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LOWER CHURCHILL PROJECT

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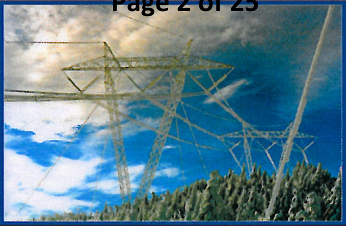

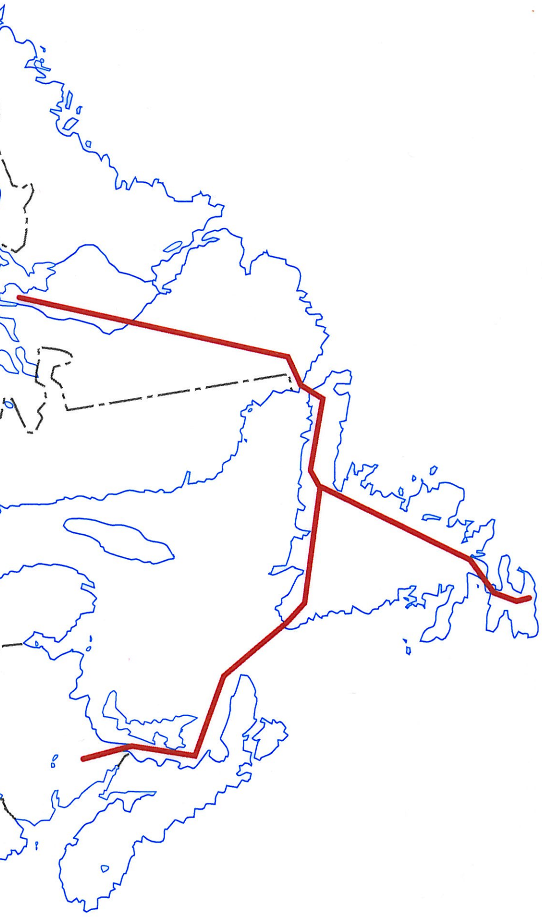

THE Lower Churchill PROJECT

March 2011

MF1330 - Hydraulic Modeling and Studies 2010 Update

Report 4: Muskrat Falls Ice Study

prepared by

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MICHAEL M. ROSALES
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Executive Summary

Nalcor Energy – Lower Churchill Project (NE-LCP) is undertaking preliminary engineering studies of the development of the hydroelectric potential of the Lower Churchill River at Gull Island and Muskrat Falls. In 2008 Hatch issued GI1070 - Ice Study (Gull Island and Muskrat Falls) to NE-LCP, the objective of which was to review the existing ice conditions in the Lower Churchill River, identify how these conditions might change as a result of the project, identify potential concerns during the construction phases of the project, and propose measures to alleviate those concerns. In that study it was assumed that the Gull Island project would be constructed before the Muskrat Falls project. The objective of the current study is to evaluate ice conditions at Muskrat Falls during and post construction, assuming Muskrat Falls is developed before Gull Island.

The current study concluded that the Muskrat Falls ice management strategy proposed in GI1070 is suitable for the case in which the Muskrat Falls facilities are constructed prior to the Gull Island facilities. This strategy includes maintaining a 25 m water level at the upstream cofferdam such that an ice cover can form and progress upstream, thereby cutting off the supply of ice to the downstream reach. Due to the complexity of the velocity regime at the cofferdam location, it is recommended that the 25 m result noted above be optimized during FEED studies.

Post-construction, a thermal cover is expected to form on the Muskrat Falls reservoir. Thermal ice conditions will prevail close to the dam while a thicker accumulation of ice will develop near the upstream end of the reservoir.

1. Introduction

Nalcor Energy – Lower Churchill Project (NE-LCP) is undertaking preliminary engineering studies of the development of the hydroelectric potential of the Lower Churchill River at Gull Island and Muskrat Falls. These sites are located 231 km and 291 km downstream respectively from the Upper Churchill hydroelectric facility that was developed in the early 1970's. The total potential capacity at the two sites is 3,074 megawatts (MW); the Gull Island site being the larger at 2,250 MW and the Muskrat Falls site having a capacity of 824 MW. In addition to the development of these sites, the overall concept includes various potential alternative power transmission arrangements involving combinations of AC and DC lines of various capacities.

In April 2007, Nalcor contracted Hatch Ltd. of St. John's to undertake a program of studies to address aspects of this development. In January 2008 Hatch issued the final report of GI1070 – Ice Study (Gull Island and Muskrat Falls) to NE-LCP. The scope of work for that study included reviewing existing ice conditions on the Lower Churchill River, identifying how these conditions might change as a result of the project, identifying potential concerns during the construction phases of the project, and proposing measures to alleviate these concerns. The objective of the current study is to evaluate ice conditions at the Muskrat Falls site during and after construction, assuming Muskrat Falls is developed prior to Gull Island.

2. Model Updates

A required input to the ICESIM model is a file containing tables to describe the open water conveyance capacity of the river. This file was generated based on the hydraulic model that was updated as part of MF1330 (Report 1: Hydraulic Modeling of the River). As expected, the hydraulic model update produced only small changes in the simulated river conveyance, so the necessary changes in the ICESIM conveyance tables were also small.

Conveyance information is also required for modeling the temperature regime of the river which is an input to ICESIM. Though little change was expected, the HEATSIM model was updated and simulations were completed to re-estimate Churchill River water temperatures. The resulting changes were indeed small and deemed to be insignificant with respect to modeling the ice regime of the river; therefore, simulated water temperatures from previous work were used in the analysis. Water temperature estimates were required for Gull Lake and Lake Winokapau (corresponding to the upstream ends of the ICESIM models used in the analysis), for two calibration years (1990-91 and 1991-92) and for two representative climate years (1972-73 and 1987-88).

Continuous water temperature measurements at km 215 (near the outlet of Lake Winokapau) were collected as part of the 2009-2010 Ice Observation Program (GI1075). These water temperatures were compared to simulated Lake Winokapau temperatures for cold, average, and warm representative climate years and although not directly comparable, the agreement was deemed to be acceptable. It should be noted that slight changes to the HEATSIM model parameters would not be expected to affect the selection of the proposed ice management strategy. Conservative estimates have been made in the modeling with respect to the amount of ice arriving at the Muskrat Falls construction site and therefore the proposed ice management strategy is considered to be robust.

3. ICESIM Model Calibration

In the GI1070 study, the ICESIM model was calibrated independently for five separate winters. Based on the minor nature of the updates as described above, it was deemed sufficient to check the calibration for two of these winters (1990-91 and 1991-92). These winters were selected as the main calibration years based on the availability of calibration data. Both of these winters were colder than average and had lower than average flows. The ice conditions reported for these winters suggested similar ice conditions for both winters, as follows. The ice front progressed upstream of Lower Muskrat Falls but stalled between the Upper and Lower Falls. At the Gull Island site, the ice cover progressed upstream to Horseshoe Rapids (approximate chainage 115 km).

Water levels at the Muskrat Falls hydrometric gauges were used as the primary calibration data. Measured water levels are available for gauges below the Lower Falls, between the Lower and Upper Falls, and above the Upper Falls for the calibration years. These water levels provide an indication of when the ice cover reaches the base of Muskrat Falls as well as the staging of the water levels as a result of the accumulation of ice in the hanging dam. It should be noted that there is some uncertainty in the geodetic datum adjustment for the gauge below the Lower Falls, but levels are expected to be within one metre.

An acceptable calibration tolerance for water levels in an open water hydraulic model is usually in the order of 10 cm. The tolerance for ice simulation models is not as high; this relates to the complexity of the ice generation, formation, and progression processes. As shown on Figures 3-1 through 3-6, simulated levels (which are shown at various points in time throughout the simulation) are within approximately one metre of measured water levels. This is deemed to be an acceptable calibration for this type of model. It should be noted that beginning in early March, all observed gauges show a pronounced drop in water level, signaling that the deterioration of the ice cover has started. The increased intensity of the solar radiation, and longer daytime periods trigger this deterioration. ICESIM is not able to simulate the deterioration of an ice cover, and therefore will tend to overpredict stages in the late winter months, as shown on these figures.

The plots of water levels below Muskrat Falls include simulated levels at two separate cross sections (42.7 km and 42.8 km). This is because the exact location of this historic gauge is unknown but is thought to be between these two model cross sections.

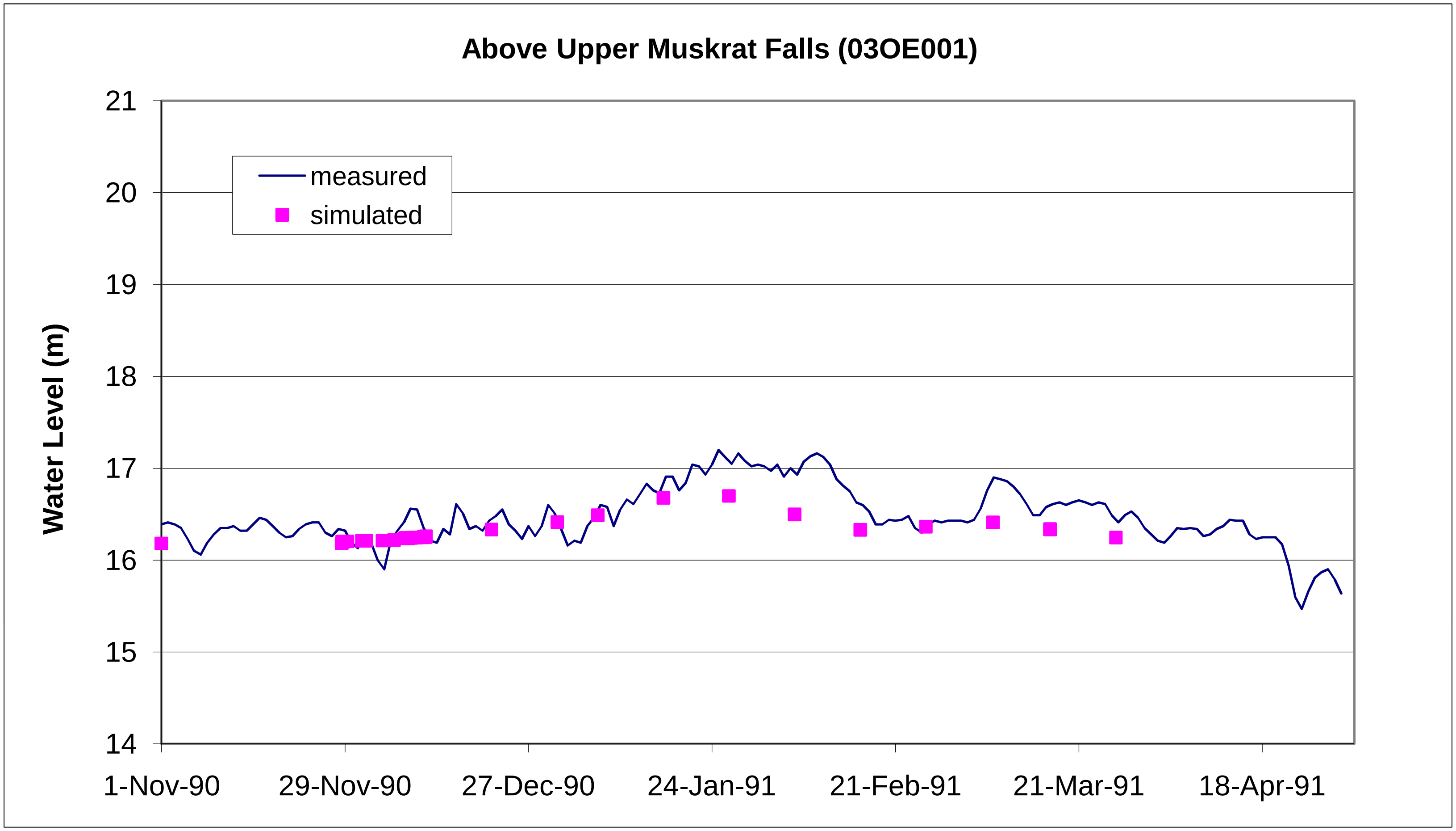

Figure 3-1
Calibration to Muskrat Falls Water Levels: 1990-91 (1 of 3)
Muskrat Falls Ice Study - 2010 Update
Nalcor Energy - Lower Churchill Project

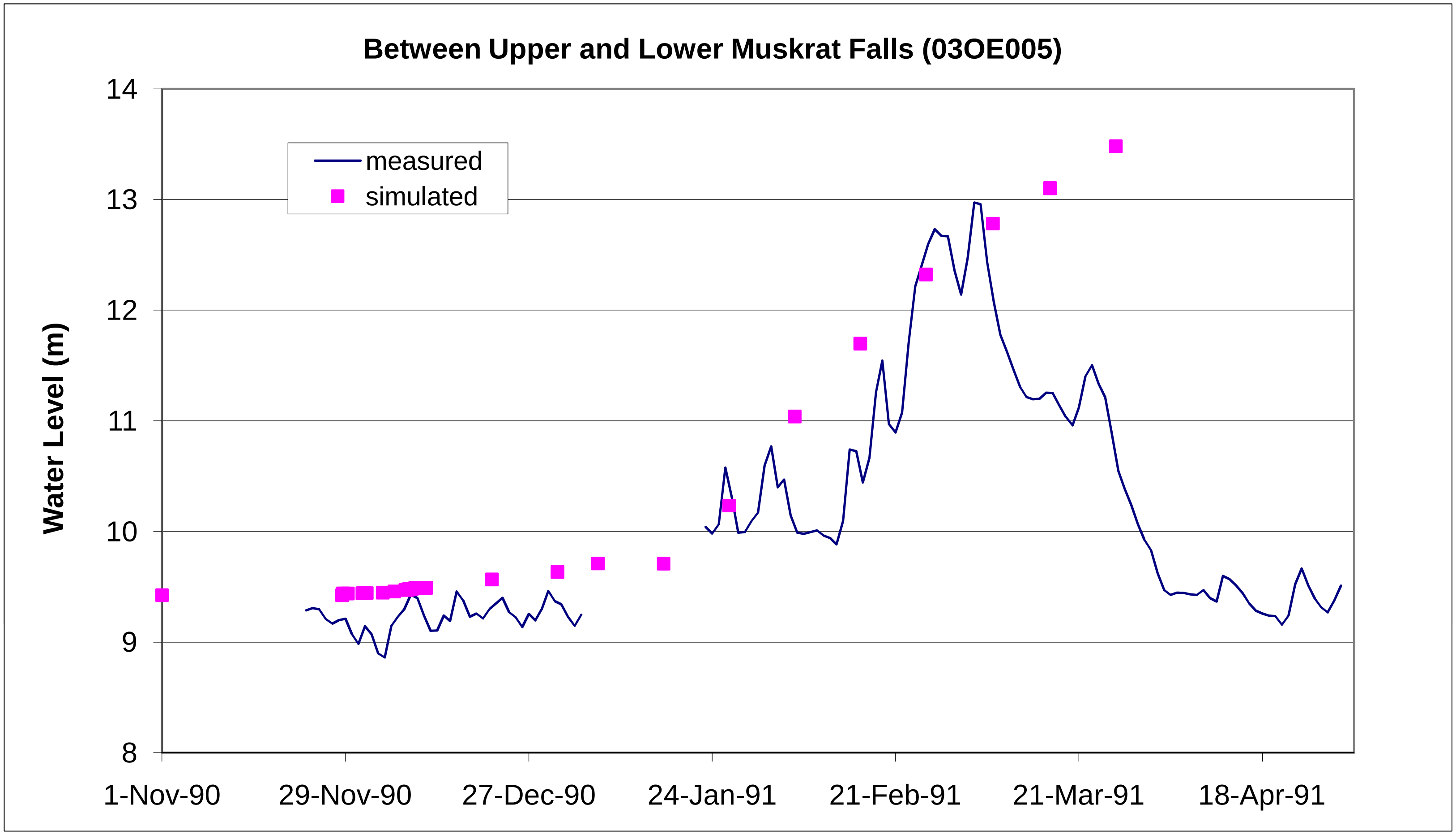

Figure 3-2
Calibration to Muskrat Falls Water Levels: 1990-91 (2 of 3)
Muskrat Falls Ice Study - 2010 Update
Nalcor Energy - Lower Churchill Project

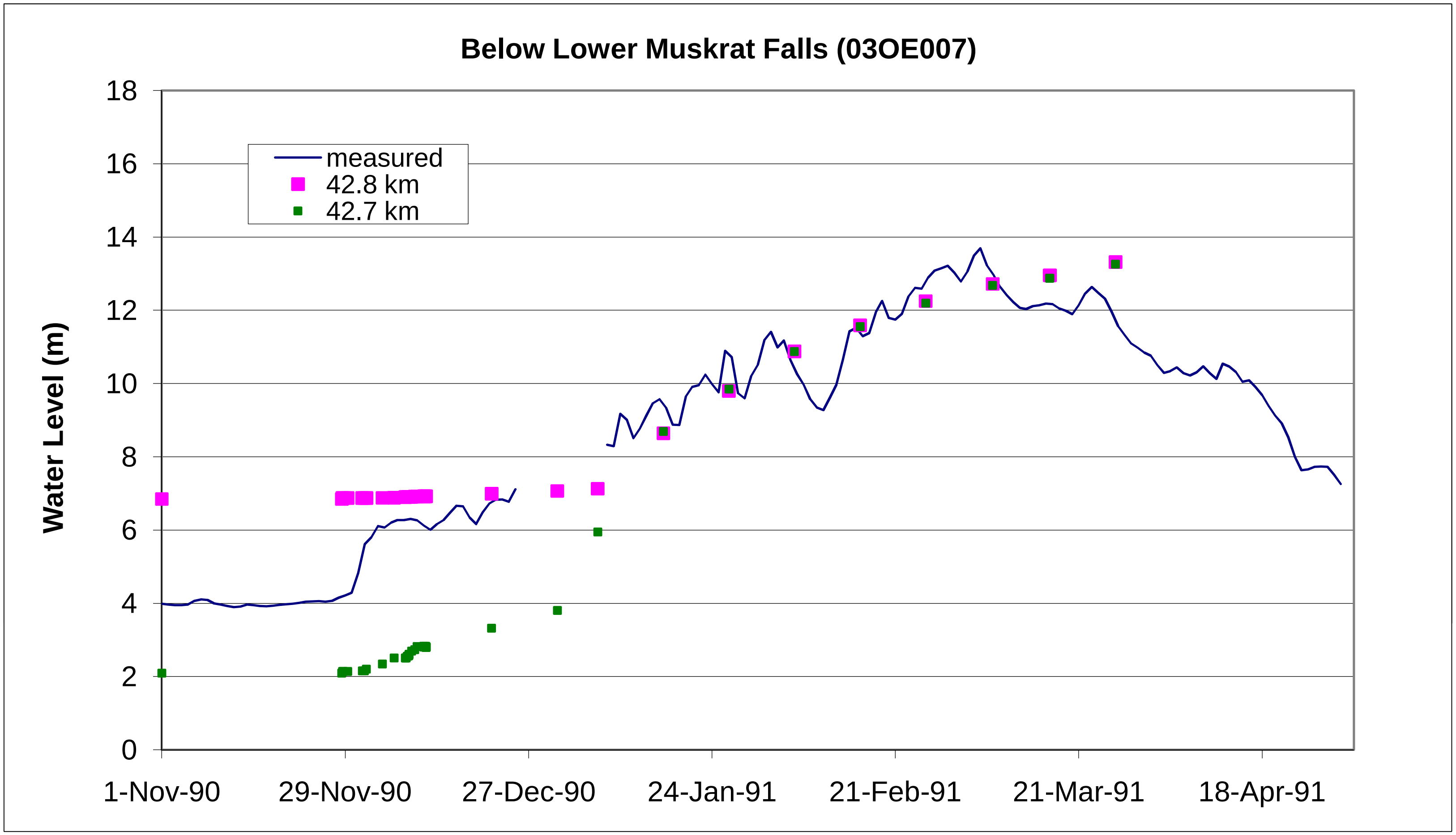

Figure 3-3
Calibration to Muskrat Falls Water Levels: 1990-91 (3 of 3)
Muskrat Falls Ice Study - 2010 Update
Nalcor Energy - Lower Churchill Project

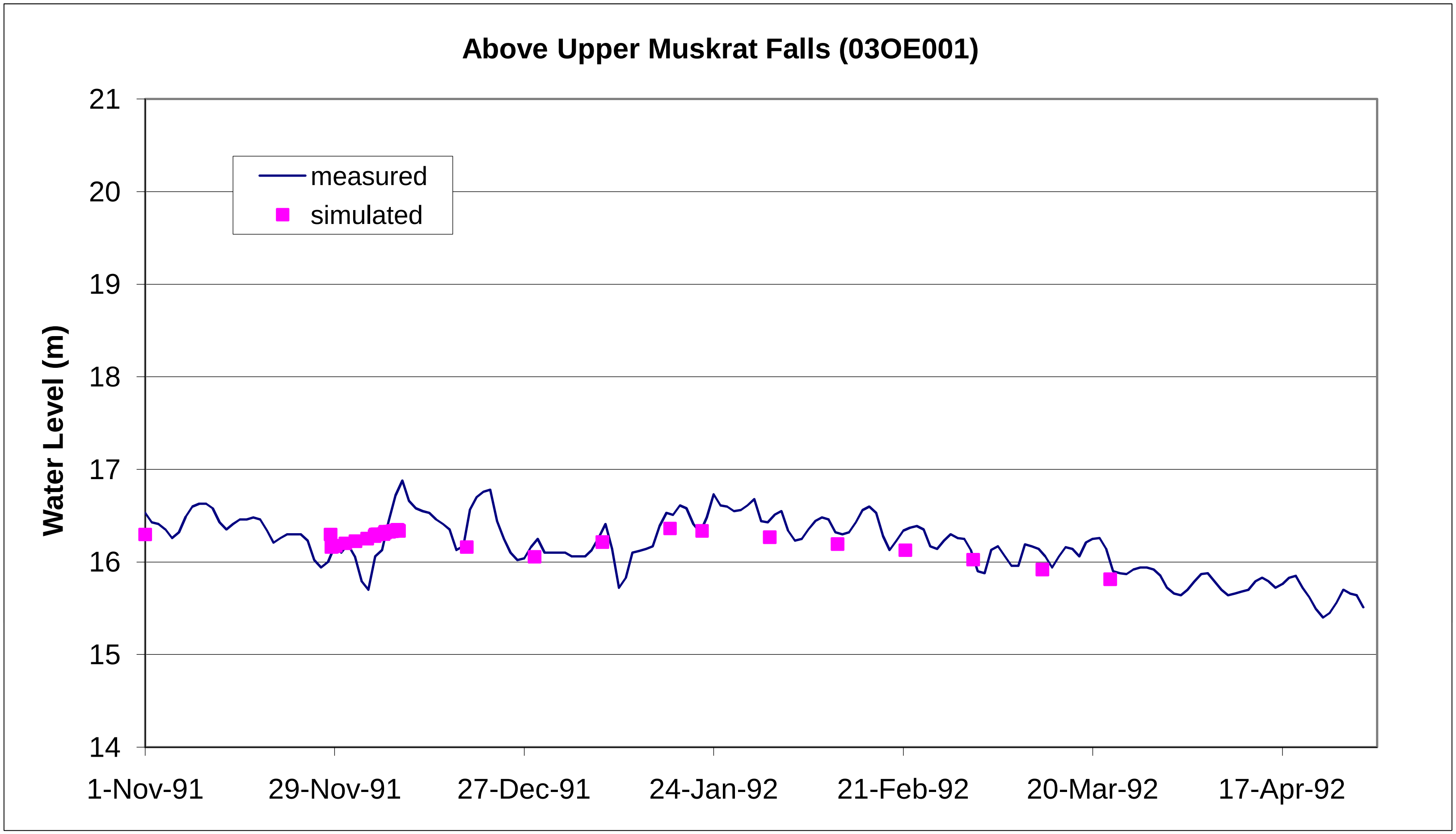

Figure 3-4
Calibration to Muskrat Falls Water Levels: 1991-92 (1 of 3)
Muskrat Falls Ice Study - 2010 Update
Nalcor Energy - Lower Churchill Project

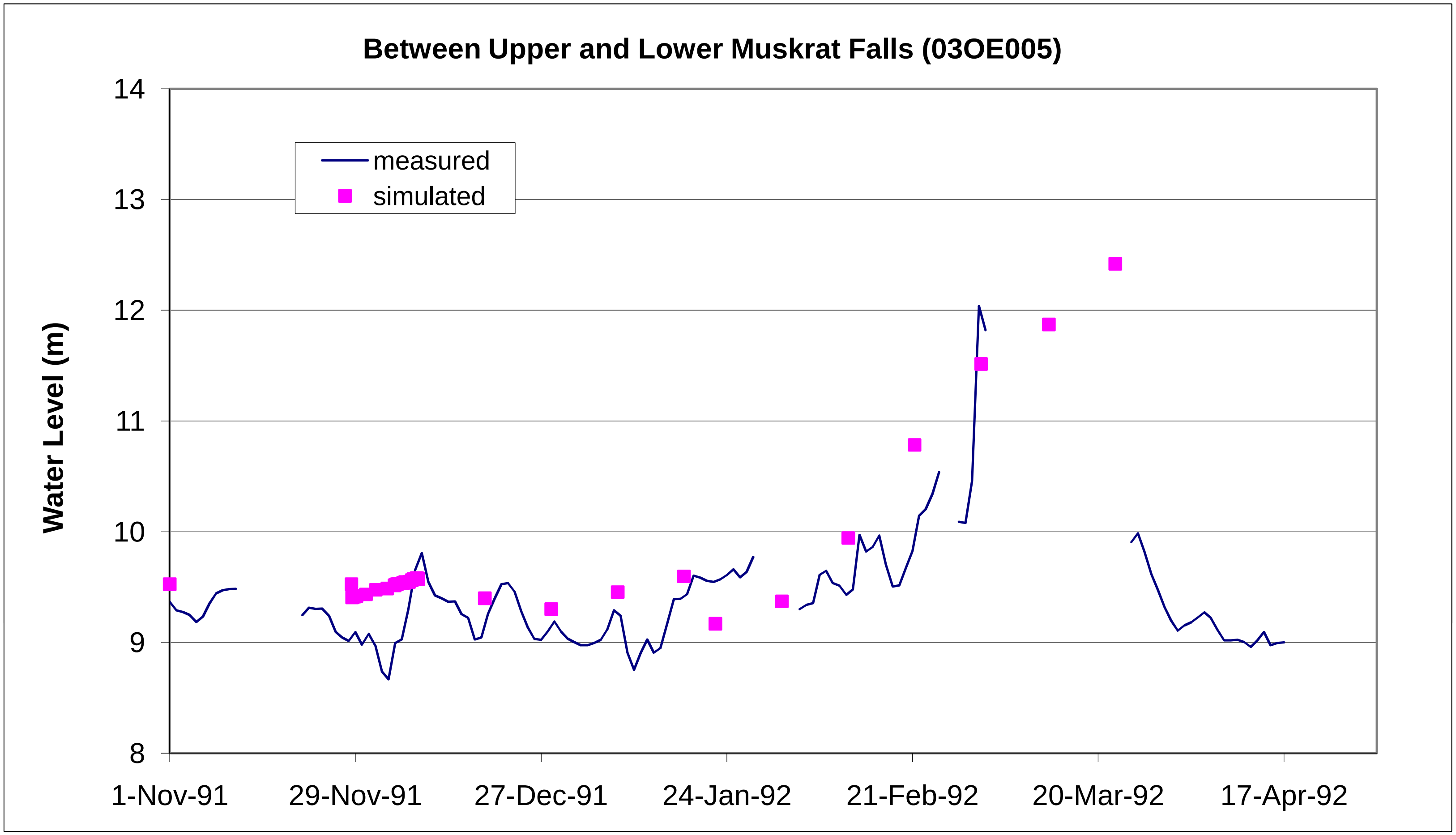

Figure 3-5
Calibration to Muskrat Falls Water Levels: 1991-92 (2 of 3)
Muskrat Falls Ice Study - 2010 Update
Nalcor Energy - Lower Churchill Project

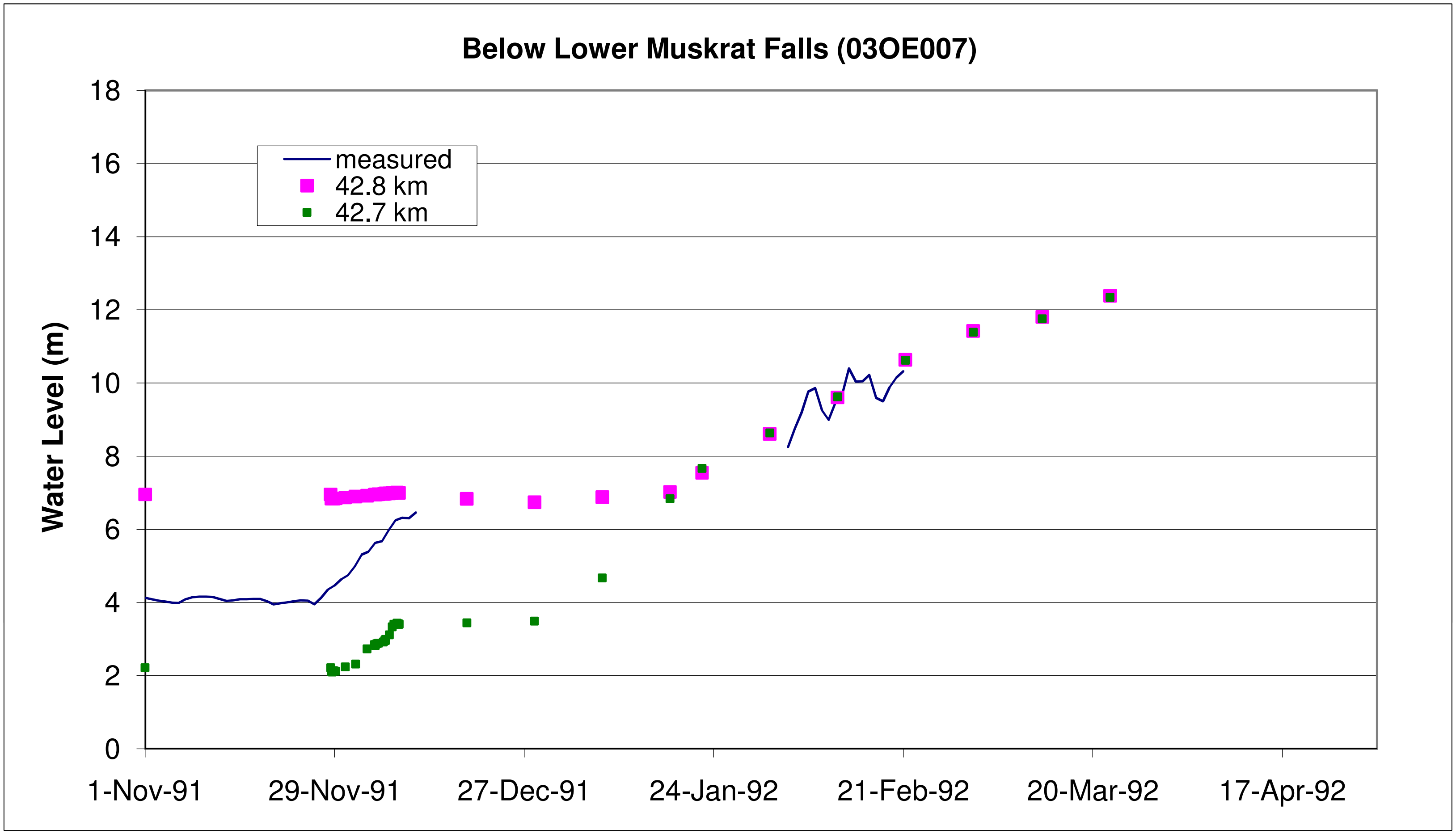

Figure 3-6
Calibration to Muskrat Falls Water Levels: 1991-92 (3 of 3)
Muskrat Falls Ice Study - 2010 Update
Nalcor Energy - Lower Churchill Project

4. Ice Management Simulations

In the GI1070 Ice Study ice conditions during construction of the Muskrat Falls project were analysed assuming the Gull Island project was in place upstream. In that case, the Gull Island reservoir and dam block the transport of ice from upstream. In the current analysis it was assumed that the Gull Island project was not yet constructed, and therefore the ice generation reach included the portion of the river upstream of the Gull Island dam site to the outlet of Lake Winokapau (no ice passes through Lake Winokapau).

4.1 Ice Control During Construction of Spillway

For the Variant 10 layout currently proposed (described in MF1050), the Muskrat Falls diversion spillway is to be constructed behind the natural river bank on the south side of the river. An analysis of historic water levels was completed as part of GI1070 to determine whether or not ice control would be required to protect the construction site from flooding. The assumption during that analysis (which is assumed to remain valid in the current study) is that the water levels adjacent to the construction site would have to reach a level of approximately 20 m to cause a flooding concern. Based on the review of historic water levels completed under GI1070, this appears to be an unlikely occurrence. It is difficult to assign an accurate estimate of the probability of occurrence of reaching a winter level of 20 m because of the extent of missing data in the water level record and the complexity of the ice formation processes at the base of Muskrat Falls. However, in the past 32 years (since full operation of the Churchill Falls hydroelectric development upstream), winter water levels at the upstream gauge have not exceeded 20 m, and necessarily, winter water levels adjacent to the construction site have been even lower. It should be noted that water levels have exceeded 20 m at the upstream gauge during spring runoff (open water conditions) at a frequency of approximately once every two years. It is assumed that flow regulation at Churchill Falls would be possible in the event that water levels adjacent to the construction site posed a risk of flooding.

In the event that the proposed construction scheme or cofferdam levels change, or if the risk of flooding cannot be tolerated, an upstream ice control option should be considered to minimize the supply of ice to the downstream reach thereby significantly reducing the size of the hanging dam at the base of Muskrat Falls.

4.2 Ice Control During Construction of Main Dam

One of the uncertainties in assessing ice conditions between the outlet of Lake Winokapau and Muskrat Falls relates to the volume of ice that is captured within the Gull Lake ice cover versus the amount of ice that is passed beneath the cover and is transported downstream towards Muskrat Falls. Due to an instability in the model, which developed when trying to simulate the complex hydraulic conditions in the large hanging dam which develops in Gull Lake, the full reach between the outlet of Lake Winokapau and Muskrat Falls could not be modeled. Rather, the ICESIM model was used to analyse this complex phenomenon by simulating two separate river reaches. The upstream model (between the outlet of Lake Winokapau and the outlet of Gull Lake) was used to develop conservative estimates of the total volume of ice generated in this reach, and the volume expected to pass through Gull Lake down into Sandy Lake. Because of its deep invert, Gull Lake will quickly form a surface cover each winter, and then acts as an efficient repository for any ice generated upstream of Gull Island Rapids. It was determined that a significant volume of ice is not passed through Gull Lake until partway through the winter (approximately mid to late January). Prior to this, the ice tends to collect within Gull Lake, and it does so until the lake's ability to "store" ice has been exceeded. The estimated volume of ice passing through Gull Lake, as determined from the upstream model, was then used as input to the downstream model which extended from the outlet of Gull Lake (or just upstream of Sandy Lake) to the Muskrat Falls cofferdam. Any ice passed from the upstream reach was provided as an incoming ice volume to the downstream model, and was allowed to accumulate and contribute to the downstream ice cover.

Similar to the ice management simulations completed under GI1070, 1/20 annual exceedance probability (AEP) monthly flows were simulated for a severe climate winter (1972-73), and for this case the downstream water level was iteratively increased to determine the minimum required water level at the Muskrat Falls cofferdam to initiate a stable ice cover upstream. This water level was determined to be 25 m which is the same as that determined in the GI1070 study; the level was not sensitive to the climate condition. Although there is a higher volume of ice to be managed compared to the scenario with the Gull Island project upstream, the water level needed to achieve a stable cover upstream of the Muskrat Falls cofferdam has not changed. The 25 m water level is actually governed by a constricted hydraulic condition in the approach channel just upstream of the cofferdam, and not by the total volume of ice generated. Figure 4-1 presents the simulated end of March ice cover profile along the modeled reach for the winter of 1972-73. The simulation was ended at this time as the model has trouble representing the deterioration of the ice cover in late winter. As shown, the profile includes a significant accumulation of ice at the upstream end of the reach (upstream of approximate chainage 70 km).

At an interim operating level of 25 m, a thermal/juxtaposed cover will form relatively quickly on the upstream reach. Ice generated upstream of Gull Island will initially be drawn under the leading edge of the Gull Lake cover and begin to collect there. Gull Lake will begin to stage, and ice generated upstream of Gull Island will be deposited within the lake. Once the ice storage capacity of Gull Lake is exceeded, ice generated upstream of Gull Island will begin to pass through Gull Lake and collect in Sandy Lake. This will lead to an increase in hydraulic gradient in both lakes and will cause an increase in stage in both. This will, in turn, allow more ice to be deposited within each. The simulation results indicate that the combined capacity of both Sandy and Gull Lake will be sufficient to store the incoming ice volumes. Although the majority of this ice will be trapped within these lakes, a very small portion of the ice volume (made up of loose frazil flocs that are close to being neutrally buoyant) may continue to "bleed through". These volumes are expected to be relatively low, however, and will deposit in the low velocity reaches just downstream of Sandy Lake. With a downstream control level of elevation 25 m, the velocities in the reach downstream of Sandy Lake are, on average, only 0.2 m/s. This is well below the expected deposition velocity for ice, and any ice passing through Sandy Lake would quickly deposit in one of these reaches.

It should be noted that for this winter, the model predicts a small accumulation of ice appearing just upstream of the construction site, at the narrowing of the river at Upper Muskrat Falls (approximate chainage 44 km). The constriction is created by the physical narrowing of the river channel just upstream of the project structures. This narrow channel increases the velocity through this short reach, and this in turn increases the hydrodynamic forces applied to the cover and also increases the Froude number of the section.

At this location some shoving and telescoping of the ice cover may occur with the effect of raising water levels and reducing velocities to the point that the ice cover can progress upstream. As noted above, simulations conducted for a 25 m forebay water level suggest that no ice will be passed downstream; however, it would be prudent to conduct further analyses during FEED studies to confirm this. Additional analysis (likely two-dimensional modeling) is recommended based on the complex velocity regime at the cofferdam. If the accumulation is deemed to be a concern, the forebay level could be raised to 26 m, and/or an ice boom could be installed just upstream of this location to ensure a stable cover is initiated in the upstream river reach. Figure 4-2 presents the ice profile for a 26 m forebay level. As shown, the accumulation of ice upstream of the cofferdam is significantly smaller in this case.

The implications of part of the upstream ice cover being lost during the winter should also be considered during future studies. A sudden loss of even a part of this cover could lead to increased staging downriver, which in turn could adversely affect any ongoing construction activities in this area.

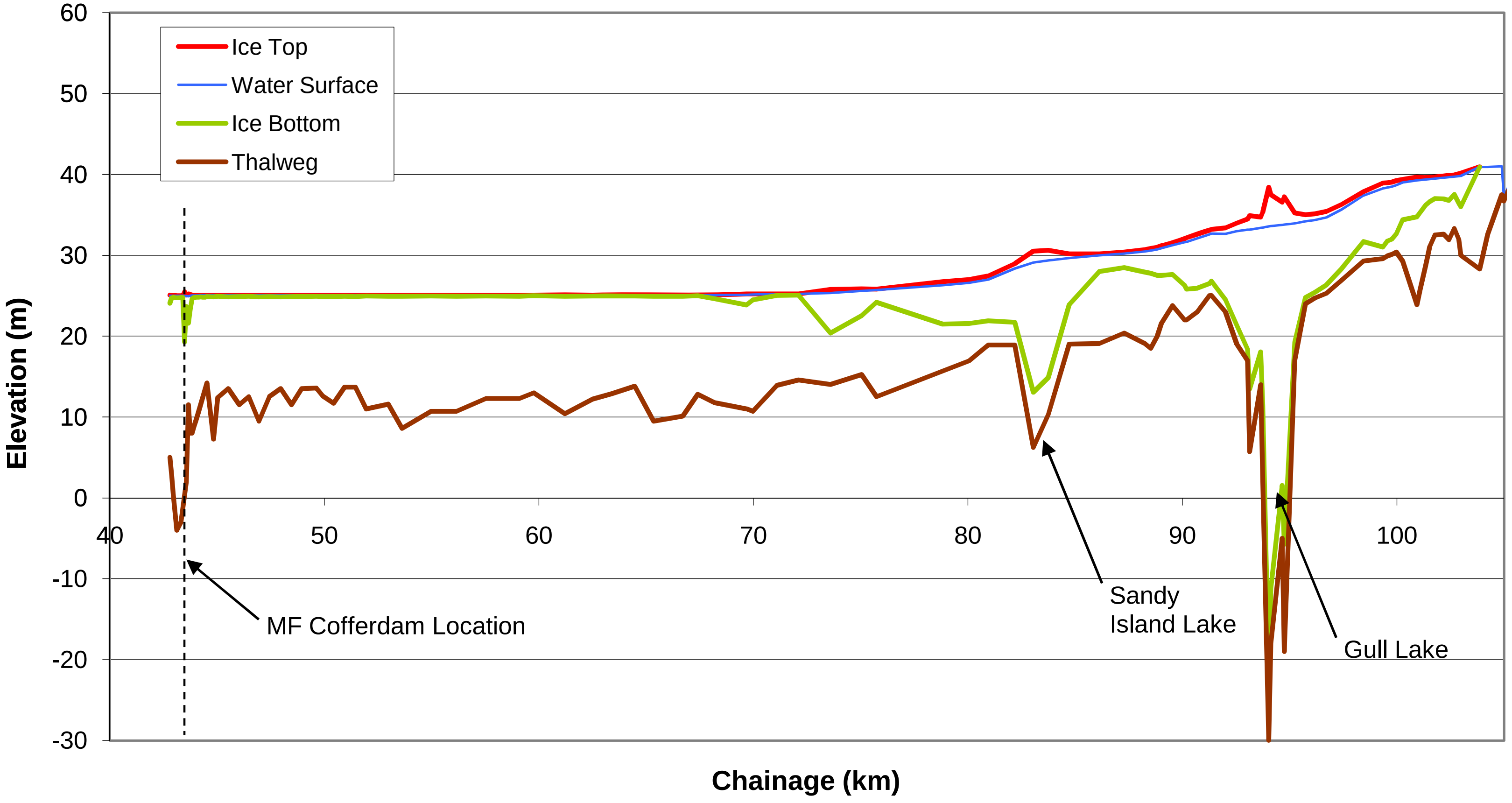

Figure 4-1
End of March Profile: 25 m Forebay Level, Severe Winter (1972-73)
Muskrat Falls Ice Study - 2010 Update
Nalcor Energy - Lower Churchill Project

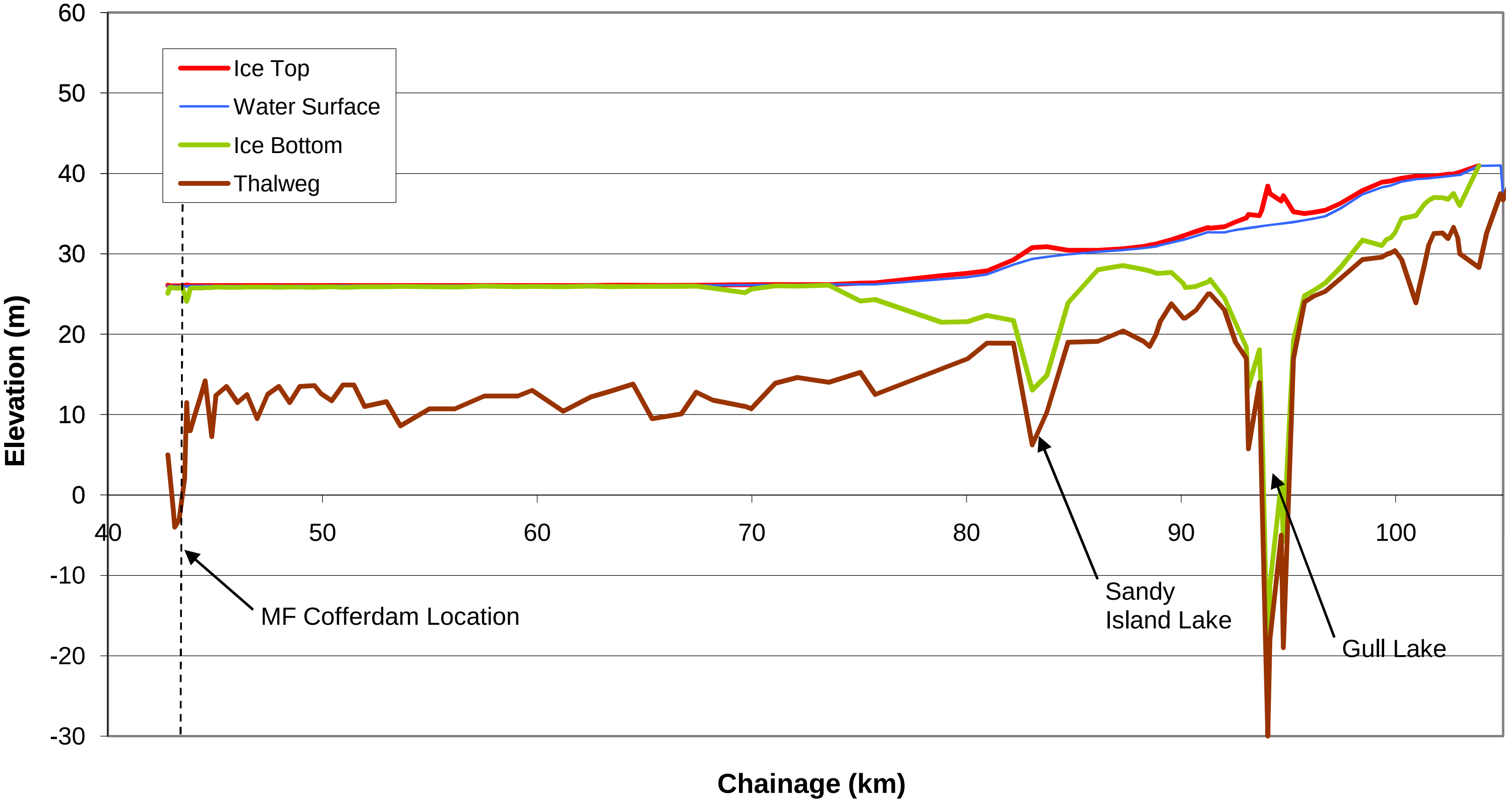

Figure 4-2
End of March Profile: 26 m Forebay Level, Severe Winter (1972-73)
Muskrat Falls Ice Study - 2010 Update
Nalcor Energy - Lower Churchill Project

5. Ice Conditions Post-Construction of Muskrat Falls (Pre-Gull Island)

5.1 Reservoir Ice Conditions

Under post-project conditions, a thermal cover can be expected to form on Muskrat Falls reservoir. Without the Gull Island dam to cut off the supply of ice from upstream, there will be ice inflowing to the upstream end of the reservoir which will lead to a thicker ice cover in that region. ICESIM was used to simulate this condition, providing confirmation that the accumulation would be limited to the upstream end of the reservoir. A thermal cover no more than one metre in thickness would be expected to persist upstream of the Muskrat Falls dam for a distance of up to 45 km.

Once a thermal ice cover has formed on the reservoir, it is possible that the cover could be affected by a rapid change in water levels resulting from increases or decreases in plant load or inflow. In the event of vertical downward movements of the water level from the freeze-in level, the ice will drop with the water in the center of the shore to shore span, leaving the ice in contact with the shore at the margins. If the level falls far enough, the cover will fail in bending sequentially from the shoreline to form hinge cracks more or less parallel to the shore line in the manner of a beam supported at its ends (the shorelines). The spacing of the cracks will depend upon the thickness of the ice and its mechanical properties. The number of segments will be determined by the extent of drawdown relative to the fracture length of the "ice beam". Should the water level rise again, the ice cover will float back upwards with the various segments remaining in place and the ice to shore contacts being maintained. This contact is important to transmit body and drag forces acting on the cover to the shoreline. Water may then seep up through the hinge cracks and locally flood over the shorefast sections of the ice cover.

In the event of a vertical movement upward from the freeze-in level with the ice cover "bonded" to the shoreline, the ice will bend upward like a beam loaded from the underside, deforming into an inverted "U" until the load carrying capacity of the "beam" is exceeded, at which time the cover will fracture from the shoreline and float free from the shore with an open water span between the cover and the shore. Before fracture, there will probably be over-flooding of the "vee" shaped near-shore portion of the ice cover. If maintained at this elevated position through a period of freezing temperatures, freezing of the ice to shore span will occur to provide a complete shore to shore cover (i.e. a new freeze-in level).

Without the Gull Island reservoir upstream, there is likely to be a change in the frequency and magnitude of water level fluctuation in the Muskrat Falls reservoir. This has been studied as part of MF1330 (Report 6: Muskrat Falls Regulation Study).

5.2 Ice Conditions Downstream of Muskrat Falls

Downstream of Muskrat Falls, ice conditions are expected to be similar to existing conditions; however, a delay in the progression of the ice cover is likely and there will be no hanging dam downstream of Muskrat Falls since the supply of ice will be physically cut off by the dam and reservoir upstream.

Results of the Ice Dynamics Study (Hatch 2007) for the post-project (Gull Island and Muskrat Falls) condition indicated a delay in the progression of the ice cover from Goose Bay to Blackrock Bridge of between three and six weeks as compared to the pre-project condition. This delay is expected to be reduced to between one and two weeks for the condition with the Muskrat Falls reservoir in place but prior to construction of the Gull Island project. The estimated delay for the Muskrat Falls only scenario is less than that predicted for the post-project (Gull Island and Muskrat Falls) scenario because in the latter scenario the Gull Island reservoir provides added thermal capacitance to the system. Although ice conditions in the immediate vicinity of Muskrat Falls will obviously be much different with the elimination of the hanging dam, and the release of water through the project's powerhouse, it is expected that in areas farther downstream, ice thicknesses will be similar to existing conditions. Hydraulic conditions in these downstream areas will not be affected significantly, and hence the same ice processes will occur to form the cover.

6. Conclusions and Recommendations

The objectives of the current study included analyzing the ice conditions at the Muskrat Falls site during and post-construction of the Muskrat Falls facilities, assuming the Gull Island facilities have not been constructed. In this case the ice-generating reach is extended upstream to the outlet of Lake Winokapau, which is the primary difference from the conditions analyzed under GI1070.

The main conclusions of the study are as follows:

- The analysis completed under GI1070 related to potential flooding of the spillway construction site remains valid. It is very unlikely that water levels would rise to 20 m which is the assumed level above which flooding is a concern.
- Though there is an increased volume of ice expected at the Muskrat Falls construction site in the case without the Gull Island facilities in place, the ice management strategy has not changed from that proposed under GI1070. The water level required at the cofferdam to provide appropriate hydraulic conditions for this cover to form was determined through ice modeling to be 25 m, which is the same level determined in GI1070.
- Post-construction of the Muskrat Falls facilities, but before construction of the Gull Island facilities, an ice cover is expected to form on the Muskrat Falls reservoir. Inflowing ice is expected to accumulate at the upstream end of the reservoir; conditions near the Muskrat Falls dam are expected to consist of a thermal cover with a thickness of approximately one metre.

Recommendations arising from this study are as follows:

- Due to the complexity of the velocity regime expected at the Muskrat Falls cofferdam and the small ice accumulation predicted just upstream of the cofferdam, it is recommended that the 25 m water level determined in this study be optimized during FEED studies.
- The implications of part of the upstream ice cover being lost during the winter should also be considered during future studies. In the event that even a part of this upstream cover breaks up and passes through the spillway, it could lead to rapid water level increases downstream of the plant that may impact any ongoing construction activities in that area.

List of References

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