. 241.6 m for Lake St. Martin. These elevations reflect the local lake bottom elevation in the vicinity where the Inlet and Outlet excavations daylight, respectively.

An overall duration curve of expected ice clearances was produced based on the expectation that the resulting probability of a given water level and ice thickness occurring are independent of one another, and that over the long-term, the distribution of lake levels and ice thicknesses is reflective of their respective duration curves. These ice clearance duration curves are shown in Figures 6 and 7 for Lake Manitoba and Lake St. Martin, respectively. Note that the shaded areas for each month reflect the thermal ice growth coefficient range mentioned in Section 2.1.

The Environmental Assessment (EA) Team has indicated that a clearance of 0.2 m is a reasonable threshold below which fish may have difficulty exiting the Channel under an ice cover based on the size of fish that are known to be in the area (maximum height of fish would be approximately 15 cm and most fish would be less than 10 cm in height). Therefore, for the purposes of this assessment, a clearance of less than 0.2 m beneath an ice cover is considered undesirable.

In reviewing Figure 6 for Lake Manitoba, it can be seen that in approximately 10% of the years (i.e., once every 10 years on average), the available clearance at the Inlet in mid-February could drop below the 0.2 m threshold. The likelihood of this occurring increases to approximately 15% of the years (i.e., once in every 6.6 years on average) in mid-March. Accordingly, there is the potential for fish to be unable to leave the portion of the LMOC upstream of the WCS during the later winter months.

In reviewing Figure 7 for Lake St. Martin, it can be seen that in approximately 3% of the years (i.e., once every 33 years on average), the available clearance at the Outlet in mid-February could drop below the 0.2 m threshold. The likelihood of this occurring increases to approximately 5% of the years (i.e., once in every 20 years on average) in mid-March.

The probability of the clearance beneath the ice cover at the Outlet being less than 0.2 m is lower than that anticipated at the Inlet due to the water level in Lake St. Martin typically rising over the course of a winter, while on Lake Manitoba it stays relatively constant. As such, the rising Lake St. Martin water level helps to offset the impact of the increasing ice cover thickness and thus results in a more constant clearance being provided over the winter months.

3. Dissolved Oxygen Assessment

A mathematical mass-balance model was developed to simulate DO concentrations in the LMOC over the course of a given winter season, both upstream and downstream of the WCS. The desktop model was then used to identify parameters that dictate the sensitivity of the DO analysis and provide an understanding of parameters that may be critical to the winter DO regime in the LMOC. Assumptions were incorporated in the model that would conservatively reflect conditions more likely to result in lower DO concentrations in the LMOC.

3.1 Model Components/Assumptions

3.1.1 LMOC DO Input/Demand Factors

DO demand in the LMOC is a product of many different factors. The degradation of organic content (such as wastewater or effluent) in water bodies results in a demand or reduction of the DO in the water column. For the purposes of this analysis, there was no distinction made between Biochemical Oxygen Demand (BOD) exerted by the degradation of organic material in the water column, and Sediment Oxygen Demand (SOD) exerted by the degradation of organic material that has settled to the bottom of the LMOC. For the LMOC, there is no wastewater discharge to contribute BOD to the water column and the low organic content expected in the incoming Lake Manitoba water would settle in the Channel during periods of no flow. Therefore the modeled oxygen demand is accounted for as SOD. Calibration is not possible as the LMOC does not exist at this time so, SOD was based on available literature rates by substrate for studies that occur in similar conditions. Furthermore, for the purposes of this analysis, diurnal fluctuations in DO due to photosynthesis and other factors such as those related to nutrient content, algae growth, fish presence, etc. were not considered.

The model assumptions for DO provided to the LMOC water column considered four primary sources as follows:

- Mixing with water from Lake Manitoba or Lake St. Martin that contains DO, or diffusion of DO from the lakes at either end of the LMOC during periods of no-flow (WCS gates closed). For this analysis, diffusion effects were not considered based on the assumption of complete isolation of the LMOC due to ice constriction at the inlet and outlet.
- Conveying water from Lake Manitoba that contains DO through LMOC (WCS gates open or by riparian flow provision).

- Surface aerating (wind in open water conditions and turbulence via flow through the WCS). This analysis was limited to normal surface/wind transfer mechanisms. Additional aeration potentially provided by turbulent flow from the opened WCS or riparian discharge structures was not considered. Surface aeration was assumed to be negligible under ice covered conditions.
- Mixing with groundwater that contains DO. The discharge of groundwater to the LMOC from the carbonate aquifer may also contribute some DO to the oxygen stores of the LMOC, however for the purposes of this analysis a conservative assumption was made that the DO concentration in incoming groundwater was 0 mg/L.

3.1.2 Estimate of Water Volume

Based on preliminary design, the LMOC base width will vary from 17 m between the Inlet and Station 112+00, to 12 m between Station 114+00 to the WCS, and 22 m from the WCS to the Outlet. The base widths at the Inlet and Outlet excavations and at some of the bridges may differ, but the effect of these deviations was considered negligible for the purposes of this analysis based on their small proportion of the Channel. The overall length of the LMOC from the Inlet to the WCS is approximately 21 km and approximately 3 km from the WCS to the Outlet with side slopes of 5H:1V.

The volume of water and average water surface top width in the LMOC upstream and downstream of the closed WCS were estimated for two winter lake levels as outlined in Section 2.2:

1. When the two lakes are at the low end of their normal operating range (i.e., Lake Manitoba at el. 247.04 m [810.5 ft] and Lake St. Martin at el. 242.93 m [797.0 ft]).
2. When the two lakes are at the extreme low winter level based on MI's 103 year routing simulations with the channels in place (i.e., Lake Manitoba at el. 246.5 m [808.7 ft] and Lake St. Martin at el. 242.4 m [795.3 ft]).

The volume of water was also calculated for each case with a conservatively assumed maximum 1.2 m thick thermal ice cover present (Section 2.1) below the water surface to represent the minimum LMOC water volume for each winter condition as summarized in Table 3-1.

Table 3-1: LMOC Estimated Water Volumes

	Lowest Normal Operating Range		**Extreme Lowest 103 Year Level**	
	U/S of WCS	**D/S of WCS**	**U/S of WCS**	**D/S of WCS**
Lake Level (m)	247.04	242.93	246.5	242.4
Water Volume in LMOC - No Ice Cover (m^3)	5,690,840	451,530	5,006,300	352,820
Surface Water Top Width (m)	74.7	56.4	70.4	51.2
Water Volume in LMOC - 1.2 m Thick Ice Cover (m^3)	4,051,790	255,450	3,463,730	174,380

3.1.3 *Initial Water Quality (DO Concentration)*

The initial DO concentration used for the assessment was based on DO saturation at a temperature of 4°C (as an assumed winter water temperature), calculated according to Bowie *et. al*, 1985 as 13.12 mg/L.

As a reference, data collected from LMOC surface water monitoring programs completed between 2016 and 2020 is summarized in Table 3-2 (KGS 2017a, 2017b, 2018; Stantec 2021a).

Table 3-2: Summary of DO Concentrations in Lake Manitoba and Lake St. Martin

Water Body	**Minimum (mg/L)**	**Maximum (mg/L)**	**Average (mg/L)**
Lake Manitoba	8.28	16.16	12.21
Lake St. Martin	9.33	12.02	10.98

Note: DO concentrations based on data from samples collected during the fall season between 2016-2020 (KGS 2017a, 2017b, 2018; Stantec 2021a).

3.1.4 *Estimate of Oxygen Demand*

Under non-flowing conditions, residual BOD from organisms would be expected to eventually settle and contribute to oxygen demand as SOD over the winter period. Therefore, for the purposes of this analysis, DO consumption was assumed to be represented by SOD. SOD generally varies depending on substrate. A limited literature review was conducted to identify appropriate values for SOD including Bowie *et al.,* 1985, Manitoba Hydro, 2012, and Casey, 1990. Potentially applicable ranges of SOD (at 20°C) were identified as follows:

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

The LMOC will be excavated in till (a mineral soil) and does not generally consist of flooded peatlands. Therefore SOD values corresponding to mineral soil of 0.07 $g/m^2/d$ were considered appropriate and were applied to the analyses. All winter SOD values were corrected within the model to an assumed winter water temperature of 4°C using relationships in Bowie *et al*., 1985. The temperature corrected rates were applied to the wetted area of the LMOC (below the ice) to estimate the exerted oxygen demand in the analysis.

3.1.5 Surface Aeration Estimate

Although the DO analysis is based on fully isolated, ice-covered conditions from November 1 to May 1, an estimate of the effect of surface/air exposure upon ice breakup was developed to determine the time required to restore DO concentrations. Oxygen transfer via wind/water surface exposure was estimated using methods outlines in Chia, *et al.,* 2003. A wind speed of 15 km/hr or 4.17 m/s was incorporated to estimate wind conditions upon ice cover breakup in May of each year in order to determine oxygen transfer to the exposed water surface. This reflects the approximate average wind speed in May based on climatic data from the Dauphin, Manitoba Environment Canada Station (Climate ID: 5040680; ECCC, 2021).

3.1.6 Groundwater Inflow Rate

The long-term winter groundwater inflow rate to the LMOC was determined as part of preliminary design (Stantec, 2021b). The estimated inflow rates adopted for the DO analysis corresponded to the calibrated groundwater model with an increased hydraulic conductivity and recharge with annual average rates ranging from 0.0022 m^3/s to 0.01 m^3/s with a total annual average inflow rate into the LMOC of 0.03 m^3/s (Stantec, 2021b). The annual average rates were then factored by 0.35 to correspond to winter recharge conditions. As a result, the groundwater discharge to the LMOC upstream of the WCS was 0.0088 m^3/s (761 m^3/d) and 0.0017 m^3/s (146 m^3/d) downstream of the WCS. These rates were used in combination with the assumption of a groundwater DO concentration of 0 mg/L to result in the largest influx of low DO groundwater to the LMOC and conservatively determine the dilution effect of an assumed anoxic groundwater input on the water quality in the LMOC.

3.2 DO Model Development

A desktop DO model of the LMOC was developed using a mass balance analysis and oxygen consumption model (Bowie *et. al* , 1985) based on the dimensions of the LMOC and the DO input and demand factors identified in Section 3.1. Lake ice cover at the Inlet and Outlet was considered effectively frozen to the bottom with no DO recharge through ice cover, thus preventing exchange of DO from the lakes or atmosphere into the LMOC.

The LMOC DO model was developed based on depth of water and Channel width and length. The model was divided into five cells, 4 upstream and 1 downstream of the WCS as illustrated in Figure 8. Each cell was further divided into four equal subbasins to facilitate computation of DO concentration variability spatially along the LMOC (1D) and temporally.

3.3 Model Scenarios

DO concentrations were calculated in daily time steps for various scenarios using the model “without riparian flow” and “with riparian flow” to simulate DO conditions in the LMOC (Table 3-3).

Table 3-3: Model Scenarios to Simulate DO Conditions in the LMOC

Model Scenario	1	2	3	4	5	6
SOD	None 0 g/m²/d	Low 0.07 g/m²/d	Moderate 0.25 g/m²/d	Moderate 0.25 g/m²/d	High 0.5 g/m²/d	Very High 1.0 g/m²/d
Riparian Flow	None	None	None	1.0 m^3/s	1.0 m^3/s	3.0 m^3/s
GW Input	0.0105 m^3/s or 907 m^3/d	0.0105 m^3/s or 907 m^3/d	0.0105 m^3/s or 907 m^3/d	0.0105 m^3/s or 907 m^3/d	0.0105 m^3/s or 907 m^3/d	0.0105 m^3/s or 907 m^3/d
Lake Levels	Extreme Lowest	Extreme Lowest	Extreme Lowest and Low	Extreme Lowest	Extreme Lowest	Extreme Lowest

In consideration of the Canadian Council of Ministers of the Environment (CCME 1999a) and the Manitoba Water Quality, Standards and Guidelines (MWS 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).

3.3.1 No Riparian Flow

Three scenarios without riparian flow were evaluated at the extreme lowest lake levels to quantify the effect of varying SOD rates and groundwater input on the DO concentration in the LMOC under ice-isolated conditions. The initial DO concentration assumed full saturation as described in Section 3.1.3, SOD rates were varied to understand the relative effect of SOD vs GW input as well as to demonstrate the potential effect on DO of buildup of organic content and the resulting increased SOD over time in the LMOC.

Scenario 1:

The first scenario confirmed that the effect of the groundwater inflow on the DO concentration in the LMOC is minimal. With the groundwater inflow estimate conservatively high, ice-covered conditions isolating the water from surface aeration, and an assumed complete ice blockage isolating the LMOC from the DO stores of the lakes on either end of the LMOC, the volume of the assumed anoxic groundwater inflow relative to the water in the LMOC was too small to reduce the average LMOC DO concentration to near the referenced guideline values.

Scenario 2:

The second scenario evaluated the combined effect of groundwater input from Scenario 1 and a low SOD rate (0.07 g/m²/d representing a river condition in mineral soils). The predicted average DO concentrations in all the cells upstream of the WCS were well above guideline values, while the DO concentration in the smallest cell (Cell 5, downstream of the WCS) was reduced to approximately 6.5 mg/L (still higher than the 5.5 mg/L referenced guideline) in early May just prior to breakup.

Scenario 3:

The third scenario modified Scenario 2 with a moderate SOD rate (0.25 g/m²/d). The moderate SOD rate would be considered representative of conditions where organic matter in the Channel would have been allowed to accumulate over time (likely more than 1 year).

In this scenario (Figure 9), at the extreme low water level, the DO concentration upstream of the WCS was predicted to fall to approximately 3.8 mg/L (higher than the mortality guideline value of 3.0 mg/L) in April. The average DO concentration downstream of the WCS in this scenario was predicted to drop below 5.5 mg/L in early January and 3 mg/L in within the following 3 weeks, with concentrations reaching zero in February and not returning to guidelines until 2 days after breakup in early May.

At the low operating level, the additional water volume in the LMOC provides sufficient DO stores to sustain an average DO concentration upstream of the WCS above 5.1 mg/L for the duration of the winter (dropping below the 5.5 mg/L guideline for the last week before breakup). However, the low lake level downstream of the WCS is insufficient to maintain DO concentrations above 5.5 mg/L beyond February and falls below 3 mg/L in March until 2 to 3 days after breakup in May (Figure 10).

3.3.2 *Riparian Flow Scenarios*

Although there are a number of potential methods of mitigating the occurrence of low DO concentrations within the LMOC and avoiding the resulting potential DO concentration issue for fish habitat, the provision of riparian flow (flow through the LMOC) is expected to provide one of the simplest mitigation measures. Additional mitigation options will be identified later in this report but for the purposes of this analysis, three additional scenarios were examined with varying rates of riparian flow provision and extreme low lake levels to evaluate what level of riparian flow would be required to mitigate the effects of various SOD rates.

Scenario 4:

Scenario 4 is a version of Scenario 3, modified to incorporate a 1.0 m^3/s riparian flow from Lake Manitoba, through the WCS and to Lake St. Martin under extreme low lake conditions. The resulting estimated average DO concentration in the LMOC was consistently well above guideline values.

Scenario 5:

This scenario examined the effect on DO of a higher SOD rate (0.5 g/m²/d, corresponding to a sandy substrate) with a minimal riparian flow (1.0 m^3/s). The analysis indicated that with a riparian flow rate of 1.0 m^3/s, the LMOC average DO concentration could be maintained well above the 5.5 mg/L guideline.

Scenario 6:

To represent a longer term buildup of organic matter on the channel bottom, an examination of a higher SOD was conducted. This scenario started with a value of 1.0 g/m²/d. The analysis indicated that a riparian flow provision of 3.0 m^3/s would maintain the LMOC average DO concentrations well above the 5.5 mg/L guideline throughout the LMOC (Figure 11).

As a further point, successive iterations of lower riparian flows and higher SODs indicated that a minimum riparian flow of 1.25 m^3/s would maintain average DO concentrations above 5.5 mg/L for a 1.0 $g/m^2/d$ SOD (Figure 12) while a riparian flow of 3.0 m^3/s could meet DO guidelines with an SOD of up to approximately 2.25 $g/m^2/d$ (Figure 13). As indicated in Section 3.1.4, such a SOD value is well in excess of typical values for mineral soils (till), which the LMOC will be excavated in and thus provision of such a riparian flow rate would likely be unnecessary.

4. Monitoring and Mitigation

4.1 DO Monitoring

Low DO concentrations in the LMOC present a risk to fish by rendering habitat less suitable. As the conditions that would result in DO concentrations of potential concern would be a product of very extreme circumstances (lowest flows forecast over 103 years, extreme cold winters that would create large masses of ice that freeze to the bottom, instantly present and persistent ice cover over a full 6 months, no DO in incoming groundwater, etc.), monitoring the DO concentration under the ice both upstream and downstream of the WCS may indicate that riparian flows or other means of oxygen addition are only rarely required.

A monitoring program for DO under ice is therefore recommended for implementation as part of any mitigation program so that mitigation measures are only deployed when necessary and to the extent required. Using a DO monitoring system to determine when and what measures to employ will provide the best information to increase the efficiency of the mitigation measure employed and reduce the adverse environmental effects.

4.2 Potential Low DO Mitigation Options

Instances of low DO can be mitigated through implementation of a number of options including:

1. Reducing buildup of organics.

The continued accumulation of organic matter between periods of WCS operations was simulated to varying degrees in the form of higher SOD values incorporated into the various model scenarios. By reducing the accumulation of organic matter in the LMOC, the resulting SOD will be reduced and exert less effect on the DO in the Channel. This could be achieved by operation of the WCS for a short period of time to remove accumulated organic matter prior to the onset of winter conditions. It is assumed that any operation of the WCS gates in order to remove accumulated organic matter would be coordinated with flows in the Fairford River and fisheries considerations (i.e., operation outside of Manitoba restricted activity timing windows for the protection of fish and fish habitat).

In addition, the construction of the Outside Drain along the west side of the LMOC will intercept and divert potentially organic-rich runoff from west of LMOC to Lake Manitoba and

Lake St. Martin where more DO is available, which will greatly assist in limiting the amount of organic material entering the Channel.

2. <u>Increasing DO by bringing flow in from Lake Manitoba.</u>

Water flow from Lake Manitoba is expected to be much higher in DO content than that in the LMOC during the winter. Incorporating riparian flow provision structures (such as valve(s) in the WCS gates) is expected to mitigate DO concerns in the LMOC by allowing the higher DO content Lake Manitoba water to be drawn through the Channel. Operation of the riparian flow structure/valve should be coordinated to maintain minimum flow in the Fairford River. Incorporation of a valve into the WCS gates is expected to be relatively low cost if it were done during the design stage.

3. <u>Mechanical aeration.</u>

Mechanical aeration over the length of the LMOC by means of air diffusers, etc. would require installation of electrical and mechanical infrastructure and maintenance over a long stretch of the LMOC. Construction and operation of such a system would introduce additional adverse environmental effects such as additional clearing and noise. It is also possible that, although access to the LMOC will be restricted, aeration of the water in the Channel could create potential safety hazards should unstable ice cover conditions form. The cost and risk posed by this option make the solution less desirable and not recommended.

4. <u>Mechanical break-up of ice on LMOC:</u>

As in other areas of the province, Manitoba Infrastructure could deploy their Amphibex (amphibious excavator) or other equipment to break-up the ice cover on the LMOC as a means of facilitating surface aeration. As this method would only break up some of the ice cover and not expose the entire water surface to the atmosphere, the efficacy of such an operation for mitigation of DO deficit would not be high and it is expected that the cost and effort expended would not necessarily result in sufficient aeration to address the issue. The adverse environmental effects related to undertaking such measures (clearing and noise generation as well as more operational access) would also increase.

5. Conclusions

Several scenarios were examined considering various SOD rates and riparian flow rates to determine whether, under extreme or low lake conditions, measures could be required to mitigate low DO conditions for the protection of fish in the LMOC. Assessment of the quality of fish habitat beyond average DO concentrations was not considered.

The analysis results (Average DO concentrations in the LMOC) were compared to a guideline value of 5.5 mg/L under a range of under-ice scenarios. Estimates of the riparian flow required to maintain DO concentrations above guidelines during the winter months were developed. Various design, operational or management changes that could mitigate the risk of low DO for the scenarios examined were described.

The analyses conducted confirm that low DO conditions have the potential to develop that could present a risk to fish in the LMOC under the extreme conditions considered, with issues more prevalent downstream of the WCS due to the smaller volume of water present there. It should be noted, however, the likelihood of complete isolation of the LMOC downstream of the WCS due to ice-isolation by freezing to the lake bottom where the Outlet daylights (3-5% of winters) is lower than the likelihood of the LMOC upstream of the WCS becoming completely isolated by freezing to the lake bottom where the Inlet daylights (10-15% of winters). Accordingly, it would be expected that fish that may be present in the LMOC downstream of the WCS during the winter would be more likely to be able to leave the Channel in the event that low DO conditions developed.

6. Recommendations

Based on the analyses conducted and the mitigation measures examined, the following measures are recommended for MI's consideration in order to facilitate maintaining average DO concentrations in the LMOC above the MWQSOG during the winter:

- Implementation of a DO monitoring system with the capability to monitor under-ice DO concentrations proximate to the WCS (both upstream and downstream).
- Should DO monitoring indicate the potential buildup of SOD, then a short-term operation of the WCS could be implemented outside of fish spawning periods to assist in removal of accumulated organic matter and/or sediment in the LMOC so as to reduce the SOD.
- Incorporation of riparian flow valves at the WCS capable of passing a minimum flow of 1.25 m^3/s. The ability to accommodate up to 3 m^3/s should be considered, if practical, to accommodate potential variations in conditions from those assumed, such as higher SOD and lower initial/incoming DO concentrations.

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Figures

Figure 1: Duration Curves of Estimated Ice Cover Thickness on Lake Manitoba and Lake St. Martin

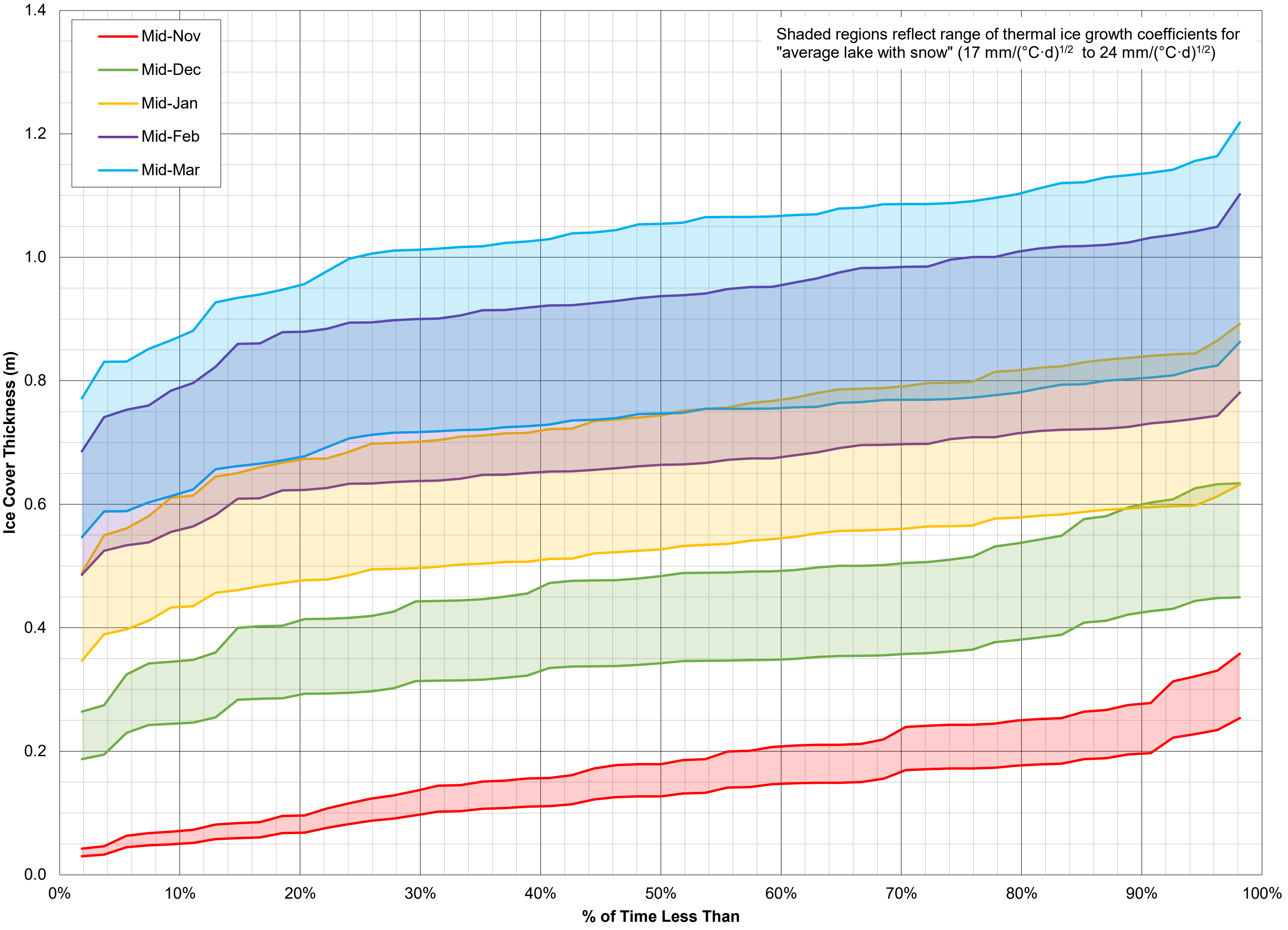


Figure 2: Spaghetti Plot Illustrating Range of MI Simulated Lake Manitoba Daily Water Levels

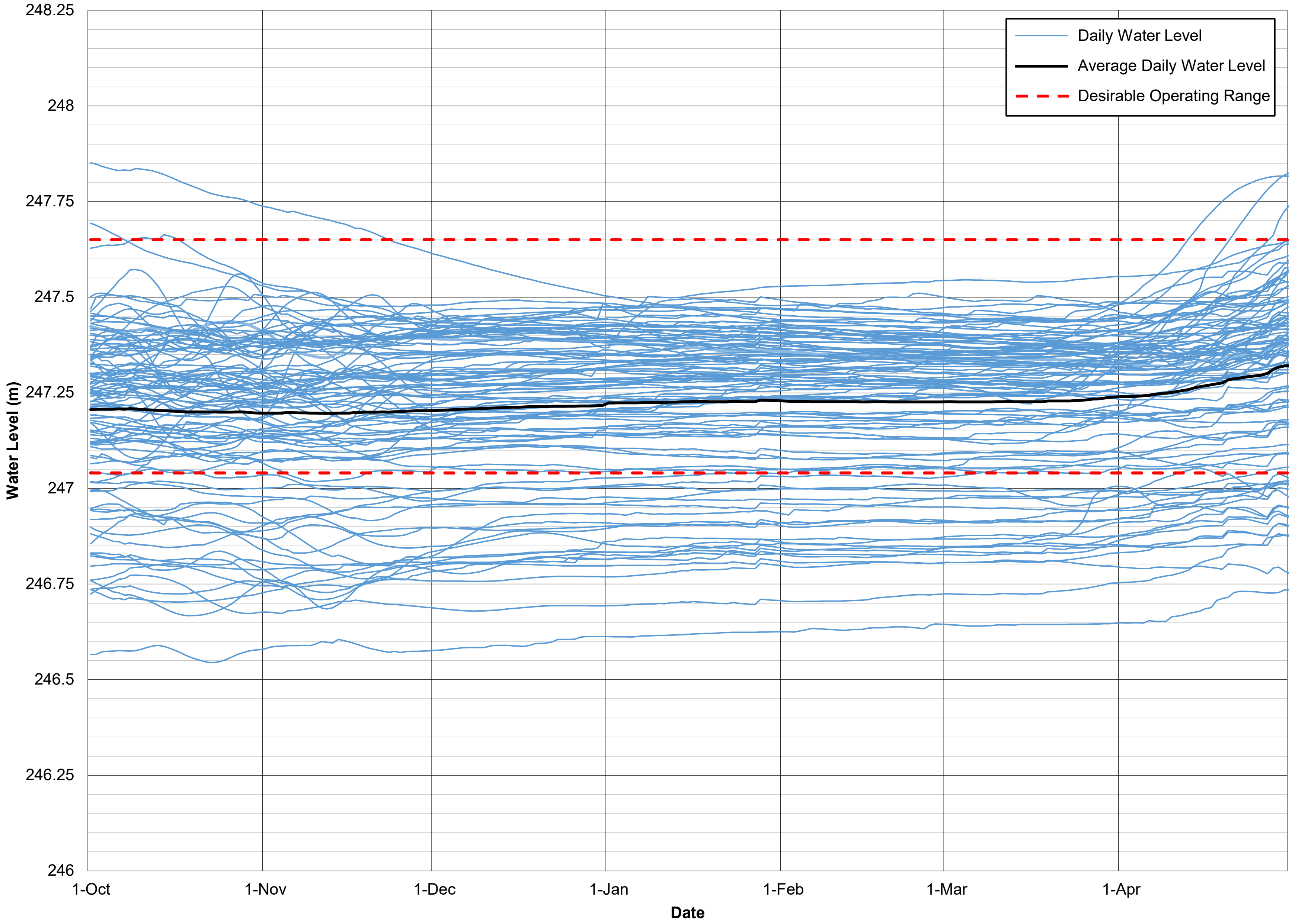


Figure 3: Spaghetti Plot Illustrating Range of MI Simulated Lake St. Martin Daily Water Levels

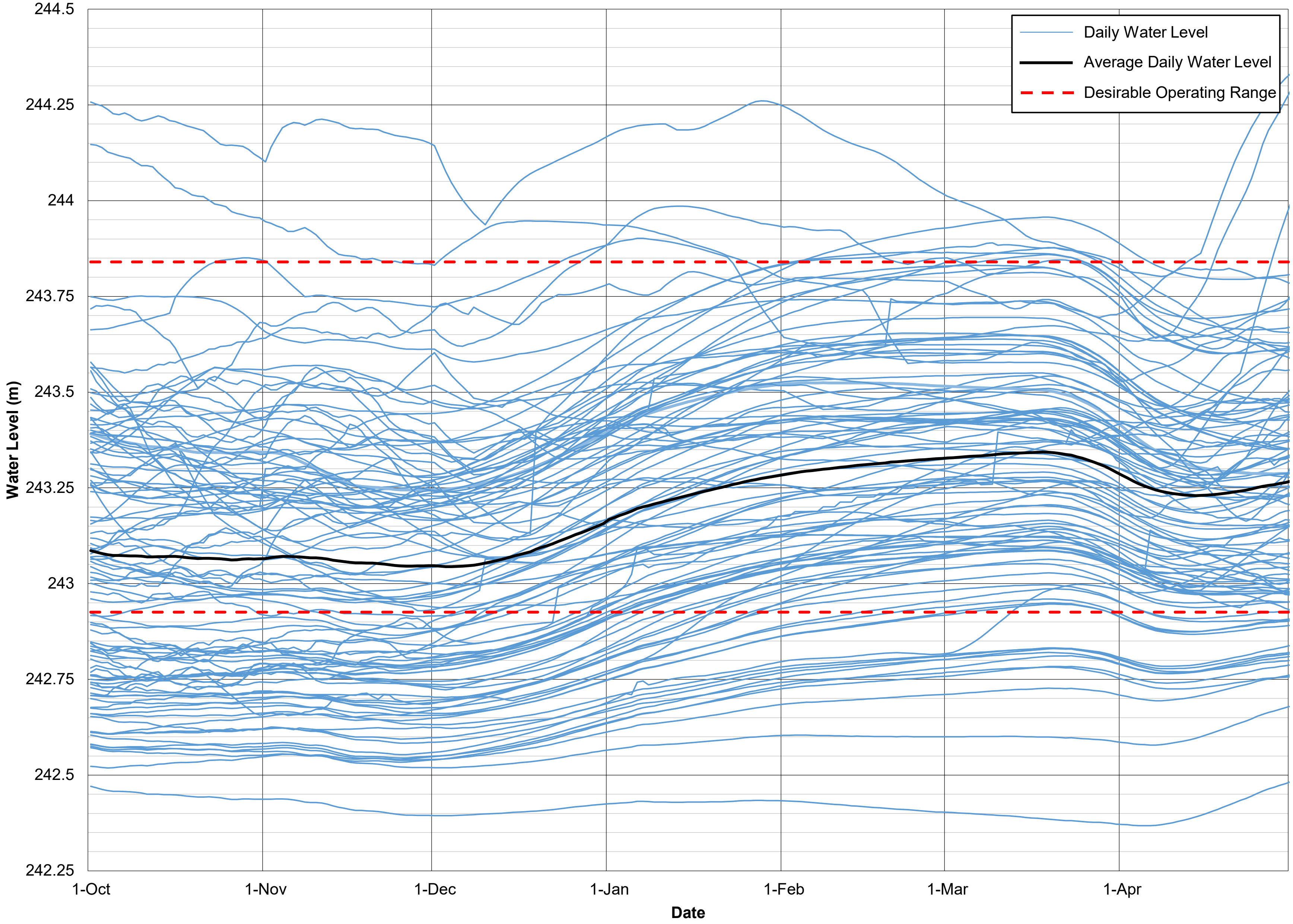
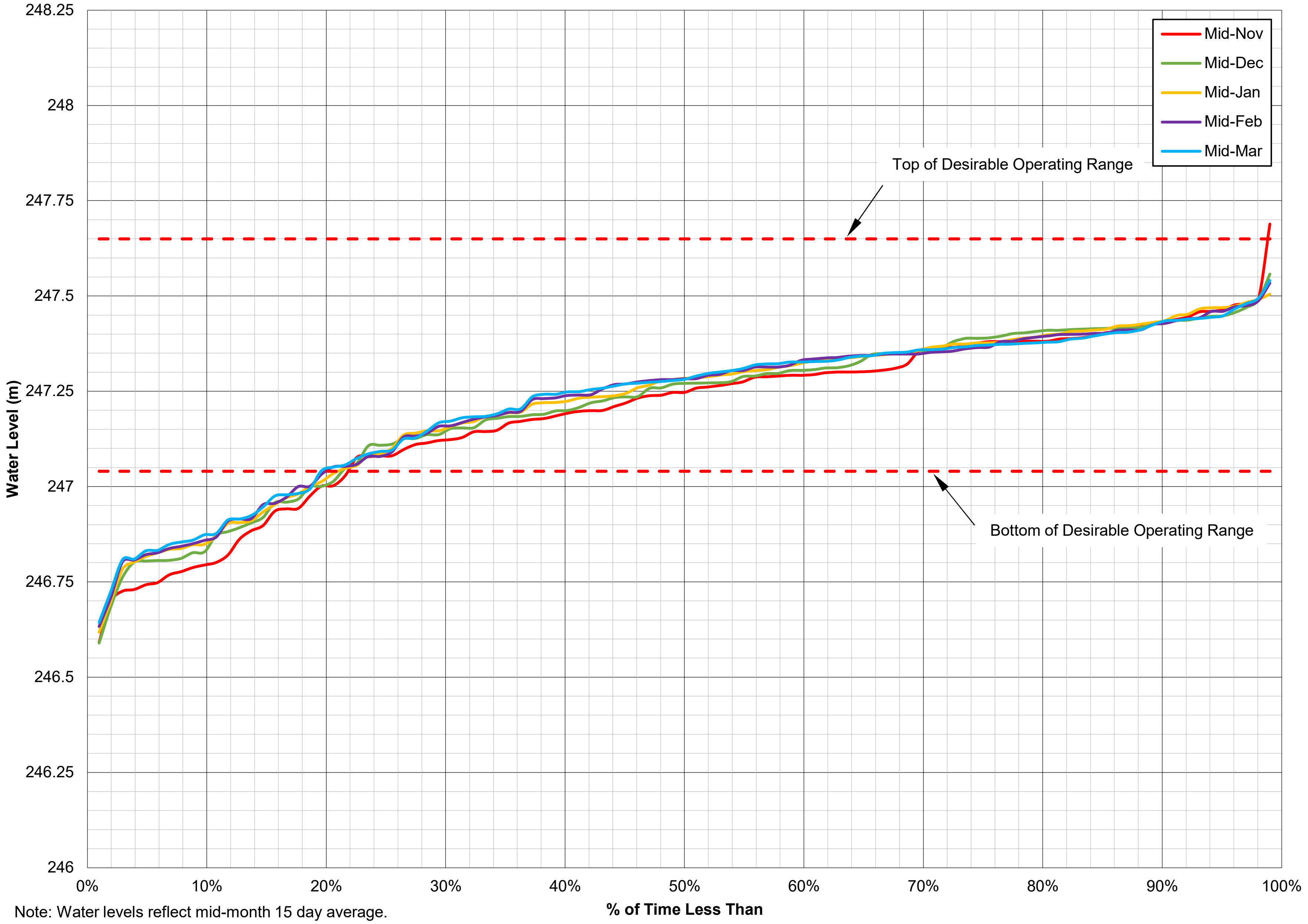
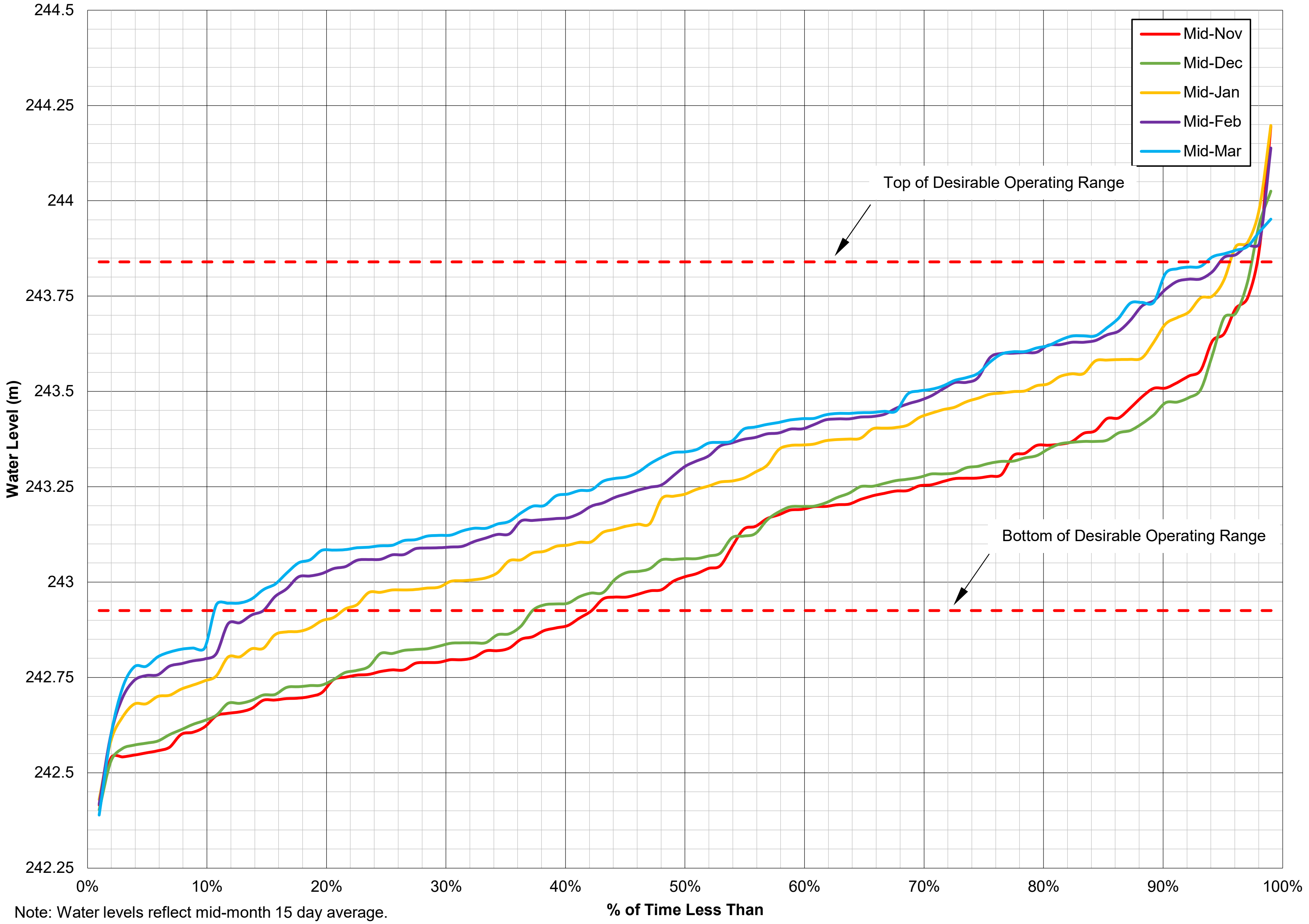


Figure 4: Duration Curve of MI Simulated Lake Manitoba Water Levels



Note: Water levels reflect mid-month 15 day average.

Figure 5: Duration Curve of MI Simulated Lake St. Martin Water Levels



Note: Water levels reflect mid-month 15 day average.

Figure 6: Duration Curves of Estimated Clearance Beneath Ice at LMOC Inlet Daylight Location (Watchorn Bay)

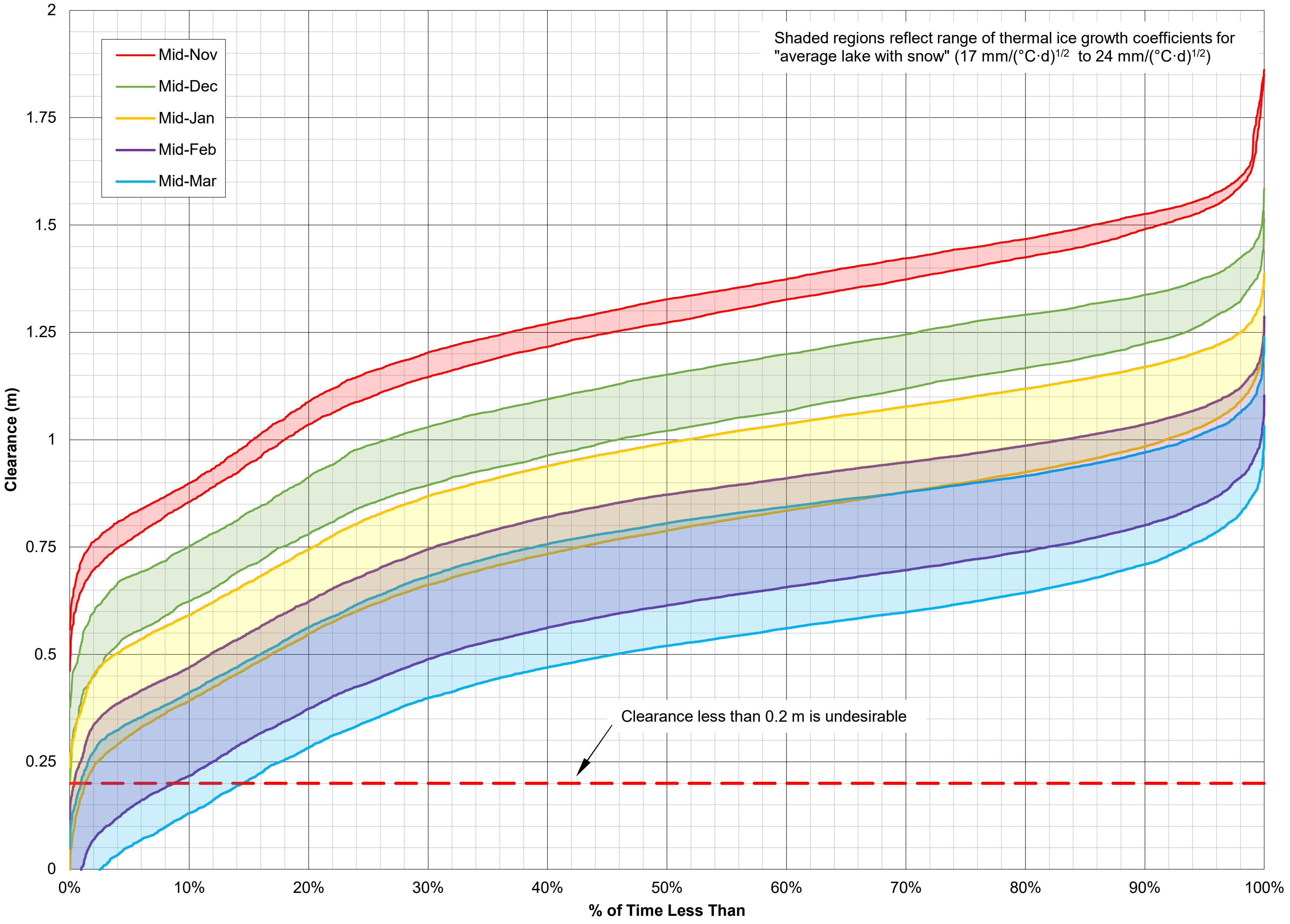


Figure 7: Duration Curves of Estimated Clearance Beneath Ice at LMOC Outlet Daylight Location (Birch Bay)

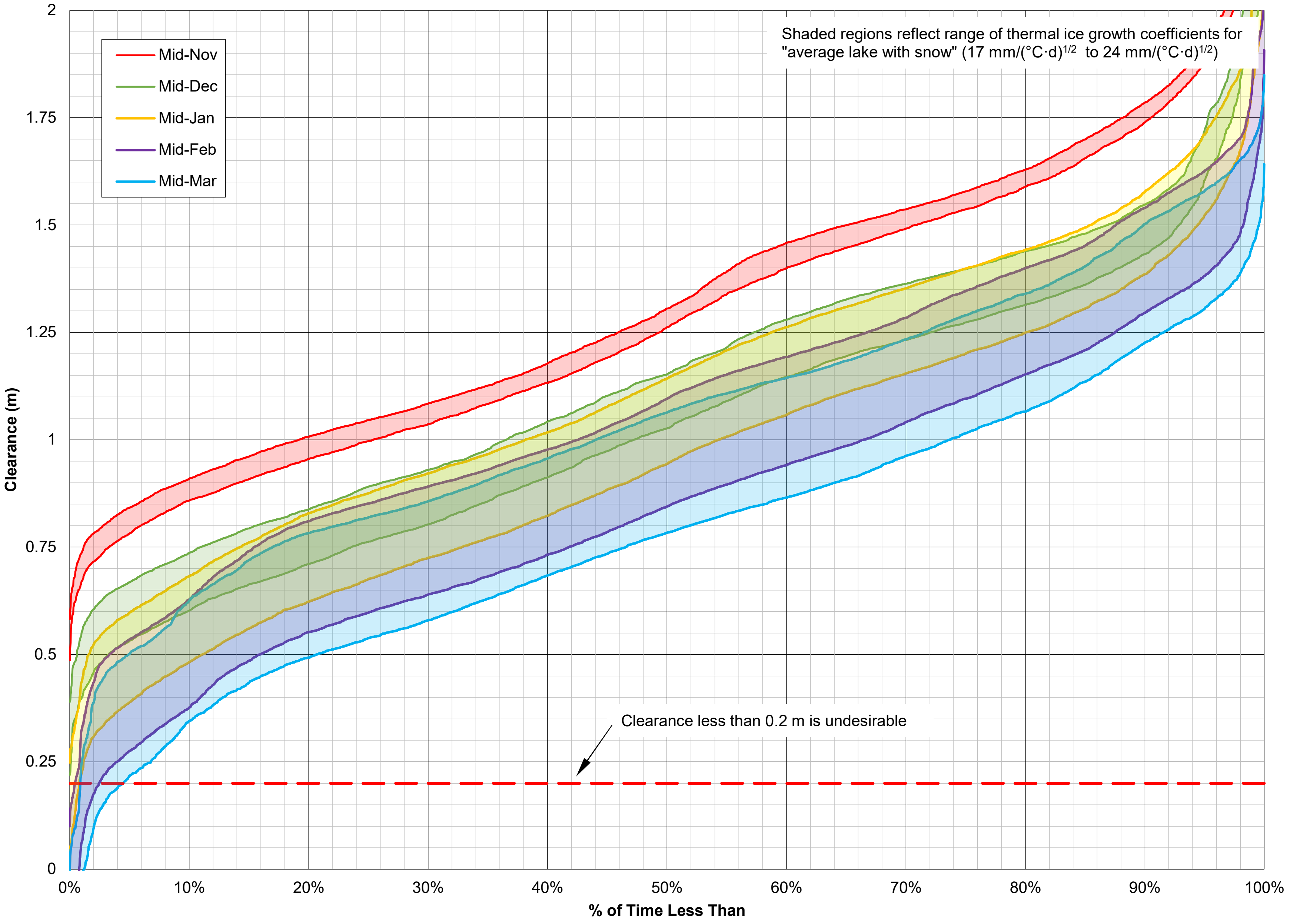


Figure 8: Conceptual LMOC DO Model

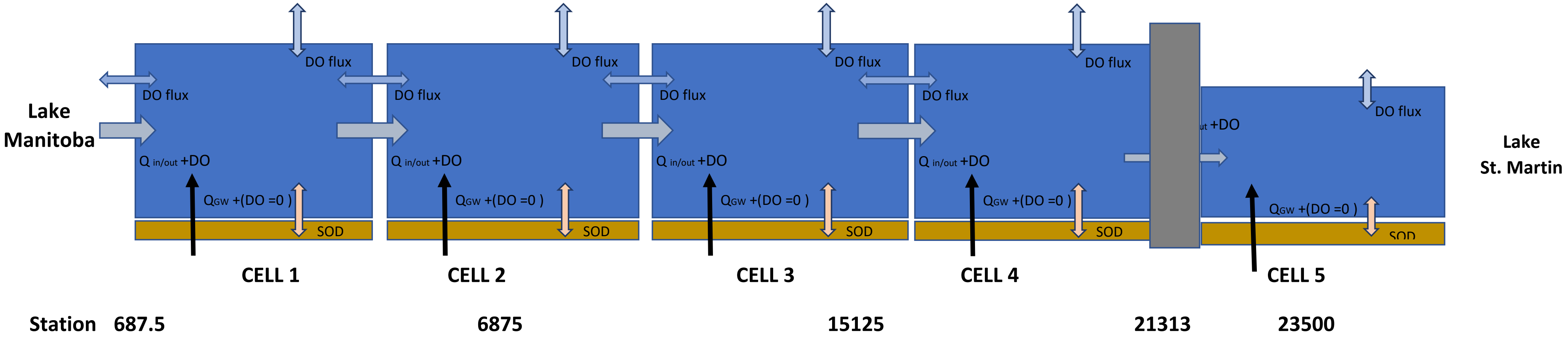
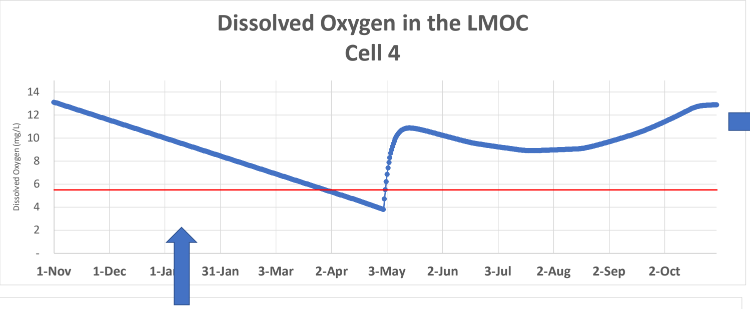
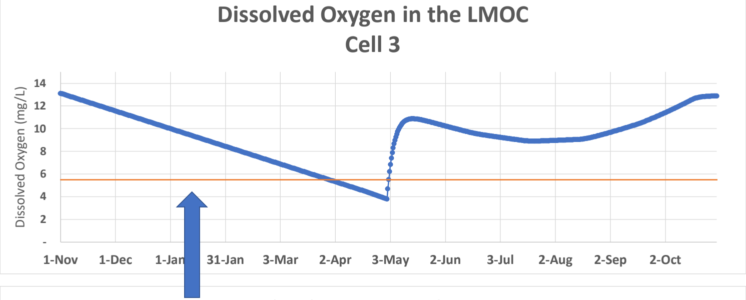
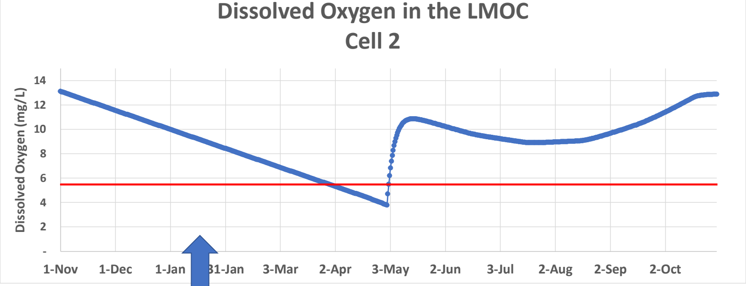


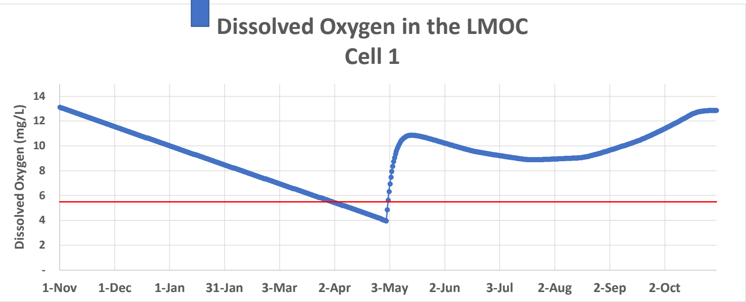
Figure 9: DO Model Scenario 3 - Extreme Low Lake Levels, No Riparian Flow, Moderate SOD

Upstream Cells

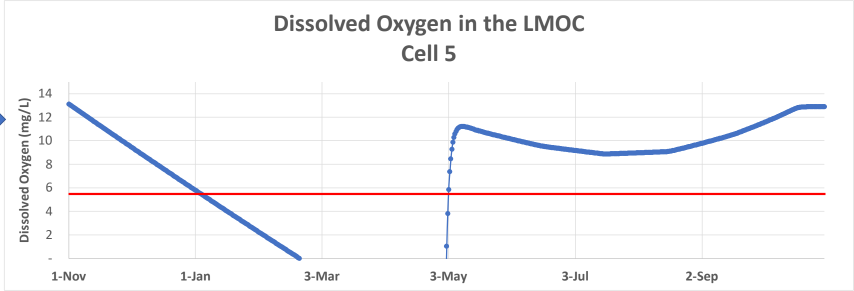








Downstream Cells



Riparian Flow	**-**	**m^3/s**
	-	**m^3/d**
U/S Pond Retention Time	**4,549.9**	**days**
D/S Pond Retention Time	**1,195.0**	**days**
Choose SOD	**0.25**	**$g/m^2/day$**
Groundwater Inflow DO	**0**	**mg/L**
TimeStep	**0.5**	**Day**
Ice off	**1-May**	

Date **29-Apr**

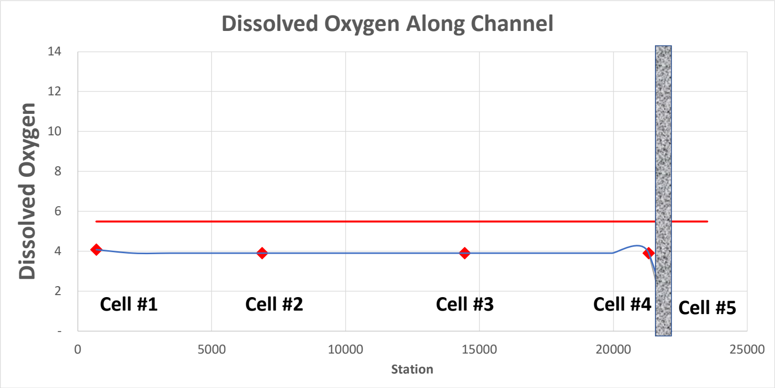
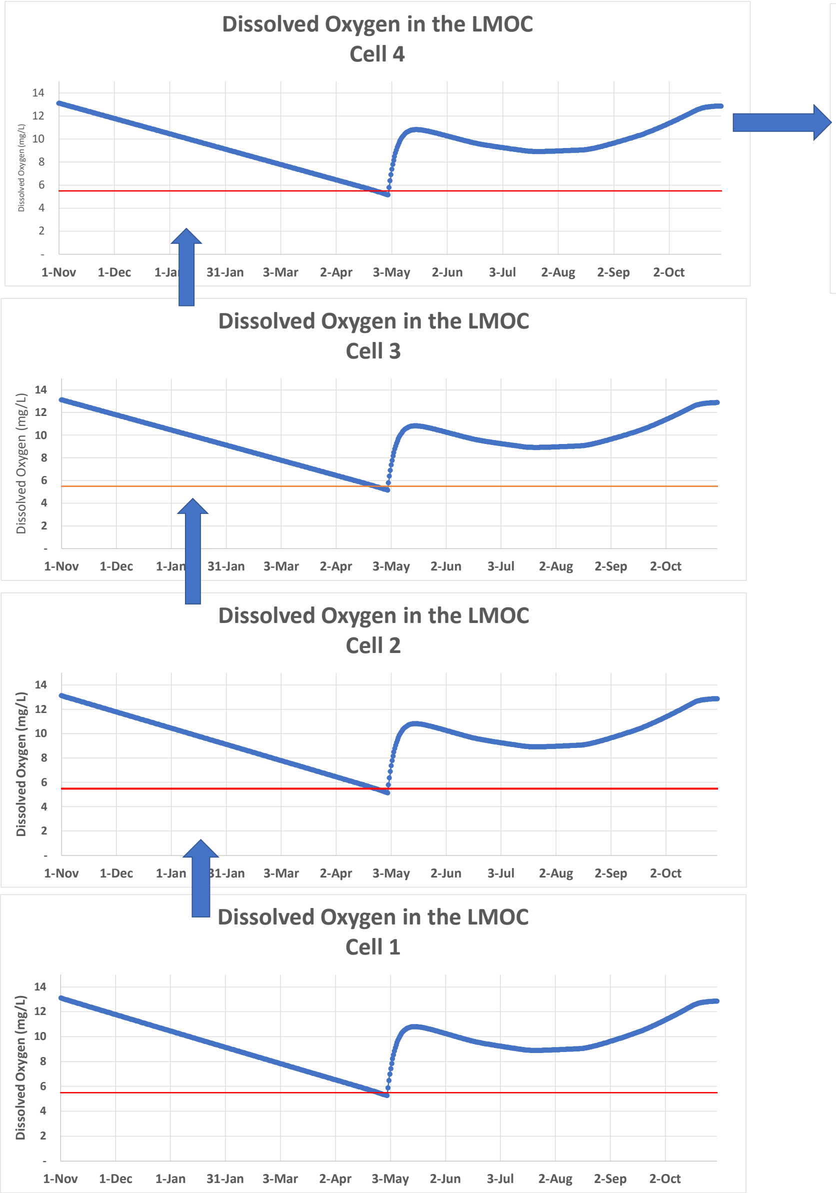


Figure 10: DO Model Scenario 3 - Low Lake Levels, No Riparian Flow, Moderate SOD

Upstream Cells



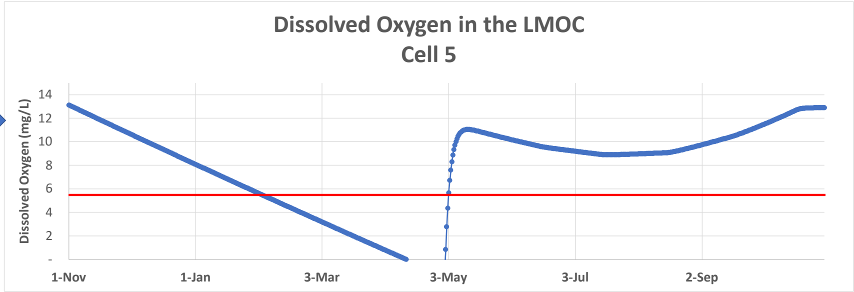
Dissolved Oxygen in the LMOC
Cell 4

Dissolved Oxygen in the LMOC
Cell 3

Dissolved Oxygen in the LMOC
Cell 2

Dissolved Oxygen in the LMOC
Cell 1

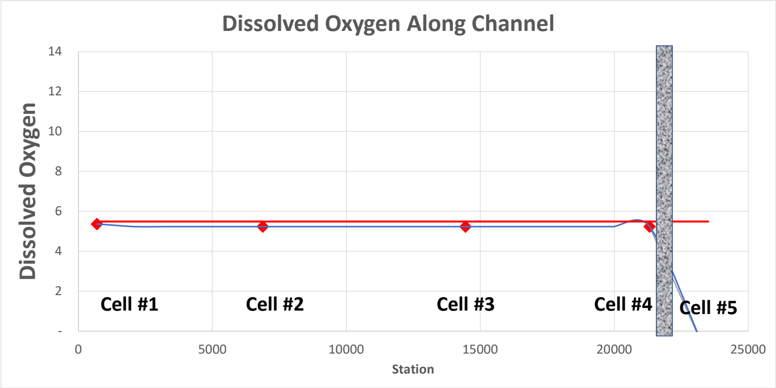
Downstream Cells



Dissolved Oxygen in the LMOC
Cell 5

Riparian Flow	**-**	**m³/s**
	-	**m³/d**
U/S Pond Retention Time	**5,322.4**	**days**
D/S Pond Retention Time	**1,750.5**	**days**
Choose SOD	**0.25**	**g/m²/day**
Groundwater Inflow DO	**0**	**mg/L**
TimeStep	**0.5**	**Day**
Ice off	**1-May**	

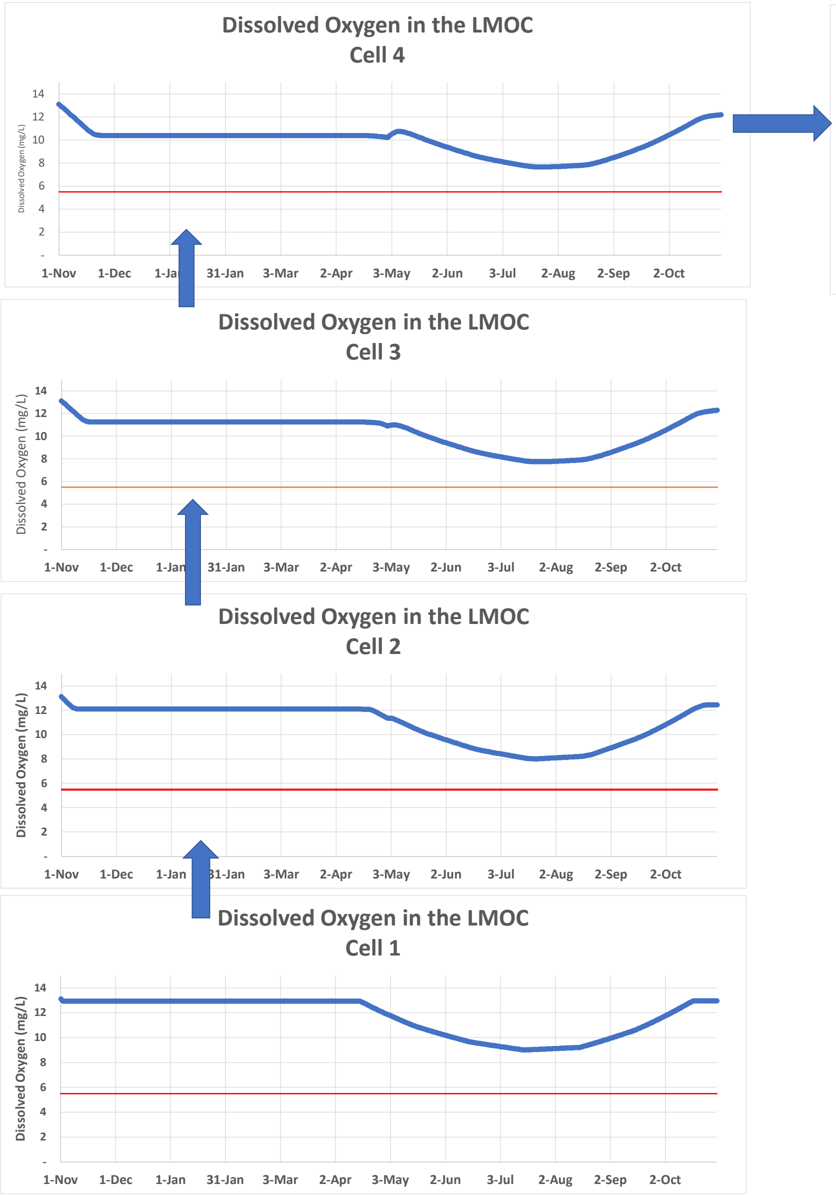
Date **29-Apr**



Dissolved Oxygen Along Channel

Figure 11: DO Model Scenario 6 - Extreme Low Lake Levels, $3m^3/s$ Riparian Flow, Very High SOD

Upstream Cells



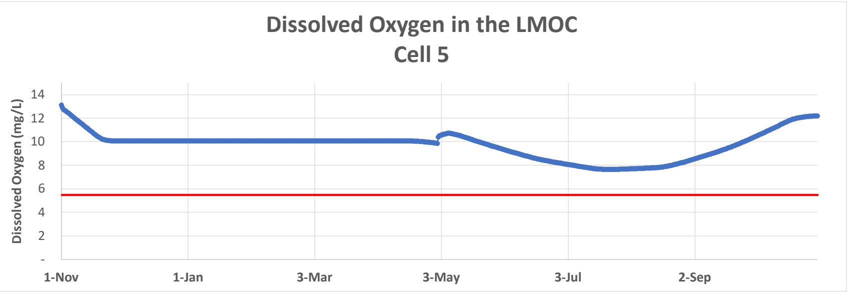
Dissolved Oxygen in the LMOC
Cell 4

Dissolved Oxygen in the LMOC
Cell 3

Dissolved Oxygen in the LMOC
Cell 2

Dissolved Oxygen in the LMOC
Cell 1

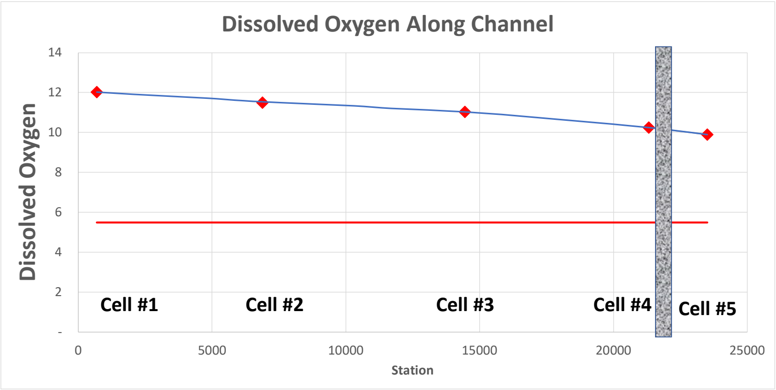
Downstream Cells



Dissolved Oxygen in the LMOC
Cell 5

Riparian Flow	**3.0**	**m³/s**
	259,200	**m³/d**
U/S Pond Retention Time	**13.3**	**days**
D/S Pond Retention Time	**0.7**	**days**
Choose SOD	**1.00**	**g/m²/day**
Groundwater Inflow DO	**0**	**mg/L**
TimeStep	**0.5**	**Day**
Ice off	**1-May**	

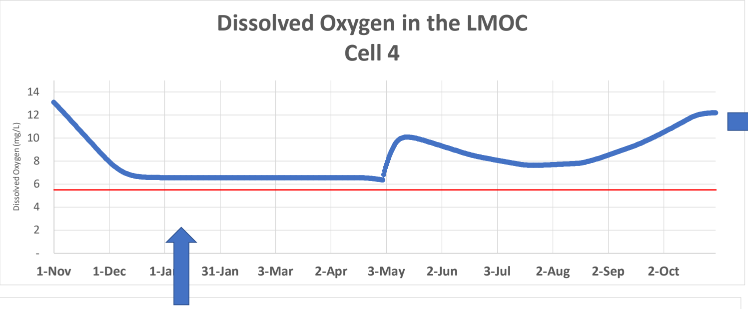
Date **29-Apr**

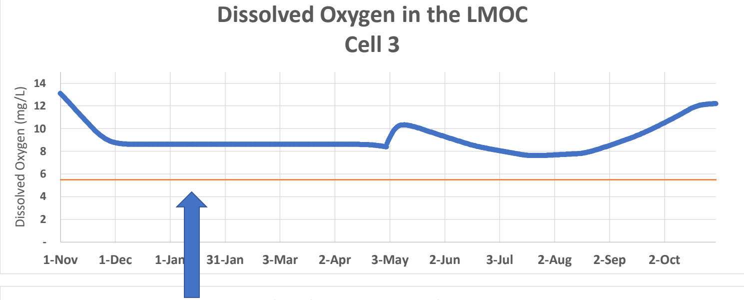


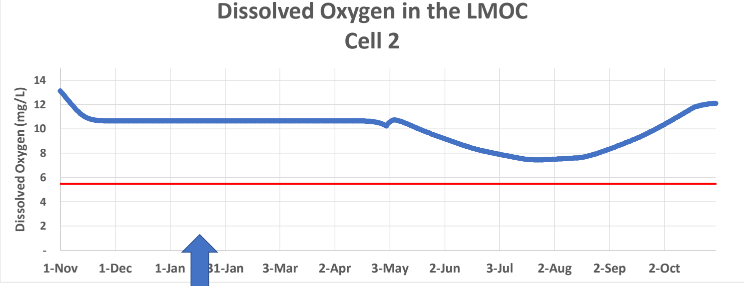
Dissolved Oxygen Along Channel

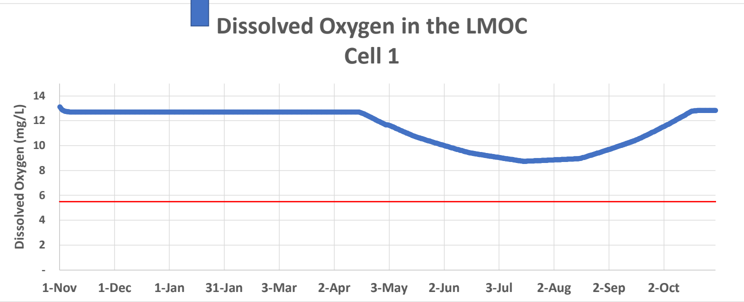
Figure 12: DO Model Scenario 6 - Extreme Low Lake Levels, 1.25 m^3/s Riparian Flow, 1.0 $g/m^2/d$ SOD

Upstream Cells

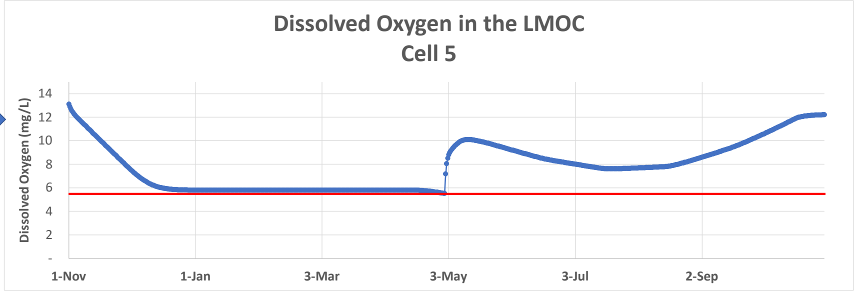








Downstream Cells



Riparian Flow	**1.3**	**m³/s**
	108,000	**m³/d**
U/S Pond Retention Time	**31.8**	**days**
D/S Pond Retention Time	**1.6**	**days**
Choose SOD	**1.00**	**g/m²/day**
Groundwater Inflow DO	**0**	**mg/L**
TimeStep	**0.5**	**Day**
Ice off	**1-May**	

Date **29-Apr**

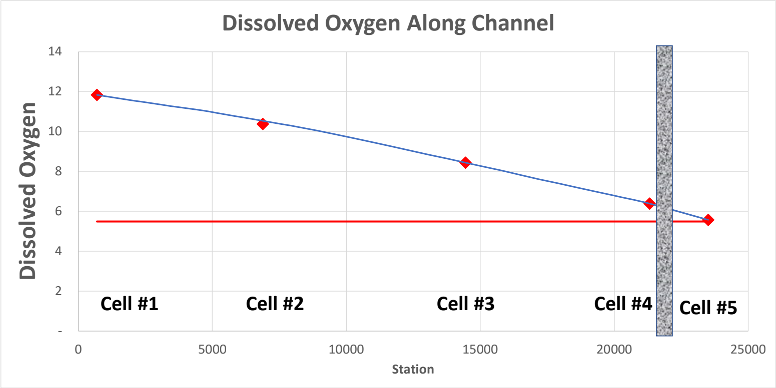
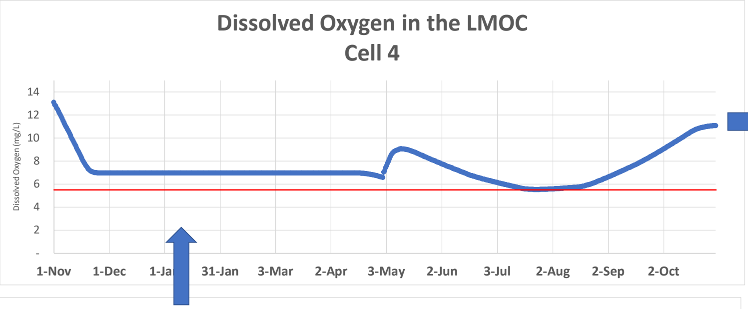
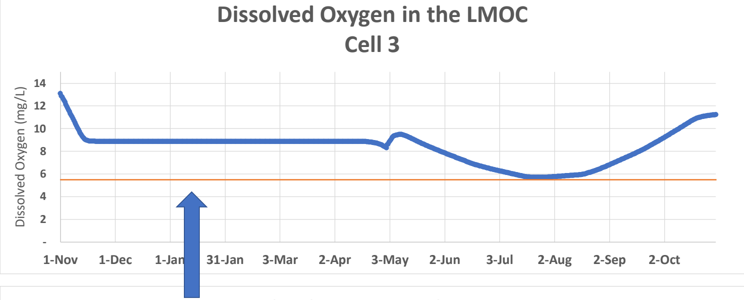
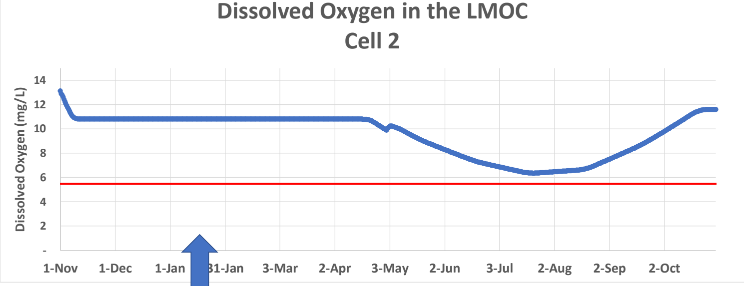


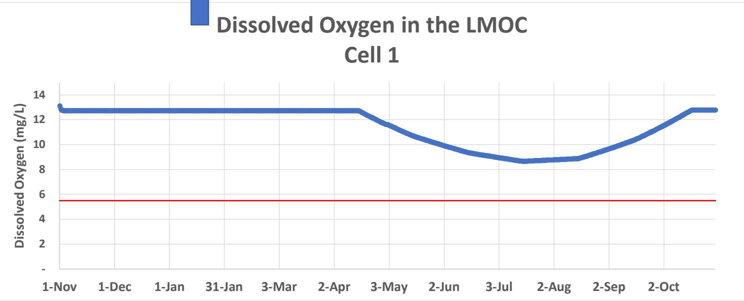
Figure 13: DO Model Scenario 6 - Extreme Low Lake Levels, 3m^3/s Riparian Flow, 2.25 g/m^2/d SOD

Upstream Cells

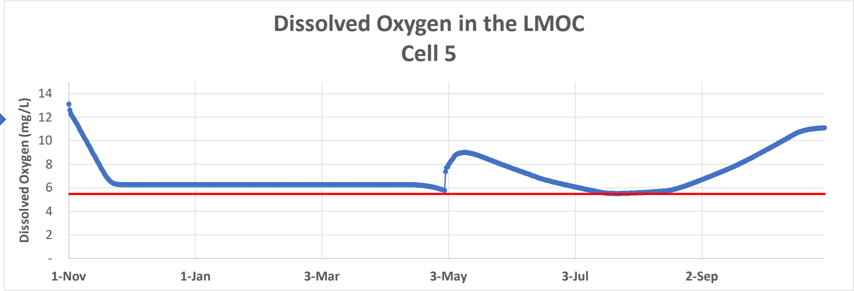








Downstream Cells



Riparian Flow	**3.0**	**m³/s**
	259,200	**m³/d**
U/S Pond Retention Time	**13.3**	**days**
D/S Pond Retention Time	**0.7**	**days**
Choose SOD	**2.25**	**g/m²/day**
Groundwater Inflow DO	**0**	**mg/L**
TimeStep	**0.5**	**Day**
Ice off	**1-May**	

Date **29-Apr**