Independent Review of the 17 May 2017 Churchill River (Labrador) Flood Event

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Introduction

Background

Mud Lake is a small community in Central Labrador, located alongside the Churchill River approximately 10 km east of Happy Valley – Goose Bay (see Figure 1). Mud Lake has a population of approximately 80 people and there is limited access to the community. There are no roads leading to the community and access is usually gained by means of boat or snowmobile.

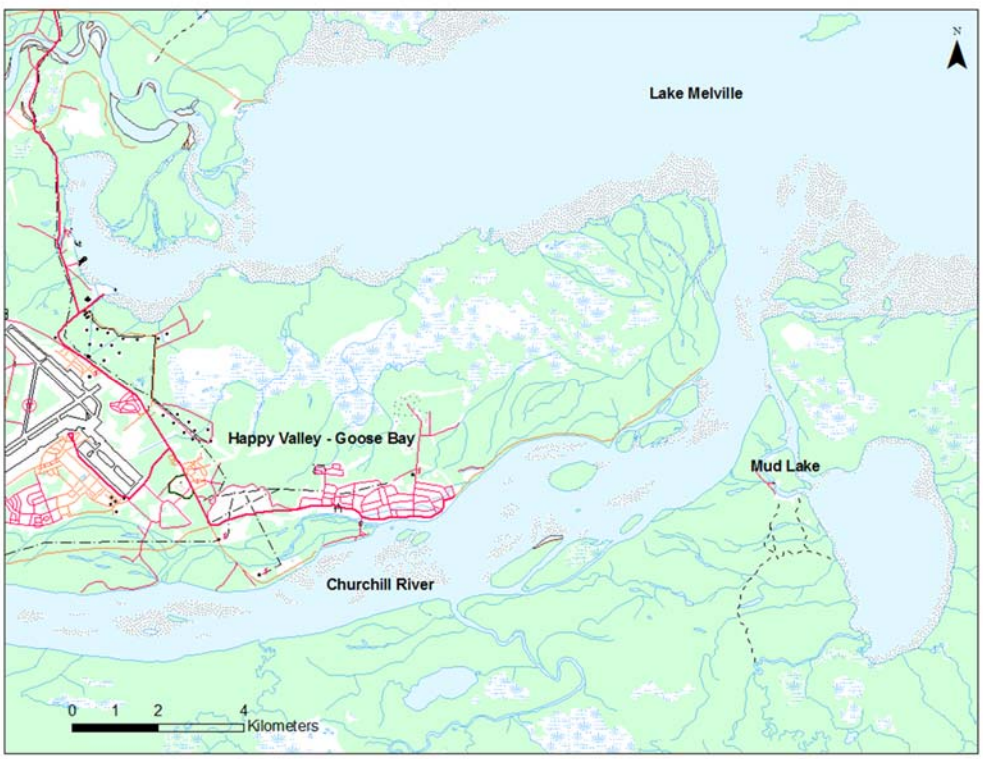


Figure 1: Map showing Mud Lake and Happy Valley – Goose Bay along the lower Churchill River in Labrador.

As reported by the hydrometric station at English Point, water levels started increasing in the Churchill River on 11 May 2017 (see Figure 2). Water levels began rising in Mud Lake on 16 May 2017. The water rose to levels deemed unsafe in the early hours of 17 May 2017 and evacuation of residents from Mud Lake to Happy Valley – Goose Bay was initiated. The evacuation had to be performed using helicopters, as water levels and ice conditions did not allow evacuation by boat. By 19 May 2017 all but one resident and most pets had been transported from Mud Lake to Happy Valley – Goose Bay and they remained there for a number of days. Extensive flooding was also reported in the Mud Lake Road region north of Happy Valley – Goose Bay on the western side of the Churchill River. Damage to properties in both areas was significant. Mud Lake has a previous history of flooding, but not to the extent of the flooding that occurred in May 2017. The Government of Newfoundland and Labrador has committed to an independent review of the 17 May 2017 flooding event, the outcome of which is given in this report.

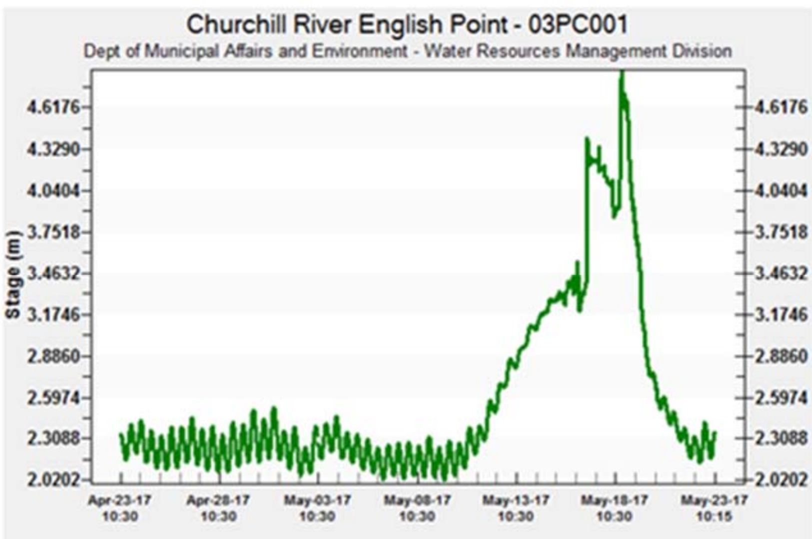


Figure 2: Stage recorded at the English Point water level station on the Churchill River.

Objectives

This is to be an independent review into the flooding which occurred in Mud Lake and Happy Valley – Goose Bay on 17 May 2017. The objectives of this review are to:

- provide a detailed explanation of the reasons for the 17 May 2017 flooding event, considering all probable factors,
- take into consideration traditional knowledge of the residents of the impacted area, and
- provide guidance as to what measures need to be implemented to mitigate and prevent future flooding and to provide advance warning to residents of Mud Lake and Happy Valley – Goose Bay.

Scope of work

The mission of the Independent Technical Expert Advisor (ITEA) was to:

- oversee the scope of work and selection of an external engineering consultant;
- act as a project authority and manage the technical aspects of the work undertaken by the external engineering consultant;
- provide an independent assessment of the adequacy of the technical work to be undertaken by the external engineering consultant;
- engage with local traditional knowledge experts;
- provide advice and recommendations to the responsible ministers with respect to the primary contributing factors to the 17 May 2017 flood in the Mud Lake area; and
- recommend measures to protect residents downstream of the Muskrat Falls reservoir against potential future floods.

The mandate of the Independent Technical Expert Advisor (ITEA) was fulfilled. The ITEA:

- finalized terms of reference (TOR) for scope of work for the external engineering consultant;
- reviewed proposals submitted by potential consultants and made recommendations for the selection of an external engineering consultant;
- supervised the work of the external engineering consultant;
- identified, designed and conducted effective consultations with local traditional knowledge experts;
- ensured that the best available data, peer reviewed engineering techniques and local traditional knowledge were used by the engineering consultant to undertake the work as per provisions of the terms of reference for the technical work;
- called and presided over meetings with the engineering consultant;
- briefed responsible ministers on a regular basis about the progress of the work being undertaken by the engineering consultant;
- consulted technical experts within Nalcor and requested any required technical assistance to carry out the mandate as needed;
- consulted technical experts within the Department of Municipal Affairs and Environment and requested any technical assistance to carry out the mandate as needed;
- reviewed the technical work undertaken by the engineering consultant for its adequacy and accuracy, provided a summary of the work and made recommendations to the responsible

ministers with respect to the primary contributing factors to the 17 May 2017 flood in the Mud Lake area;

- recommended measures to protect residents downstream of Muskrat Falls reservoir against potential future floods; and
- attended a minimum of two community meetings, one prior to the beginning of the study and another prior to the release of the final report.

The external engineering consultant chosen for this project was KGS Group. Their report can be found in Appendix 1.

Process

June 2017:

- Independent Technical Expert Advisor (ITEA) appointment
- Initial assessment of the 17 May 2017 flood
- Initial data collection
    - meteorological & hydraulic data
    - satellite imagery
    - photos from helicopter flights
    - webcam photos
    - digital elevation maps
    - river cross-sections

July 2017:

- Selection of an external engineering consultant by:
    - drafting and sending out a Request for Proposals
    - reviewing proposals and selecting the consultant KGS Group from Winnipeg, Manitoba
- Site visit activities included:
    - aerial reconnaissance of the Churchill River basin
    - tour of the Muskrat Falls construction site
    - ground visit of flooded areas along Mud Lake Road and Mud Lake
- Public meetings at Mud Lake and Happy Valley – Goose Bay to gain:
    - insight from traditional/local knowledge
    - perspectives of the Town of Happy Valley – Goose Bay
- Additional, ongoing data collection

August & September 2017:

- Further input from local residents was acquired through telephone conversations, emails and photographs
- A review of the technical work undertaken by the engineering consultant was carried out
- An additional site visit via a boat tour of the lower Churchill River was carried out with Mud Lake resident David Raeburn
- Presentations at Mud Lake and Happy Valley – Goose Bay were given to receive comments and feedback from local residents
- Finalising data collection
- Final report (end of September 2017) with:
  - synopsis of events leading to the 17 May 2017 flood
  - recommendations for flood protection measures
  - suggestions for flood warning measures

Study site

For the purpose of this study, the Churchill River catchment area was divided into three basins, as shown in Figure 3:

Upper basin – with the outlet at Churchill Falls; this is the largest of the basins which has a very large capacity for water storage,

Middle basin – the drainage area between the Churchill Falls and Muskrat Falls outlets, and

Lower basin – the most downstream portion of the catchment area from Muskrat Falls to the confluence of the Churchill River at Lake Melville; this is a relatively small basin compared to the other basins, but it is very responsive to the middle basin's hydrology.

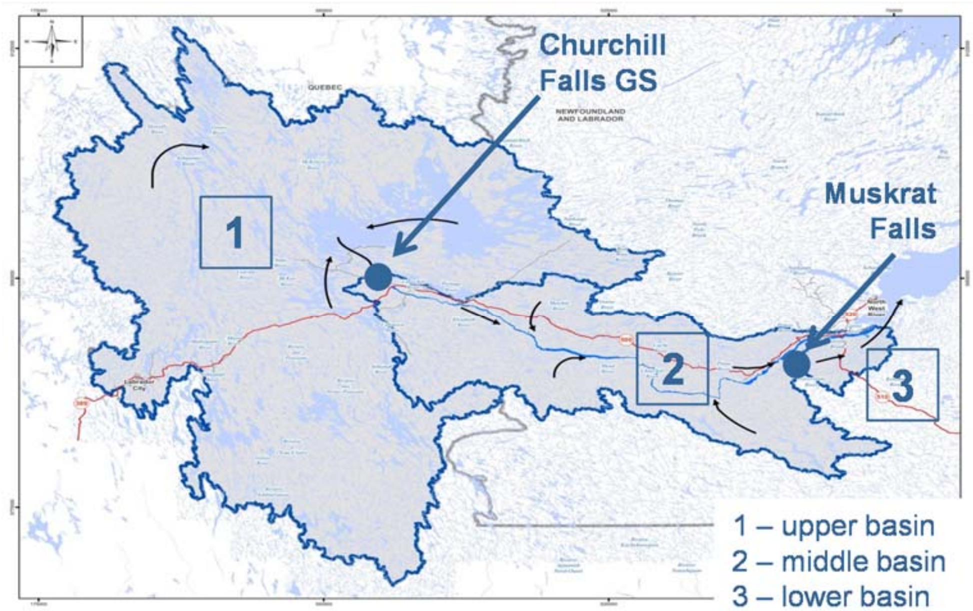


Figure 3: Basins of the Churchill River catchment area. The outlet of the upper basin, Basin 1, is Churchill Falls; the outlet of the middle basin, Basin 2, is Muskrat Falls; the lower basin, Basin 3, empties into Lake Melville.

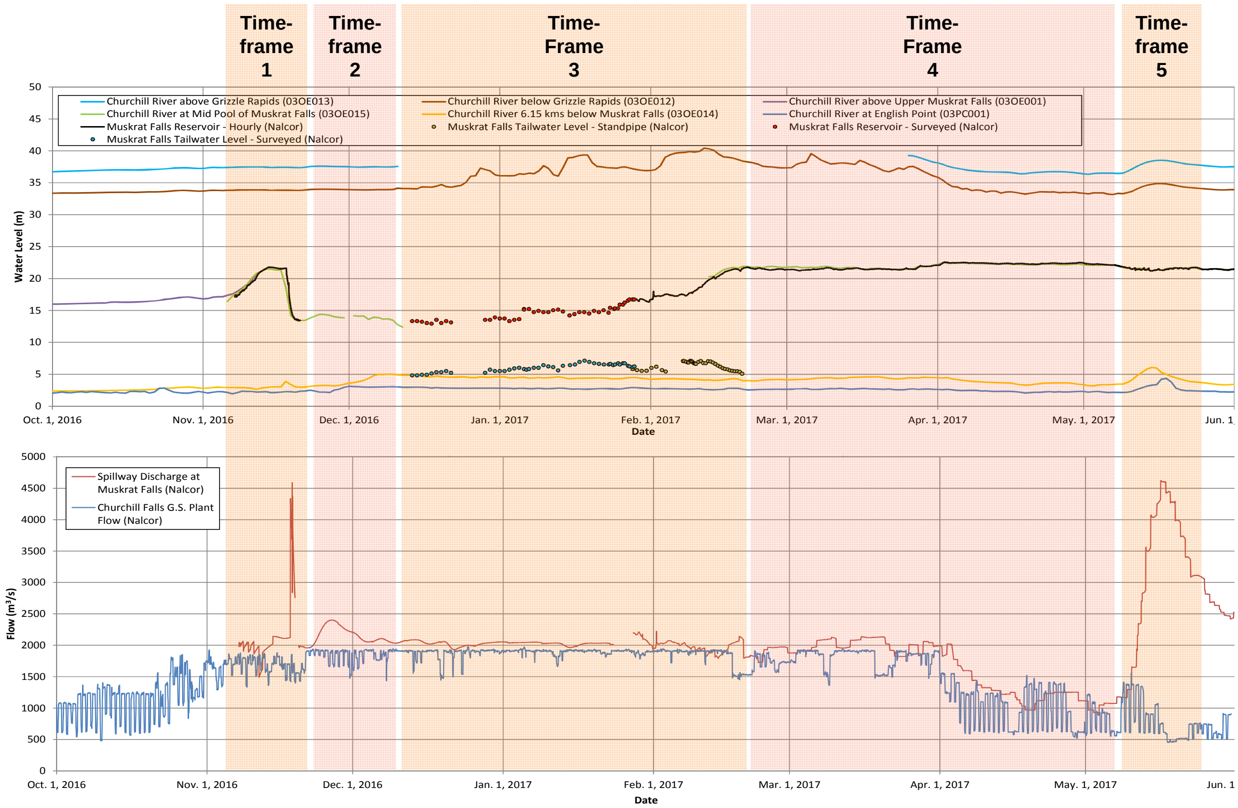
Events leading to 17 May 2017 ice-jam flood

This section, along with references to Appendix 1, provides a detailed explanation of the reasons for the 17 May 2017 flooding event. A timeline approach was taken to describe the meteorological and hydrological setting, from the autumn of 2016 to the spring of 2017 (1 October 2016 – 31 May 2017), to point to the events that led to the flooding of the lower Churchill River on 17 May 2017. The timeline also provides a structure to help organize the data and the discussion, in which key events that led to that flooding can be highlighted. The idea of a timeline was spurred on by knowledge conveyed by the residents of Mud Lake and Happy Valley – Goose Bay and a report provided by one of the Mud Lake residents, David Raeburn (Raeburn, 2017). That report describes the river and ice conditions from November 2016 until after the flood in May 2017 and includes a timeline of the Muskrat Falls spillway operations.

Graphs of the gauge water levels and river flows, shown in Figure 4, provide a framework for the timeline. The top graph in Figure 4 shows the water levels, starting at the water level gauges at Grizzle Rapids:

- CHURCHILL RIVER ABOVE GRIZZLE RAPIDS (03OE013), data from Environment and Climate Change Canada

- CHURCHILL RIVER BELOW GRIZZLE RAPIDS (03OE012), data from Environment and Climate Change Canada



Legend:

- Churchill River above Grizzle Rapids (03OE013)
- Churchill River below Grizzle Rapids (03OE012)
- Churchill River above Upper Muskrat Falls (03OE001)
- Churchill River at Mid Pool of Muskrat Falls (03OE015)
- Churchill River 6.15 kms below Muskrat Falls (03OE014)
- Churchill River at English Point (03PC001)
- Muskrat Falls Reservoir - Hourly (Nalcor)
- Muskrat Falls Tailwater Level - Standpipe (Nalcor)
- Muskrat Falls Reservoir - Surveyed (Nalcor)
- Muskrat Falls Tailwater Level - Surveyed (Nalcor)

Figure 4: Five timeframes in sequence extending across the time period 1 October 2016 – 31 May 2017. A zoom of each timeframe is found in Figure 5 (Timeframe 1), Figure 7 (Timeframe 2), Figure 12 (Timeframe 3), Figure 14 (Timeframe 4) and Figure 19 (Timeframe 5), each accompanied by their own discussions.

The water level gauges immediately upstream and downstream of Grizzle Rapids are at higher elevations than those at Muskrat Falls:

- CHURCHILL RIVER ABOVE UPPER MUSKRAT FALLS (03OE001), data from Environment and Climate Change Canada

- CHURCHILL RIVER MID POOL (03OE015), data from Environment and Climate Change Canada

The gauges at Muskrat Falls are at higher elevations than the water level gauges along the lower reach of the Churchill River between Muskrat Falls and Lake Melville:

- CHURCHILL RIVER 6.15 KMS BELOW LOWER MUSKRAT FALLS (03OE014), data from Environment and Climate Change Canada
- CHURCHILL RIVER ENGLISH POINT (03PC001), data from Environment and Climate Change Canada

The Muskrat Falls gauge CHURCHILL RIVER ABOVE UPPER MUSKRAT FALLS was discontinued due to the construction of the Muskrat Falls site, but replaced by the gauge CHURCHILL RIVER MID POOL. Water levels of the Muskrat Falls reservoir were also recorded by Nalcor. Several water level time series are shown for Muskrat Falls, which often overlap and generally coincide, showing consistency of the data from different sources. Point data of the Muskrat Falls tailwater levels were also surveyed during the formation and progression of the hanging ice dam immediately downstream of Muskrat Falls, to track the backwater staging induced by the hanging dam.

All gauge datums are geodetically referenced, except for the gauge at English Point, which has a relative reference datum point.

The bottom graph of Figure 4 shows flows, time series which were only recorded at two locations, Churchill Falls and Muskrat Falls, which were made available by Nalcor. The outflows from Churchill Falls can have a large daytime variability due to the hydropeaking operations to supply electrical power during high energy demand periods. The Muskrat Falls outflow is also shown, from when the spillway operations began until the end of May 2017.

The timeline is subdivided into five timeframes to provide structure and ease of flow in the discussion and highlight key events that contributed to the spring flooding.

Meteorological data was also drawn primarily from Environment and Climate Change Canada’s stations at Churchill Falls (CHURCHILL FALLS A), Goose Bay (GOOSE A) and Schefferville, Quebec (SCHEFFERVILLE A).

Timeframe 1 (7 – 22 November 2016)

Referring to Figure 5 for the first timeframe, open-water conditions prevailed during most of the month of November 2016. After the first week in November 2016, the water level in the Muskrat Falls forebay increased, coinciding with decreasing flows through the spillway to raise the water level to an elevation of 21.7 m, to the intended winter forebay level (1a in Figure 5). This would have provided a stabilized ice cover in the forebay to reduce frazil ice formation and hem the progression of a hanging ice dam downstream of Muskrat Falls. On 18 November 2016, the spillway gates were opened to rapidly release the water from the forebay and drop the water level to approximately that of the river's natural flow regime (1b in Figure 5). This quick operation over a period of approximately two days was in response to a leaking cofferdam. The water release caused a large increase in flow, from 2,120 to 4,590 m^3/s (1c in Figure 5). The water levels recorded at the gauge 6.15 km downstream of Muskrat Falls responded with a water level rise immediately after the flow release from Muskrat Falls (1d in Figure 6). The response was rapid, with the water levels dropping back down to pre-peak conditions by 21 November 2016 (1e in Figure 6), well before river freeze-up. The same peak response was not observed at the water level gauge at English Point (1f in Figure 6). A small peak was recorded, later than expected on 24 November 2016 (1g in Figure 6), but the water level dropped to its pre-peak water levels by 25 November 2016 (1h in Figure 6), still a few days before the river began freezing over along the lowest reach of the Churchill River. Much of the peak may have been attenuated due to the off-channel flow into creeks and streams branching off from the Churchill River into storage. This artificial release and the dissipation of the flow downstream from Muskrat Falls occurred before backwater staging commenced along the lower Churchill River due to freeze-up.

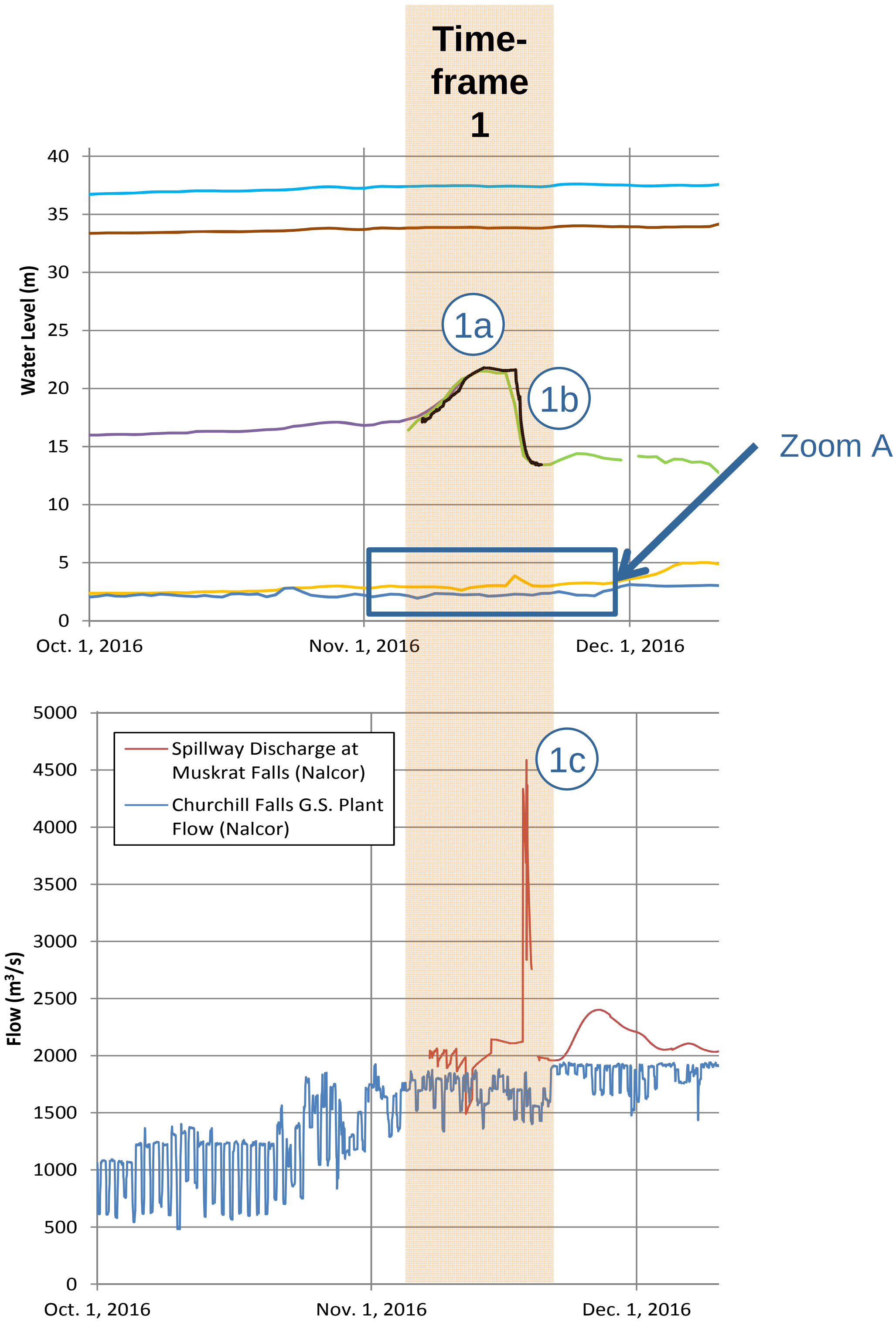


Figure 5: Timeframe 1 (7 – 22 November 2016). Zoom A is provided in Figure 6. The legend is shown in Figure 4.

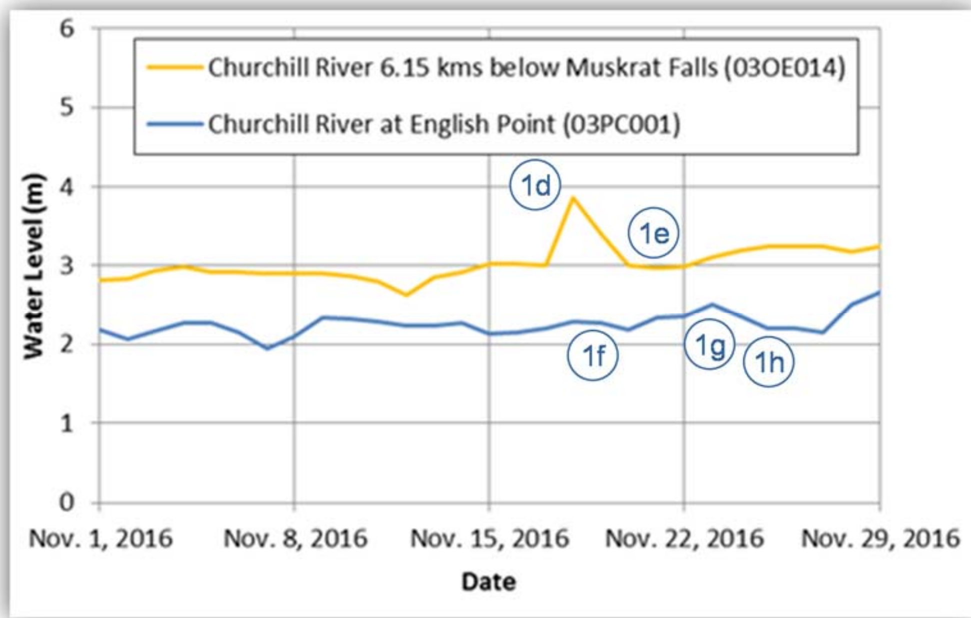


Figure 6: Zoom A from Figure 5 providing more detail of the water levels recorded at the gauge 6.15 km downstream of Muskrat Falls and at the English Point gauge.

Timeframe 2 (22 November 2016 – 12 December 2016)

This section makes reference to Timeframe 2, shown in Figure 7. After the artificial release from Muskrat Falls, described in the previous timeframe, a large natural influx of water passed through Muskrat Falls, with the flow increasing from 1,940 to 2,400 m^3/s (2a in Figure 7). This influx occurred after the artificial lowering of the water level of the Muskrat Falls site forebay. An important question to pose is: "What was the source of this influx?". By inspection of the flows from Churchill Falls, one can infer that, other than the daytime fluctuations due to hydropeaking, the average flow from Churchill Falls remained relatively constant throughout this period (2b in Figure 7). This points to the source of the flow stemming from the middle basin of the Churchill River catchment area between the Churchill Falls and Muskrat Falls outlets. The water level in the Muskrat Falls reservoir also increased somewhat (≈0.5 m) in relation to this flow influx (2c in Figure 7). The spillway gates remained open and no operation of the gates was carried out during this period of influx. Evidence of the influx is also observable in the increased water levels (≈0.2 m) recorded at the Grizzle Rapids gauges (2d in Figure 8).

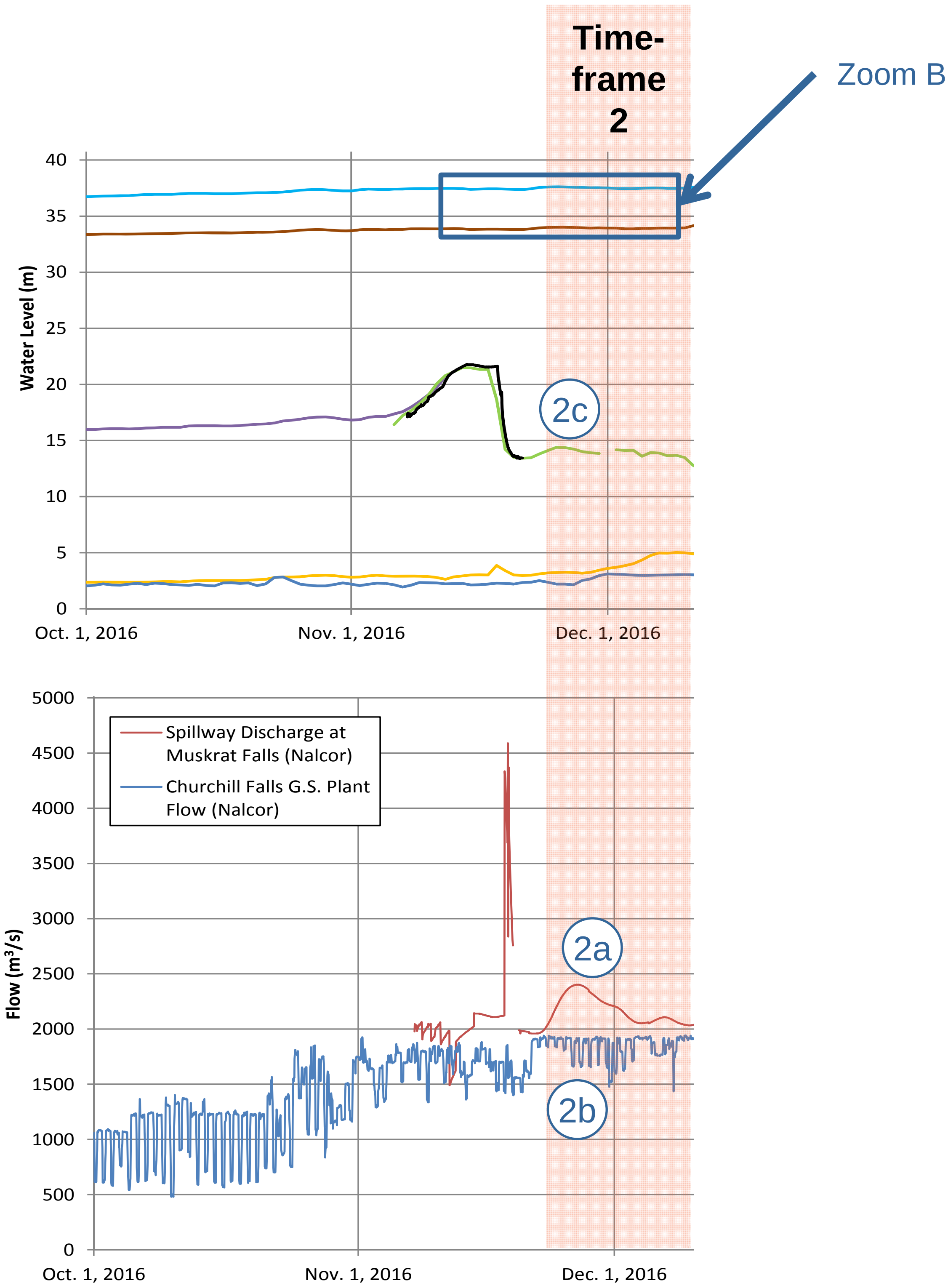


Figure 7: Timeframe 2 (22 November 2016 – 12 December 2016). Zoom B is provided in Figure 8. The legend is shown in Figure 4.

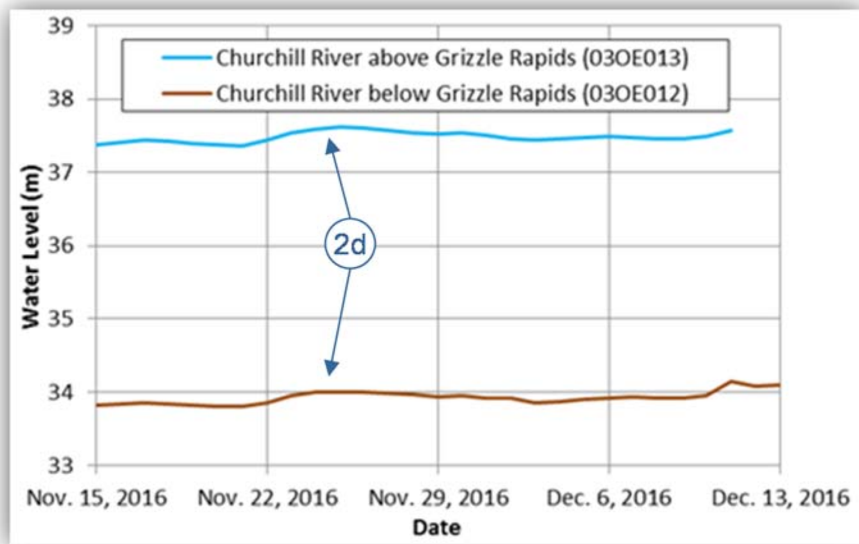


Figure 8: Zoom B from Figure 5 of the water levels recorded at the gauges at Grizzle Rapids.

Insight into the source of the flow influx can be obtained from the flows recorded on the Pinus River (see Figure 9). The Pinus River is a tributary of the Churchill River, with its confluence situated between Grizzle Rapids and Muskrat Falls. Flows in the Pinus River, and potentially other tributaries, increased during the second half of November 2016 (2e in Figure 9), which most likely would have contributed to the flow influx passing through Muskrat Falls. A previous runoff event in the Pinus River subbasin caused a higher discharge peak in late October 2016 (2f in Figure 9) – the flows did not recede to values that preceded the runoff event (2g in Figure 9). This is indicative of a higher baseflow in a tributary subbasin whose soils were more saturated than during the beginning of November before the runoff events occurred. The second peak (2e in Figure 9) coincides with the peak of the influx flowing through Muskrat Falls (2c in Figure 7) and Grizzle Rapids (2d in Figure 8).

Rain depths measured at Churchill Falls and Goose Bay (see Figure 10) indicate that the total rainfall during the months of October and November 2016 was above the 30 year average for those months. Even with missing data from the November 2016 record, the total rainfall at Churchill Falls was more than five times the average for November. More details regarding the actual rain events are provided in Section 8.1 of Appendix 1.

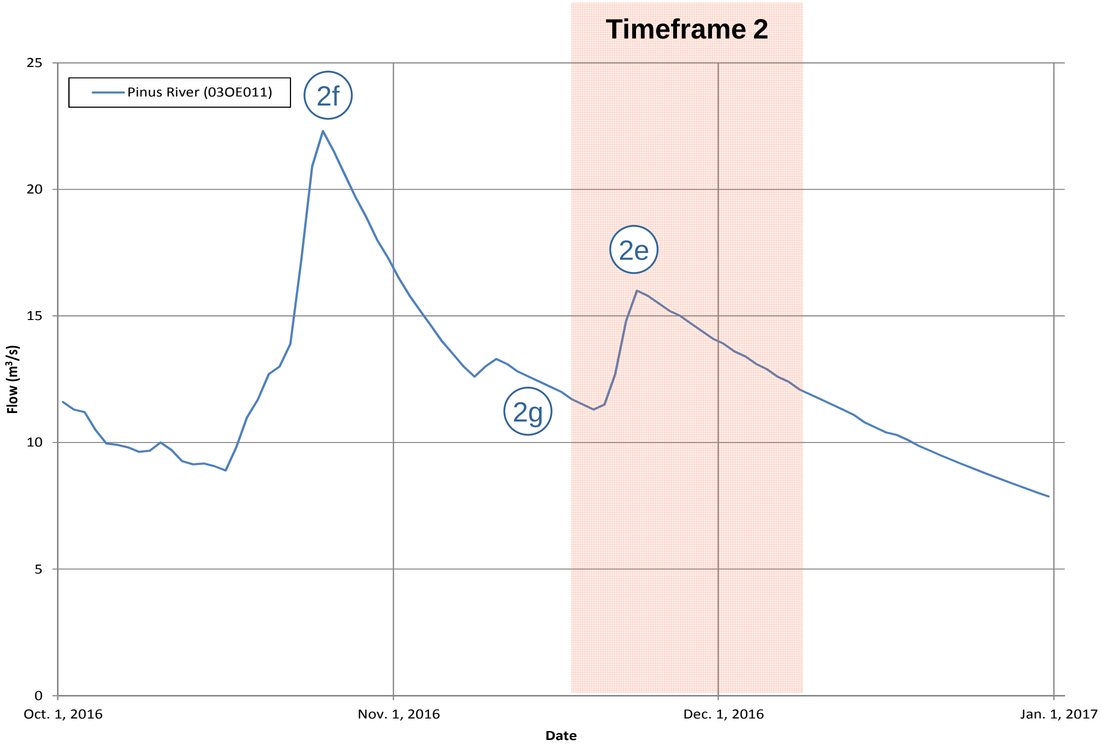


Figure 9: Flows recorded in the upper basin of the Pinus River for October – December 2016.

The flows from the tributaries and the higher-than-normal rainfall conditions provide a likely argument for the influx originating from the middle basin of the Churchill River catchment area.

The backwater staging from the formation of the ice cover started on 27 November 2016 and progressed upstream to reach the gauge 6.15 km downstream of Muskrat Falls approximately 5 days later. The sequence of the freeze-up at Mud Lake Crossing can be seen from the webcam photos in Figure 11. The photo taken on 26 November 2016 shows mostly open-water conditions with some skim ice forming along the river banks. More border ice is evident in the 27 and 29 November 2016 photos, with an open channel of flowing water appearing far out in the river. The water level between 26 and 27 November decreased somewhat (0.05 m), but increased 0.52 m by 29 November 2016. At total freeze-over on 1 December 2016, the water level had increased another 0.44 m for a total staging of 0.91 m during the freeze-up. This was the maximum staging amount, after which the water levels progressively decreased throughout the winter. This freeze-up staging was the highest recorded since 2010, when the English Point gauge began recording water levels. The flow at the beginning of freeze-up was the second highest flow recorded at freeze-up since 1975. This freeze-up occurred during the natural influx of runoff stemming from the middle basin, which discharged into the lower Churchill River.

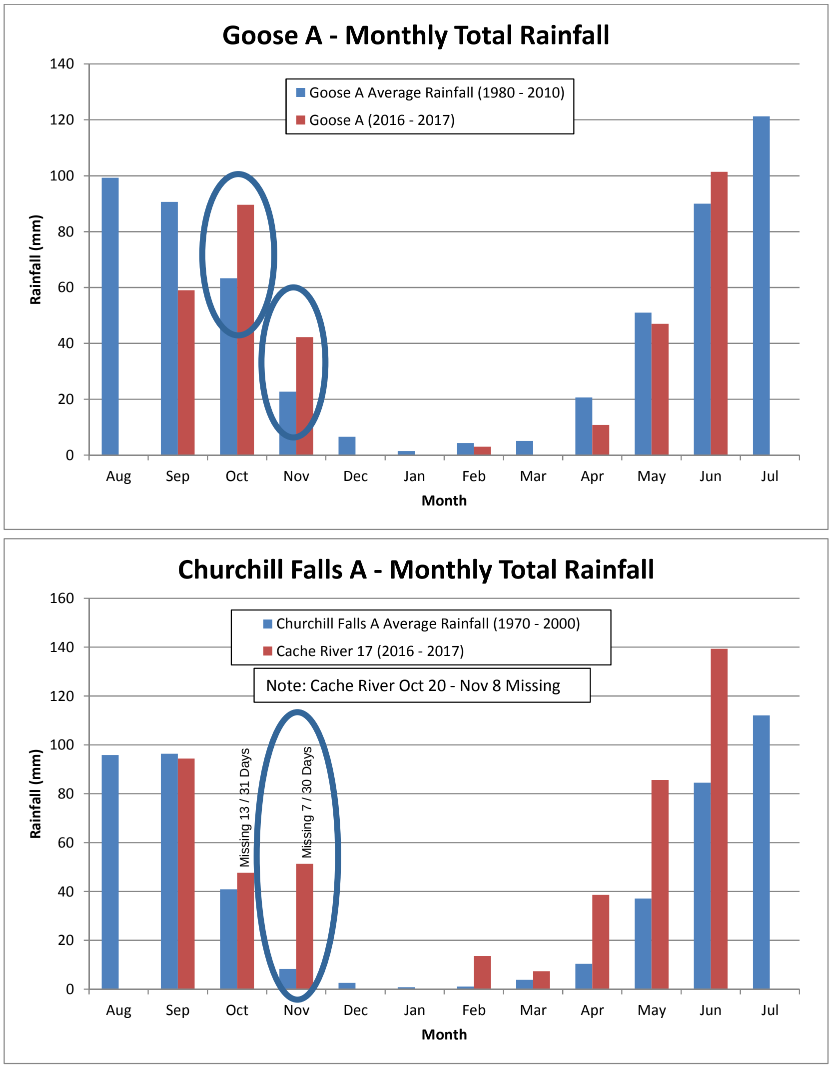


Figure 10: Total monthly rainfall recorded at Goose Bay (top panel) and Churchill Falls (bottom panel) from August 2016 to July 2017 (red bars), along with the 30-year averages (blue bars). Ellipses indicate total rainfall depths much higher than the 30-year average.

Figure 11: Selected webcam photos showing the progression of freeze-up of the lower Churchill River at Mud Lake Crossing.

Timeframe 3 (12 December 2016 – 23 February 2017)

The reader is referred to Figure 12 for the following discussion of Timeframe 3. The spillway gates at Muskrat Falls remained open until 5 January 2017 (3a in Figure 12). From 5 January 2017 to 20 February 2017, the spillway gates were operated to slowly increase the water level in the Muskrat Falls site forebay (3b in Figure 12). Flows through Muskrat Falls decreased slightly (3c in Figure 12) as the water level in the forebay rose. The outflow from Churchill Falls remained relatively constant (3d in Figure 12). The tailwater levels at the Muskrat Falls site increased steadily throughout February 2017 due to the growth and extension of the hanging ice dam immediately downstream of Muskrat Falls (3e in Figure 12). The initial formation of the hanging ice dam can be seen in a satellite image acquired 5 December 2016 in Figure 13. Water levels recorded at the gauge 6.15 km downstream of Muskrat Falls and at English Point steadily decreased during this time period (3f in Figure 12).

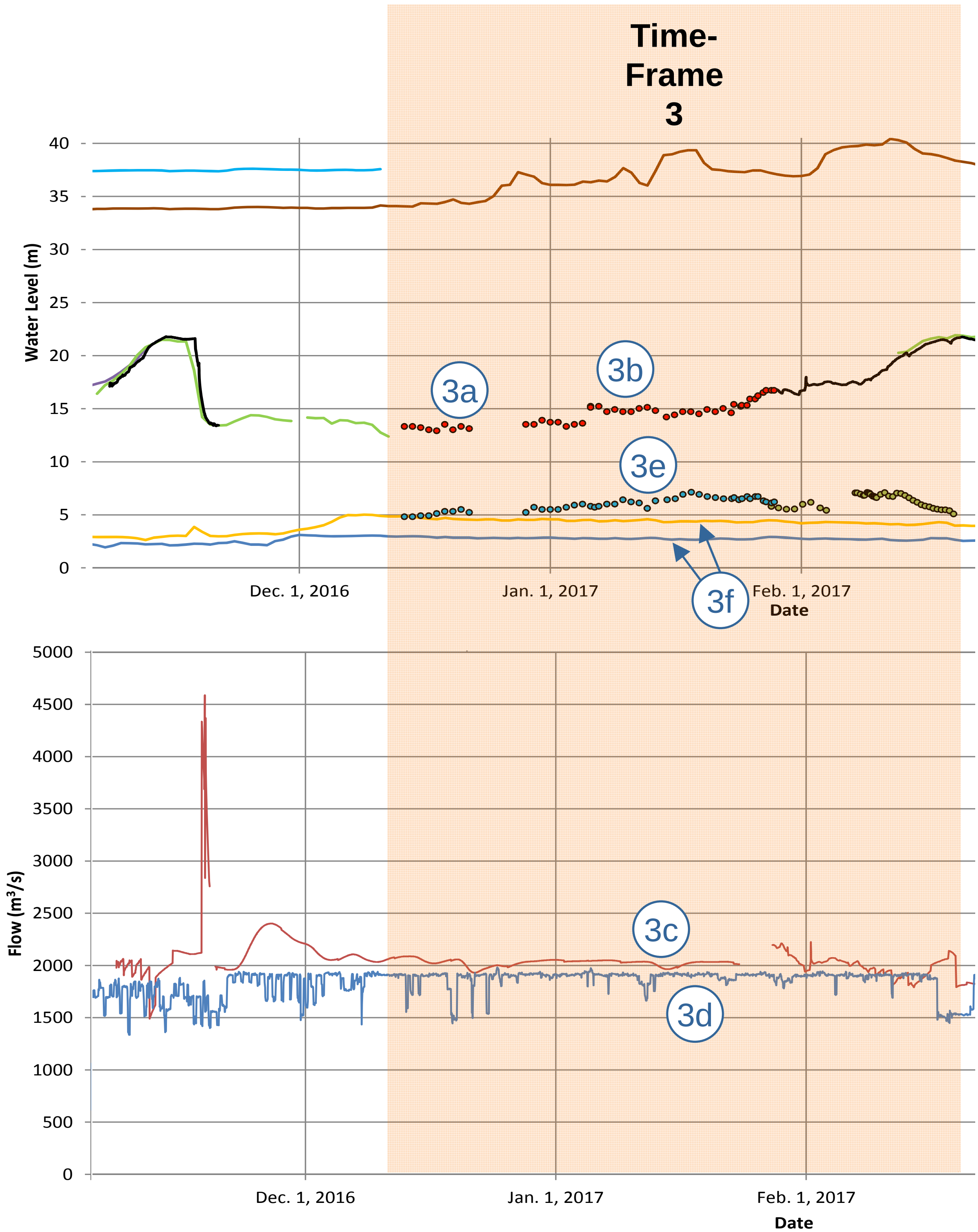


Figure 12: Timeframe 3 between 12 December 2016 and 23 February 2017. The legend is provided in Figure 4.

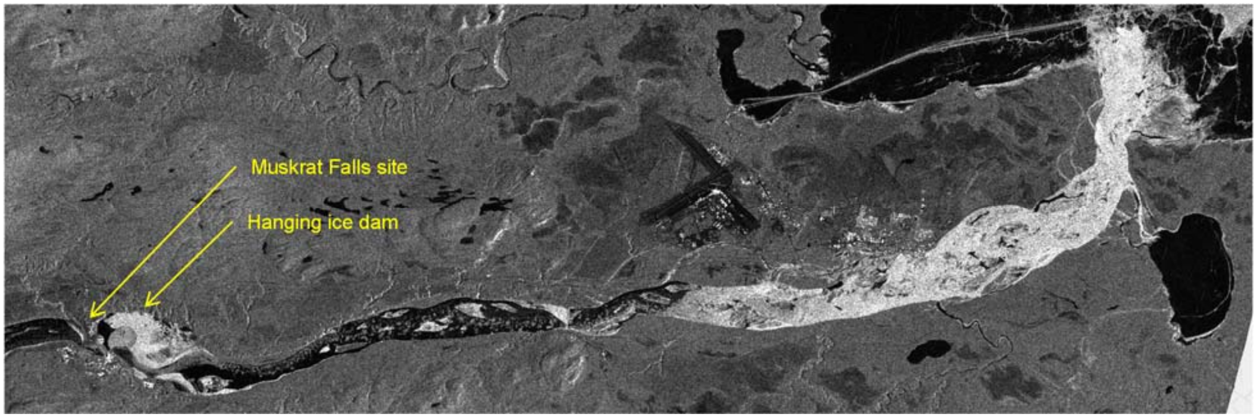


Figure 13: Sentinel-1 image acquired 5 December 2016 showing the formation of the hanging ice dam, immediately downstream of the Muskrat Falls construction site.

Timeframe 4 (23 February 2017 – 7 May 2017)

In early April 2017, the outflows from Churchill Falls were reduced relatively quickly (≈ 1 week) from approximately 1,900 to 900 m^3/s (4a in Figure 14). Accordingly, the flow through Muskrat Falls (4b in Figure 14) and the water levels downstream of Muskrat Falls also decreased (4c in Figure 14). This may have be the time when the ice along the lower Churchill River grounded on the sandbars, as was shared by local residents. As flows and water levels drop, so do ice covers, which hinge and break off at the banks and drop with the lowering of the water to become grounded on sandbars. An example of remnants of the ice cover on a sandbar is shown in Figure 15.

Water levels in the Muskrat Falls forebay remained relatively constant during March 2017 (4d in Figure 14), only increasing slightly from ≈21.5 m to ≈22.5 m at the end of March/beginning of April 2017 (4e in Figure 14), by operating the Muskrat Falls spillway gates. Between 1 and 7 May 2017, the reservoir water level was lowered to 22.1 m, just before the spring freshet (4f in Figure 14).

The water levels at Grizzle Rapids also indicate the drops in flow at the end of March/beginning of April 2017 (4g in Figure 14). The water levels recorded immediately downstream of Grizzle Rapids were variable prior to the Churchill Falls outflow drop (4h in Figure 14), perhaps due to ice staging, but after the drop, the variability ceases and the water levels remained fairly steady until the spring freshet (4i in Figure 14). However, the ice cover from Sandy Island Lake to Muskrat Falls remained intact throughout this period of time as indicated by the MODIS satellite image shown in Figure 16.

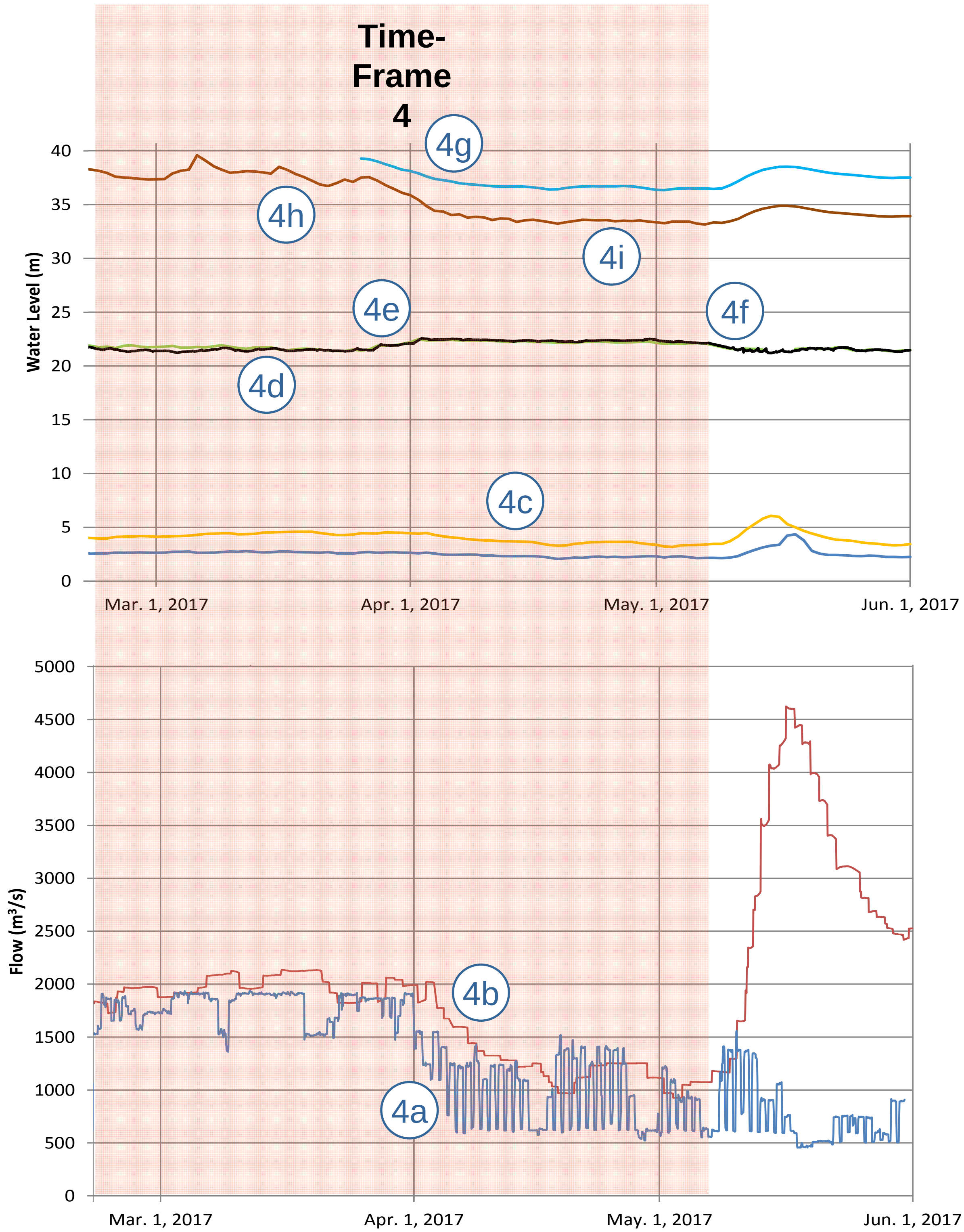


Figure 14: Timeframe 4 between 23 February and 7 May 2017. The legend is provided in Figure 4.

Figure 15: Remnants of the ice cover grounded on a sandbar along the lower Churchill River. Photo taken by Melissa Best on 24 May 2017 (used with permission).

Figure 16: MODIS satellite image acquired 25 April 2017 showing intact ice cover between Sandy Island Land and Muskrat Falls.

Snowfall during this timeframe was at or below the normal depths recorded at the end of each month during the 2016 – 2017 winter (see Figure 17). More detail on the spatial distribution of snow depths and snow water equivalent amounts across the Churchill River catchment area are provided in Section 8.1 of Appendix 1. The lower-than-average snow led to thicker ice along water bodies. Unfortunately, ice thickness measurements were not carried out during the 2016 – 2017 winter. However, Figure 18 shows simulated thicknesses of the ice cover in Goose Bay for the end of April for each year between 1959 and

2017. The end-of-April ice thickness for 2017 was 0.93 m, the fifth highest of the 1959 – 2017 time series.

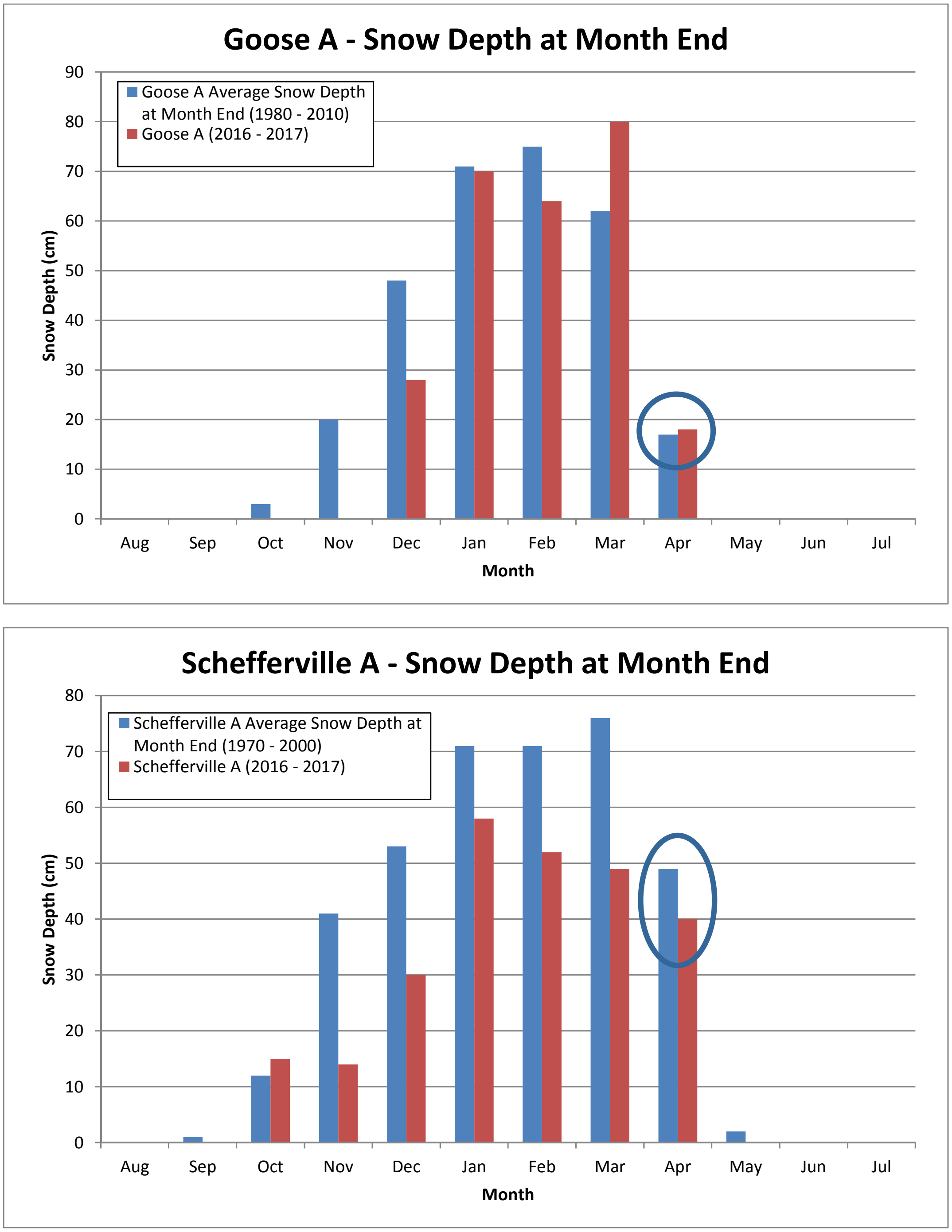


Figure 17: Total snow depths recorded at the end of each month at Goose Bay (top panel) and Schefferville Airport (bottom panel) from October 2016 to April 2017 (red bars), along with the 30-year averages (blue bars), illustrating the lower-than-normal snow depths during the 2016 – 2017 winter. Circles indicate normal or less-than-normal snow depth months close to the time of spring freshet.

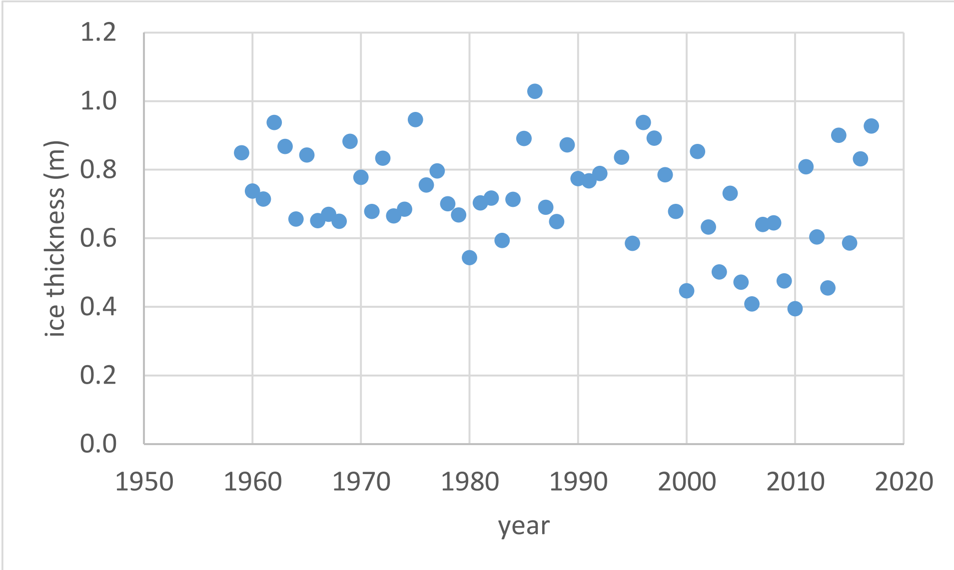


Figure 18: Simulated ice thicknesses at the end of April for each year between 1959 and 2017 (data provided by Nalcor). Thicknesses have been estimated based on available record of daily air temperatures and snow depths at the Goose Bay (Goose A) meteorological station.

Timeframe 5 (7 – 17 May 2017)

This discussion on the last timeframe, Timeframe 5, leading up to the 17 May 2017 flood, accompanies Figure 19. On 10 May 2017, the flow began rising at Muskrat Falls to quickly reach a peak of 4,624 m^3/s by 16 May 2017 (5a in Figure 19). The day-mean flow was 4,530 m^3/s on 17 May 2017, when the ice cover breakup and ice jamming occurred along the lower Churchill River, leading to flooding in Mud Lake and along Mud Lake Road. The spillway gates were operated to keep the water level in the forebay as steady as possible hence, upstream inflows to the reservoir would approximately balance the outflow through the spillway (5b in Figure 19) (more details in Section 8.2 of Appendix 1). The average outflow from Churchill Falls was relatively constant, other than the day-to-day variations from hydropeaking (5c in Figure 19). The outflows were in the lower quartile of the long-term record (more details shown in Section 8.3 of Appendix 1). Hence, the high flows through Muskrat Falls cannot be attributed to the outflow from Churchill Falls.

During the period of high flows through the spillway, the water level of the reservoir upstream of Muskrat Falls was dropped approximately 1 m, from 22.5 to 21.5 m (5d in Figure 19). A water level drop during the time of the rising limb of the flow hydrograph does coincide with some additional water release from Muskrat Falls reservoir. Over the 12 days of release, this corresponds to an additional 44 m^3/s of flow, which is less than 1% of the peak discharge of 4,624 m^3/s through the spillway (more details provided in Section 7.0 of Appendix 1). Hence, the data indicates that the additional flow release from Muskrat Falls was minimal and that the flow that passed through the spillway corresponds to the natural inflow to the reservoir from the middle basin of the Churchill River catchment area. This corresponds to the water level rises of about 2 m at the gauges at Grizzle Rapids (5e in Figure 19). This local inflow was due to the more than twice the normal amount of rainfall that occurred in April and May 2017 (see Figure 20). Exacerbating the runoff volume during the freshet, much snow fell at the beginning of May 2017, with a total snow depth of over 20 cm recorded at the beginning of May 2017. Figure 21 shows the daily amount of snow remaining on the ground in the month of May 2017. Snow remained on the ground until 12 May 2017. Before all the snow melted, however, a large rain-on-snow event occurred from 6 to 8 May 2017 with a total rain depth of over 25 mm recorded over those three days, as shown in Figure 22. This event will have occurred on snow and frozen ground, exacerbating the runoff event. These events are verified spatially through MODIS satellite imagery shown in Figure 23, where the snow signal decreases substantially from 5 May 2017 (top panel) to 13 May 2017 (bottom panel), during which time much of the snow cover had melted. Almost 20 mm of rain also fell on 16 and 17 May 2017, which would have generated local runoff and additional discharge into the river to increase the already high flow that caused the ice jamming and subsequent flooding at Mud Lake and Mud Lake Crossing.

Due to the flow through the Muskrat Falls spillway, the gauges downstream of Muskrat Falls recorded a rise in water levels, approximately 2.5 m at the gauge 6.15 km downstream of Muskrat Falls (5f in Figure 19), and water level rises at the English Point gauge (5g in Figure 19). A zoomed in time series of water levels recorded at 15 minute intervals is provided in Figure 24. An initial ≈1 m rise of the water level at English Point on 16/17 May 2017 (see 5h in Figure 24) caused ice jamming and flooding along the lower Churchill River. Another ≈0.6 m rise to peak on 18 May 2017 (see 5i in Figure 24) exacerbated the flooding. Figure 25 shows satellite images of the lower Churchill River before (top panel) and after (bottom panel) the formation of the ice jam at Mud Lake/Mud Lake Crossing. The ice cover extent along the lower Churchill River before the ice jamming can be discerned from the 16 May 2017 image. This ice cover collapsed due to the high flows to form the jam in the night from 16 to 17 May 2017.

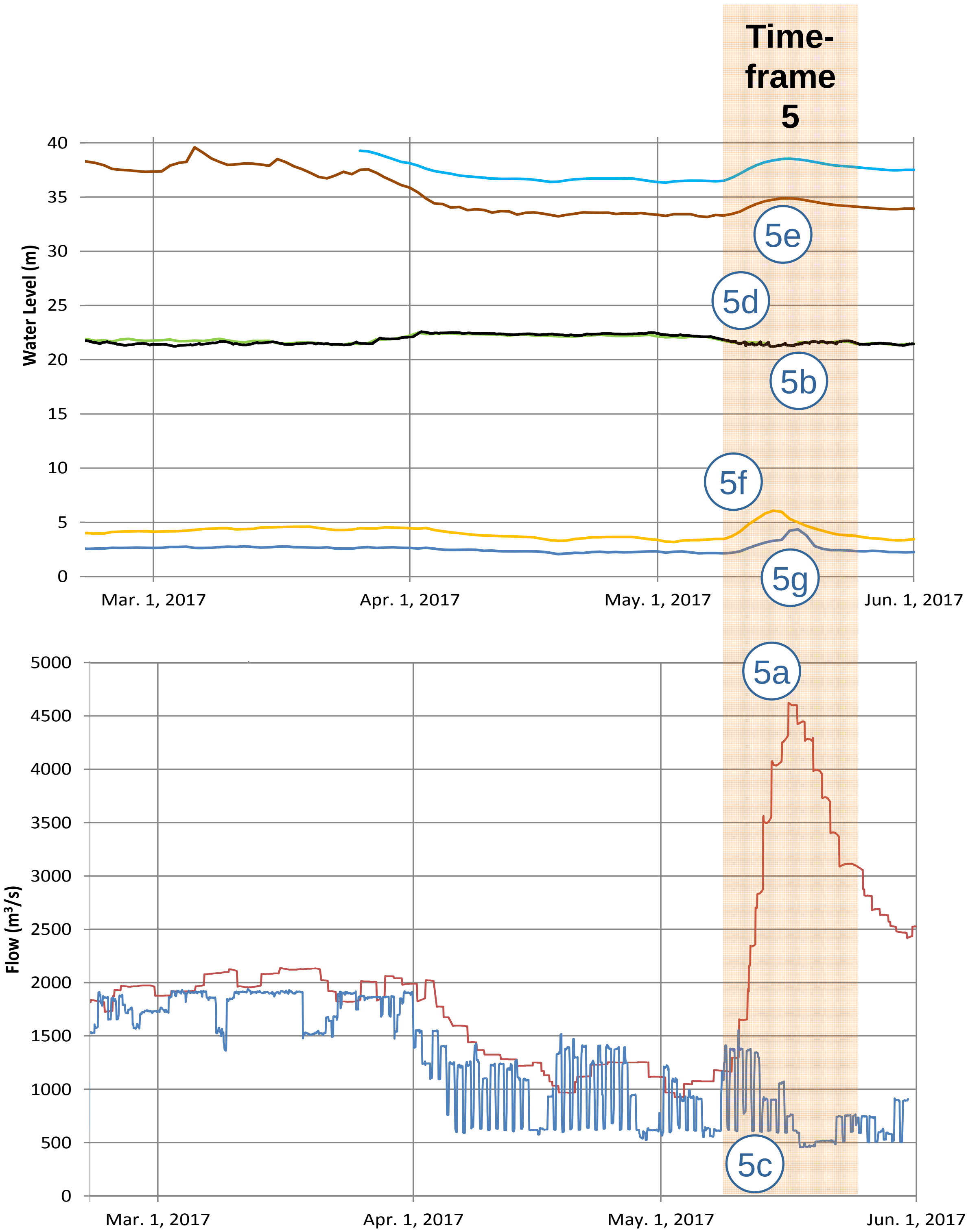
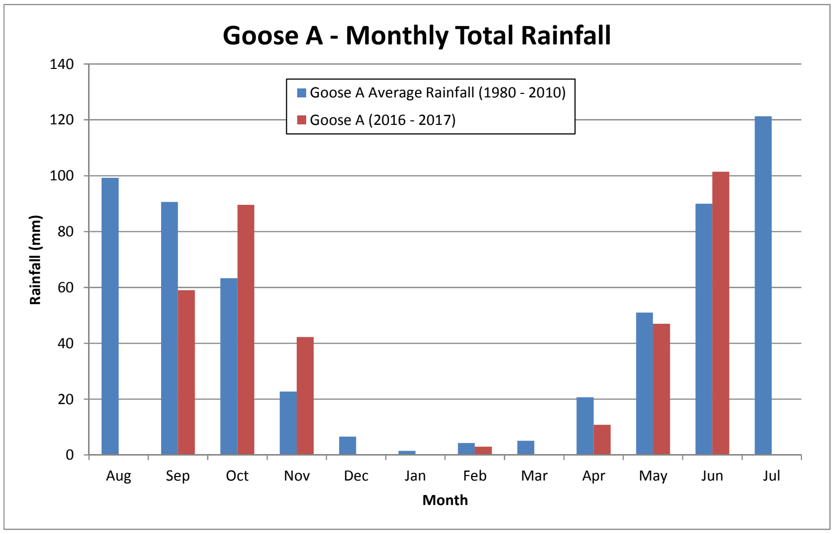


Figure 19: Timeframe 5 between 7 and 17 May 2017. The legend is shown in Figure 4.



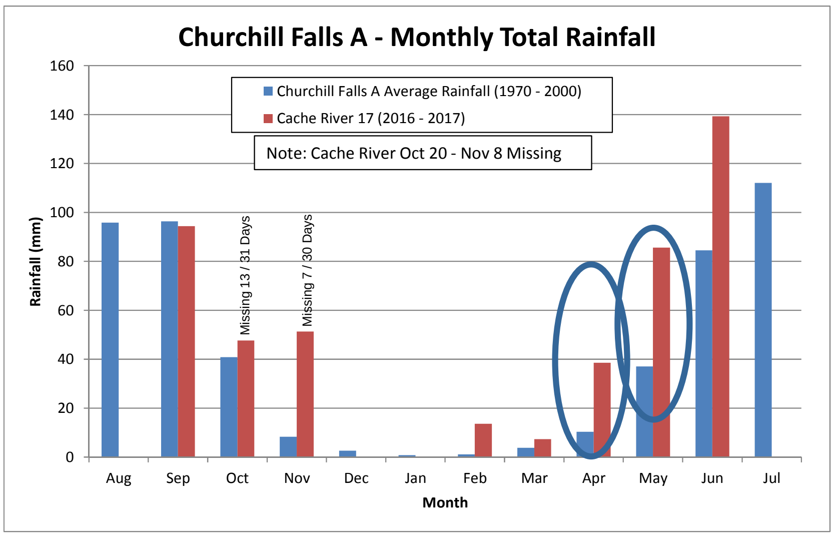


Figure 20: Total monthly rainfall depths recorded at Goose Bay (top panel) and Churchill Falls (bottom panel) from August 2016 to July 2017 (red bars), along with the 30-year averages (blue bars), illustrating the twice-than-normal rain depths (indicated by ellipses) that would have occurred in the middle basin of the Churchill River catchment areas in April and May of 2017.

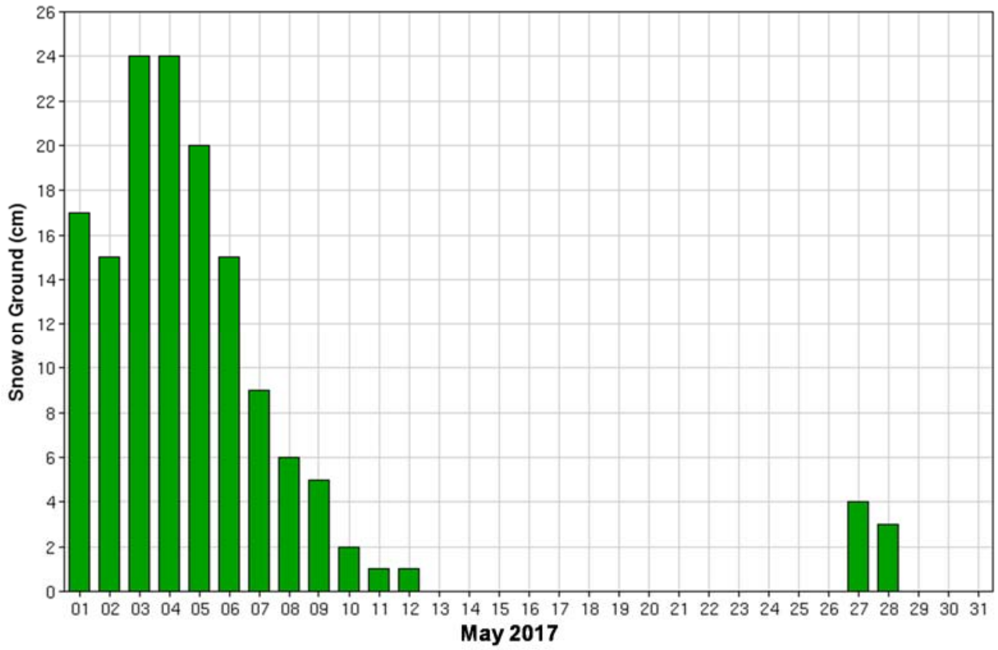


Figure 21: Daily depths of snow-on-ground recorded in Goose Bay during May 2017

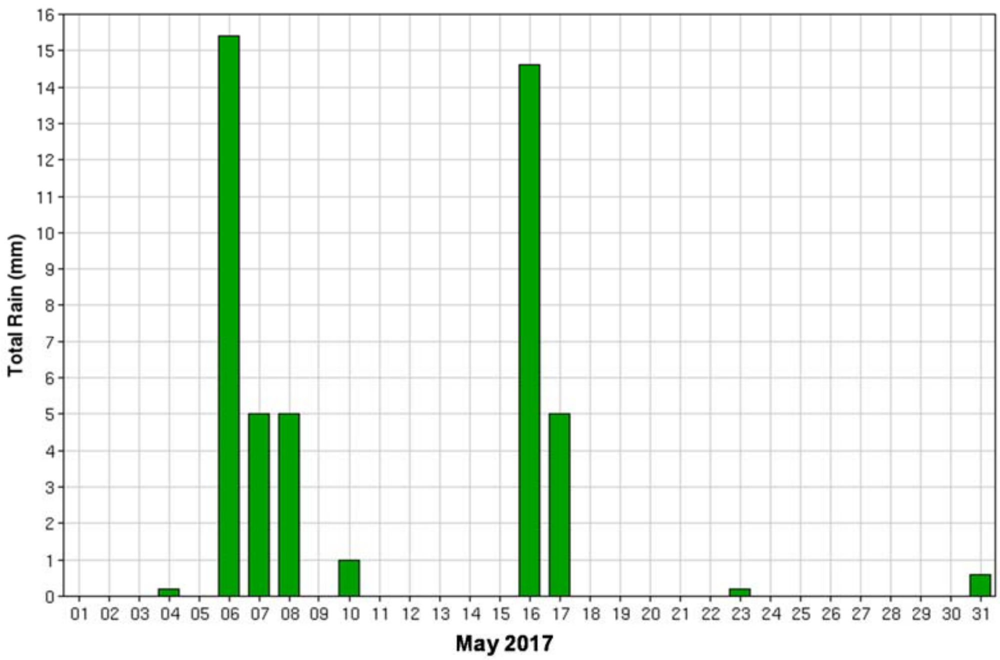


Figure 22: Daily total rain depth recorded in Goose Bay for May 2017.

Figure 23: Sequence of MODIS satellite imagery showing the snow cover on the ground within the Churchill River catchment area in May 2017. There is a substantial reduction in the snow cover signal from 5 May 2017 (top panel) to 13 May 2017 (bottom panel).

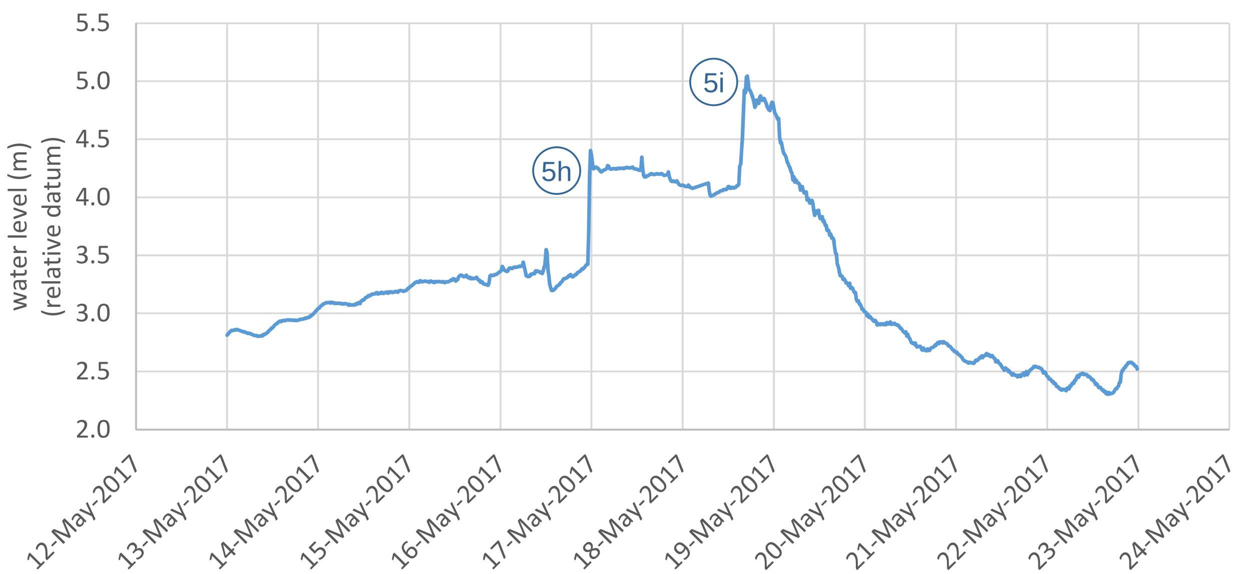


Figure 24: Water levels recorded at English Point against a relative datum at 15 minute intervals 13 – 23 May 2017.

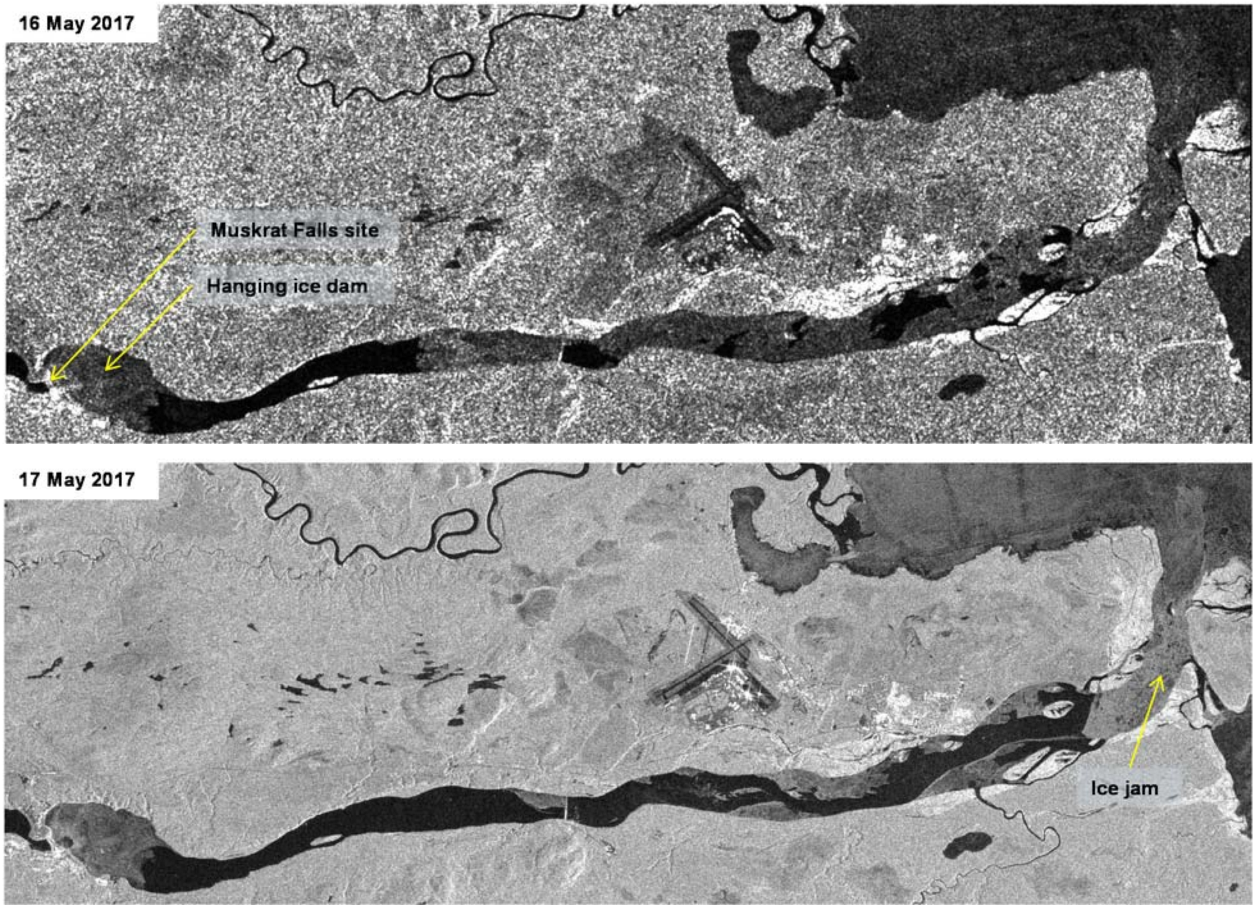


Figure 25: Sentinel-1 satellite images of the lower Churchill River before (16 May 2017; top panel) and after (17 May 2017; bottom panel) the ice jam at Mud Lake/Mud Lake Crossing

Conclusion

The main conclusions of this review regarding the causes of the 17 May 2017 flood event are:

Autumn 2016

The high flows that led to the elevated water levels along the lower Churchill River at the time of the initiation of freeze-up and ice cover progression upstream from Lake Melville were caused by a natural runoff event of water influx, primarily stemming from the middle basin of the Churchill River catchment area. An artificial release of water from the Muskrat Falls forebay did travel down the lower Churchill River but occurred prior to the natural influx from the middle basin. The artificial water released from the forebay had already dissipated before the natural influx discharge and the freeze-up occurred along the Churchill River's lower reach.

Winter 2016 – 2017

The snow depths in the Churchill River catchment area were of normal or slightly less-than-normal values compared to the long-term average. Had a deeper snowpack been present at the end of the 2016 – 2017 winter, higher runoff volumes during the freshet may have occurred which could have, potentially, led to more severe ice jamming and flooding along the lower Churchill River. On the other hand, deeper snow may have decreased ice thicknesses and lessened the severity of the jam. The normal or less-than-normal snowpack that was actually present at the end of the 2016 – 2017 winter may have lessened the high freshet runoff volumes then they could have been. The severity of the ice jam and the subsequent ice-jam flooding may have increased or decreased due to differences in the snowpack characteristics. Without numerical modelling capabilities, it is difficult to determine to what degree a potentially deeper snowpack could have increased runoff or reduced ice thicknesses and to determine the outcome of the severity of ice jamming and ice-jam flooding.

Spring 2017

The high freshet discharge that occurred during May 2017 was caused by natural events, particularly the rain-on-snow event in the middle basin of the Churchill River and the high rainfall event just prior to and during the May 2017 flood in the Churchill River's lower basin. These events led to the high flows that caused the ice jam and ice-jam flooding along the lower Churchill River. The Muskrat Falls spillway was operated in such a manner as to release the same amount of water through the spillway that was flowing into the reservoir; hence, the ice-jam flood event of 17 May 2017 along the lower reach of the Churchill River cannot be attributed to the operations of the spillway.

Recommendations

This section provides guidance on what measures need to be implemented to mitigate and prevent future flooding and to provide advance warning to residents of Mud Lake and Happy Valley-Goose Bay. Important measures that should be carried out to protect residents downstream of Muskrat Falls reservoir against potential future floods are the implementation of:

Community-based monitoring program

I recommend that a community-based monitoring program be established for the region, for Mud Lake community members and other stakeholders so that both knowledge systems, traditional/local knowledge and western science, can be utilised to inform how monitoring along the lower Churchill River can be carried out and to develop indicators to understand and track changes in the environment of the river (e.g. increased sedimentation and movement of sandbars along the river's lower reach). Other areas in Canada have begun establishing community-based monitoring programs, for example communities along the Slave River in the Northwest Territories (Mantyka-Pringle et al., 2017). The community-based monitoring program should incorporate a process of gathering traditional/local and western scientific knowledge to establish a way forward to monitor the environment and assess future flood hazards. An example of such a two-eyed seeing approach (http://www.integrativescience.ca/Principles/TwoEyedSeeing/) using both traditional knowledge and western science to understand ice cover conditions and fish migrations along the Slave River can be found in Baldwin et al. (2017), Das et al. (2015), Lindenschmidt et al. (2016) and NWT CIMP (2017).

Developing a community-based monitoring program requires a long-term commitment to interactive discussions and input from all stakeholders, including community members, reservoir operators, government agencies, etc. Such a program would provide a stronger voice from community members and provide an avenue for co-management of the environment and impacts and hazards to the environment associated with activities along the Churchill River. I suggest that a partnership be initiated amongst the stakeholders of the community-based monitoring project in order to establish a unit through which the monitoring program can be administered. An example of such a partnership in the Northwest Territories is the Slave River and Delta Partnership (http://www.nwtwaterstewardship.ca/srdp).

The community-based monitoring program could provide a framework for the establishment of flood and ice management plans, described next.

Flood Management Plan

A flood management plan should be established that incorporates, but is not limited to, the following:

- Flood forecasting capabilities
    - Extend the gauging network for additional water level and flow monitoring. Additional gauges along the lower Churchill River would be pertinent for calibrating and validating computer models simulating ice-jam flood staging along this vulnerable river reach.
    - Build up modelling capabilities to make predictions regarding potential ice jamming and flooding along the lower Churchill River. Models should include those that can simulate the hydraulics and river ice behavior along the lower Churchill River and estimate the runoff from the Churchill River watershed, particularly the middle and lower basins.

- Flood preparedness
  - A Flood Manual should be drafted which lays out flood protection activities, operational protocols and emergency response coordination at various river flood stages. The City of Winnipeg, for example, has such a manual. Areas of flood preparedness and flood fighting include land drainage sewer system operation and isolation, operation of flood infrastructure (i.e. operation of gates, flood pump stations, storm retention basins, etc.), primary dike raises or closures, deployment of temporary sandbag diking, isolation of natural drainage channels to prevent overland flooding from internal drainage and river backup and identification of critical facilities, to name a few. The manual relies on provincial forecasts both flood outlooks months in advance, as well as daily forecasts. The manual utilizes a built-in hydraulic profile calculator to convert the forecasted flows to flood levels. The application defines all flood activities based on trigger and activation levels and also includes an activity tracking module so each days' actions can be tracked. To assist with the visualization of the flood systems, the flood manual was develop with a fully integrated GIS module that allows for mapping of all systems and activities.
- Flood risk assessment:

  Flood risk is an assemblage of both:
  - Hazard: probability of occurrence (return period) together with the intensity of an ice jam flood (flood water depth and extent) establishes the hazard induced by the flood event. Although relatively straight forward for open water conditions, considerable effort is required to establish ice-affected stage frequency curves. Some approaches are provided in Beltaos (2011), Lindenschmidt et al. (2015, 2016) and White (2009).
  - Vulnerability: using land-use information and damage costs as functions of flood water depth and extent, the vulnerability of certain land-use types (e.g. residences) that would be exposed to a flood and their susceptibility to damage by the flooding can be assessed.

  Both hazard and vulnerability are combined to calculate the flood risk, which represents the long-term expected damages due to flooding. Flood risk assessment would serve as a basis for carrying out cost-benefit analyses of mitigation options (e.g. constructing a floodwater diversion channel or ring dikes or elevating roads and houses prone to flooding; more details to flood mitigation measures are provided in Section 10 of Appendix 1).
- Emergency response plan
  - An early warning system should be in place to warn residents of potential ice jamming and flooding through, for example, text messaging, sirens or radio broadcasting.

- An example of a mobile phone application that provides hydraulic information for rivers and issues flood warning and advisories is *AB Rivers* (Alberta Rivers: Data and Advisories), which is available free-of-charge from Apple's App Store.
- Evacuation routes and plans should be established for different flood scenarios. The plans should also provide measures of relief for people affected by flood events.

- Dam/spillway operations

  The operations mandates of the Churchill Falls and Muskrat Falls hydropower generating facilities should be extended to include flood reduction measures (see also Section 10 of Appendix 1 for further details):
  - Operating Churchill Falls and Muskrat Falls generating stations with a common operations plan so as to provide the best water management and flood reduction strategy for the Churchill River.
  - Extending the live storage capacity at the Muskrat Falls reservoir to buffer inflowing discharge peaks and reduce the flood impact downstream
  - Adjust outflows from Churchill Falls, particularly during river freeze-up and ice-cover breakup, to reduce the hazard of ice jam flooding

Ice Management Plan

Additionally, an Ice Management Plan should be implemented. Ice management plans are already in place for other rivers in Canada, e.g. the Red River (Beltaos et al., 2000; Topping et al., 2008), the Peace River (through a task force of several stakeholders to manage flows and ice along the Peace River; see Jasek, 2008) and the Athabasca and Clearwater rivers at Fort McMurray (in particular monitoring the breakup of the ice covers; see http://www.environment.alberta.ca/forecasting/RiverIce/AthabascaRiverArchive.html). Some components that an ice management plan can include, but not be limited to:

- Tracking ice cover characteristics and behavior throughout the winter season, from the onset of freeze-up to the end of breakup, also including an assessment of the hazards and risks of ice-jam flooding.
- Intensifying ice thickness monitoring using, for example, ground penetrating radar technology to determine variations in thicknesses of the ice cover along the river (areas of thicker ice may point to locations more prone to jamming).
- Pre-cutting and/or pre-breaking the ice cover to weaken the ice at ice-jam prone areas, hence providing a corridor for continued flow of ice runs to reduce the risk of flooding.

- Carrying out systematic bathymetric surveys of the river bottom to establish areas of sediment erosion and accretion, the latter being a potential location for ice flow constrictions; this would provide insight if dredging would be feasible to reduce ice-jam flood hazard, point to locations where dredging should be carried out and provide estimates of the amount of sediment to be removed.

More details of these plans would need to be addressed and specifics of the plans would have to be tailored to the Churchill River during the conceptualisation, development and implementation of these plans.

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29 September 2017

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Signature or Member Number
(Member-in-Responsible Charge)

Appendix 1:

KGS Group report:

Independent Review of the May 17th, 2017 Churchill River Flood Event

KGS GROUP
CONSULTING ENGINEERS

Newfoundland Labrador

INDEPENDENT REVIEW OF THE MAY 17TH, 2017 CHURCHILL RIVER FLOOD EVENT

FINAL – REV 0

KGS Group 17-3217-001
September 2017

PREPARED BY:

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Senior Consultant

David S. Brown, P.Eng.
Water Resources Department Head /
Associate Principal

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September 27, 2017

File No: 17-3217-001

Global Institute for Water Security, University of Saskatchewan
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ATTENTION: Dr. Karl-Erich Lindenschmidt, Ph.D., P.Eng.
Independent Technical Expert Advisor

RE: Independent Review of the May 17th, 2017 Churchill River Flood Event
Final Report – Rev 0

Dear Dr. Lindenschmidt:

KGS Group is pleased to submit our final report documenting our independent review of the May 17th, 2017 Churchill River Flood event.

We thank you for the cooperation and assistance that you have provided during this fast tracked review process.

Sincerely,

David S. Brown, P.Eng.
Water Resources Department Head /
Associate Principal

DSB/as

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STATEMENT OF LIMITATIONS AND CONDITIONS

THIRD PARTY USE OF REPORT

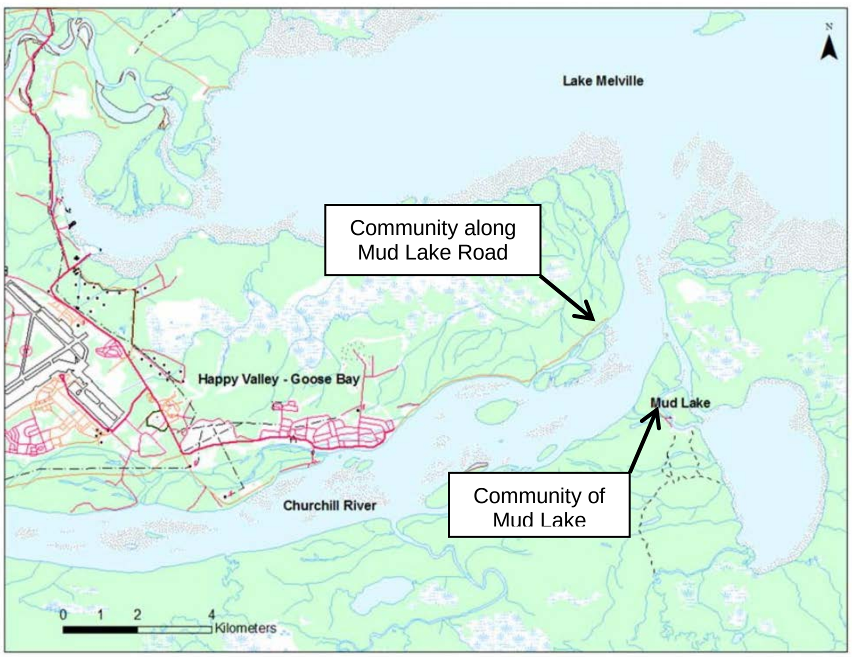
This report has been prepared for the Government of Newfoundland and Labrador and the Independent Technical Expert Advisor, Dr. Karl-Erich Lindenschmidt, to whom this report has been addressed. Any use a third party makes of this report, or any reliance on or decisions made based on it, are the responsibility 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.

Due to the short timeframe involved in this study, some of the analyses carried out as part of this flood review were done using raw data that has not undergone normal quality assurance procedures, or data that underwent an abbreviated quality review process. Accordingly, KGS Group cannot guarantee the accuracy of the data discussed herein, and accepts no responsibilities for damages, if any, resulting from any inaccuracies in the data or any future corrections or revisions applied to the data.

1.0 INTRODUCTION

Major flooding occurred along the Churchill River in Central Labrador in May of 2017 and caused the evacuation of residents from Mud Lake to Happy Valley-Goose Bay. As a result of this flood, the area sustained extensive flood damages to properties in the area. Two main areas sustained the majority of the flood damages (1) the community of Mud Lake, and (2) as area known as Mud Lake Road. A map that shows the location of each community relative to the river and the Town of Happy Valley – Goose Bay is shown in Figure 1.1.

FIGURE 1.1
LOCATION MAP



Source: Government of Newfoundland and Labrador (2017)

Mud Lake is a small community alongside the Churchill River in central Labrador, located approximately 10 km east of Happy Valley - Goose Bay on the south side of the Churchill River. There is a population of approximately 80 people in Mud Lake residing in approximately 45 homes. Damages occurred to 23 homes in the community. Although many residents have moved back after the flood, there are still a number of residents whose homes remain too severely damaged to be inhabited. There are no roads leading to the community and access is usually gained by means of boat or snowmobile. Photo 1.1 shows an aerial image of the community of Mud Lake.

PHOTO 1.1
COMMUNITY OF MUD LAKE

The area of Mud Lake Road is located to the east of the Town of Happy Valley – Goose Bay. There are approximately 22 homes along the Mud Lake Road. Damages occurred to 11 homes along Mud Lake Road, and similarly to Mud Lake, there are still a number of residents that are not able to move back home due to excessive flood damages. The residents of Mud Lake use a river access point at the end of Mud Lake Road to travel across the river. Photo 1.2 shows an aerial image of the community along Mud Lake Road.

PHOTO 1.2
COMMUNITY ALONG MUD LAKE ROAD

As reported by the hydrometric station at English Point, water levels started to increase in the Churchill River on May 11, 2017 and subsequently the water levels began rising in Mud Lake on May 16, 2017. The water rose to levels deemed unsafe on the early hours of May 17, 2017 which triggered the evacuation. The evacuation had to be performed using helicopters as water levels and ice conditions were not amenable to evacuation by boat. As of May 19, 2017 all but one resident and most pets had been transported from Mud Lake to Happy Valley - Goose Bay and remained there for a number of days. As previously noted, today, some of the residents are still living in Happy Valley - Goose Bay area and unable to move back home.

After the flood event, the Government of Newfoundland and Labrador committed to an independent review of the May 17, 2017 flooding event. KGS Group was selected in a competitive proposal process to undertake the review. This report describes the findings by KGS Group.

This work has been done in a short period of time and is built on review of existing reports and other documentation. Opinions regarding the causes of the flood event were developed by KGS Group and are based on a combination of observations, photographs, and descriptions offered by local residents, examination of the previous work by others, review of observations and photographs/videos by Nalcor and its consultants. Experience of KGS Group in similar river conditions and application of well-established rules of thumb and guidelines also helped to form our conclusions and recommendations.

KGS Group has accepted and used all data supplied with the implicit assumption that all data is accurate and has undergone suitable quality assurance reviews by others.

1.1 OBJECTIVES

The objectives of the independent review, as defined in the Terms of Reference for this work, are as follows:

- Provide a detailed explanation of the reasons for the May 17, 2017 flooding event considering all probable factors.
- Provide guidance on what measures need to be implemented to mitigate and prevent future flooding and to provide advance warning to residents of Mud Lake and Happy Valley- Goose Bay.
- The review will take into consideration traditional knowledge of the residents of the impacted area.

1.2 SCOPE OF WORK

The specific Scope of Work associated with the independent review, as defined in the Terms of Reference for this work, for which KGS Group has followed includes the following tasks:

- Gathering information and local evidence from relevant stakeholders including traditional knowledge experts.
- Review of previous studies of flood occurrences in other dammed rivers of similar latitude during spring melt.
- Review of ice jam occurrences on the Churchill River and in the surrounding region.
- Review of climatic and hydrometric data.

- Review of any relevant available data sets.
- Review of water level and discharge data from Muskrat Falls and Smallwood Reservoirs and other relevant gauges within the Churchill River catchment area.
- Review of operational practices at Muskrat Falls development and Churchill Falls development.
- Review photographic record and satellite ice imagery of the ice conditions in preceding years and 2017.
- Review bathymetric cross-sections of the Churchill River.
- Review data related to tidal influences from the Atlantic Ocean.
- Review ice observation program reports.
- Review relevant reports undertaken by Nalcor.
- Review actions and impacts of the Muskrat Falls project since Fall 2016 and associated implications for the Community of Mud Lake and the Town of Happy Valley-Goose Bay.
- Recommended actions to mitigate and prevent future flooding in Mud Lake and Happy Valley-Goose Bay and to provide advance warning to residents of Mud Lake and Happy Valley-Goose Bay.

1.3 PROJECT TEAM

KGS Group assembled a skilled technical team to carry out an independent flood review of the 2017 flood on the Churchill River that included experienced hydraulic engineers and technical experts. The flood review was carried out by KGS Group's Water Resources Department Head and Associate Principal, David S. Brown, P.Eng. and Senior River Ice Engineering Expert, Rick Carson, P.Eng. Project support was provided by Intermediate Water Resources Engineer Andrew Weiss, P.Eng. Mr. Brown was KGS Group's representative at the site visits and open houses carried out as part of the flood review.

KGS Group retained Pete Zuzek, P.Geo. from Zuzek Inc. to assess and review the coastal hydraulics, including any potential tidal effects.

To ensure the independent nature of this review, KGS Group's project team worked directly with the Independent Technical Expert Advisor, Dr. Karl-Erich Lindenschmidt, P.Eng. who was hired by the Province of Newfoundland and Labrador to oversee the review.

2.0 DATA REVIEW

At the onset of the project, as well as throughout the study duration, KGS Group was provided a significant amount of data by the Government of Newfoundland and Labrador. Throughout the project duration as KGS Group was carrying out the review, additional data was provided. A number of data requests were also made of KGS Group for additional information and data of which that information was subsequently provided. There were a few instances in which data was not provided and was indicated that it was not available. For example, ice thickness data measurements for 2017 as they were not recorded as they were in past years.

The data provided to KGS Group was obtained by the government from a number of sources, including in house at the Water Resources Management Division, within the Department of Municipal Affairs and Environment, Water Survey of Canada, and Nalcor. A list of the data that was provided is shown in Table 2.1.

TABLE 2.1
DATA PROVIDED TO KGS GROUP FROM GOVERNMENT OF NEWFOUNDLAND AND LABRADOR

DATE RECEIVED	DATA
18/07/2017	2011-2012 Ice Front Satellite Imagery
18/07/2017	2013 - 2017 C-Core Satellite Imagery
18/07/2017	HEC-RAS Model Section Location Maps
18/07/2017	HEC-RAS Model Cross Sections
18/07/2017	2017 Helicopter Photos
18/07/2017	Historic Freeze Up Dates (1972 - 2016)
18/07/2017	Ice Observation Reports: 1981 - 2016
18/07/2017	LiDAR Data along the Churchill River
18/07/2017	Hourly Provincial Weather Station Data at Mud Lake for 2010 - 2017 (NLENCL0004)
18/07/2017	Hourly Provincial Weather Station Data at Muskrat Falls for 2014 - 2017 (NLENCL0006)
18/07/2017	Muskrat Falls Reservoir Level and Spillway Discharge (May 10 - May 20, 2017)
18/07/2017	Muskrat Falls Stage-Storage Curve
18/07/2017	Station Coordinates for NLENCL0004 and NLENCL0006
25/07/2017	Mud Lake Property Assessment

TABLE 2.1 (CONTINUED)
DATA PROVIDED TO KGS GROUP FROM GOVERNMENT OF NEWFOUNDLAND AND LABRADOR

DATE RECEIVED	DATA
25/07/2017	GIS Shapefiles: basin delineation, hydrometric stations, WQMA stations, etc.
25/07/2017	Grizzle Rapids Imagery (July 1, 2010 - Oct 5, 2016)
25/07/2017	Mud Lake Imagery (July 22, 2010 - May 31, 2017)
25/07/2017	Churchill River Watershed and Monitoring Presentation
25/07/2017	Churchill River Hydrometric Network Maps
25/07/2017	Various Imagery of the 2017 Flood at Mud Lake and Mud Lake Road
25/07/2017	Presentation describing May 17 2017 Flood Event
28/07/2017	Churchill River Hydraulic Model Calibration Data
28/07/2017	2017 Flood Progression Maps
28/07/2017	Melville Lake Buoy Data for 2015-2017 (NLENWQ0002)
28/07/2017	Report Describing the Historic Review of Ice Jams on the Lower Churchill River and Goose River
01/08/2017	Churchill Falls Generating Station Plant Flows (November 1, 2016 to May 31, 2017)
01/08/2017	Joint Review Panel Information Requests
01/08/2017	Upper Churchill River Snow Data
01/08/2017	Lower Churchill River Snow Data
01/08/2017	2009 - 2016 First Snowmobile and Boat Crossing Dates
02/08/2017	Department of Fisheries and Land Resources Weather Station Data (Cache River, Churchill Falls, Grand Lake, Kenamu River, Moose Head Lake, Paradise River)
03/08/2017	Hatch Report: Effect of the Lower Churchilll Project on the Mud Lake Winter Crossing
03/08/2017	Hatch Report: Mud Lake Freezeup Observations
03/08/2017	Hatch Report: Ice Dynamics of the Lower Churchill River
03/08/2017	La Salle Ice Study - Appendix F
03/08/2017	Shawmont Newfoundland Limited Report: Lower Churchill River Ice Observations and Studies
03/08/2017	SNC Lavalin Report: Effects of Ice Progression during Construction of Muskrat Falls Hydropower Development
03/08/2017	Muskrat Falls Operational Data for November, 2016 to May, 2017 (Levels and Flows)
03/08/2017	Nalcor Presentation for Muskrat Falls Development
08/08/2017	Freedom of Information Requests
08/08/2017	Nalcor Surveyed Water Levels at Mid Pool and Standpipe Levels Downstream for December, 2016 to January, 2017
09/08/2017	Topographic Information along the Churchill River

TABLE 2.1 (CONTINUED)
DATA PROVIDED TO KGS GROUP FROM GOVERNMENT OF NEWFOUNDLAND AND LABRADOR

DATE RECEIVED	DATA
09/08/2017	Muskrat Falls Bathymetry Data
09/08/2017	Modis Satellite Imagery
11/08/2017	Churchill Falls Generating Station Plant Flows for 2010 - 2016
11/08/2017	NHC Report: Lower Churchill Hydroelectric Generation Project Sedimentation and Morphodynamics Study
11/08/2017	Hatch Report: EIS0019 - Sediment Plume Analysis
11/08/2017	Jacques Whitford Environment Limited Report: Water and Sediment Quality of the Churchill River
11/08/2017	Jacques Whitford Environment Limited Report: Water and Sediment Modelling in the Lower Churchill River (Final Report)
11/08/2017	Minaskuat Limited Partnership Report: Water and Sediment Quality in Churchill River - Environmental Baseline Report
16/08/2017	Churchill River Bridge Drawings & Maps
21/08/2017	Hatch Report: Blackrock Bridge FLOW-3D Scour Study
21/08/2017	SGE Acres Report: Scour on the Churchill River at Blackrock Bridge
21/08/2017	SGE Acres Report: Proposed Blackrock Bridge: Follow-up Hydraulic Estimates
13/09/2017	2012 Churchill River Satellite Imagery (RadarSat, MODIS, Landsat, WorldView)
14/09/2017	Digital Terrain Model of Mud Lake
20/09/2017	Simulated Ice Thickness at Goose Bay (1958 – 2016)

In addition to the data that was provided by the Government of Newfoundland and Labrador there was also information (anecdotal, photographs, observation data, etc.) provided by the local residents as part of the public consultation process described in Section 4.0. KGS Group also obtained a number of other reports and information to supplement that from the Government of Newfoundland and Labrador. Table 2.2 summarizes the supplementary data that was obtained by KGS Group, including the source.

TABLE 2.2
DATA OBTAINED BY KGS GROUP FROM OTHER SOURCES

SOURCE	DATA
Nalcor Website	Lower Churchill River Hydroelectric Generation Project Environmental Impact Statement
Nalcor Website	Lower Churchill River Project – Ice Formation Environmental Effects Monitoring Plan
Nalcor Website	Hatch Report: The Lower Churchill Project: EIS0017 – Further Clarifications and Updating of the 2007 Ice Dynamics Report
Nalcor Website	Hatch Report; The Lower Churchill Project – MF1330 – Hydraulic Modeling and Studies – 2010 Update
Nalcor Website	SNC Lavalin Report; Lower Churchill Project Log Boom for Ice Control During Impoundment
Nalcor Website	Hatch Report: Muskrat Falls Ice Study – 2013 Update Final Report
Nalcor Website	Hatch Report: Muskrat Falls Winter Headpond Freeze-up Program
Nalcor Website	SNC Lavalin Report: Lower Churchill Project Component 1: Review of Ice Study Work
Water Survey of Canada	Historic Flow Data for Churchill River above Upper Muskrat Falls (03OE001)
Water Survey of Canada	Historic Flow Data for Churchill Falls Powerhouse (03OD005)
Water Survey of Canada	Historic Flow Data for East Metchin River (03OD007)
Water Survey of Canada	Historic Flow Data for Churchill River below Metchin River (03OD009)
Water Survey of Canada	Historic Flow Data for Minipi River below Minipi Lake (03OE003)
Water Survey of Canada	Historic Water Level Data for Churchill River above Upper Muskrat Falls (03OE001)
Water Survey of Canada	Historic Water Level Data for Pinus River (03OE011)
Water Survey of Canada	Historic Water Level Data for Churchill River below Grizzle Rapids (03OE012)
Water Survey of Canada	Historic Water Level Data for Churchill River above Grizzle Rapids (03OE013)
Water Survey of Canada	Historic Water Level Data for Churchill River 6.15 kms Below Lower Muskrat Falls (03OE014)
Water Survey of Canada	Historic Water Level Data for Churchill River at English Point (03PC001)
Water Survey of Canada	Historic Water Level Data for Churchill River above Upper Muskrat Falls (03OE001)
Water Survey of Canada	2016 Flow Data For Pinus River (03OE011)
Water Survey of Canada	2016 Water Level Data for Pinus River (03OE011)
Water Survey of Canada	2016 Water Level Data for Churchill River below Grizzle Rapids (03OE012)
Water Survey of Canada	2016 Water Level Data for Churchill River above Grizzle Rapids (03OE013)
Water Survey of Canada	2016 Water Level Data for Churchill River 6.15 kms Below Lower Muskrat Falls (03OE014)
Water Survey of Canada	2016 Water Level Data for Churchill River at English Point (03PC001)
Water Survey of Canada	2016 Water Level Data for Churchill River above Upper Muskrat Falls (03OE001)
Water Survey of Canada	2017 Water Level Data for Churchill River below Grizzle Rapids (03OE012)

TABLE 2.2 (CONTINUED)
DATA OBTAINED BY KGS GROUP FROM OTHER SOURCES

SOURCE	DATA
Water Survey of Canada	2017 Water Level Data for Churchill River above Grizzle Rapids (03OE013)
Water Survey of Canada	2017 Water Level Data for Churchill River 6.15 kms Below Lower Muskrat Falls (03OE014)
Water Survey of Canada	2017 Water Level Data for Churchill River at English Point (03PC001)
Water Survey of Canada	2016 Water Level Data for Churchill River at Mid Pool (03OE015)
Water Survey of Canada	2017 Water Level Data for Churchill River at Mid Pool (03OE015)
Water Survey of Canada	03OE001 Rating Curve & Measurements
Environment Canada	1980 - 2010 Climate Normals for Goose Airport (8501900)
Environment Canada	1970 - 2000 Climate Normals for Churchill Falls Airport (8501131)
Environment Canada	1980 - 2010 Climate Normals for Wabush Airport (8504177)
Environment Canada	1970 - 2000 Climate Normals for Schefferville Airport (7117823)
Environment Canada	2016 - 2017 Climate Data for Goose Airport (8501900)
Environment Canada	2016 - 2017 Climate Data for Churchill Falls Airport (8501131)
Environment Canada	2016 - 2017 Climate Data for Wabush Airport (8504177)
Environment Canada	2016 - 2017 Climate Data for Schefferville (7117827)
Environment Canada	2016 - 2017 Climate Data for Schefferville Airport (7117823)

3.0 SITE RECONAISANCE

As part of the flood review, a site reconnaissance was carried out at the onset of the study. The site reconnaissance was done at the same time as the first round of public open houses (described in Section 4.0). The site reconnaissance was completed by Mr. David Brown of KGS Group and the Independent Technical Expert Advisor, Dr. Karl-Erich Lindenschmidt one week after the project award to KGS Group on July 26 and 27. Mr. Haseen Khan and Ms. Maria Murphy (representatives from the Government of Newfoundland and Labrador) accompanied Mr. Brown and Dr. Lindenschmidt on the site reconnaissance as well as made all arrangements for transportation while in Goose Bay. The site reconnaissance consisted of a number of aspects as described in the following subsections.

3.1 HELICOPTER TOUR OF THE CHURCHILL RIVER AND MUD LAKE AREA

The helicopter tour departed from Goose Bay Airport and flew northwest along the Goose Creek and norths side of the Churchill River watershed to the upper basin at the Churchill Falls development. After the aerial tour of the abandoned Twin Falls development and the Churchill Falls development, the tour flew over the Churchill River downstream to the Muskrat Falls development, then proceeding further downstream to the confluence of the Churchill River with Lake Melville. The tour finished with a tour over the community of Mud Lake and the residences along Mud Lake Road. Photos 1.1 and 1.2 were taken during the helicopter tour.

The helicopter tour provided the review team with a good opportunity to view the river. A number of notable observations were made during the helicopter tour:

- The watershed to on the north side of the Churchill River consists of forest and a numerous wetlands and bogs.
- The reservoirs upstream of the Churchill Falls powerhouse are vast and have very large storage volume.
- The reach of the Churchill River downstream of the Churchill Falls development is a well-defined river channel with steep high valley walls. The flow in the river appeared relatively swift with the exception of the reaches that consist of Winokapaa Lake and Gull Lake.
- A number of cottages were observed along the river that appeared to be situated relatively close to the river.

- A number of locations along the shores of the river downstream of Gull Rapids and upstream of Muskrat Falls were deforested in preparation for the future forebay raising. There were also areas immediately bounding the river that were not deforested.
- The lower reach of the river was characterised by numerous sand bars. Many of the sand bars appeared to have existed for many years as they were covered with trees and vegetation, however, a number of sand bars were bare sand that showed the typical signs of growth and decay.
- Significant damage was present along the banks of the lower reach of the river in the vicinity of the ice jam. Photo 3.1 shows an example of the destructive force of the ice jam that occurred in May 2017 and illustrates a number of mature trees along the shoreline flattened.

PHOTO 3.1
DAMAGE ALONG BANKS OF CHURCHILL RIVER FROM ICE JAM

3.2 TOUR OF MUSKRAT FALLS DEVELOPMENT

Mr. Gilbert Bennet of Nalcor provided the review team a tour of the Muskrat Falls project site. During the course of the tour, the following project aspects were visited:

- Forebay;
- Spillway (upstream and downstream);
- Cofferdam Dam for the Main Dam (upstream and downstream);
- Powerhouse; and
- North Spur (upstream and downstream).

During the tour, Mr. Bennett provided commentary regarding the project and ongoing construction activities. The following bullets highlight the notable points of the discussion relative to the operations over the fall and winter of 2016/2017.

- The challenges that Nalcor faced with the reservoir filling in the fall and the subsequent lowering of the forebay to allow for the cofferdam repairs.
- The challenges associated with monitoring the forebay water levels after the lowering of the forebay in late November as the new gauge that was installed that fall was intended to record water levels in the range of the forebay impoundment, and not those associated with the pre-construction levels.
- It was also explained that the ice boom was not installed over the past winter due to the challenges associated with the lowering of the forebay in November and subsequent raising of the forebay in mid-winter.
- Mr. Bennett noted that the hanging ice dam that always formed downstream of Muskrat Falls pre construction also formed in the winter of 2017. It was noted that once the forebay was raised to elevation 21.5 m in mid-winter the growth of the hanging ice dam slowed notably. This was because the forebay froze over and ice was not able to freely flow through the spillway as it did in the early winter months.

3.3 TOUR OF MUD LAKE COMMUNITY

As noted above, during the helicopter tour the review team carried out an aerial tour of the Mud Lake Community. In addition to the aerial tour, just prior to and just after the public meeting in Mud Lake on July 27, 2017, the review team walked around the main town site where the church, school, community centre, and bridge are located. The following bullets highlight some of the notable observations made during the tour.

- The development at Mud Lake is situated at a relatively low elevation relative to the water level.
- A number of houses appeared to still be uninhabited and had flood damaged contents outside.
- There are a number of natural channels to the northwest of the community that appear to be historic overflow channels from the Churchill River which would convey flow towards and into Mud Lake and the Mud Lake channel. These channels consisted of bogs and wetlands.
- The footbridge along the north side of the community that crosses one of the historic overflow channels was damaged.

3.4 TOUR OF MUD LAKE ROAD

The review team carried out a driving tour along Mud Lake Road to the location of the Mud Lake crossing. The following bullets highlight some of the notable observations made during the tour.

- The developments along Mud Lake Road are situated at a relatively low elevation relative to the Churchill River water level.
- A number of houses appeared to still be uninhabited and had flood damaged contents outside.
- The banks of the river at the location where the Mud Lake residents dock their boats appeared to have notable and recent erosion.

3.5 BOAT TOUR OF THE CHURCHILL RIVER

In addition to the site reconnaissance carried out on July 26 and 27, and in response to input obtained during the first round of open houses described in Section 4.0, the review team toured the river in the vicinity of the Mud Lake Crossing by boat. The boat tour was completed on September 7. Mr. Dave Raeburn provided transportation with his pontoon boat for the review team. Unfortunately the weather was not favourable, as it was overcast, windy and rainy. Nonetheless, the boat tour provided value to the review team. The following points highlight some of the notable observations made during the tour.

- The banks of the river are relatively low, however, a significant extent of the banks show signs of recent bank erosion.
- In the vicinity of the May 2017 ice jam, the banks show signs of significant damage to the trees (See Photo 3.2)
- Some of the woody debris along the shoreline consisted of old trees that were either transported down river from upstream or had fallen into the river in the lower reach years ago.
- Much of the river is quite shallow, with the exception of the deep main flow channels.
- Due to the shallow nature of the channel, the team could not get close to any of the sandbars.
- Numerous boulders were noted on the river bottom near English Point.

PHOTO 3.2
TREE DAMAGE ALONG BANKS OF LOWER CHURCHILL RIVER

4.0 PUBLIC CONSULTATION

A critical component of the flood review was to obtain local traditional knowledge. This was accomplished through a series of meetings and public open houses that make up the public consultation process.

4.1 ROUND ONE PUBLIC CONSULTATION

The intention of the round one consultation was to introduce the review team to the public, describe the scope and objectives of the study, and to listen to and obtain the public knowledge and experiences. The public consultation for round one was comprised of:

- A public meeting in the community of Mud Lake held on July 26, 2017
- A public meeting in Happy Valley – Goose Bay held on July 27, 2017; and
- A meeting with the Town of Happy Valley – Goose Bay on July 27, 2017.

The public consultation was led by Dr. Karl-Erich Lindenschmidt with the assistance of Mr. David Brown. The location, meeting time, and all advertisements for the public meetings were done by the Government of Newfoundland and Labrador. Each of the public meetings lasted for a duration of approximately 75 minutes. All attendees at the public open houses signed a sign in sheet. Copies of the sign in sheets are provided in Appendix A.

The public meetings were well attended and were considered by the review team to be quite valuable. The local residents provided stories of their experiences during the flood, provided their observations of the river during the fall, winter, and into the spring, their opinions of the cause of the flood, their historic observations. A number of their key opinions came out of the discussions at the public meetings, and are summarized below:

- The flood event in May 2017 was the worst that the area has experienced in over 200 years. Some of the oldest residents that have lived in the area for over 80 years do not recall any flood event that was this severe.
- The flooding occurred extremely fast in the middle of the night. The experience was scary and life threatening.

- The river froze up at record high levels. The residents do not recall the freeze up level ever being as high. The ice surface was flat over all of the sandbars and extended from shore to shore, which is not a normal occurrence.
- By the end of the winter the ice was very thick, much thicker than normal.
- Over the winter, the river levels subsided notably. When the levels decreased the ice broke and floated on the lowered water surface, hinging at the banks. Over the sand bars, the ice became grounded. After the ice collapsed the surface was extremely rough and the snowmobile trail was more challenging to traverse than normal.
- There has been a systematic growth of the sandbars over the years. The increased sediment deposition has made more sandbars and created much shallower river channel. Dredging of the river should be considered.
- The construction of the highway bridge crossing the Churchill River changed the sediment dynamics in the river. The depth of the river at the bridge location was noted as about 14 feet deep, and now after a number of years, it is reported to be over 140 ft. All of this sediment was transported downstream.
- During the flood in May there was a significant amount of debris that flowed downstream.
- The snow cover was not abnormal; some considered snow less than normal.
- In the weeks leading up to the flood, there was no snow left on the ground in Mud Lake. The snowmobiles were put away for the year.
- The emergency lowering of the Muskrat Falls reservoir in late November 2016 caused an increase in the water level in the lower river which led to the high freeze up levels.
- The ice cover did not “rot” or “candle” in place in the spring as it normally does prior to break up. In the spring of May 2017 the ice was thick and solid. It was noted that the ice was not ready to move.
- There was no warning of the flood and ice jam. The residents were taken by surprise.
- The river changed after the construction of the Churchill Falls development.
- Damage from ice jam extended high up the banks and knocked over many trees. Roots were noted over 10 feet above channel banks. If the forest was not situated between the river and the community of Mud Lake, it was felt that the community would have been totally destroyed.
- Wind can affect the water levels on the lower river. With a northeast wind, levels go up and with a south west wind, levels goes down.
- The temperature was not warm this spring leading up to the flood.
- The Churchill Falls development had a huge impact on changing the river. Many sandbars formed after that project was commissioned. One elderly resident noted that when she was a young girl, there were very few sandbars in the river; now there are many.

- Normally the ice jam occurs at the mouth of the river. In 2017 the ice jam was a bit further upstream.
- May 1 was the last snowmobile crossing this spring, which was one week later than normal.

Other underlying opinions from the local residents included:

- The residents believe that the flood was caused directly, and as a result of, Nalcor and the Muskrat Falls project.
- It was the opinion that the cause of the flooding started in November 2016.
- When the ice boom could not be installed, the cofferdam should have been removed.
- It is the opinion of the residents that Nalcor and the Government of Newfoundland and Labrador do not monitor the lower Churchill River downstream of Muskrat Falls and as such have very limited knowledge of that part of the river.
- The opinions and requests of the residents downstream of Muskrat Falls have not been acknowledged during the public consultation process and environmental licensing process for the Muskrat Falls development.

At the meeting Mr. Dave Raeburn provided the review team a report that he had written describing his opinion and review of why the flood occurred. Appended to that report was a listing of the Muskrat Falls spillway operations that was provided by Nalcor during over the month's preceding the flood. The spillway operations log defined the date in which any changes to spillway operation and reservoir level was made. Mr. Raeburn's report and operations log highlight the emergency operation in November in which the reservoir was drawn down by approximately 8 m over a period of approximately days. A copy of this report and operation log is provided in Appendix A.

The above noted points were considered in the review and assessed and referenced throughout this report.

In addition to the two public meetings, the review team held a meeting with the Town of Happy Valley – Goose Bay on July 27, 2017. At this meeting Mr. Wyman Jacque and Mr. Frank Brown provided the review team a summary of the issues that the town faced during the flood. The following key points were relayed at this meeting.

- Flood damages occurred along the banks of the river at the water treatment facility and along the water supply wells. The riprap armouring was damaged and eroded.
- Back flooding up drainage ditches in the Mud Lake Road area occurred which flooded out land on the north side of the road.
- The park at Birch Island sustained damage to the newly constructed infrastructure.
- The town did not have any records of water levels along the river
- Ice jams occur frequently in the lower river at the confluence with Lake Melville, however, never as extreme as in May 2017.
- The town has started to work with Nalcor on emergency planning and notification systems. These systems would include anyone living downstream of Muskrat Falls.
- Goose River also flooded this past year. It was the worst flooding on that river in a number of years.

4.2 POST ROUND ONE PUBLIC CONSULTATION

In the days and weeks following the round one public meetings, local residents provided the review team with a number of photographs taken during the flood, during the flood evaluations, and after the flood that show the damage to the area and the thickness of the ice rafted on shore during the ice jam. The residents also provided copies of letters that were written by the residents. Copies of the photos and documentation are provided in Appendix B.

As well as the follow up information provided by email, the review team had a subsequent telephone meeting with Mr. Dave Raeburn on August 14, 2017. As part of this phone discussion, Mr. Raeburn noted that there were very large trees along the south shore of the river that were knocked over to a 45 degree angle by the ice. Photo 4.1 shows a picture of this tree that was provided by Mr. Raeburn.

The photo also shows significant tree scarring from the ice and provides evidence that an ice jam of this severity has not occurred for a very long time. Mr. Raeburn estimated the age of the tree at 30 to 50 years.

PHOTO 4.1
LARGE DIAMETER TREE PUSHED OVER BY ICE JAM

Source: Dave Raeburn (Aug 13, 2017)

The review team also had a follow up meeting with the Town of Happy Valley – Goose Bay on August 10, 2017. A number of members from the town were present for this phone meeting. Many of the topics that were discussed at the July 27 meeting with the town were discussed at this meeting with the larger audience. However, some additional key points were relayed at this meeting as noted below.

- In recent years there is less water flowing along the north side of the river than there used to be due to sandbar growth and sediment deposition. It has shifted more to the south side.
- It was questioned what the cumulative effects of Churchill Falls, the new causeway and bridges, as well as Muskrat Falls have on the lower river. It was noted that this aspect was beyond the scope of the flood review.
- There was no knowledge of any river cross section surveys completed to track or observe sediment growth.
- The town has no recorded water levels along the Churchill River.
- The town would like to receive notice from Nalcor for any changes in flow release, not only those associated with floods or emergencies.

4.3 ROUND TWO PUBLIC CONSULTATION

The intention of the round two consultations was to provide the local residents an overview of the preliminary findings of the study and to further seek comments and information from the local residents. The public consultation for round two was comprised of:

- A public meeting in the community of Mud Lake held on September 7, 2017 (5 pm to 7 pm); and
- A public meeting in Happy Valley – Goose Bay held on September 7, 2017 (8 pm to 12:30 am).

The public consultation was led by Dr. Karl-Erich Lindenschmidt with the assistance of Mr. David Brown. To facilitate the summary of the preliminary findings, Mr. Brown stepped through the preliminary results with the support of a Microsoft PowerPoint presentation. A pdf copy of the presentation slides is provided in Appendix C.

The location, meeting time, and all advertisements for the public meetings were done by the Government of Newfoundland and Labrador. Each of the public meetings lasted for a duration of approximately 75 minutes. All attendees at the public meetings signed a sign in sheet. Copies of the sign in sheets are provided in Appendix C.

The public meetings were well attended and were considered by the review team to be valuable.

The presentation for the preliminary findings focused on reviewing the data along a timelines of the flood progression which started prior to the fall freeze up. The presentation reviewed the streamflow, and water level, data along the river, as well as the climate data in the basin. The presentation provided a summary of the most significant factors that lead to the flood, and provided a summary of possible mitigation measures that should be reviewed under further study. Due to the short timeframe for the meeting, the presentation of the preliminary findings was only able to briefly summarize the content of this report.

The overwhelming response and comments from the residents were that they did not concur with the preliminary findings of the study. The residents' opinion is still that Nalcor and Muskrat Falls are the cause of the flood.

Aside from the lack of support for the preliminary findings, there was good discussion regarding potential mitigation measures that should be followed up with further study. As well, the local residents provided some additional information that was reviewed and noted in this final report. A summary of these key notes is provided below.

- It was noted that the ice boom that was never installed in the forebay of Muskrat Falls. This was considered to be a critical component of what led to ice flowing downstream to compound the severity of the ice jam.
- It was noted that there was very little data on the ice conditions in the winter of 2017, including no ice thickness measurements for 2017.
- It was noted that although November 2016 did appear to be quite wet, it was considered that this condition had occurred in the past and that a review of only 30 year climate normal would not adequately capture the true severity or routineness of such November rains.

A significant portion of the discussion at the Happy Valley – Goose Bay public meeting centred on the potential mitigation measures and watershed monitoring. It was noted that there is relatively little information recorded on the basin to give a true sense of forecasting of possible flood events and ice jams. The notion of a flood management program and ice monitoring program was discussed. These mitigation measures are further discussed in Section 10.0.

At the meeting, Mr. Robert Way provided a number of enlightening thoughts and information. At the end of the meeting Mr. Way provided the review team with a Microsoft PowerPoint presentation file that contained some of his preliminary findings. In the days following the meeting Mr. Way provided another Microsoft PowerPoint presentation file that provided additional information and a summary of Mr. Way's review of the flood event. A pdf copy each of Mr. Way's presentation files is provided in Appendix C. Mr. Way's second presentation files contains a number of slides that review the rainfall and streamflow data which suggest findings similar to KGS Group's preliminary review, in terms of greater than normal rains and above normal runoff in the fall. Mr. Way's presentation also suggests that there is not enough information available that can prove or disprove that Nalcor and Muskrat Falls were at fault. This is not the opinion of KGS Group, as described further in this report. Mr. Way also makes a point in his presentation that due to the lack of monitoring in the Churchill River watershed and the lack of ice monitoring in the lower Churchill River there is a lack of understanding at both Nalcor and the Government of Newfoundland and Labrador to effectively allow either organization to adequately advise downstream residents of flood or ice jam threats.

5.0 GENERIC FACTORS THAT CONTRIBUTE TO ICE JAMS AND FLOODING IN RIVERS

In KGS Group's experience from many other rivers in cold climates, the following factors are the most common natural contributors to flooding in rivers, particularly in spring ice jams:

- Low river banks that have a low tolerance of rises in water levels as ice jams form.
- Wide shallow rivers that are prone to form thick ice jams during the breakup period.
- High river flows in the ice formation phase in late fall/early winter that cause the initiation of the river ice cover at a relatively high stage. That stage must then be exceeded in the spring before the river ice can move out and flush downriver.
- Cold severe winters that foster the growth of thick, thermally developed ice over the course of the winter.
- Modest snowfall, so that frost penetration, particularly in severe winters, can accentuate ice growth in the river.
- Shallow river channels that have areas prone to grounding of ice.
- High river flows that rise rapidly before the end-of-winter ice cover has been able to deteriorate.
- Severe river bends or changes in the direction of the river course. Sharp bends, presence of sand bars, or narrowing of the channel often impede release of ice.
- Low gradient rivers and deltaic reaches of river can be prone to ice jamming.
- Wet watershed antecedent conditions prior to freeze up.
- Large volumes of rain coincident with snowmelt.
- Rapid onset of snowmelt (i.e. sudden change from cold winter weather to warmer spring weather), with limited opportunity for deterioration of the river ice.

There can also be non-natural contributors to flooding that would consist mainly of misoperation of a hydraulic structure. For example, this could consist of the failure to close a flood gate or improper operation of a spillway gate.

These and other, more site specific, factors have been considered in the review of the flood event of May 2017 at Mud Lake, as described in Section 8.0.

6.0 DESCRIPTION OF THE CHURCHILL RIVER

6.1 DRAINAGE BASIN

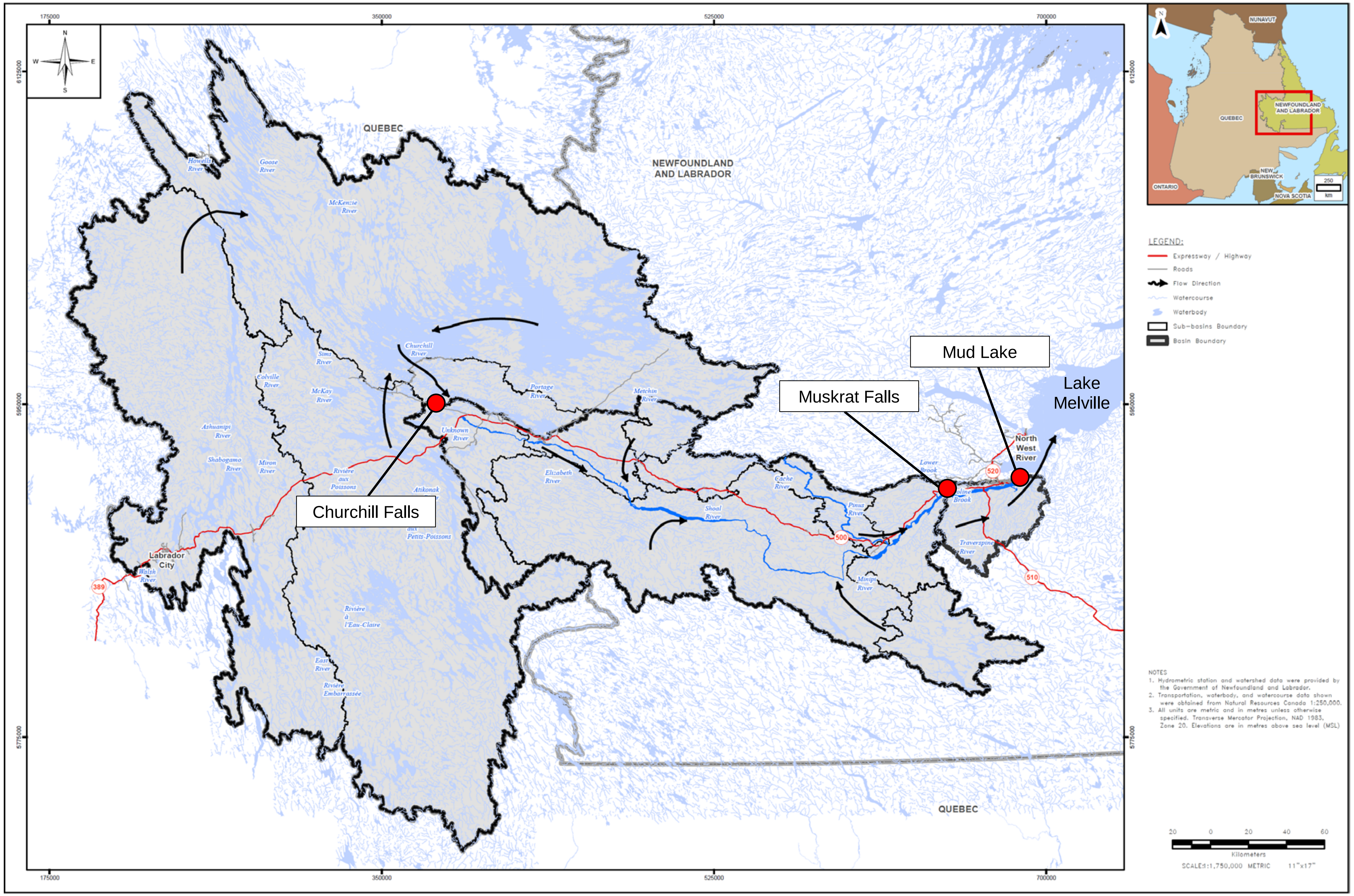
The Churchill River watershed originates at the Provincial boundary between Quebec and Newfoundland and Labrador, and drains approximately 94,300 km^2 into Lake Melville, and ultimately the Atlantic Ocean. For purposes of this review, we have divided the Churchill river watershed into three main sub-basins, (1) the upper Churchill River Basin that extends from the upstream basin boundary (i.e. headwaters) to the Churchill Falls Generating Station, (2) the central basin that extends from the Churchill River Generating Station to the Muskrat Falls Generating Station Development, and (3) the lower basin that extends from the Muskrat Falls Generating Station Development to Lake Melville. The three main basins are shown on Figure 6.1.

The upper basin drains approximately 69,400 km^2. Nearly 90 dams and dikes in the upper Churchill River basin direct flows to the Churchill Falls Generating Station. Prior to passing through the Churchill Falls Generating Station, water is stored in the approximately 7,000 km^2 Smallwood Reservoir. The upper Churchill River basin includes several large lakes and tributaries, including Lobstick Lake, Michikatamu Lake, Atikonak River, McPhayden River, Ashuanipi River, McKenzie River, and Kepimits River.

The middle Churchill River basin drains approximately 92,500 km^2, of which 23,050 km^2 is local drainage. Flow in the middle basin is largely regulated by the outflows from the Churchill Falls Generating Station; however local flow contributions due to snow melt and rainfall can represent a significant portion of the flow contribution in the basin. Major tributaries in the middle Churchill River Basin include Pinus River, Fig River, Metchin River, Lower Brook and Upper Brook.

The lower Churchill River basin drains approximately 94,320 km^2, of which approximately 1,850 km^2 is local drainage. Flow in the middle basin is governed by outflows from the Churchill Falls Generating Station and local flow contributions from the middle and lower basins. The lower Churchill River basin conveys flow into Lake Melville prior to ultimately being conveyed to the Atlantic Ocean.

FIGURE 6.1
CHURCHILL RIVER WATERSHED



6.2 TOPOGRAPHY OF DRAINAGE BASIN

As described in the Environmental Impact Statement for the Muskrat Falls Development prepared by Nalcor Energy, the terrain of the Churchill River drainage basin is generally characterized by rolling hills, with several areas of exposed Precambrian granite bedrock. Most of the drainage basin falls into the Taiga Shield Ecozone, with the area along Churchill River between Lake Melville and the Churchill Falls Generating Station falling into the Boreal Shield Ecozone.

The landscape of the upper drainage basin of the Churchill River consists largely of lakes, bogs, and Spruce and Lichen woodlands. Soils overlaying the bedrock are typically composed of rock, till, and glaciofluvial material. Immediately downstream of Churchill Falls, the terrain is characterized as a forested region of plains and wide valleys with bogs prevalent where land drainage is poor.

Upstream of Muskrat Falls, the terrain along the watershed boundary is a plateau region characterized by bogs in low lying areas, with scattered tree growth typical throughout the area. Along the Churchill River, the landscape is characterized as a poorly drained coastal plain, with bogs developed extensively throughout the area. Soils along the Churchill River consist largely of deep glacial deposits.

Downstream of Muskrat Falls, considerable sedimentation of the Churchill River channel takes place which results in a braided river channel near the town of Happy Valley – Goose Bay, with large sand bars in the main channel of the river. At the mouth of the Churchill River at Lake Melville, the river exhibits delta type features, including a wide alluvial fan with several small side channels.

6.3 HYDROELECTRIC DEVELOPMENT WITHIN THE CHURCHILL RIVER BASIN

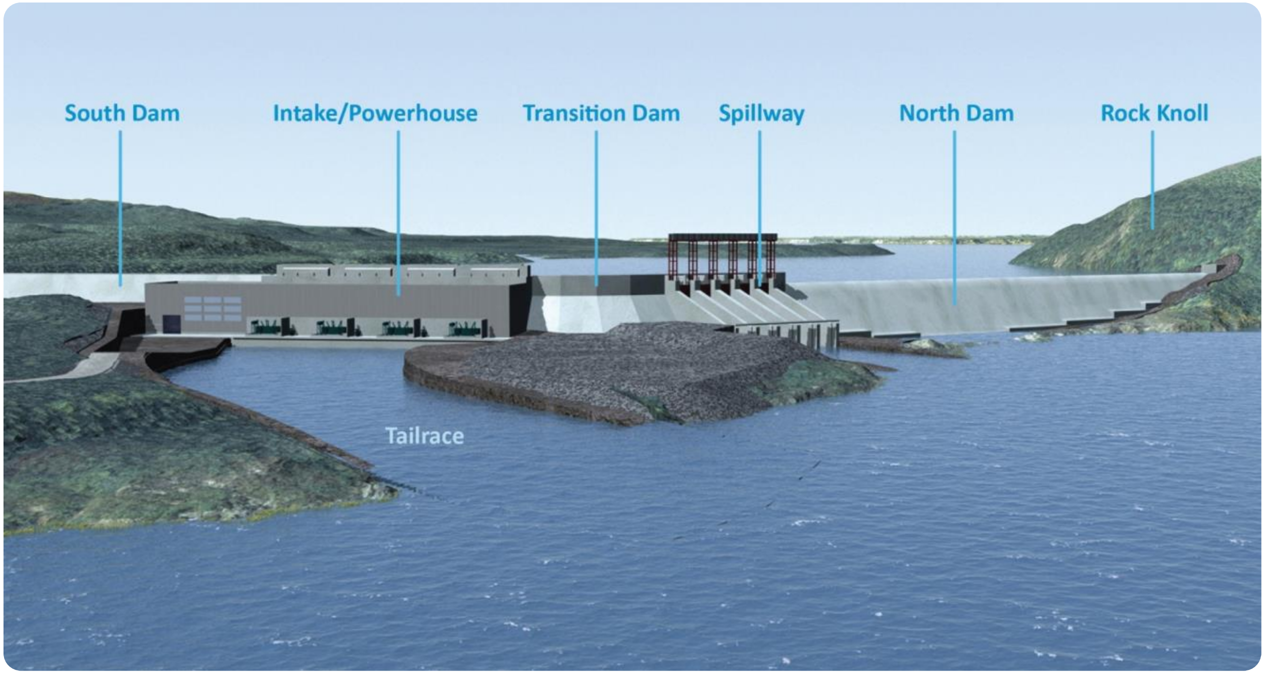
The development of hydroelectric generation within the Churchill River basin began in 1954 with the construction of the Menihek Generating Station on Lake Menihek, and was followed shortly thereafter by the construction of the Twin Falls Generating Station in 1960 to provide power for various mining operations in the region. Power from these two generating stations proved instrumental in the construction of the Churchill Falls Generating Station and associated dikes, which went into operation in 1974. Following the construction of the Churchill Falls Generating Station, the Twin Falls Generating Station was taken out of operation due to the higher energy generated Churchill Falls.

The Churchill Falls Generating Station, as shown in Figure 6.2, is located at approximately the centre of the Churchill River Watershed and has a generation capacity of 5,428 MW. Water is stored in the approximately 7,000 km^2 Smallwood Reservoir, which is controlled by several dikes, dams and control structures. Outflow from the Churchill River Generating Station is typically maintained at approximately 1,400 m^3/s although can vary day by day.

FIGURE 6.2
CHURCHILL FALLS G.S. DEVELOPMENT

As part of the ongoing hydroelectric development of the Churchill River, Nalcor is presently undertaking the construction of the Muskrat Falls Generating Station, located at Muskrat Falls. Upon completion, the Muskrat Falls Generating Station will consists of a 325 m long south dam connecting the south Churchill River bank to the powerhouse, a 188 m long four-turbine powerhouse structure, a transition dam connecting the powerhouse to the spillway, a four-bay spillway with submerged radial gates, and a 432 m long dam connecting the spillway to the north bank of the Churchill River, as shown in Figure 6.3.

FIGURE 6.3
MUSKRAT FALLS G.S. DEVELOPMENT



Source: Nalcor Energy (2013)

The Muskrat Falls Generating Station, upon completion, will have an installed generation capacity of 824 MW, and will operate as close as possible to the Full Supply Level (FSL) of 39 m. When completed, the total discharge from the powerhouse will be 2,660 m^3/s. Excess flow would either be stored in the reservoir, which has been designed for additional storage in order to handle, in emergencies, extreme flood events up to a maximum flood elevation of 44 m, or conveyed through the spillway. The spillway structure has been designed to accommodate the Probable Maximum Flood flow of 22,420 m^3/s. At present, construction of the spillway has been completed, and construction of the powerhouse is underway.

6.4 LOWER CHURCHILL RIVER BATHYMETRY

KGS Group was provided cross sections of the Churchill River extending from Lake Melville to Gull Island that were based on bathymetric surveys carried out in 1975, 1979 and 2006. Nalcor also provided KGS Group with bathymetric contour data near Muskrat Falls and Gull Island collected in 2006 and 2007.

While the bathymetric information was fairly limited, a review of the cross sections from the town of Happy Valley – Goose Bay to Lake Melville shows that the river section is generally quite shallow for the majority of the river width, with the exception of the main thalweg that can be quite deep. The river in this reach is braided with numerous sandbars that split the flow paths into several smaller channels. A Google Earth image of the braided channel and numerous sand bars near Happy Valley – Goose Bay is shown in Figure 6.4.

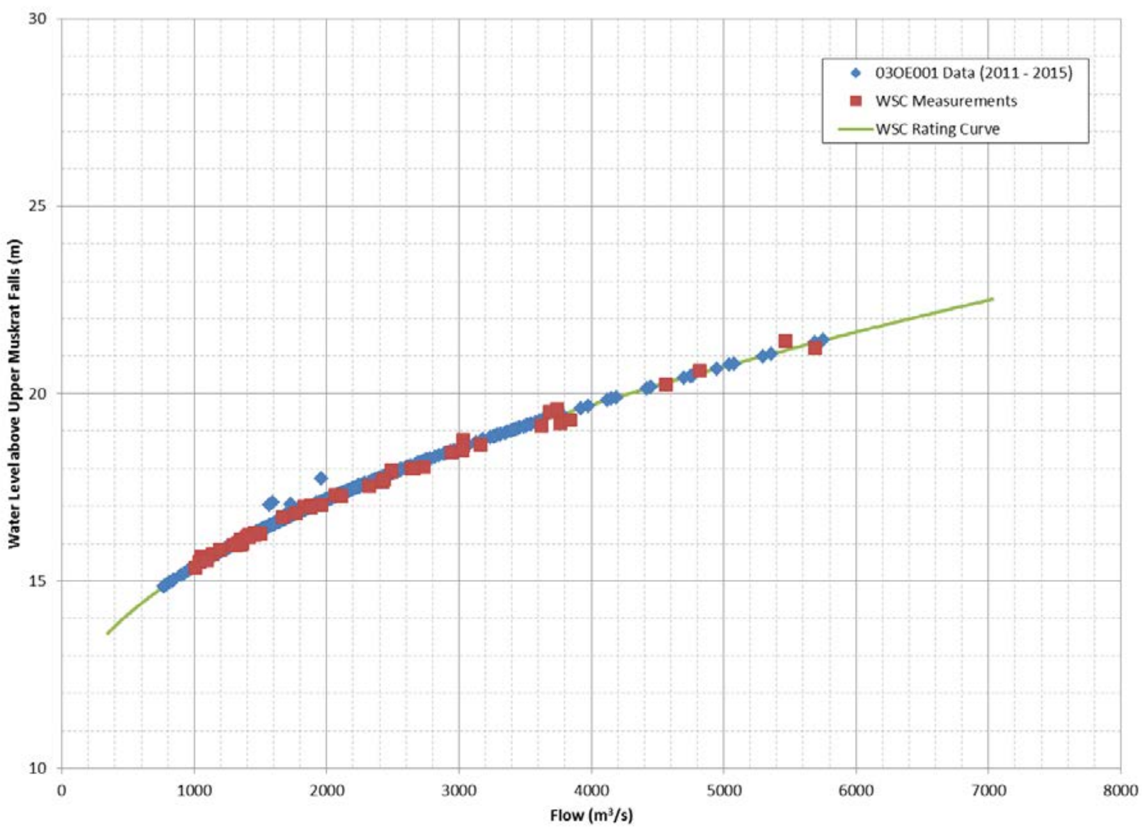
FIGURE 6.4
LOWER CHURCHILL RIVER

Source: Google, DigitalGlobe, CNES/Airbus (2017)

6.5 STAGE DISCHARGE RELATIONSHIPS AT MUSKRAT FALLS AND LOWER CHURCHILL RIVER

In addition to the 2016 water level data on the Churchill River above Upper Muskrat Falls, WSC provided KGS Group with a stage-discharge relationship at their gauge 03OE001 upstream of Muskrat Falls, as well as the water level and flow measurements taken to develop that relationship. The stage discharge relationship (herein also referred to as a rating curve) and the measurements, from which it was derived, as well as the historic water levels and flows on the Churchill River at Upper Muskrat Falls, are shown in Figure 6.5.

FIGURE 6.5
STAGE – DISCHARGE RELATIONSHIP ABOVE MUSKRAT FALLS (PRE-DEVELOPMENT)



Based on the flow records available for the Churchill River above Upper Muskrat Falls, KGS Group assessed the stage-discharge relationship at two additional locations on the Churchill River, (1) 6.15 km downstream of Muskrat Falls (i.e. WSC Gauge 03OE014), and (2) at English Point (i.e. WSC Gauge 03PC001). To develop the open water stage-discharge relationships (i.e. non ice-affected conditions), only water levels and flows from May 20 to September 20 were considered. It should be noted that the water levels at English Point are not referenced to a geodetic datum, and therefore cannot be directly compared to the water levels at the other two gauges. Nonetheless, the relative changes in water level corresponding to changing flows can be compared, and can be used to draw conclusions regarding the hydraulic response of the river at each location.

These stage-discharge relationships are shown in Figures 6.6 and 6.7. The recorded data associated with the complete year as well as only the open water conditions are also shown on these figures.

FIGURE 6.6
STAGE – DISCHARGE RELATIONSHIP 6.15 KM BELOW MUSKRAT FALLS

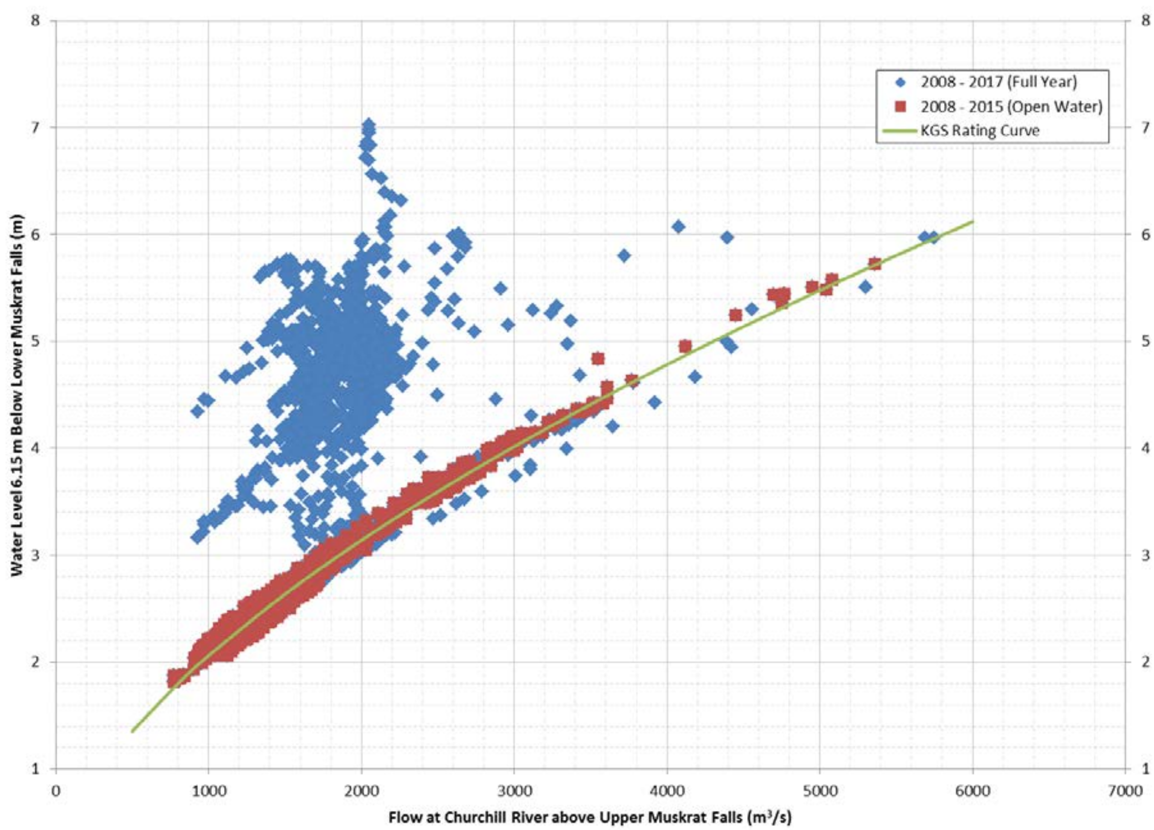
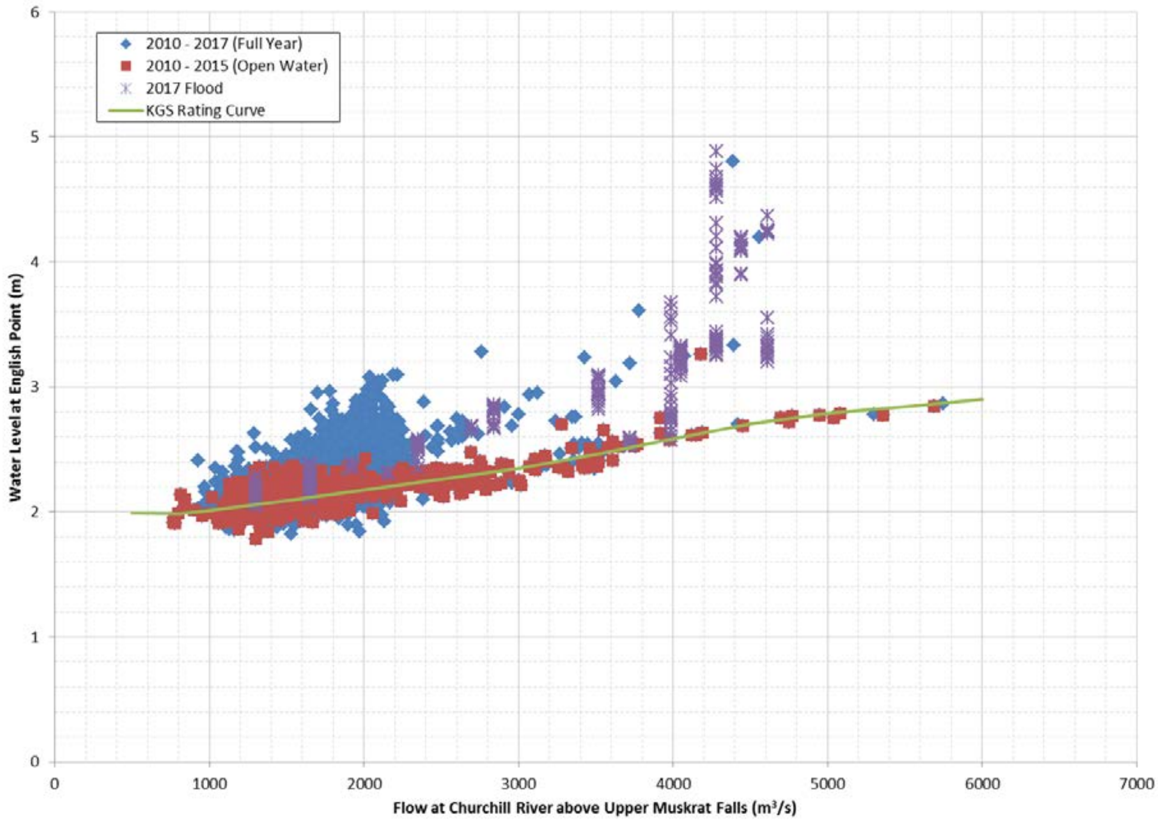


FIGURE 6.7
STAGE – DISCHARGE RELATIONSHIP AT ENGLISH POINT



The three stage-discharge relationships show considerably different water level responses for increasing flows at each location. Above Upper Muskrat Falls, for large changes in flows, there is a correspondingly large increase in water level above Muskrat Falls. For example, an increase in flow from 1,000 m^3/s to 5,000 m^3/s results in a water level increase of approximately 5.2 m. This response is due to the considerable natural constriction of the river at Muskrat Falls.

At 6.15 kms downstream of Muskrat Falls, an increase in flow from 1,000 m^3/s to 5,000 m^3/s results in a smaller increase in water levels of 3.4 m. At English Point, the water level response is further dampened due to the close proximity to Lake Melville and additional small channels leading to the lake as part of the alluvial fan, with a water level increase of approximately 0.8 m for a corresponding increase in flow from 1,000 m^3/s to 5,000 m^3/s.

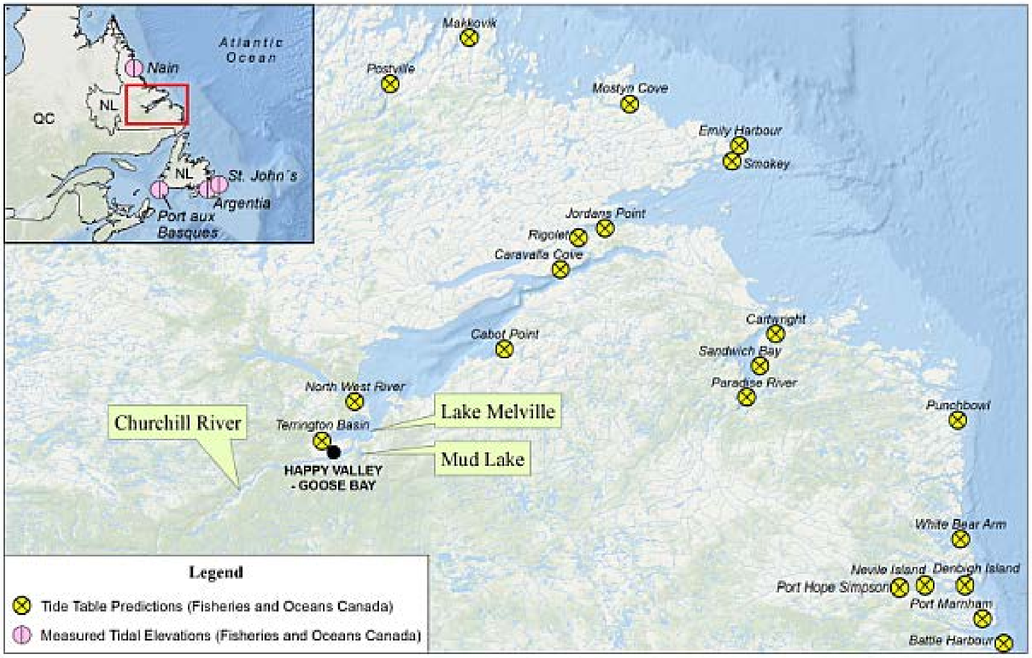
A comparison of the full year and open water data shows that the ice cover, as well as ice jamming on the Churchill River can have significant impacts on the stage-discharge relationship at both locations downstream of Upper Muskrat Falls. At 6.15 km downstream of Muskrat Falls, water levels as high as 4 m above the open water rating curve have been recorded under ice conditions for corresponding flows. At English Point, the water levels as high as 2.1 m above the open water rating curve have been recorded for corresponding flows.

6.6 TIDAL EFFECTS

The lower Churchill River is subject to tidal influence. However, due to the relative location of the lower Churchill River to the Atlantic Ocean, the influence is significantly reduced compared to the tidal effects along the coastline.

Annual tide tables are published for seven regions across Canada by the Department of Fisheries and Oceans. The tables predict the timing of daily high and low tides throughout the year. The locations with published tide estimates for the Lake Melville region are shown in Figure 6.8. The network of tidal gauges that record the actual tidal fluctuations in Eastern Canada is limited given the large geographic area and highly irregular coastline. The closest gauge to Happy Valley - Goose Bay is located in Nain, approximately 350 km to the north. The location of the Nain tidal gauge relative to the lower Churchill River is shown in Figure 6.8.

FIGURE 6.8
TIDE TABLE PREDICTIONS FOR THE LAKE MELVILLE REGION



The tidal prediction tables for the location closest to the mouth of the Churchill River at Melville Lake is the Terrington Basin. It shows that the maximum tidal range at this location is 0.75 m, compared to 2.03 m at Emily Harbour, for example.

6.7 WIND EFFECTS

Local residents from Mud Lake and the community of Mud Lake Road have indicated that significant wind events can cause an increase in water levels near Mud Lake. This increase of water levels, known as wind setup, occurs primarily during open water conditions and is governed by three main factors, specifically (1) the straight-line length of open water upon which the wind can push the water, known as fetch length, (2) the average depth of the water body upon which the wind is acting, and (3) the sustained wind speed acting in the fetch direction. While KGS Group did not carry out a detailed assessment of any historic wind setup events on Lake Melville, general conclusions regarding the potential for wind setup can be made given the bathymetry of Lake Melville and the fetch length along both Lake Melville and Goose Bay.

Two different conditions can result in wind setup near Mud Lake, specifically a north east wind that pushes water from the north east end to the south west end of Lake Melville, and a north wind that pushes water from the north end of Lake Melville into Goose Bay. The fetch length associated with a north east wind is approximately 100 km, and the average depth of Lake Melville, based on available navigation information, is approximately 100 m along the centreline of the lake. The fetch length associated with a north-north-east wind is approximately 60 km, with an approximate average depth of 50 m. According to Environment Canada Climate Normals for Goose Airport, the most common wind direction during April, May and June, and July are from the north east.

While it was not within the scope of this study to carry out a detailed analysis of the potential for wind setup on Lake Melville, wind conditions on September 20, 2007 provide an example of the potential for wind setup. Recorded wind speed at the Goose Bay Airport was sustained above 52 km/h from the north-north-east for over 6 hours. This sustained wind, which would have acted on the 60 km fetch length, would have resulted in a wind setup of at least 0.05 m. For greater sustained wind speeds in the same direction, a higher level of wind setup would occur.

In winter periods when Lake Melville is covered by ice, the shearing effects of wind on the water surface and the potential for wind setup are expected to be considerably less than in open water conditions.

6.8 PROPENSITY FOR FLOODING DUE TO ICE COVER FORMATION AND SPRING ICE JAMS

The Churchill River is wide and shallow. This is particularly true in the immediate study area near Mud Lake. This characteristic lends itself to significant rises in water level (herein referred to as “staging”) during both ice formation and ice breakup when movement and accumulation of fragmented ice occurs in the area.

Detailed analysis of river ice processes using computerized numerical models was not requested in the scope of work for KGS Group, nor would it be possible in the short timeframe allotted for this independent study. Nevertheless, KGS Group often uses a simplified empirical method to roughly estimate the potential for ice staging in a river. This technique has proven to be successful for KGS Group on other rivers and has been applied to the Churchill River near Mud Lake.

This simple technique involves the criteria presented in the now classic technical paper that was published in the American Society of Civil Engineers' Journal of Hydraulics (Pariset, Hausser, Gagnon, 1966). Based on their extensive experience with ice jams in Quebec, Pariset et. al. have shown that the following algorithm must not have a value greater than 0.0028 for an ice jam to form and remain in a stable stationary condition without washing downstream, or building to even higher stages.

$$\frac{(BV^2)}{(C^2H^2)} < 0.0028$$

where:

B is river width (ft)
V is velocity in the channel without an ice cover (ft/s)
C is Chezy C value of the ice covered river
H is the minimum stage (ft) to which the jam must occur for the cover to remain solidly in place

The stage at which this value becomes equal to or less than 0.0028 provides a simple means to roughly estimate the minimum water level for a given river flow that would be required to form a stationary ice jam due to the accumulation of fragmented ice. The technique shows that an ice jam could only stay in place at relatively high water levels in the lower river near Mud Lake, well above the top of the river banks. Actual stages in 2017, or in other years, may have been lower than the minimum theoretical stage for a stable ice jam for many reasons, including:

- Release of ice downstream into Lake Melville before the full ice jam could achieve a stable condition.
- Spillage of flow laterally out over the riverbanks so as to violate the assumptions of the constrained river course within the river banks.
- Ice cover not fully consisting of fragmented ice, with some large solid monolithic ice floes that cause the ice cover to be more stable than a melee of small fragments of broken ice.

- Length of the jam of fragmented ice may not have reached the minimum required to achieve the computed stages (a length equivalent to at least 2-3 river widths would be required).
- Combinations of the above.

Nevertheless, this analysis has demonstrated clearly to KGS Group that there is real potential for high stages during ice covered periods, particularly during the formation phase, as well as during the destruction stage, when accumulations of broken ice from upstream are unable to sweep through into Lake Melville.

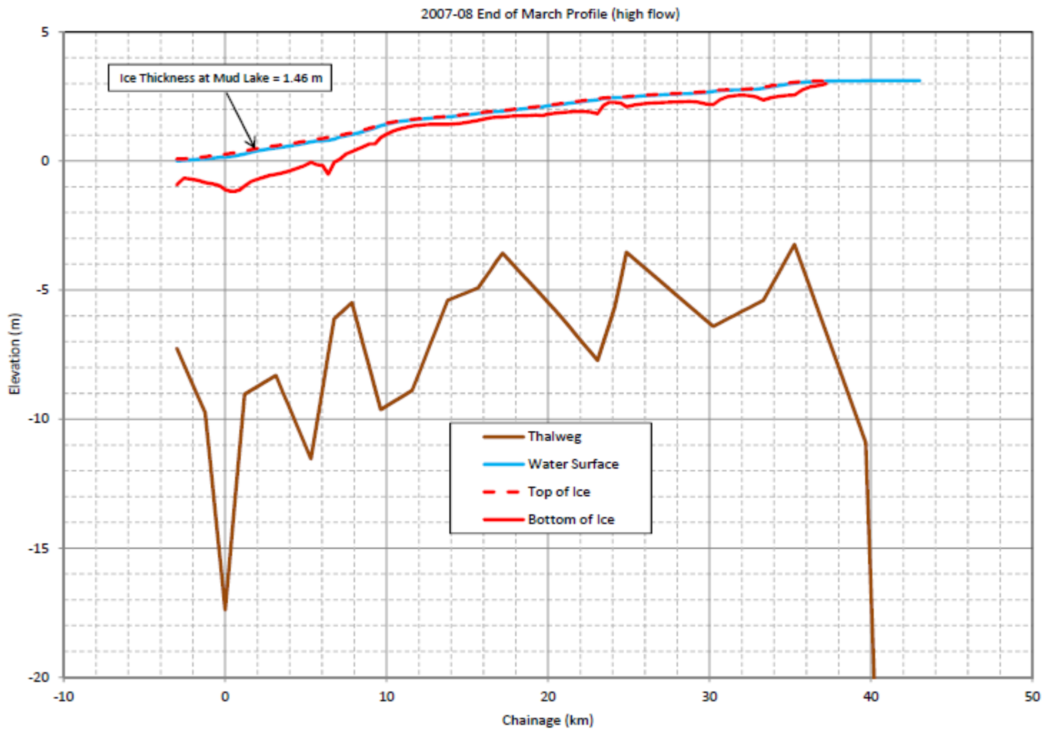
Because of this propensity for sudden substantial rises in water levels, and the low river banks and land adjacent to the river banks, it would be expected that flooding due to ice would have been a frequent problem at Mud Lake before 2017. This is supported by a series of newspaper clippings from "The Labradorian" since 1976 that were provided to KGS Group (Appendix D). They reveal that there has been a history of flooding at Mud Lake due to ice accumulations. From the events described in the newspaper articles, this seems to occur, on average, approximately once every 5 years. The most recent previous notable flood event was in 2012. Granted, the previously recorded flood levels were not as severe as that of 2017, however they clearly show a tendency that could be worsened by a chance combination of adverse factors.

KGS Group also examined, as part of this propensity for ice jamming and flooding, the gradient of the riverbed and river surface profile. Flattening of the river slope in the downstream direction could slow the river flow and decrease its capacity to keep ice runs moving. Reductions in the river gradient between Happy Valley – Goose Bay and Lake Melville would encourage the formation of ice jams, particularly in the spring. This is a well-known causative factor for ice jams in the Red River north of Selkirk, Manitoba, where the river gradient gradually declines as it approaches the delta area where it enters Lake Winnipeg. Ice jams are a constant threat each year in this vulnerable area.

The gradient of the Churchill River, as well as a profile of the thalweg (i.e. the deepest part of the river at any particular location) is shown in Figure 6.9. It demonstrates that there is no discernible flattening of the river slope as it approaches Lake Melville, and in fact the surface gradient actually steepens slightly in the last 10 km downstream of Happy Valley - Goose Bay.

It appears from this evidence that the river slope does not in itself contribute to reductions in flow velocity and ice jamming potential near Mud Lake.

FIGURE 6.9
RIVER GRADIENT FROM LAKE MELVILLE TO MUSKRAT FALLS

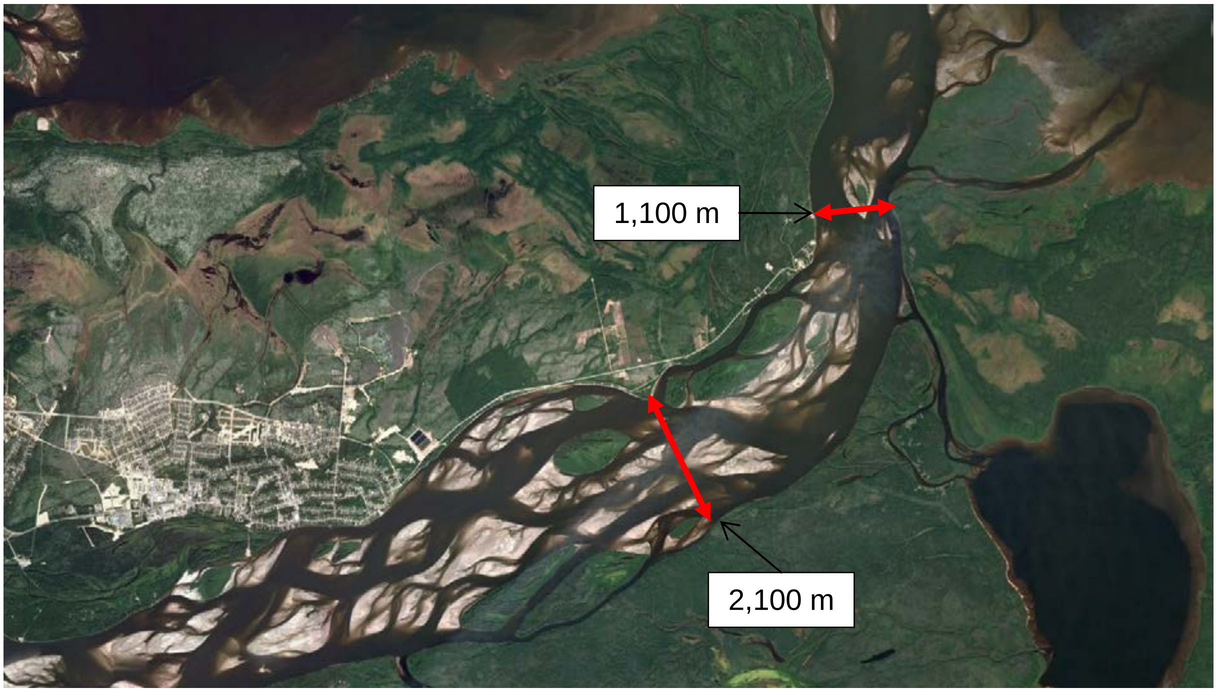


Source: Muskrat Falls Ice Study – 2013 Update Final Report (Hatch, 2013)

6.9 "BOTTLENECK" AT ENTRANCE TO MELVILLE LAKE

The lower river is vulnerable to flooding from ice jams, as described in Section 6.8. This appears to be compounded by the reduction in width of the river as it approaches and enters Lake Melville. The width decreases from over 2100 m to less than 1100 m near English Point, as shown in Figure 6.10. This bottleneck would tend to encourage the formation of an ice bridge in the early winter as ice pans begin to accumulate. The ice bridge would contribute to the potential for advancement of a leading edge of the ice cover upriver from English Point. This is described well in previous reports by the Hatch. Similarly, this natural funneling would tend to impede and delay the successful flushing of broken ice through the river into Lake Melville in spring. The effect of this funneling is difficult to credibly quantify with the current state of the art in river ice engineering. Nevertheless, it is considered to be a factor that can contribute to ice jamming and potential for staging due to ice.

FIGURE 6.10
MOUTH OF LOWER CHURCHILL RIVER AT MELVILLE LAKE

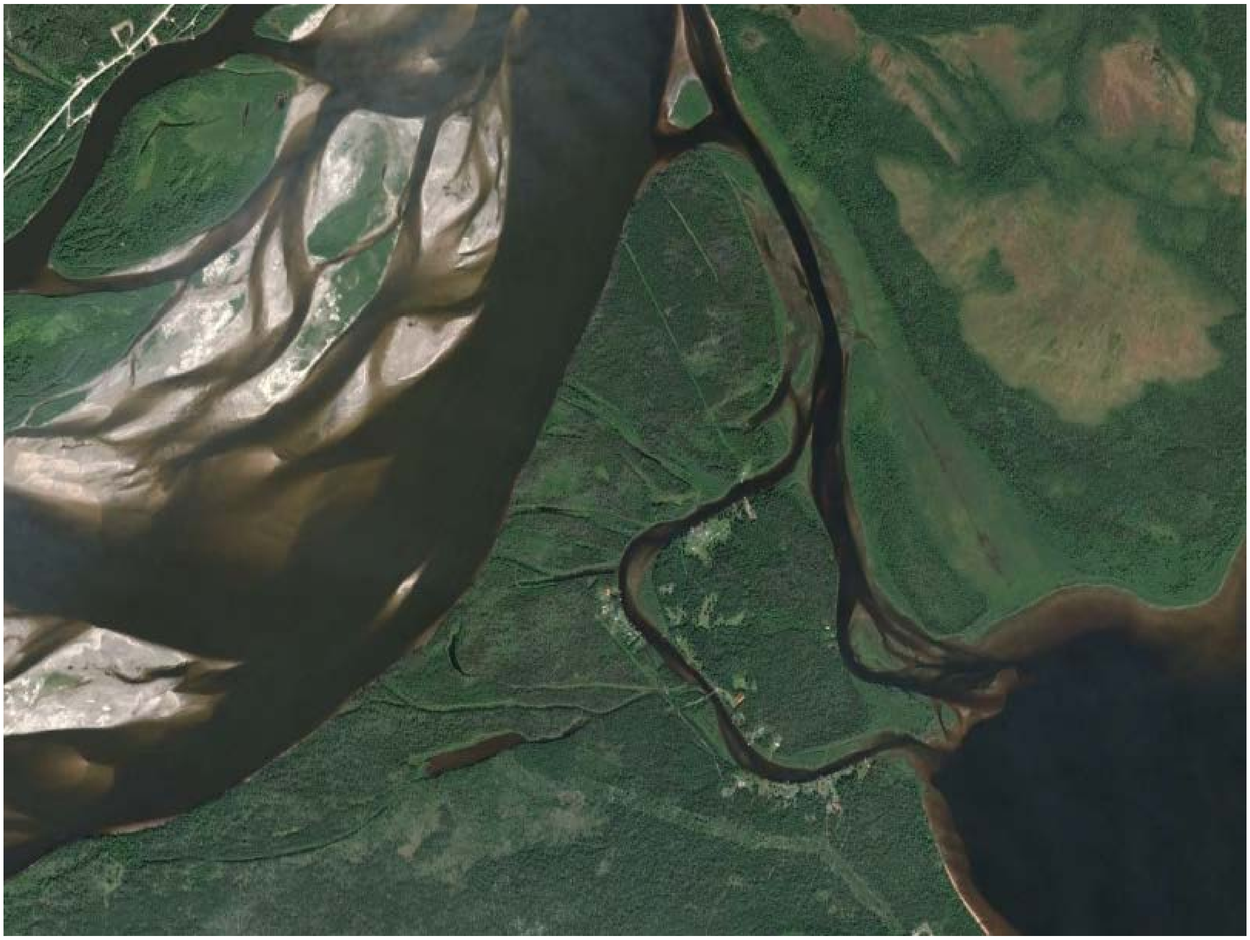


Source: Google, DigitalGlobe, CNES/Airbus (2017)

6.10 OVERFLOW FEATURES NEAR MUD LAKE

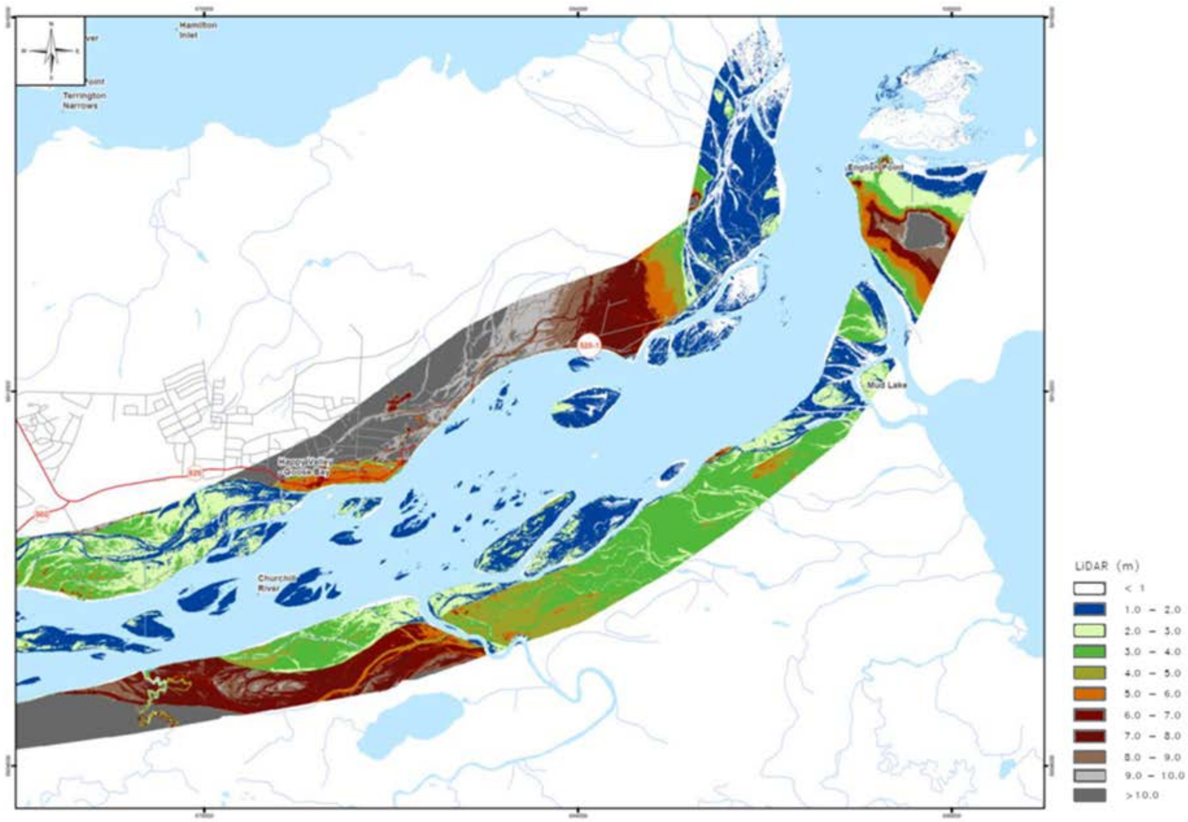
Examination of aerial photographs of the area and the available LiDAR data reveals the existence of several small side channels that emanate from the river along both shorelines. Figures 6.11 and 6.12 show these features.

FIGURE 6.11
OVERFLOW CHANNELS ALONG SHORE OF LOWER CHURCHILL RIVER NEAR MUD LAKE



Source: Google, DigitalGlobe (2017)

FIGURE 6.12
LIDAR SURVEY DATA ALONG BANKS OF LOWER CHURCHILL RIVER



These channels appear to be normally dry, or contain marsh lands and do not convey water during normal conditions in the river. They appear to be established routes where overflow from the river has periodically occurred historically in the past. It is difficult to confirm the dominant process that formed these channels, but they are likely a result of either or both:

- Overflow due to high stages from ice jams in the area, either during the ice formation phase or during ice runs and ice jam formation in spring.
- Overflow due to high stages during large floods, possibly combined with surges from Lake Melville or tidal effects.

It is clear that the area of Mud Lake has historically been prone to flooding, going back probably well before the establishment of the community of Mud Lake. This is consistent with the opinions reached as described in Sections 6.8 and 6.9.

6.11 TYPICAL ICE FORMATION PROCESSES IN THE LOWER CHURCHILL RIVER

Ice cover formation between Lake Melville and Muskrat Falls typically has followed the sequence listed below. This description is based on KGS Group's interpretation of the various ice reports that are listed in Section 2.0:

- Early formation of an ice cover on Lake Melville in late November or early December. This is normally a smooth ice cover typical of still water bodies.
- The relatively high velocities in the river upstream of Lake Melville typically prevents, to any major extent, the formation of a thermal ice cover as would be expected on the still waters of the lake downstream. Instead, ice that forms over most of the length of the river surface with a high velocity is swept downriver as slush ice pans that gradually coalesce and solidify.
- Advancement of the ice cover on the river upstream of English Point typically occurs by juxtaposition (the process of accumulating slush ice pans at the leading edge of an advancing ice cover), assisted to some extent by modest development of shorefast or border ice. The juxtaposition can either occur due to accumulation against ice on Lake Melville, or against an ice bridge that arches across the narrowing of the river near English Point (see Figure 6.10).

The formation of a stable ice cover near Mud Lake typically has occurred in late November / early December. There is a long record of the first date of crossing the river by snowmobile at Mud Lake. Review of the photographs of the river as well as the ice observation reports over the recent years suggests that the first crossing is within approximately one to two days of the establishment of an ice cover. The record of first snowmobile crossing has been used therefore as a proxy to indicate the ice cover formation each year since 1972. Table 6.1 provides a listing of the first snowmobile crossing each year. The ice cover formation typically has caused an abrupt rise in water level due to the impeding effect of the newly formed ice cover on the river flow. That ice cover normally forms from a combination of ice pans accumulating by juxtaposition, as well as thermally developed ice around or over sand bars and adjacent to the shore where velocities are low enough to permit lateral advancement of the border ice.

TABLE 6.1
DATE OF FIRST SNOWMOBILE CROSSING AT MUD LAKE

YEAR	FIRST SNOWMOBILE CROSSING DAY	YEAR	FIRST SNOWMOBILE CROSSING DAY	YEAR	FIRST SNOWMOBILE CROSSING DAY	YEAR	FIRST SNOWMOBILE CROSSING DAY
1972	22-Nov	1985	18-Nov	1996	01-Dec	2007	30-Nov
1975	25-Nov	1986	13-Nov	1997	23-Nov	2008	05-Dec
1976	17-Nov	1987	28-Nov	1998	30-Nov	2009	09-Dec
1977	30-Nov	1988	01-Dec	1999	23-Nov	2010	07-Jan[1]
1978	19-Nov	1989	24-Nov	2000	25-Nov	2011	02-Dec
1979	24-Nov	1990	01-Dec	2001	04-Dec	2012	02-Dec
1980	29-Nov	1991	02-Dec	2002	22-Nov	2013	02-Dec
1981	23-Dec	1992	19-Nov	2003	07-Dec	2014	24-Nov
1982	28-Nov	1993	13-Nov	2004	07-Dec	2015	01-Dec
1983	29-Nov	1994	27-Nov	2005	11-Dec		
1984	23-Nov	1995	29-Nov	2006	04-Dec		

Note: 1. First Snowmobile Crossing Occurred January 7, 2011

The ice cover then continues to advance upstream along the river by the process of juxtaposition of incoming ice pans that are swept along in the open water. Some areas are partially covered by border ice before the juxtaposition process reaches that location. The advancement usually reaches the high velocities at the foot of Muskrat Falls within a few weeks of the initialization near Mud Lake. The advancement of the ice front is temporarily halted at Muskrat Falls, where the high velocities over the falls cause the incoming ice on the river surface to be drawn under the advancing ice cover to form a massive hanging ice dam. In some years there is enough ice produced upstream of Muskrat Falls to permit the falls to be drowned out by the hanging ice dam. As discussed in Section 8.0, this hanging ice dam will cease to form after the reservoir has been fully impounded at Muskrat Falls.

6.12 TYPICAL ICE BREAKUP BETWEEN MUSKRAT FALLS AND LAKE MELVILLE

Based on KGS Group's review of the various reports that describe the natural processes on the river, the breakup of the ice has typically been as described in the ice observation report of 2015-2016 by SNC Lavallin. The following is a quotation from that report:

> "*Open water first appeared in the river originating from Mud Lake and along the northern bank of the Churchill River, just east of Happy Valley-Goose Bay, on May 10. Ice cover conditions remained the same until May 15, where new leads developed and existing leads widened. The ice cover rapidly deteriorated beginning May 16. Most of the Mud lake area was ice free by May 19 while ice cover remained on Lake Melville. The ice below Muskrat Falls was extremely thick and this is typically the last area in the lower reach of the Churchill River to become ice free*."

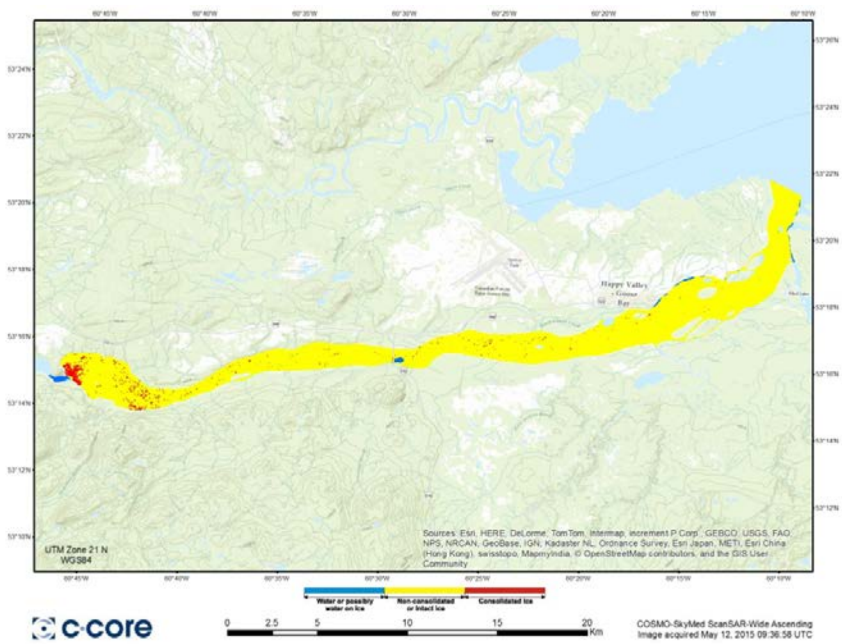
The key feature of this succinct description is the initial breakup of ice and formation of open water areas in the reach near Mud Lake, prior to the influx of the bulk of broken ice from upstream of Happy Valley – Goose Bay. The ice runs from the upstream reaches of the river would then be able to pass by the Mud Lake area into Lake Melville without undue hangup and jamming.

Opening of the river first near Mud Lake appears to have been the typical pattern under normal river conditions. This sequence of normal ice breakup is typified by the observations of the river in the spring of 2015, and shown in a series of maps from the 2014-2015 Ice Observation Report by C-Core. Figures 6.13, 6.14, and 6.15 illustrate the ice extents on May 12, 2015, May 20, 2015 and, May 23, 2015 respectively. Although they are only snapshots of the evolution of the breakup and widely separated in time, they do demonstrate the typical breakup sequence. Shielding of the Mud Lake area from early inflows of broken ice from upstream would typically have been due to factors that include:

- Only a modest rate of rise in river flow that does not cause early breakup of the river upstream of Happy Valley - Goose Bay; this appears to be potentially assisted to some extent by the new Blackrock Bridge that was completed near Happy Valley - Goose Bay in 2010. The bridge may have the ability to restrict ice movement downstream to the width of the bridge opening, thereby delaying the influx of ice to the Mud Lake area.
- Slow melting / breakup of the massive hanging ice dam that had, under natural conditions, formed downstream of Muskrat Falls, extending downriver typically from approximately 4 to 10 km below the falls.
- Extended periods of ice deterioration before the onset of spring runoff.

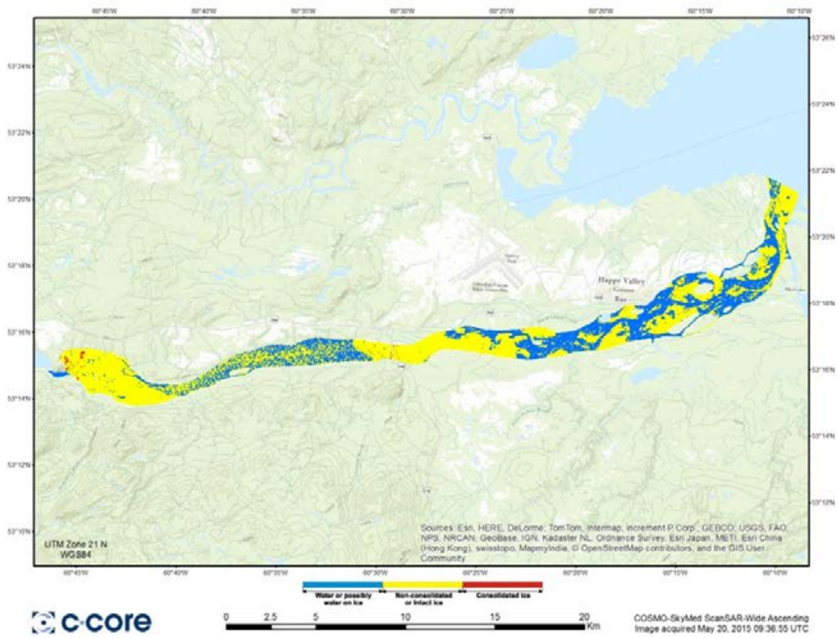
Without these shielding effects, the river near Mud Lake would become increasingly prone to ice jam formation during the transitory period of spring breakup. ***The larger and more sudden the influxes of broken ice from upstream are, the more susceptible the lower river to the formation of temporary ice jams would be.***

FIGURE 6.13
ICE CLASSIFICATION ON THE LOWER CHURCHILL RIVER (MAY 12, 2015)



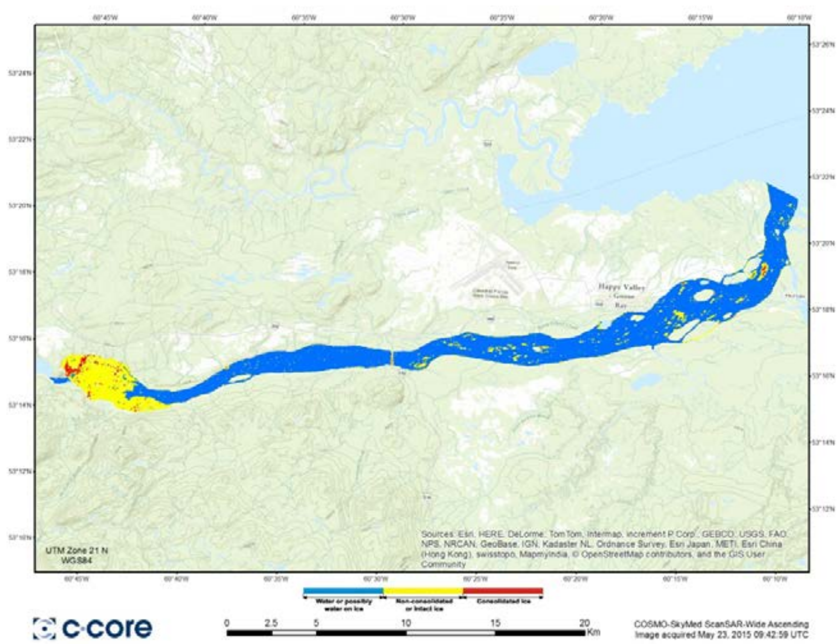
Source: 2014-2015 Ice Observation Survey Mud Lake Crossing, Lower Churchill River LC-EV-107 (Sikumiut Environmental Management Ltd., 2015)

FIGURE 6.14
ICE CLASSIFICATION ON THE LOWER CHURCHILL RIVER (MAY 20, 2015)



Source: 2014-2015 Ice Observation Survey Mud Lake Crossing, Lower Churchill River LC-EV-107 (Sikumiut Environmental Management Ltd., 2015)

FIGURE 6.15
ICE CLASSIFICATION ON THE LOWER CHURCHILL RIVER (MAY 23, 2015)



Source: 2014-2015 Ice Observation Survey Mud Lake Crossing, Lower Churchill River LC-EV-107 (Sikumiut Environmental Management Ltd., 2015)

The effects of the elimination of the hanging ice dam at Muskrat Falls, and the potential for earlier spring release of ice where the hanging ice dam previously existed, have not been noted by KGS Group in any of the documentation available for this study.

7.0 MAY 17TH, 2017 FLOOD EVENT

As indicated in the introduction of this report, major flooding occurred along the Churchill River in central Labrador in May of 2017 that required the evacuation of residents from Mud Lake. The water levels along the Churchill River started increasing from the normal winter levels on May 11, 2017. Subsequently, the water levels began rising in Mud Lake on May 16, 2017. The peak of the flood occurred in the evening hours of May 18, 2017, then stabilized briefly at a level slightly lower than the peak water level until the early hours of May 19, 2017, and then receded gradually over the following weeks. This flood has been reported by the local residents as the worst flood in the history of their community. During the public consultations it was indicated that "*nothing was normal about the flood in May*", starting as early as the preceding fall when high flows occurred in the Churchill River, combined with spillway releases from Muskrat Falls and a high stage at freeze-up level on the river. KGS Group considered this information in comprehensive review of the recorded flows and water levels on the Churchill River that occurred from October 1, 2016 through to May 31, 2017 to develop a sound understanding of the flood event.

There are many water level and flow gauges operated by the Water Survey of Canada (WSC) within the Churchill River watershed. Many of the gauging stations have been discontinued over time; however, there are still a number of active stations. Figure 7.1 provides a map that shows all of the active and discontinued WSC gauging stations in the basin. To supplement the recorded information from WSC, flows and water levels were also provided by Nalcor for both the Churchill Falls Generating Station and the Muskrat Falls project site. The primary gauging stations that define the hydraulic conditions along the Churchill River from October 1, 2016 through to May 31, 2017 are listed in Table 7.1, ordered from upstream to downstream.

Typically the WSC recorded data that is obtained within the past 12 to 18 months is under review in quality assurance processes by WSC and is provided publically only as provisional data. Due to the critical nature of this review, WSC fast-tracked the quality review of the provisional data and provided published data to KGS Group for all those stations noted in Table 7.1.

Figure 7.2 shows a time series graph of the recorded flows and water levels along the main stem of the Churchill River for the recorded data listed in Table 7.1.

FIGURE 7.1
CHURCHILL RIVER WATERSHED – WATER SURVEY OF CANADA GAUGING STATIONS

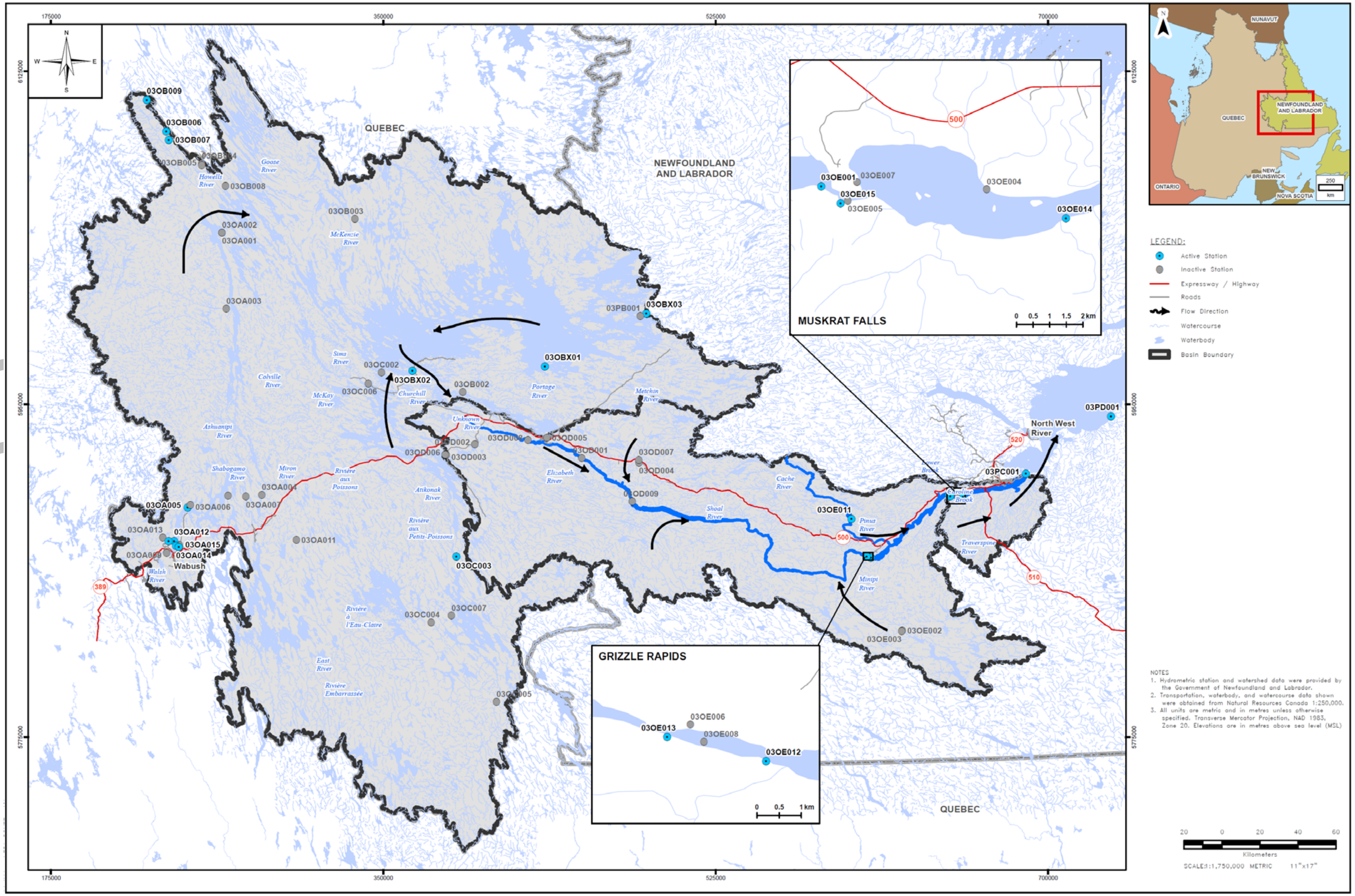
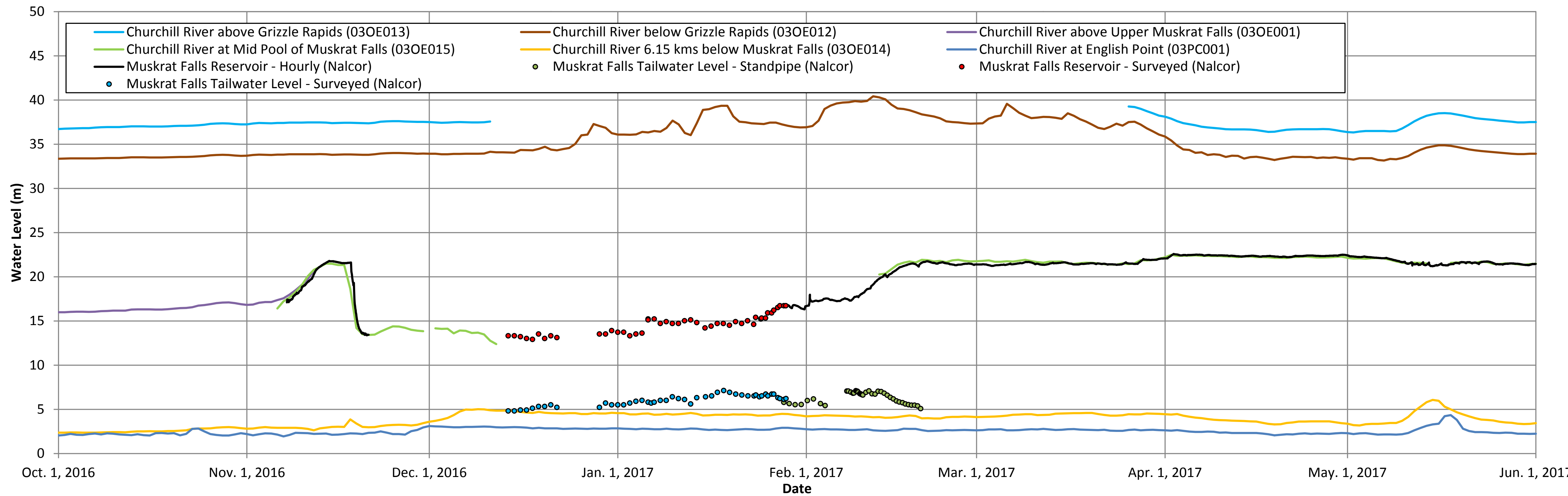
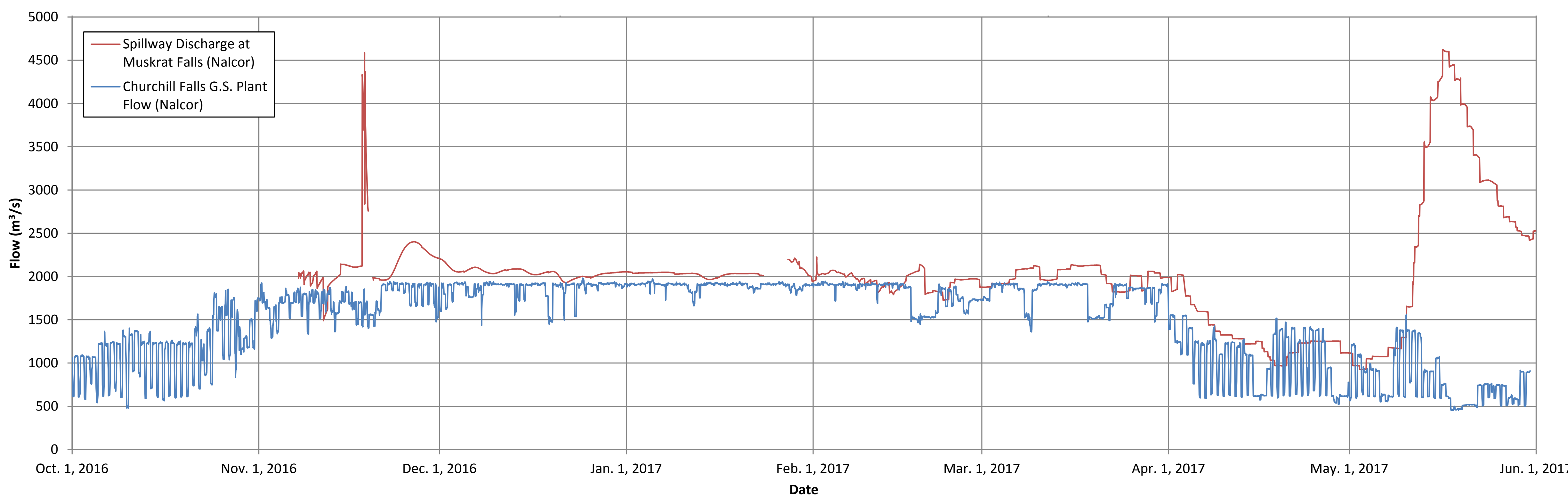


TABLE 7.1
HYDROMETRIC DATA SOURCES (OCTOBER 1, 2016 THROUGH TO MAY, 2017)

GAUGE NAME / NUMBER	DATA TYPE	SOURCE	NOTES
Churchill Falls G.S. Plant Flow (Note 1)	Hourly Flow	Nalcor	Continuous hourly data provided. No spillway flow at Churchill Falls during the time period.
Churchill River above Grizzle Rapids (03OE013)	Daily Water Level	Water Survey of Canada	Data Missing (Dec. 12 to Mar. 25)
Churchill River below Grizzle Rapids (03OE012)	Daily Water Level	Water Survey of Canada	Complete daily record available
Churchill River at Mid Pool of Muskrat Falls (03OE015)	Daily Water Level	Water Survey of Canada	Data from Dec. 12, 2016 to Feb. 13, 2017 was deemed unusable by WSC due to water levels being below gauge level.
Muskrat Falls Reservoir	Hourly Water Level	Nalcor	Gauge Data provided (Nov. 7 to May 31)
Muskrat Falls Reservoir	Water Levels	Nalcor	Surveyed reservoir levels provided during time that automated gauge data was not available. Non continuous record.
Spillway Discharge at Muskrat Falls	Flows	Nalcor	Nearly continuous record of spillway flows provided. Includes flows that were passed through operation of the spillway as well as uncontrolled flows through the spillway with all gates open.
Muskrat Falls Tailwater Level	Water Levels	Nalcor	Surveyed tailwater levels provided during winter period. Non continuous record.
Muskrat Falls Tailwater Level (Standpipe)	Water Levels	Nalcor	Standpipe levels provided for some days in February. Non continuous record.
Churchill River 6.15 kms below Muskrat Falls (03OE014)	Water Levels	Water Survey of Canada	Continuous daily record.
Churchill River at English Point (03PC001)	Water Levels	Water Survey of Canada	Continuous daily record. This data is not geodetic and provided on a local datum. As such it cannot be directly compared to the other recorded water levels. However the magnitude of change in the water levels are accurate.

FIGURE 7.2
CHURCHILL RIVER WATER LEVELS AND FLOWS (OCTOBER 1, 2016 THROUGH TO MAY 31, 2017)





The following observations were based on a review of the water levels and flows shown in Figure 7.2. The observations start at the upstream reach at the Churchill Falls G.S., moving progressively downstream to English Point.

Churchill Falls G.S. Outflows

- The Churchill Falls plant outflows can vary hour by hour in any given day, however they are maintained generally at the same flow rate for certain time periods.
- The flows in October and November averaged around 1,300 m^3/s, then on November 21 rose and continued at an average of 1,900 m^3/s throughout the winter until late March.
- In late March the outflows from Churchill Falls were reduced to an average of about 900 m^3/s for April and early May. During this time the outflows ranged between 600 m^3/s to 1,550 m^3/s.
- On May 17, the outflows were reduced to an average of about 600 m^3/s, ranging from about 450 m^3/s to 900 m^3/s, to reduce the flow being conveyed downstream.

Water Levels above Grizzle Rapids

- The water levels above Grizzle Rapids were relatively constant through the fall of 2016.
- The water levels rise of about 0.75 m in mid to late December immediately preceding the gauge being taken out of operation. This rise is likely the result of winter staging.
- The gauge data picks up again in late May and shows a gradual reduction in level through to early April. This reduction in water level coincided with the reduced outflows from Churchill Falls G.S.
- The water levels remained relatively constant through to mid-May when they rise about 2 m from May 10th to May 18th. This rise in water level is likely caused by the local spring runoff from the drainage basin between the Churchill Falls G.S. and Grizzle Rapids, as the outflows from Churchill Falls G.S. were not increased at this time.

Water Levels below Grizzle Rapids

- The water levels at the gauge below Grizzle Rapids display very similar response as those upstream of Grizzle Rapids (described above).
- The recorded data below Grizzle Rapids is however continuous through the winter and shows signs of staging from ice from late December through to the early part of April.
- Similar to the gauge above Grizzle Rapids an approximate 2 m rise in water levels was recorded from May 10 to May 18.

Flows and Water Levels at Muskrat Falls

- The next location downstream on the river that the water levels were recorded is at the mid pool above Muskrat Falls, also referred to as the Muskrat Falls Reservoir now that the spillway is in operation. Since the spillway went into operation in the fall of 2016, flows were also recorded at this location by Nalcor.
- The recorded flows indicate that there was a sharp increase in spillway release on November 18 and 19. Over this period of time the spillway gates were fully opened to rapidly draw down the partially impounded reservoir. Just prior to the lowering of the reservoir levels, there were problems observed at the cofferdam across the main river channel. The reservoir levels were subsequently lowered on an emergency basis to bring down the reservoir levels from elevation 21.5 m to 13.5 m over the two days to allow for repairs to be done to the cofferdam. The recorded water levels at the WSC gauge as well as the reservoir levels recorded by Nalcor show this rapid draw down in water level.
- By November 21 the reservoir level was completely drawn down to pre-impoundment levels and the gates of the spillway remained open until early January when Nalcor began slowly impounding the reservoir again. The water level records between this time (i.e. November 21 and January 23) were not able to be recorded by the two automated water level stations on the reservoir, with newly installed equipment.
- The newly installed equipment was configured to operate and record levels that were expected throughout the winter. The newly installed gauges were setup with the orifice lines at El. 18.9 m and 21.5 m due to topographical features of the area and distance limitations, respectively. Therefore they can only record water levels above this elevation. The water levels between November 21 and January 23 were below the 18.9 m elevation, and as a result there was no data from these stations after reservoir drawdown.
- Water levels were however, recorded by alternate means during portions of this time. After the draw down on November 18th the original monitoring equipment at the mid pool station (WSC 03OE001) was reactivated as that station was able to report data in the pre-impoundment range. However, shortly after reactivation, there were large fluctuations in the water level readings. WSC reviewed this data and was able to provide water level records from November 21 through to December 12. It was noted by WSC however, that this data within this time frame was not produced to regular WSC standards for many reasons. Due to safety protocol at the dam site WSC were not allowed to be within 3 m of the water's edge thus WSC was unable to confirm the water level during site visits. Therefore, the gauges were set to and are corrected to water level observations supplied to WSC by Nalcor. In comparing some of the levels supplied by Nalcor versus the logged data WSC noted some differences which could be attributed to many factors such as water level surge and the location the water levels were taken in relation to the gauge. As well the possibility of slope (draw down) of the reservoir when gates are open. After December 12, the data from that gauge was deemed by WSC as unusable until the reservoir levels rose high enough on February 13.

- In addition to the WSC data, in mid-December, Nalcor engaged one of their contractors on site to begin daily survey measurements of the water level in the mid pool until January 23. After January 23, the automated gauges were able to record the data again.
- Over the period of time in which the spillway gates were fully opened and the reservoir was at pre-impoundment levels (i.e. November 21 to January 5) the recorded flows passed through the spillway were relatively constant near 2,000 m^3/s, which would be expected as the outflows from Churchill Falls remained fairly constant and around 1,900 m^3/s.
- There was however a very notable influx of flow between November 23 and December 3, when the flow rose and peaked at about 2,400 m^3/s. As noted above, during this time there were no spillway operations as all the gates were fully opened which suggests that this flux of water was passed through the Muskrat Falls project site from upstream. Based on the Churchill Falls G.S. outflows, there was not a flood peak released, so this would suggest that this peak was driven from local runoff between Churchill Falls and Muskrat Falls.
- Between January 5 and February 23, the spillway gates were operated to increase the water level in the reservoir in a gradual manner. The recorded water level data illustrates this rise in reservoir level, while the flow record shows a gradual reduction of flows being passed through the spillway from about 2,000 m^3/s to about 1,750 m^3/s while the Churchill Falls outflow remained relatively constant.
- Between February 23 and March 27 the reservoir level remained constant at El. 21.5 m and the spillway was operated to maintain that level passing the inflow through the site. Between March 27 and April 7, the spillway was operated to raise the reservoir level to EL. 22.5 m. Between April 7 and May 11 the reservoir level was once again held constant and the spillway was operated to maintain that level passing the inflow through the site.
- In early April, the spillway flow records show a reduction of flows from about 2,000 m^3/s to an average of about 1,150 m^3/s by about April 16. This reduction of flow corresponds to the flow reduction from Churchill Falls G.S.
- Between April 30 and May 12 the spillway gates were operated to reduce the reservoir levels from El. 22.1 m to 22.5 m. The information provided to the downstream stakeholders by Nalcor indicates that this was done to ensure the water levels upstream of the project would not increase above El. 22.5 m due to the spring runoff. The reservoir levels were then held relatively constant at El. 21.5 through past the end of May.
- On May 10 the flows at Muskrat Falls began to increase quickly, peaking at a maximum outflow of 4,624 m^3/s on May 16.
- During the initial days of the rising limb of the flood hydrograph the reservoir level was reduced from El. 22.5 m to 21.5 m between April 30 and May 12 (as noted above). This reduction of 1.0 m in reservoir level would have added approximately 46,000,000 m^3 of water to the spring flood peak. Averaged over the those 12 days in which the reservoir was lowered result in a modest increase of 44 m^3/s to the flow passed through the Muskrat Falls spillway during that time (less than 1% of the peak flow). Any possible

effects related to the operations of Muskrat Falls between the fall of 2016 and the flood in May of 2017 are described in Section 8.2.

- After May 12, the reservoir level was maintained at a constant elevation of 21.5 m, which means that the high peak flows being passed through the spillway in the days following were simply the inflow to the reservoir from the upstream basin being passed through the project site. When considering that the outflows from Churchill Falls G.S. were generally held constant in the days leading up to the peak on May 17 and then further reduced on May 17, the influx of water could not be a result of a flow release at Churchill Falls. The water level records at Grizzle Rapids, described previously did however, show increase in water level of about 2 m at the time of the spring peak. This suggests that the influx of water to the Muskrat site was a result of runoff from the local basin between Churchill Falls G.S. and Muskrat Falls. This aspect is further described in Section 8.2.

Water Levels below Muskrat Falls (i.e. Muskrat Falls Tailwater Level)

- Tailwater levels at Muskrat Falls were provided over the winter period from December 14 through to February 19.
- These water levels show a gradual rise in the water level at the downstream side of Muskrat Falls, peaking in mid-January at El. 7.1 m. This is consistent with the continual growth of the hanging ice dam that forms downstream of Muskrat Falls.
- The data also shows that once the reservoir levels were nearly stabilized at El. 21.5 m that the tailwater started to reduce.

Water Levels at 6.15 km below Muskrat Falls

- The water levels recorded downstream of Muskrat Falls show a generally constant water level in the fall at approximately El. 3 m.
- The data shows a spike in water level on November 18 and 19 of about 0.9 m, as shown in Figure 7.3. This spike is a direct response of the sudden release of water from the Muskrat Falls reservoir. What is interesting to note however, is that on November 20, the water level at the gauge is reduced back to El. 3 m. This suggests that the effect of the large release of water from the Muskrat Falls forebay had only a very short term effect on the water levels in the lower Churchill River.
- The data does however show an increase of water level starting on November 29 through to December 7, in which the water level rose from El. 3.0 m to El. 5.0 m. This rise in river level on the lower river is a response of the influx of flow in late November described above, coinciding with the freeze up of the lower river which occurred over the same period of time. The water levels then ranged between El 4.0 m and El 4.6 m to the end of March.
- In early April, the water levels decreased to El. 3.5 m mainly due to the reduction of outflows from Churchill Falls and remained at approximately that level until May 10.

- On May 10 the water levels rose from El. 3.5 m to just over El 6.0 m on May 17 after which the levels declined back to El. 3.5m by the end of May, as shown in Figure 7.4. This rise was a result of the large flow that the Churchill River experienced, as well as the disrupting effect of temporary ice runs/jams, as described above.

FIGURE 7.3
CHURCHILL RIVER HOURLY WATER LEVELS 6.15 KMS D/S OF MUSKRAT FALLS (FALL 2016)

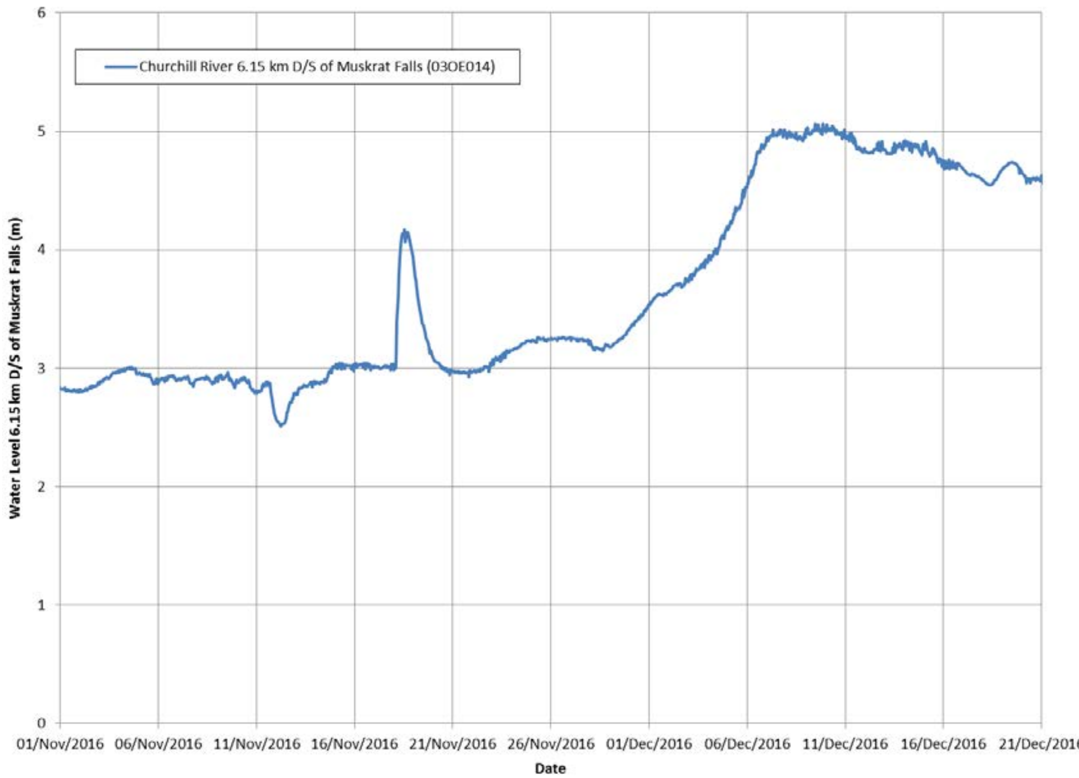
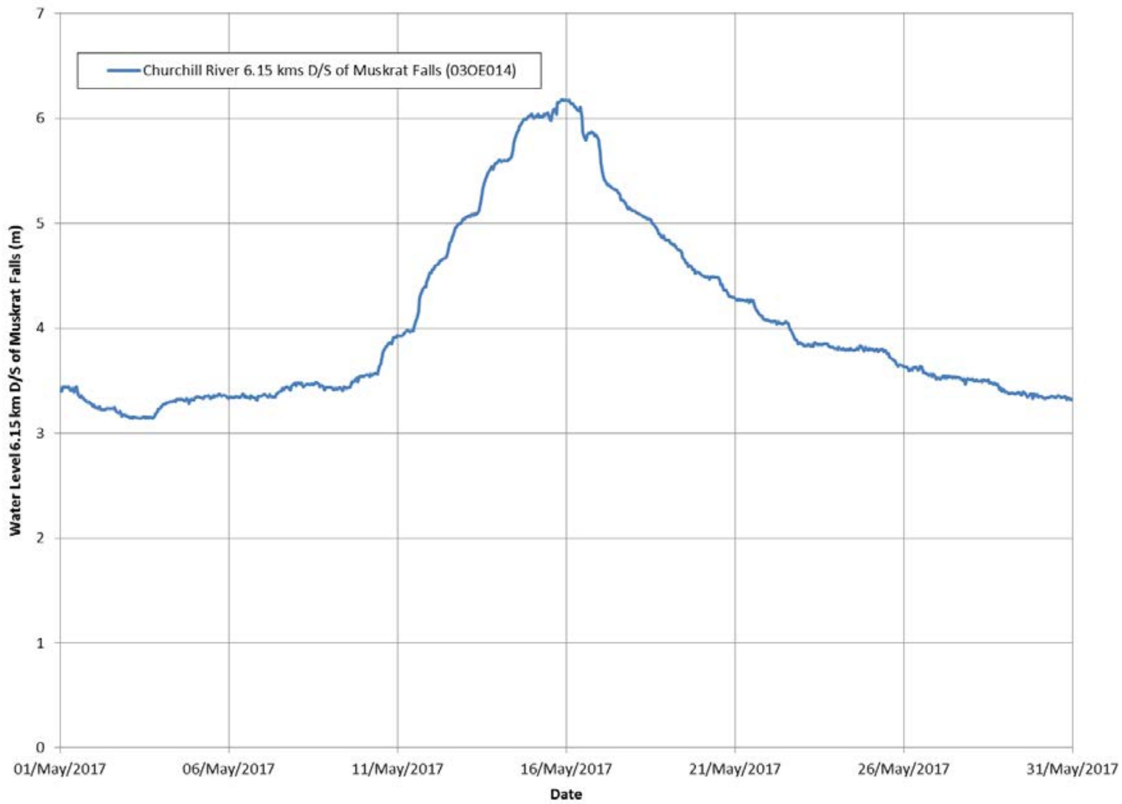


FIGURE 7.4
CHURCHILL RIVER HOURLY WATER LEVELS 6.15 KMS D/S OF MUSKRAT FALLS (MAY 2017)



Water Levels at English Point

- The water levels recorded at English Point show generally the same trend as the levels upstream at the gauge 6.15 km downstream of Muskrat Falls.
- It should be noted that the data from this gauge is not geodetically referenced so it cannot be compared directly to the upstream gauge, however, changes in water level will be accurate.
- Of particular interest is that unlike the water level response at the gauge 6.15 km downstream of Muskrat Falls, the water level record at English Point does not show any response or increase in water level associated with the sudden release of flow from Muskrat Falls on November 17 and 18, as shown in Figure 7.5. This would suggest that the effects of the release of water were fully dissipated by the time the flow reached English Point.
- The recorded data does show a sudden rise of about 1.0 m between November 28 and December 1, which coincides with both the influx of flow in late November and the freeze up of the lower river.

- Water levels gradually rose by 1.2 m between May 11 to May 16. During the early hours of May 16, the water levels suddenly rose by 1.0 m. The water level then gradually receded by 0.3 m between May 17 and May 18, then again suddenly rose by 0.9 m during the evening of May 18. Water levels then receded from May 19 to May 22, as shown in Figure 7.6. The sudden rises in water level were caused by ice jams/runs on the Churchill River.

FIGURE 7.5
CHURCHILL RIVER HOURLY WATER LEVELS AT ENGLISH POINT (FALL 2016)

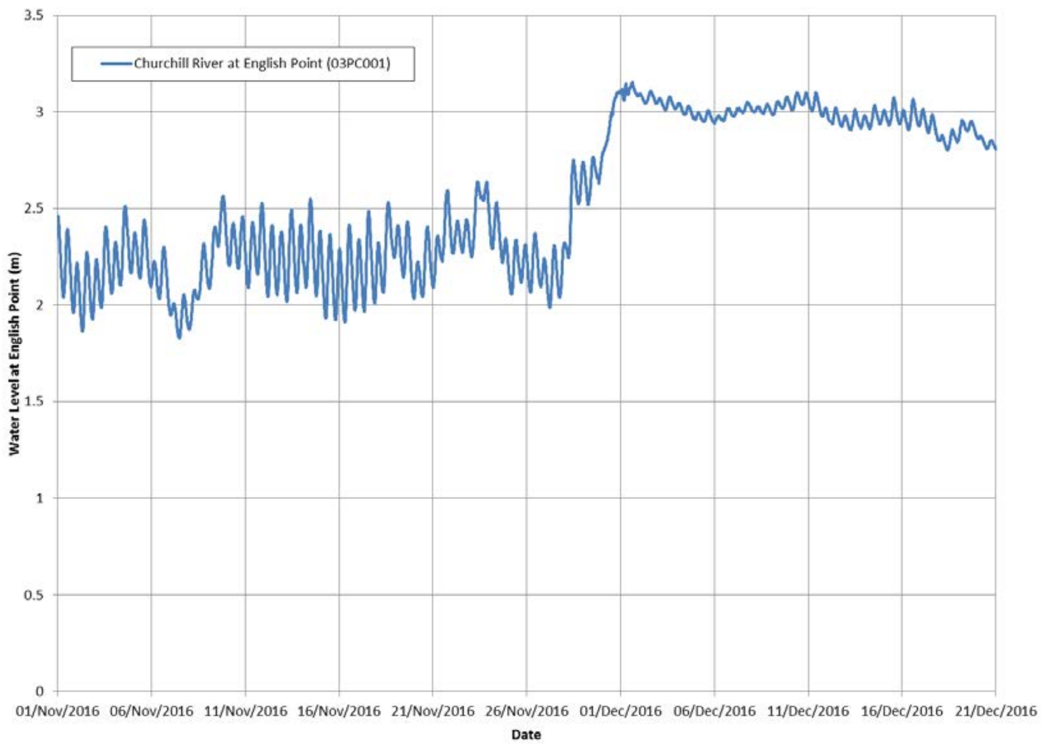
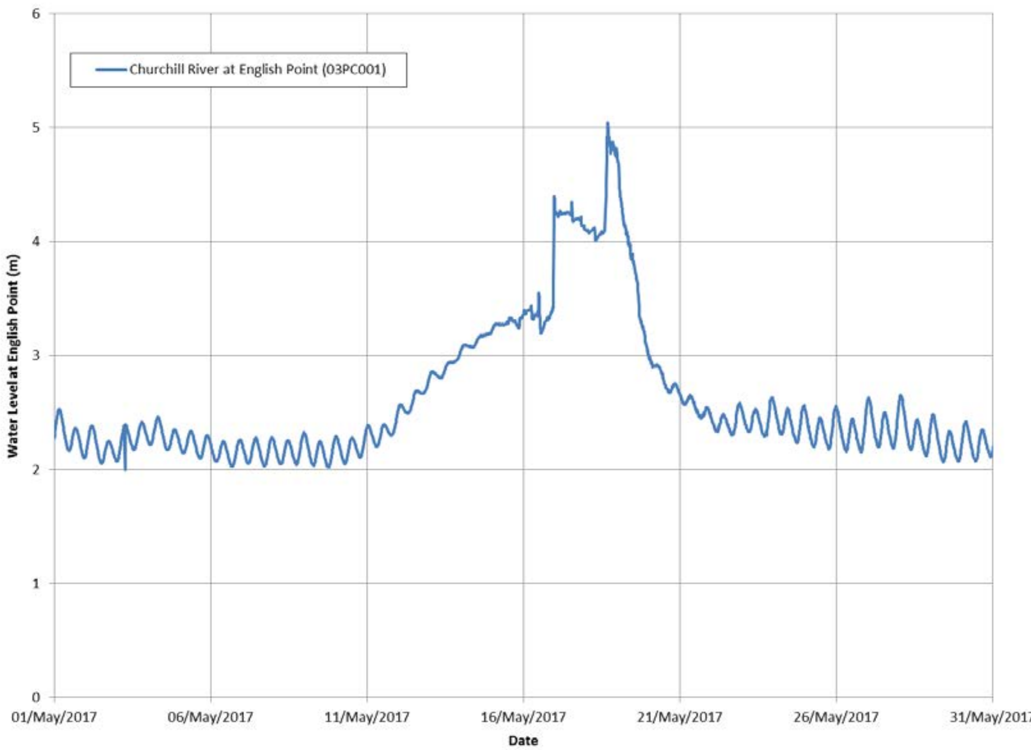


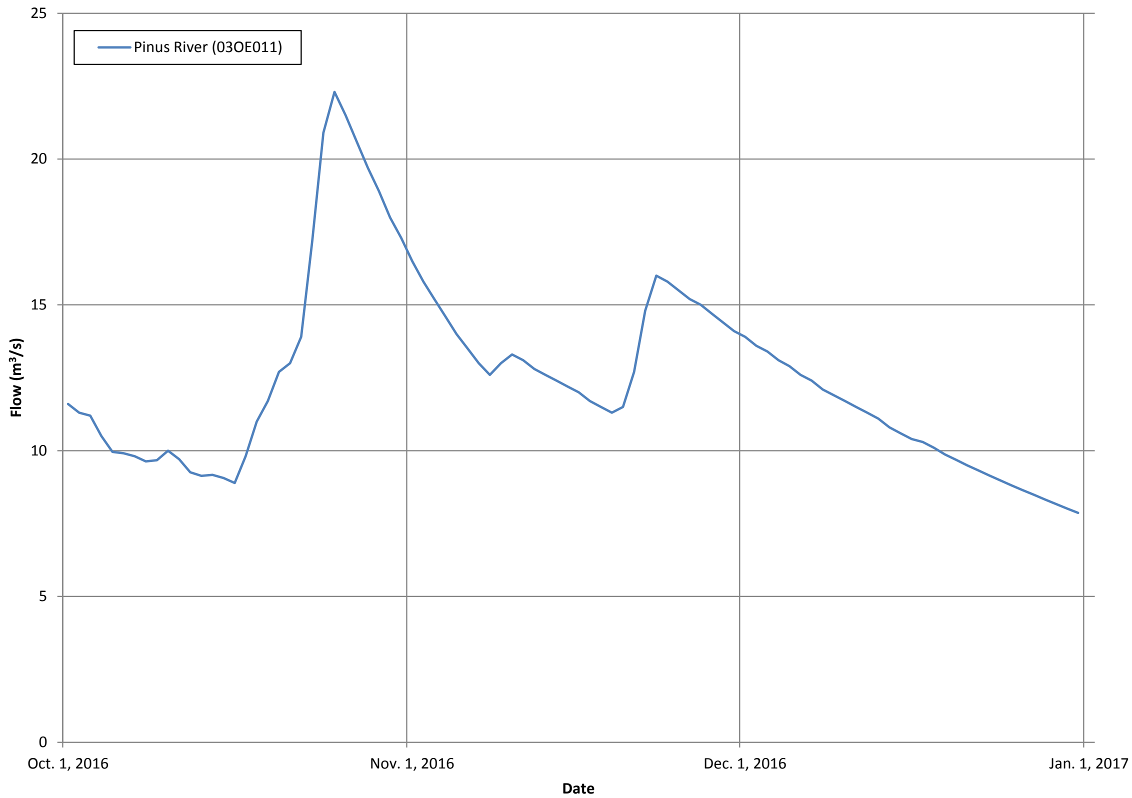
FIGURE 7.6
CHURCHILL RIVER HOURLY WATER LEVELS AT ENGLISH POINT (MAY 2017)



As described in the bullets above, the recorded data suggest that there were two flow peaks that passed Muskrat falls in November of 2016. The first peak was directly as results of the rapid draw down of the reservoir on November 18 and 19. The data downstream of Muskrat Falls showed that the water levels at 6.15 km below Muskrat Falls responded by rising 1.0 m and then quickly receding to the pre Muskrat Falls release levels. However, at English Point there was no recorded rise in water level, which suggests that the effects of the release of water had declined markedly by the time the flow reached English Point. Also of particular note is that at the time of the release from Muskrat Falls on November 18 and 19, the lower river was fully open and freeze up had not yet commenced.

The data suggests however that the second flow peak at the end of November was not a result of any releases from Churchill Falls or Muskrat Falls and therefore must have been a result of local runoff between Churchill Falls and Muskrat Falls. To further investigate this fact, recorded flows from any tributaries between Churchill Falls and Muskrat Falls were reviewed to see if they also show an increase in water level and flow at the end of November. Unfortunately the only tributary that had recorded flows in the fall of 2016 was the WSC gauge 03OE011 (Pinus River). Figure 7.7 shows the recorded flows at this gauge. As evident on Figure 7.3, the Pinus River also experienced an increase in flow at the end of November. This further supports that the peak flows passed downstream of Muskrat Falls were a response of runoff in the watershed downstream of Churchill Falls and Muskrat Falls. Further assessment of this late November flow peak is described later in this report in Section 8.1.

FIGURE 7.7
PINUS RIVER FLOWS (OCTOBER 1ST 2016 TO DECEMBER 31, 2016)



8.0 FACTORS LEADING TO THE MAY 17TH, 2017 FLOOD EVENT

Review of the official records, videos, photographs, reports, as well as testimonies by local residents has led KGS Group to conclude that the following events and conditions could have contributed to the flood event in 2017.

Some of the factors listed are difficult, or impossible to quantify reliably. Some must remain opinion, based on experience elsewhere, and left unsubstantiated with the extent of specific data now available for the Churchill River. In some instances, further analysis and study, outside of the scope of this review, may help to further clarify the causal effects of some potential factors. Any recommended additional studies or analyses have been identified where noted. Other aspects are readily able to be analyzed and tested scientifically with data in hand. Both categories of factors are discussed herein. A summary overview of the most dominant issues based on KGS Group's opinions is presented in Section 9.0

8.1 HYDROLOGIC CONDITIONS

In general in northern climates, the greater the spring runoff is to a river, and the earlier that runoff occurs, the greater is the potential for ice jam formation and flooding. Spring floods have long been a focus of scientific observation and forecasting in the Red River Valley of southern Manitoba. Four key factors have been identified as the main causes of high spring flood flows, and are the subject of flood forecasting techniques that have been effectively used in Manitoba and elsewhere. They are:

- Soil moisture content in the fall before freezeup, usually following, and a result of, heavy fall rains.
- Snow depth and snow-water equivalent at the end of winter, potentially able to melt and runoff to the river.
- Rate of snowmelt, driven mostly by the air temperatures after widespread snowmelt has commenced.
- Rainfall during the snowmelt period.

These are expected to be similar contributors to spring flood generation in the Churchill River watershed. Each has been examined with climatic data available for this study.

Soil Moisture Before Freeze Up

Specific data on soil moisture content and pooling in bogs in the drainage area between Churchill Falls and Mud Lake is not available. Nevertheless, it is clear that the boggy topography that comprises much of the drainage area upstream of Happy Valley – Goose Bay has a propensity to store water. However, a direct indication of the likelihood of high soil moisture and pooled water in bogs is the amount of rainfall that occurred prior to freeze up. Meteorological stations are located at a number of locations throughout the watershed, and are shown in a map in Figure 8.1. Table 8.1 provides a summary of the recorded data at the various stations that were examined.

TABLE 8.1
STATISTICS OF THE CLIMATE STATIONS WITHIN THE CHURCHILL RIVER WATERSHED

STATION NAME / NUMBER	DATA TYPE	SOURCE	NOTES
Schefferville (7117827) Schefferville A (7117823)	Daily Temperature, Precipitation and Snow Depth, Climate Normals	Environment Canada	Complete daily temperature, precipitation, and snow depth. Rainfall and snowfall data missing for Sept 2016 – Jul 2017. Climate Normals consider 1970 – 2000.
Wabush A (8504177)	Daily Temperature and Precipitation, Climate Normals	Environment Canada	Approximately 50% of the daily temperature and precipitation data are missing. Climate Normals consider 1980 – 2010.
Churchill Falls A (8501131)	Daily Temperature and Precipitation, Climate Normals	Environment Canada	Approximately 50% of the daily temperature and precipitation data are missing. Climate Normals consider 1970 – 2000.
Goose A (8501900)	Daily Temperature, Precipitation, rainfall and snowfall, Monthly Precipitation and Snow Depth, Climate Normals	Environment Canada	Complete daily and monthly records available. Climate Normals consider 1980 – 2010.
Moose Head Lake 16 (Wabush)	Hourly Temperature & Rainfall	Government of Newfoundland and Labrador Department of Municipal Affairs and Environment	Hourly temperature and rainfall record available from Aug. 21, 2016 – Jul. 26, 2017. Missing data between Oct. 20, 2016 and Nov. 8, 2016.

TABLE 8.1 (CONTINUED)
STATISTICS OF THE CLIMATE STATIONS WITHIN THE CHURCHILL RIVER WATERSHED

STATION NAME / NUMBER	DATA TYPE	SOURCE	NOTES
Churchill Falls 23 (Churchill Falls)	Hourly Temperature & Rainfall	Government of Newfoundland and Labrador Department of Municipal Affairs and Environment	Hourly temperature and rainfall record available from Jun. 9, 2016 – Jul. 26, 2017.
Cache River 17 (Cache River)	Hourly Temperature & Rainfall	Government of Newfoundland and Labrador Department of Municipal Affairs and Environment	Hourly temperature and rainfall record available from Aug. 21, 2016 – Jul. 26, 2017. Missing data between Oct. 20, 2016 and Nov. 8, 2016.
Muskrat Falls (NLENCL0006)	Hourly Temperature, Precipitation, Rainfall and Snowfall	Government of Newfoundland and Labrador Department of Fisheries and Land Resources	Complete hourly temperature, precipitation, rainfall and snowfall data available from Jul 19, 2014 – Jun. 29, 2017.
Mud Lake Crossing (NLENCL0004)	Hourly Temperature, Precipitation, Rainfall and Snowfall	Government of Newfoundland and Labrador Department of Fisheries and Land Resources	Complete hourly temperature, precipitation, rainfall and snowfall data available from Aug. 7, 2010 – Jun. 29, 2017.

The total monthly rainfall was compared to the climate averages at a number of the climate stations, as shown in Figures 8.2 to 8.4. Of particular interest is that the monthly total rainfall at Goose Bay Airport station shown in Figure 8.2 indicates that the total rainfall that occurred in November before freeze-up was almost twice the long term average at the Goose Bay airport. A comparison of the monthly rainfall data for the Cache River and Moose Head Lake provincial climate stations to the Climate Normals at the nearby Environment Canada Churchill Falls Airport (Churchill Falls A) and Wabush Airport (Wabush A) climate stations is shown in Figures 8.3 and 8.4. Although notably incomplete (i.e. missing a significant number of days of record), these figures illustrate that the rainfall in October was near to greater than average, while the rainfall that fell in November was well above average. Even with the missing data the rainfall that fell in November is over 400% of the normal long term average.

FIGURE 8.1

CLIMATE STATIONS WITHIN THE CHURCHILL RIVER WATERSHED

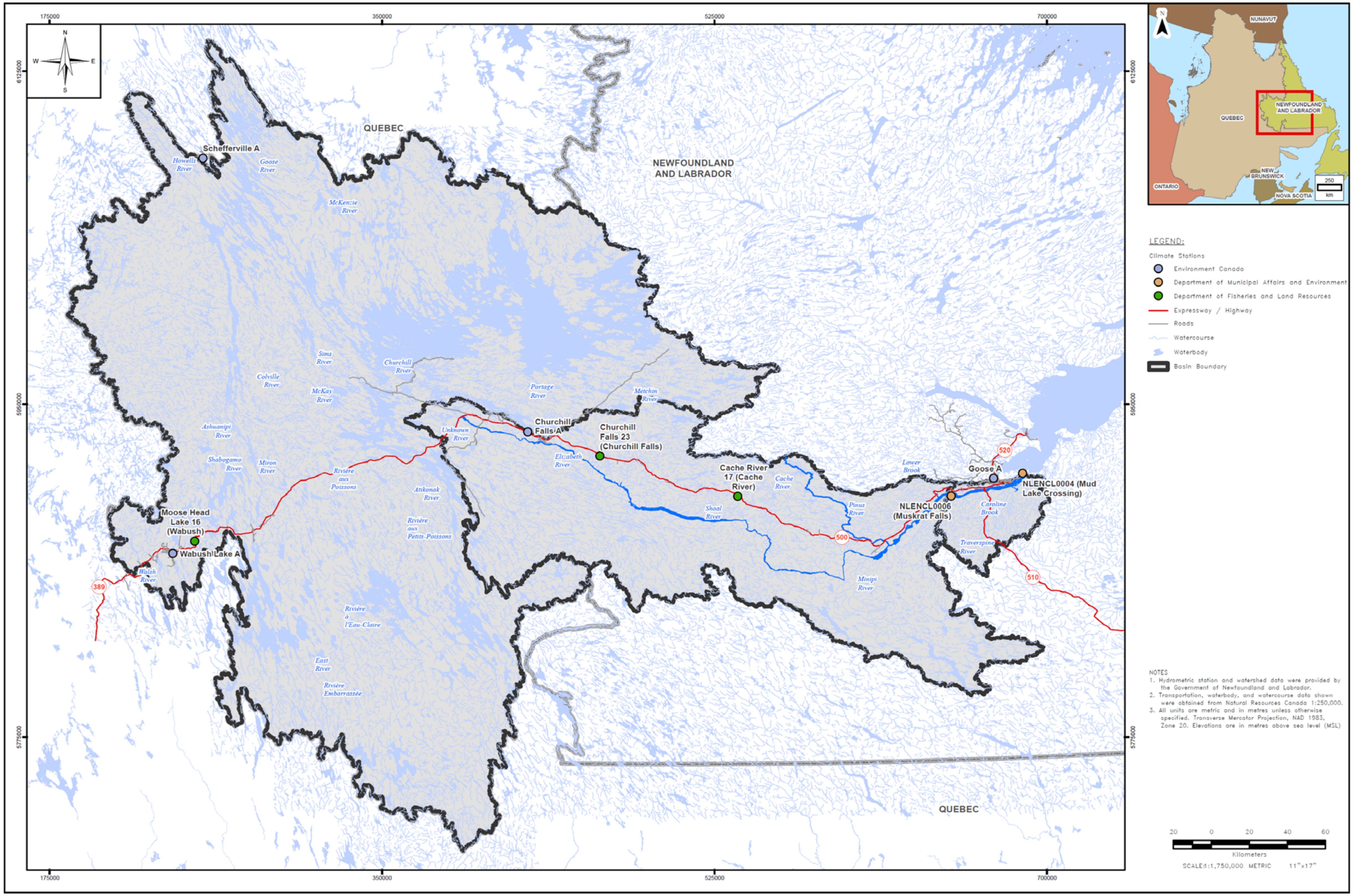


FIGURE 8.2
MONTHLY RAINFALL AT GOOSE BAY AIRPORT

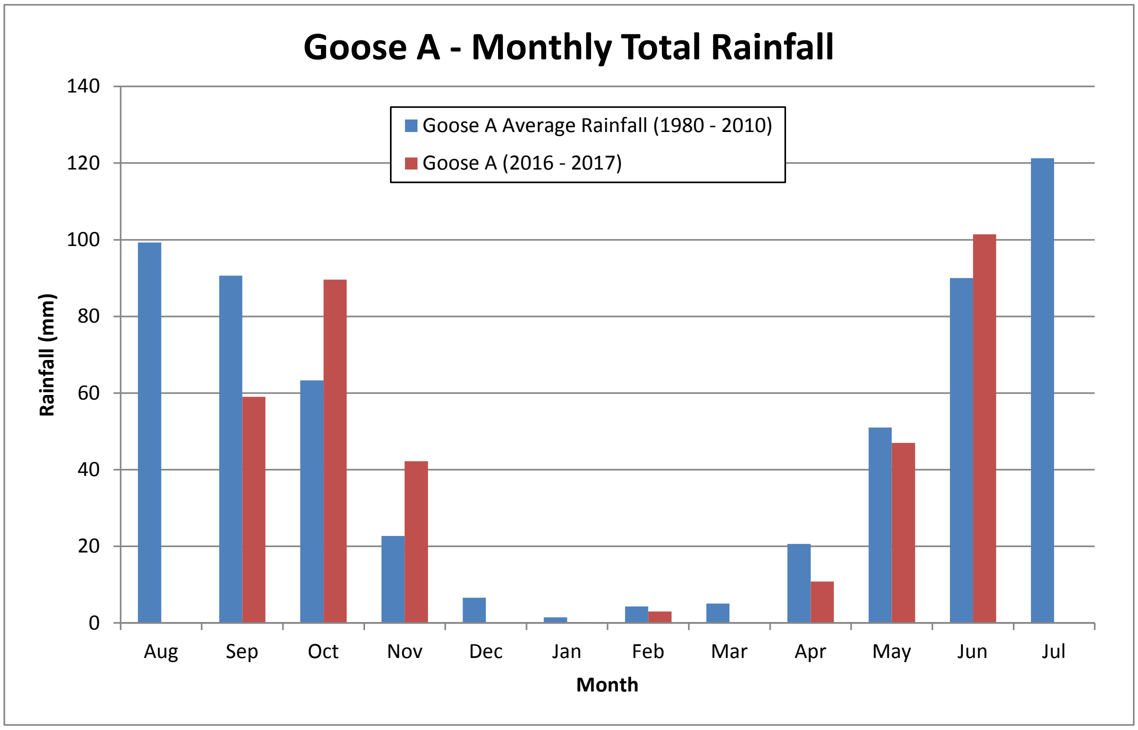


FIGURE 8.3
MONTHLY RAINFALL AT CACHE RIVER

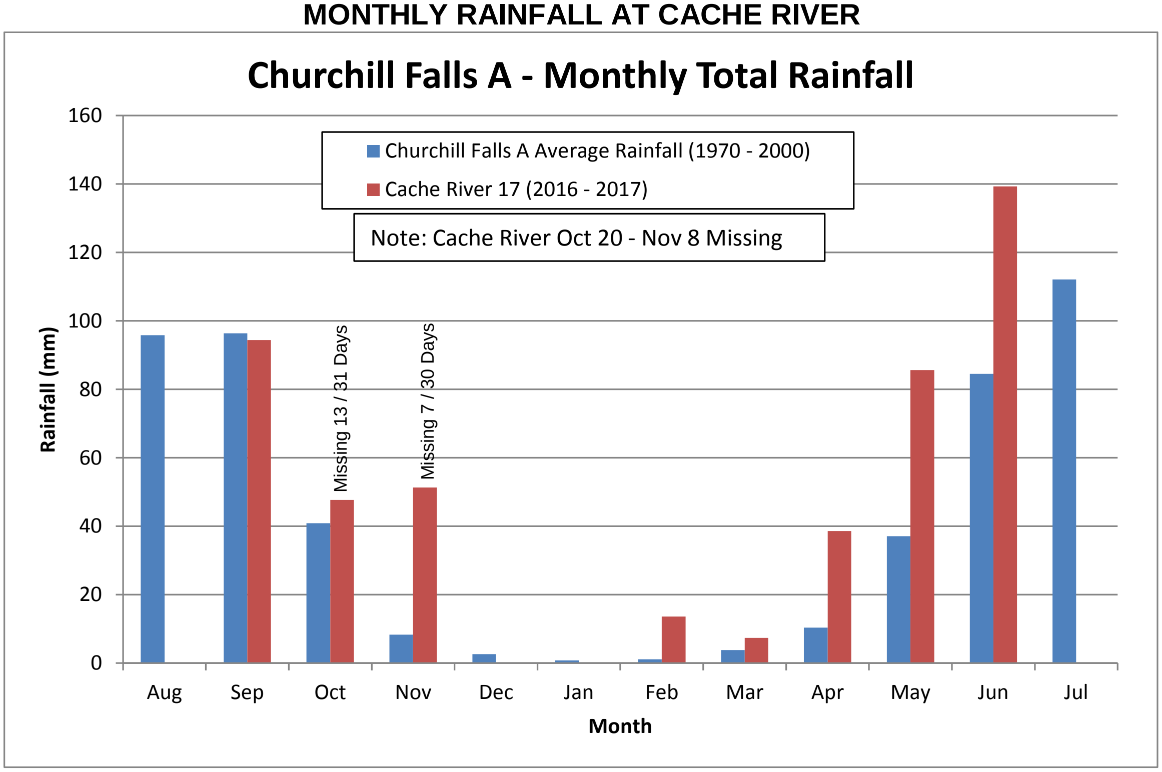
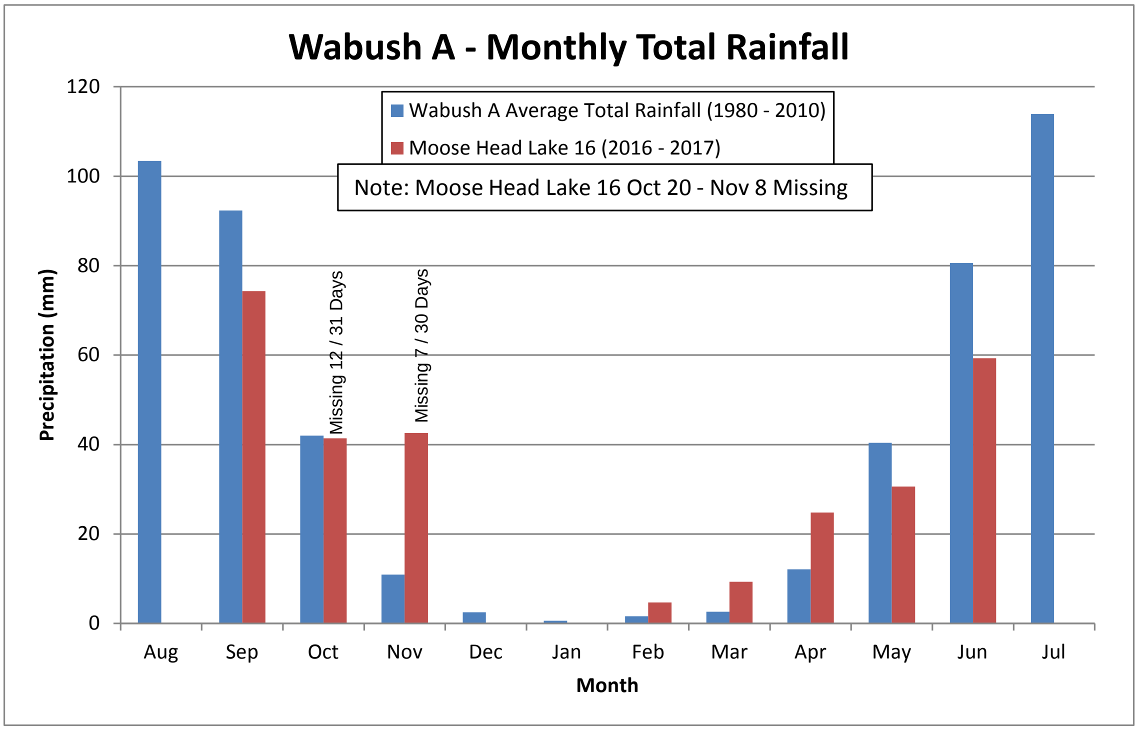


FIGURE 8.4
MONTHLY RAINFALL AT WABUSH AIRPORT



The recorded data clearly shows significantly greater than normal precipitation in November in the lower Churchill watershed, compared to the long term average, including the area between Churchill Falls and Muskrat Falls. This evidence indicates that the watershed would almost certainly have experienced abnormally wet antecedent conditions going into freeze up, and that would have carried through to the spring season. It is KGS Group's opinion that this would have intensified runoff potential due to snowmelt and rainfall, and would have generally added to the water that would tend to run off in spring.

The significantly greater than normal rainfall in November also supports the notion presented in Section 7.0. It was suggested there that the peak flows that passed downstream of Muskrat Falls in late November at the start of freeze up on the lower Churchill River was a response of runoff in the watershed downstream of Churchill Falls and Muskrat Falls. To further confirm this, the precipitation and rainfall data for the Goose Bay Airport, Cache River, Muskrat Falls, and Mud Lake Crossing climate stations was shown as cumulative precipitation and rainfall through the months of October and November and shown in Figures 8.5 to 8.8.

FIGURE 8.5

CUMULATIVE PRECIPITATION AND RAINFALL AT GOOSE BAY AIRPORT (OCTOBER AND NOVEMBER 2016)

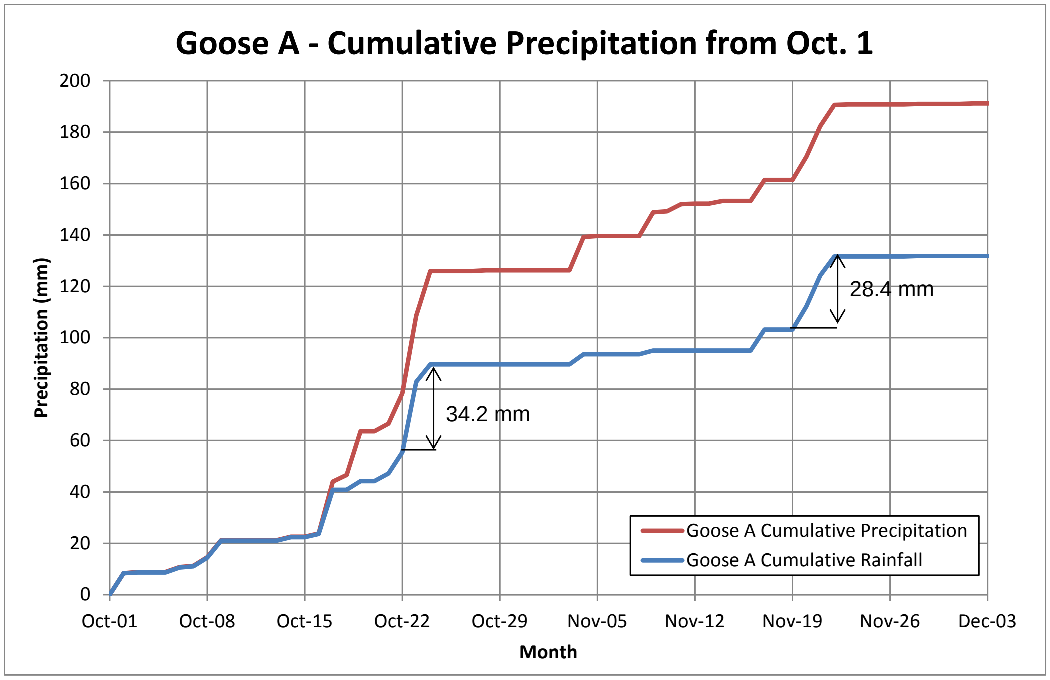


FIGURE 8.6

CUMULATIVE PRECIPITATION AND RAINFALL AT CACHE RIVER (OCTOBER AND NOVEMBER 2016)

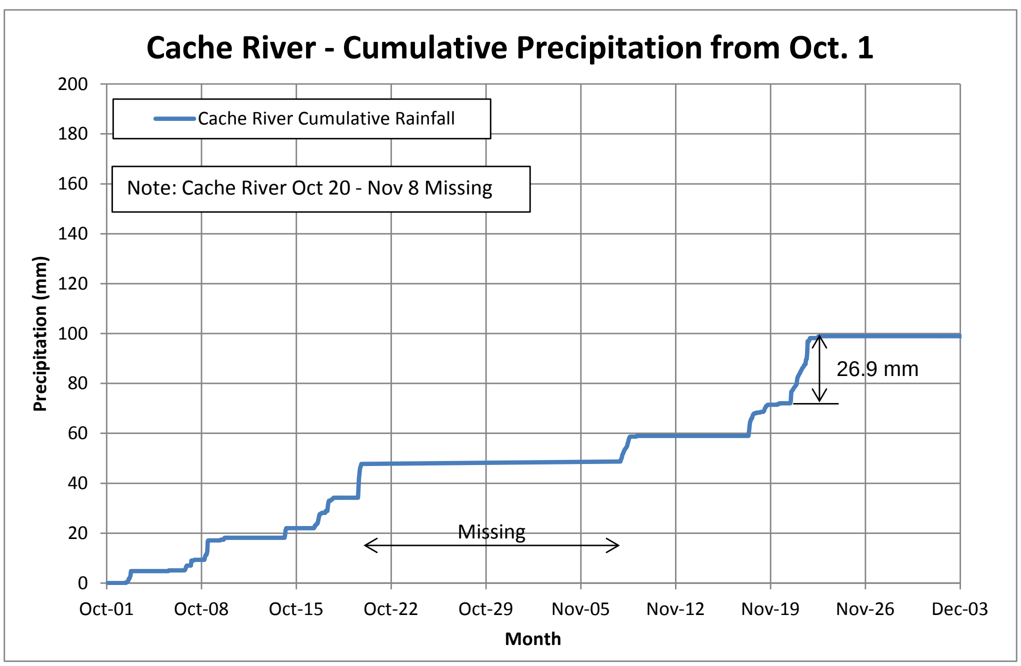


FIGURE 8.7
CUMULATIVE PRECIPITATION AND RAINFALL AT MUSKRAT FALLS (OCTOBER AND NOVEMBER 2016)

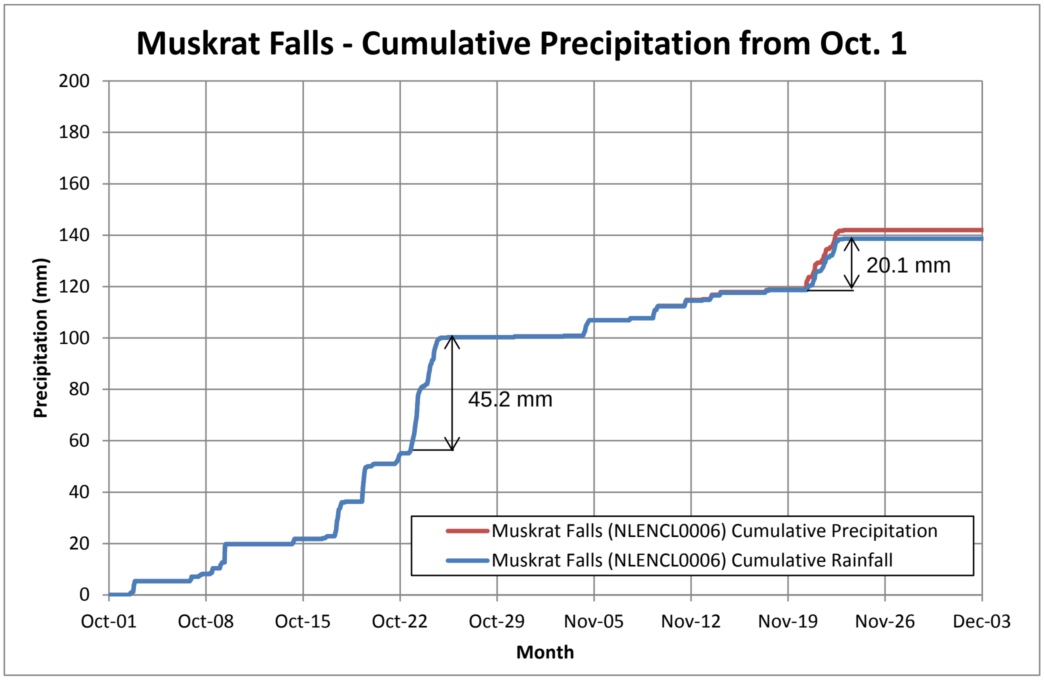
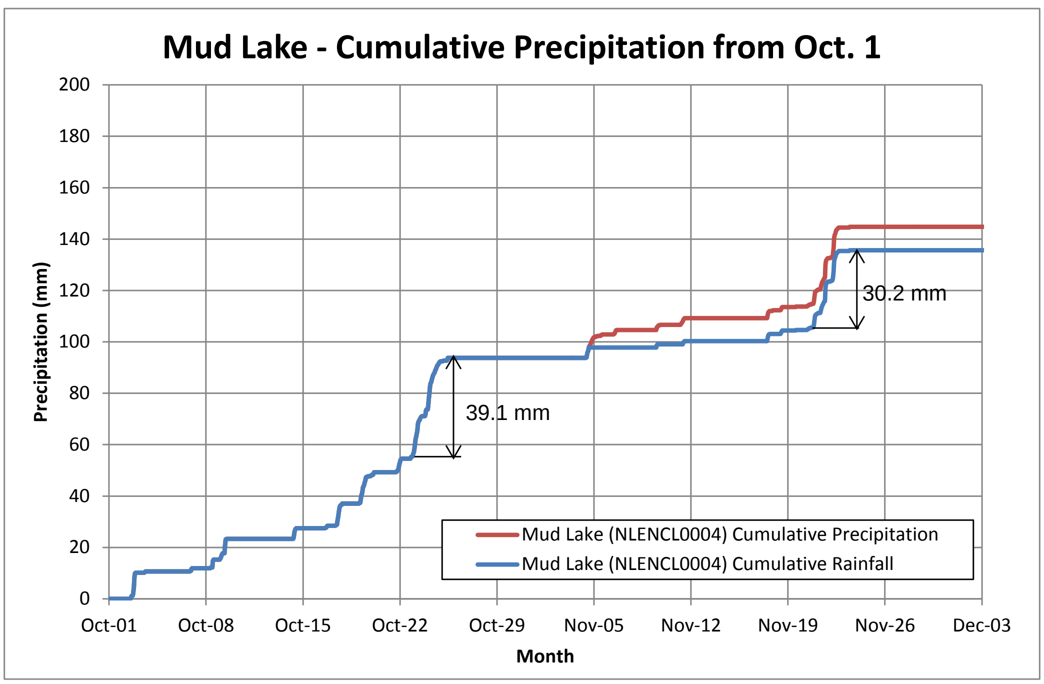


FIGURE 8.8
CUMULATIVE PRECIPITATION AND RAINFALL AT MUD LAKE CROSSING (OCTOBER AND NOVEMBER 2016)



The cumulative rainfall graphs for each of the stations clearly indicates two major rain events occurred in October and November. The first event occurred on October 23 which shows in the lower basin of the Churchill River in the area of Muskrat Falls and Goose Bay - Happy Valley received between 34.2 mm and 45.2 mm of rain. The second rain event is shown to have occurred on November 20 and 21 with rainfall amounts ranging from 20.1 mm and 30.2 mm. In the watershed between Churchill Falls and Muskrat Falls, the Cache River station shows a total rainfall of 26.9 mm. These exceptional events clearly contributed to the above normal precipitation for November shown in Figures 8.2 to 8.4 inclusive.

It is clear to KGS Group that this large rain event on November 20 and 21, which occurred on a wet drainage basin, caused the high influx of flow into the Lower Churchill River. That burst of river flow began to pass through the Muskrat Falls project site starting on November 26 and resulted in the sudden rise in river stages at the Mud Lake Crossing. That rise persisted throughout the ice formation period between November 28 and December 1 and ultimately contributed to the abnormally high water levels at freeze up described by local residents.

Snow Depth at End-of-Winter

Snow records are available for a number of locations throughout the Churchill River watershed as shown on Figure 8.9. Snow data is available from the climate stations as listed in Table 8.1, as well as a number of other locations recorded by Nalcor. All of the snow gauges located in the upper portion of the Churchill River basin include snow depth and snow water equivalent (SWE) information at the end of each month of the winter (i.e. January, February, March, and April). These stations also include long term average values for both the snow depth and SWE. The three gauging stations in the lower Churchill River Watershed (TLH, Gull, and Minipi) only include the snow depth and SWE at the beginning of May. No long term average data was provided with these gauge data.

Figure 8.10 provides a summary of the snow depth and SWE for all of the gauge data provided by Nalcor. All of the data provided for the upper basin has been compared to the long term average and is shown on Figure 8.11 in terms of percent of normal. It can be seen that throughout most of the drainage basin, the snow depth and SWE was near normal (i.e. within +/- 10% of average) or less than normal (i.e. 60 to 90% of average).

Snow depth information was also available at the Environment Canada climate stations at the Goose Bay Airport and at the uppermost part of the drainage basin at the Schefferville Airport. A comparison of the snow depths recorded in the winter of 2016/2017 to the 30 year long term averages is shown in Figures 8.12 and 8.13. The data shown in these figures indicates that the snow depth at Goose Bay was near normal, while the snow depths at the upper end of the drainage basin were generally below normal.

Based on all of the snow records in the catchment both upstream and downstream of Churchill Falls, it has been concluded that snow depths were generally either at or below normal. The amount of snow does not appear to have contributed to abnormal spring runoff that reached the Muskrat Falls to Mud Lake reach of the Churchill River. It may, however, have contributed to the growth and strength of the ice on the river between Mud Lake and Lake Melville, and on Lake Melville itself, as discussed in Section 8.4.

FIGURE 8.9
SNOW GAUGING STATIONS IN THE CHURCHILL RIVER WATERSHED

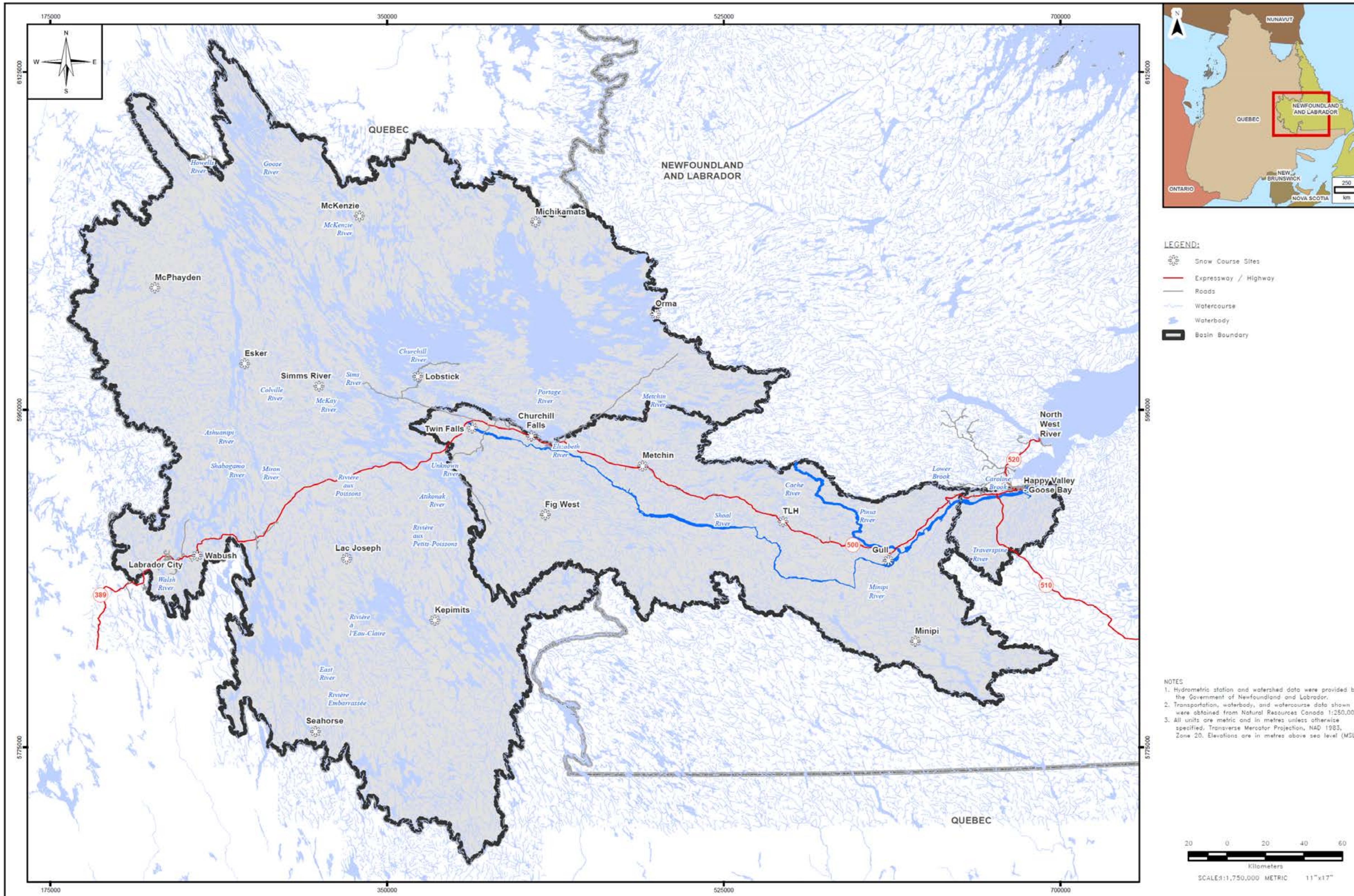


FIGURE 8.10

RECORDED SNOW DEPTH AND SWE IN THE CHURCHILL RIVER WATERSHED

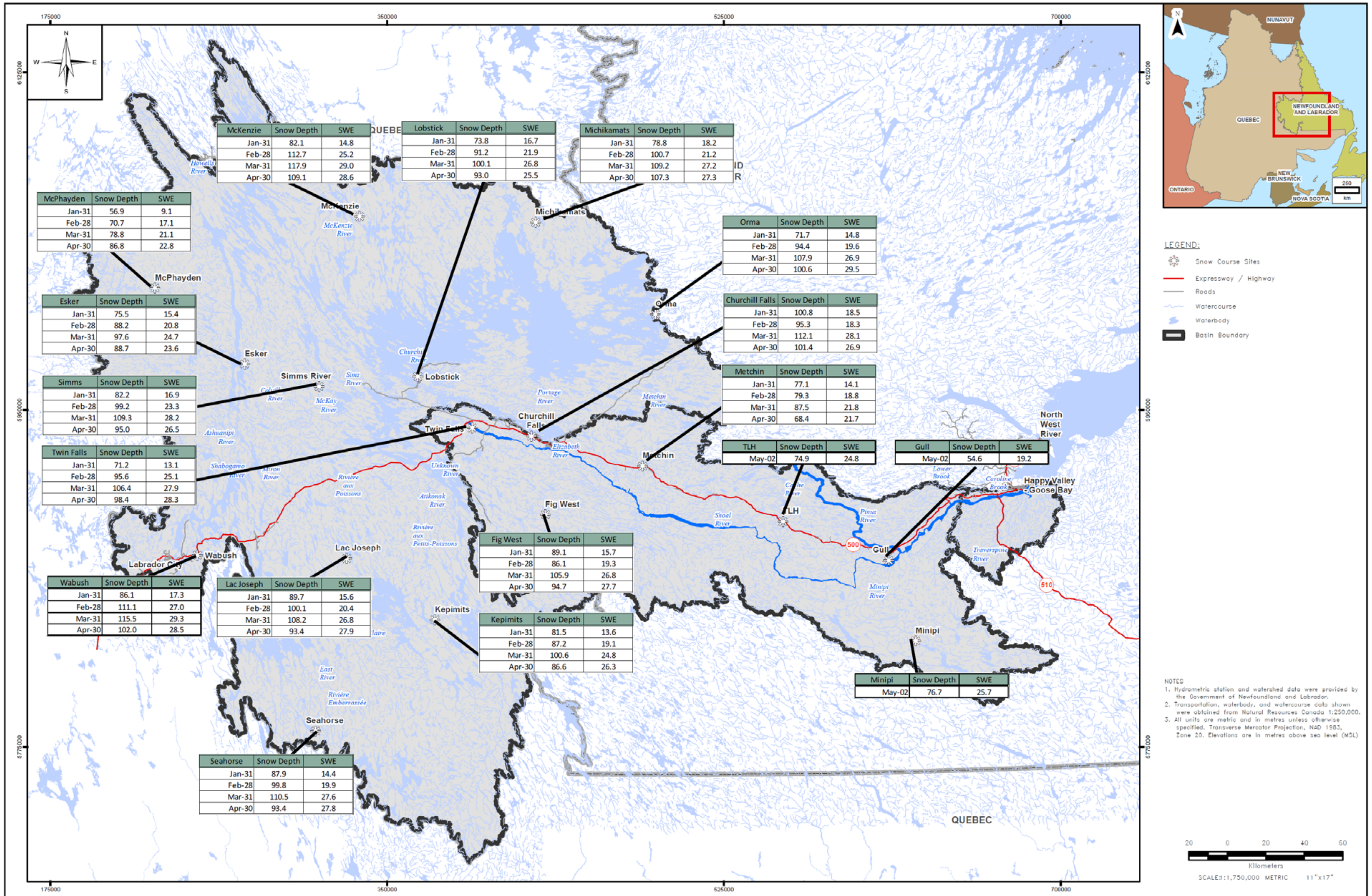
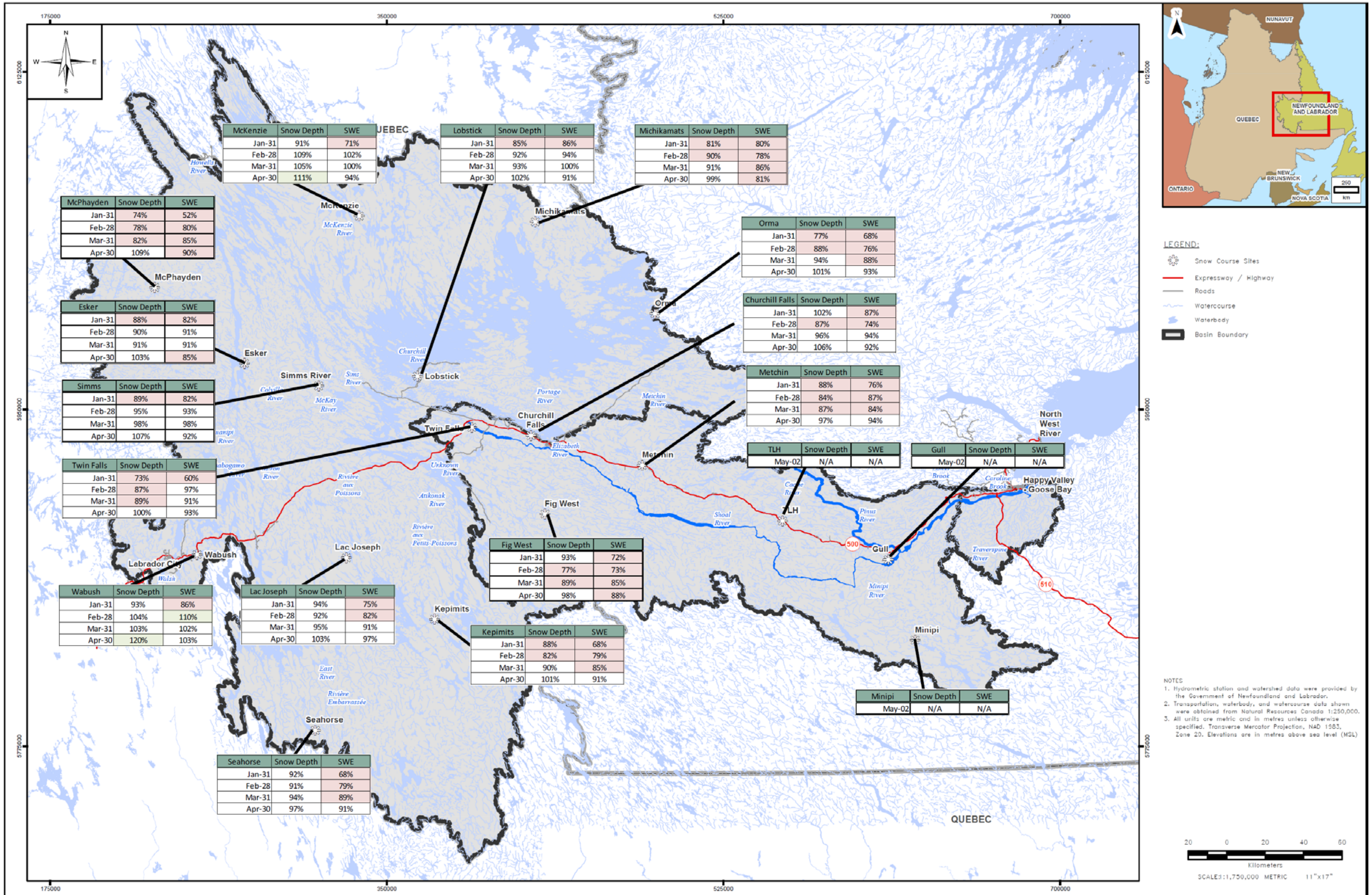


FIGURE 8.11
COMPARISON OF SNOW DEPTH AND SWE IN THE CHURCHILL RIVER WATERSHED TO NORMAL CONDITIONS



McKenzie	Snow Depth	SWE
Jan-31	91%	71%
Feb-28	109%	102%
Mar-31	105%	100%
Apr-30	111%	94%

Lobstick	Snow Depth	SWE
Jan-31	85%	86%
Feb-28	92%	94%
Mar-31	93%	100%
Apr-30	102%	91%

Michikamats	Snow Depth	SWE
Jan-31	81%	80%
Feb-28	90%	78%
Mar-31	91%	86%
Apr-30	99%	81%

McPhayden	Snow Depth	SWE
Jan-31	74%	52%
Feb-28	78%	80%
Mar-31	82%	85%
Apr-30	109%	90%

Orma	Snow Depth	SWE
Jan-31	77%	68%
Feb-28	88%	76%
Mar-31	94%	88%
Apr-30	101%	93%

Esker	Snow Depth	SWE
Jan-31	88%	82%
Feb-28	90%	91%
Mar-31	91%	91%
Apr-30	103%	85%

Churchill Falls	Snow Depth	SWE
Jan-31	102%	87%
Feb-28	87%	74%
Mar-31	96%	94%
Apr-30	106%	92%

Simms	Snow Depth	SWE
Jan-31	89%	82%
Feb-28	95%	93%
Mar-31	98%	98%
Apr-30	107%	92%

Metchin	Snow Depth	SWE
Jan-31	88%	76%
Feb-28	84%	87%
Mar-31	87%	84%
Apr-30	97%	94%

TLH	Snow Depth	SWE
May-02	N/A	N/A

Gull	Snow Depth	SWE
May-02	N/A	N/A

Twin Falls	Snow Depth	SWE
Jan-31	73%	60%
Feb-28	87%	97%
Mar-31	89%	91%
Apr-30	100%	93%

Fig West	Snow Depth	SWE
Jan-31	93%	72%
Feb-28	77%	73%
Mar-31	89%	85%
Apr-30	98%	88%

Wabush	Snow Depth	SWE
Jan-31	93%	86%
Feb-28	104%	110%
Mar-31	103%	102%
Apr-30	120%	103%

Lac Joseph	Snow Depth	SWE
Jan-31	94%	75%
Feb-28	92%	82%
Mar-31	95%	91%
Apr-30	103%	97%

Kepimits	Snow Depth	SWE
Jan-31	88%	68%
Feb-28	82%	79%
Mar-31	90%	85%
Apr-30	101%	91%

Minipi	Snow Depth	SWE
May-02	N/A	N/A

Seahorse	Snow Depth	SWE
Jan-31	92%	68%
Feb-28	91%	79%
Mar-31	94%	89%
Apr-30	97%	91%

FIGURE 8.12
SNOW DEPTH AT THE GOOSE BAY AIRPORT

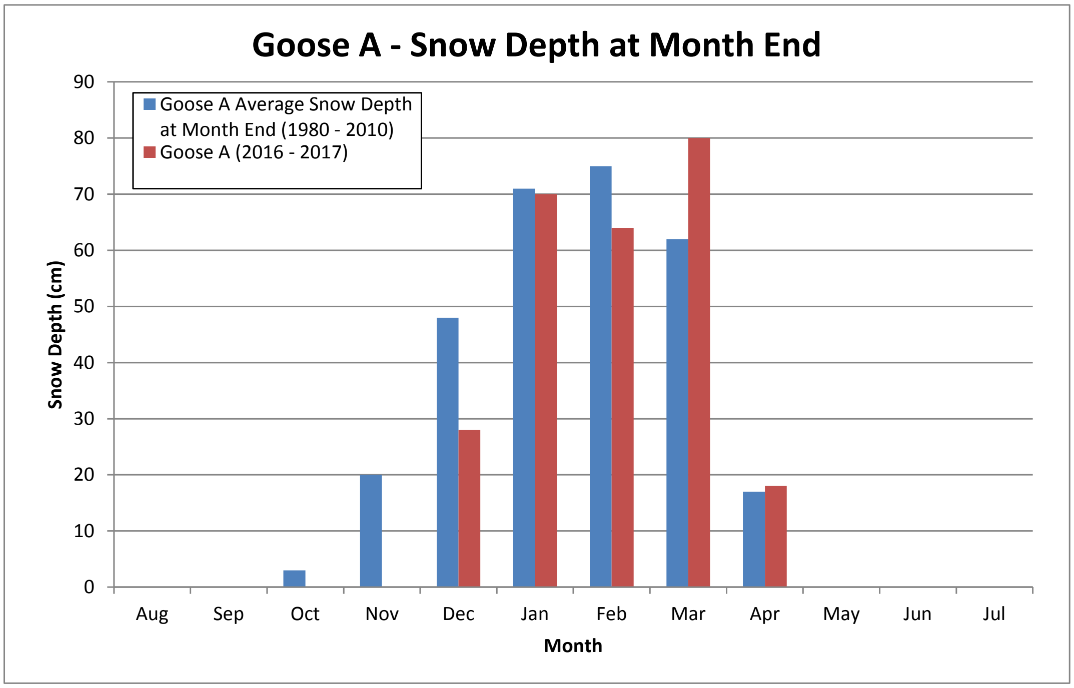
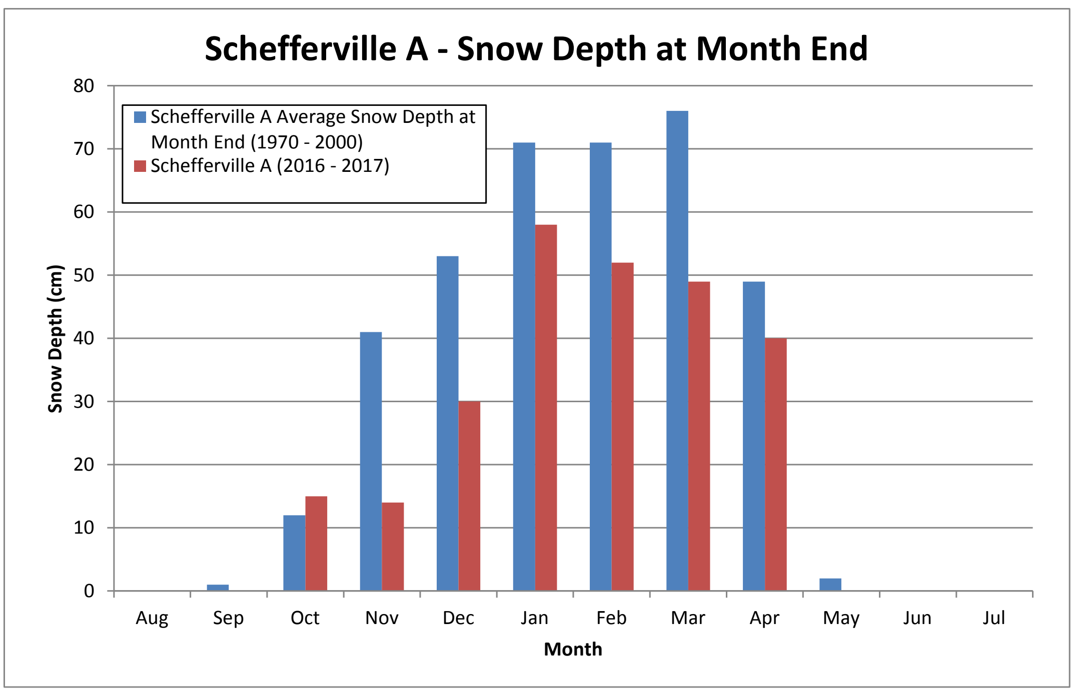


FIGURE 8.13
SNOW DEPTH AT THE SCHEFFERVILLE AIRPORT

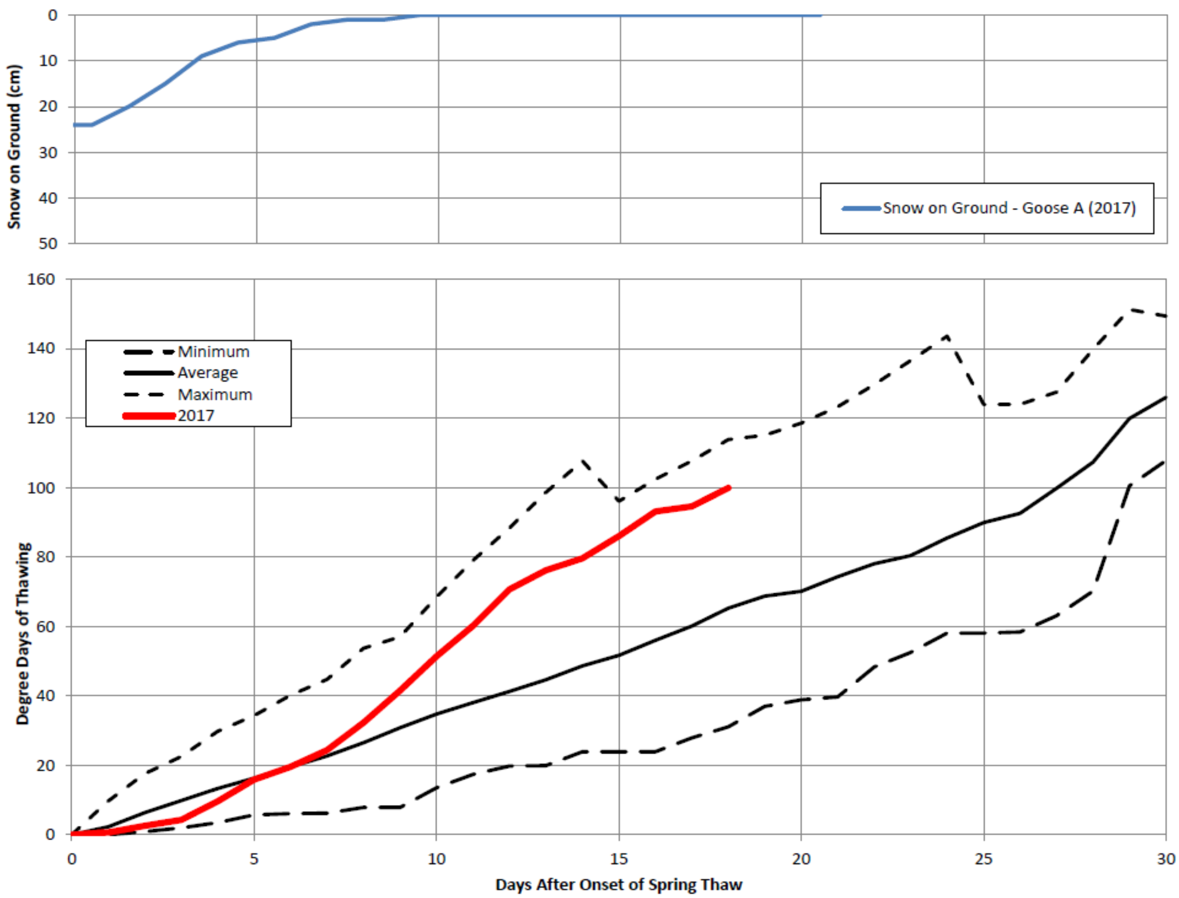


Rate of Snowmelt

The rate of snowmelt was investigated primarily using the number of degree days of thaw (i.e. the reverse of the degree days of freezing, and measures the number of degrees per day above freezing). The degree days of thaw were calculated between the last spike in the measured snow on the ground at Happy Valley- Goose Bay, and the time at which the river ice would be in a critical state of breakup and potential jamming at Mud Lake.

Figure 8.14 shows the calculated degree days of thaw at the Goose Bay Airport climate station compared to the historical average, as well as the range of the degree days of thaw for all the years. The data shown on Figure 8.14 is baselined to the date at which the last significant snowfall occurred. The 2017 thaw developed rapidly and at a greater than average rate over the next 10 days. The actual date in which the rapid thaw commenced in 2017 is May 7. This preceded the start of the flood hydrograph on May 10, and the delay reflects the runoff period for the melting snow and water retained in ponds to reach the river system.

FIGURE 8.14
DEGREE DAYS OF THAW AND SNOW ON GROUND AFTER ONSET OF SPRING THAW (GOOSE BAY AIRPORT)



This analysis would suggest that once it commenced, the snowmelt in the spring of 2017 occurred much more quickly than would normally be expected. This relatively sudden melt, combined this the residual effect of the retained water from the late fall rains over the catchment resulted in a rapid response and rise of the inflows to the Churchill River in the reach below Churchill Falls. The rapid snow melt also appeared to cause the increased spring flows in the Churchill River to occur earlier than normal, relative to the onset of the spring thaw.

Rainfall during Snowmelt Period

Rain-on-snow during the snowmelt period can rapidly increase the rate of runoff to the receiving waterbody. To investigate the possibility that this phenomenon occurred in the Churchill River watershed, the rainfall data at the Goose Bay Airport, Cache River, Muskrat Falls, and Mud Lake climate stations was investigated. Figures 8.15 to 8.18 show the cumulative precipitation and rainfall in April and May at the time of the snowmelt.

The data indicates that in early April there was a large rain event that that resulted in 6.6 mm to 30.7 mm of rain on the watershed between Churchill Falls and Mud Lake. The Cache River gauge, which is representative of the watershed between Churchill Falls and Muskrat Falls, experienced 30.7 mm of rain. There was also a significant rain event experienced in early May in which between 26.7 mm and 31.9 mm of rain fell on the drainage basin, the greatest being at the Cache River station, also located between Churchill Falls and Muskrat Falls. This amount of rain on snow during or prior to the snowmelt period is believed to have significantly increased the rate of runoff to the Churchill River.

It is clear that the rain on snow events of April and early May would have contributed to the rapid rate of runoff and the flashy nature of the May 2017 spring flood in the lower Churchill River.

FIGURE 8.15
CUMULATIVE PRECIPITATION AND RAINFALL AT GOOSE BAY AIRPORT (APRIL AND MAY 2017)

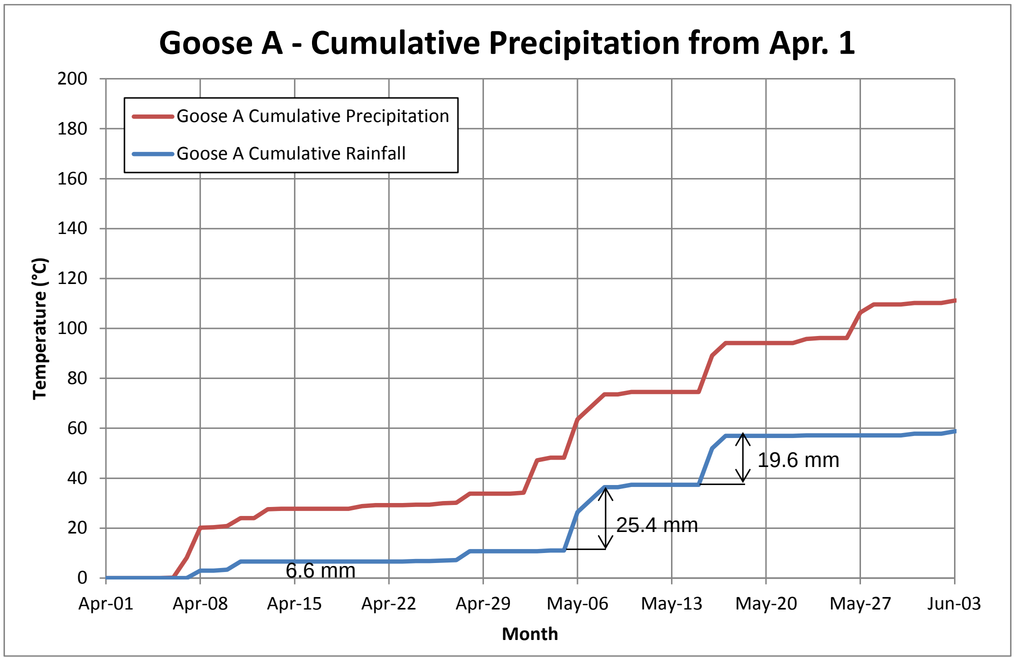


FIGURE 8.16
CUMULATIVE PRECIPITATION AND RAINFALL AT CACHE RIVER (APRIL AND MAY 2017)

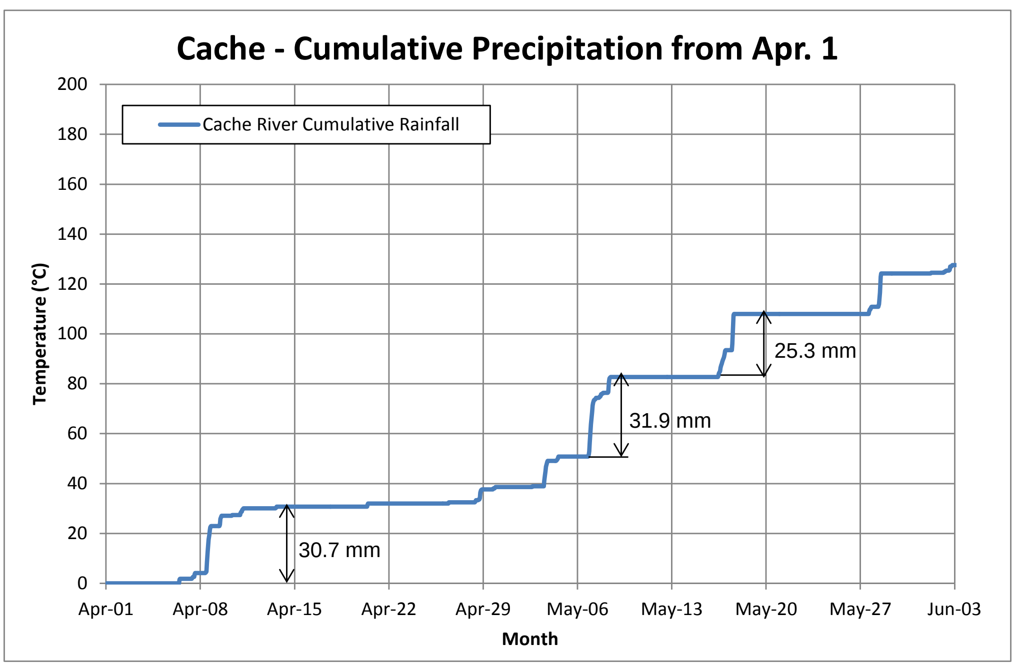


FIGURE 8.17
CUMULATIVE PRECIPITATION AND RAINFALL AT MUSKRAT FALLS (APRIL AND MAY 2017)

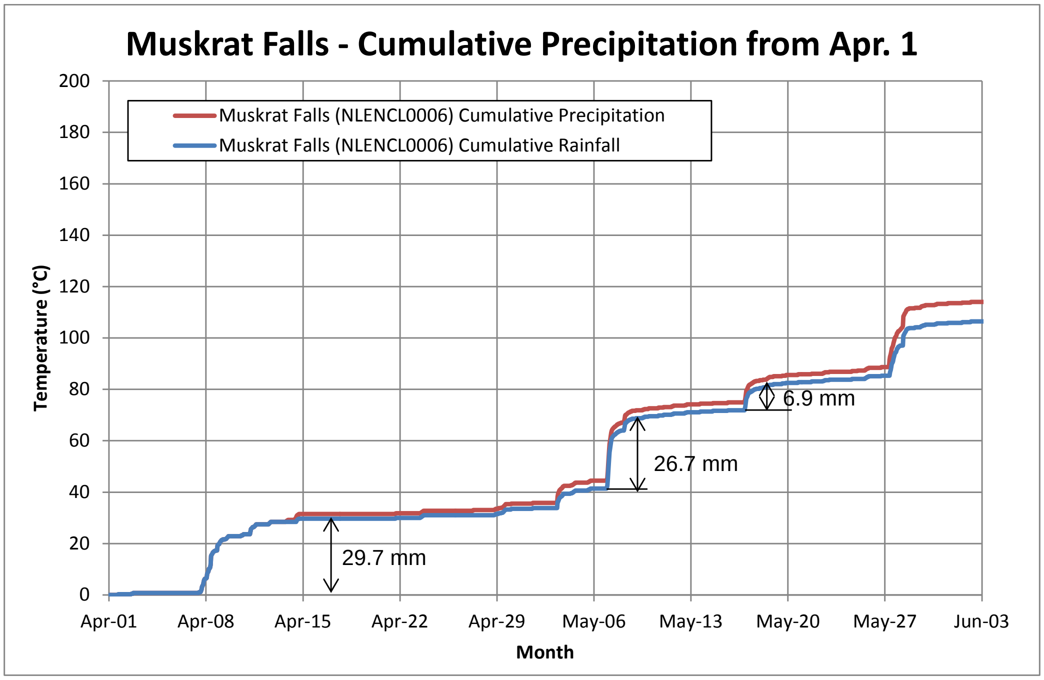
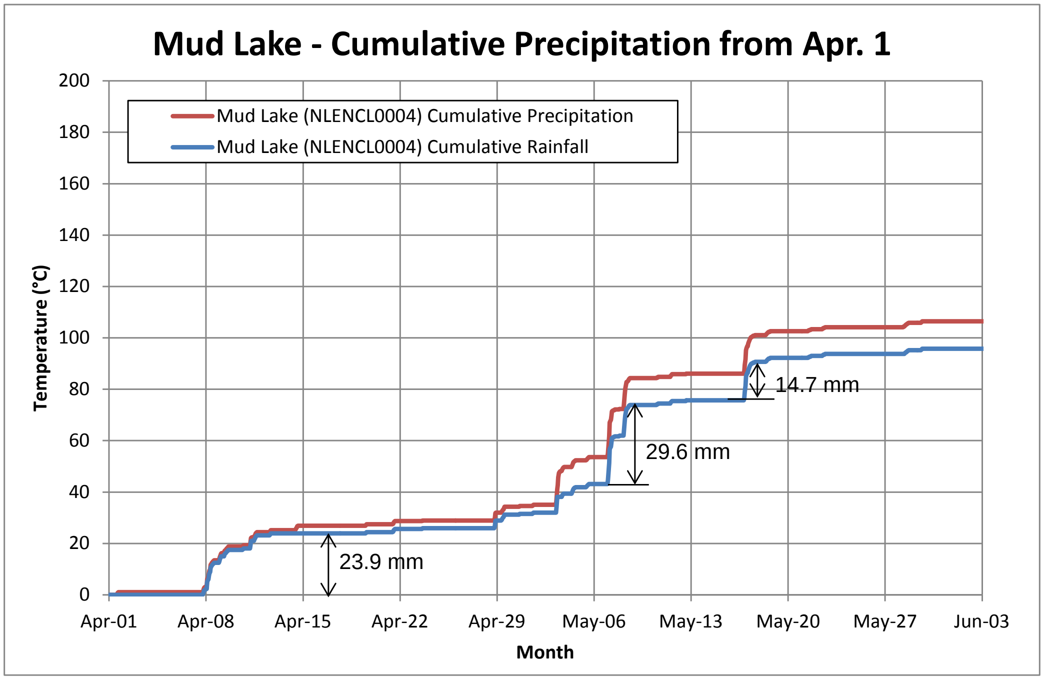


FIGURE 8.18
CUMULATIVE PRECIPITATION AND RAINFALL AT MUD LAKE CROSSING (APRIL AND MAY 2017)



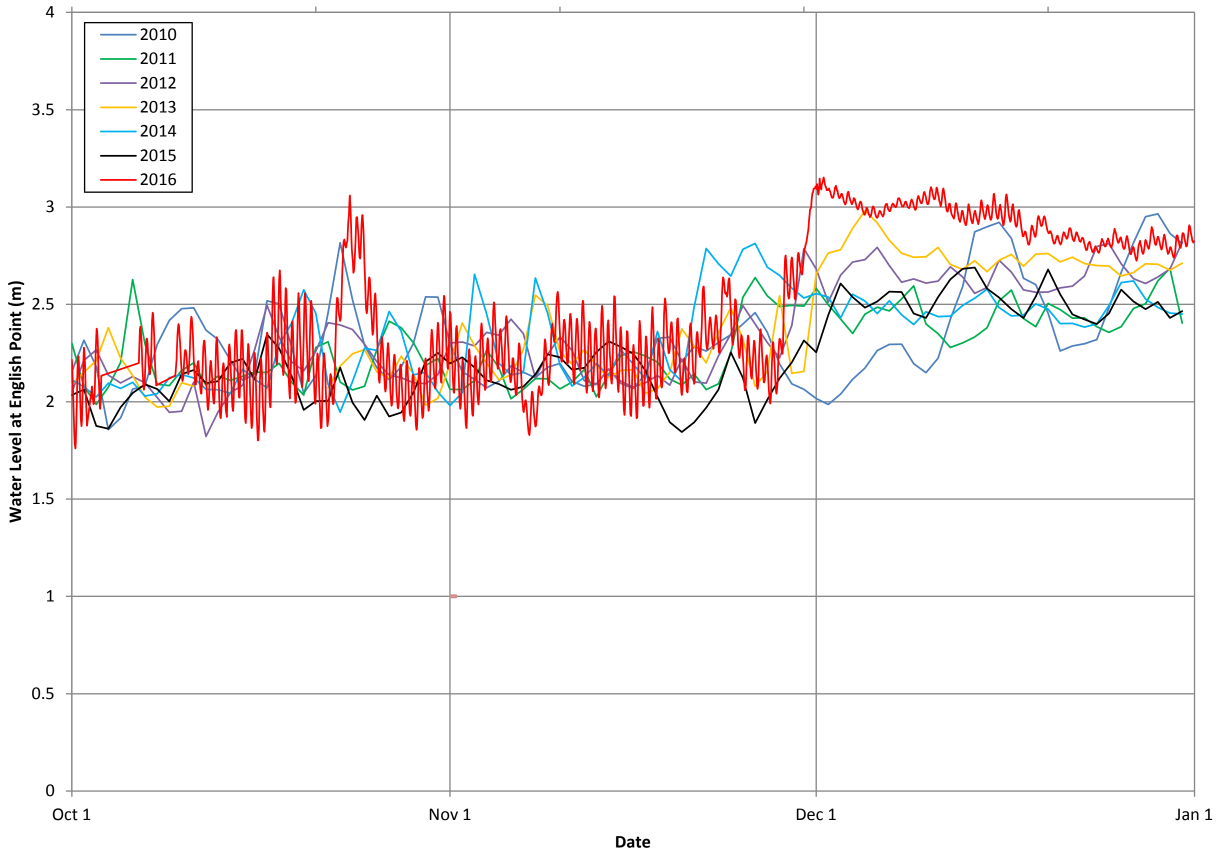
8.2 RIVER WATER LEVEL AND FLOW AT TIME OF RIVER ICE FORMATION

Abnormally high water levels and large river flows at the time of formation of the ice cover in early winter lead to several triggers that would generally be expected to exacerbate spring ice jamming and flood potential in spring near Mud Lake. They include:

- The potential for high stages due to the rafting of fragmented ice in the main channels (amongst the sand bars) during the formation period. The greater the flow at formation, the higher is the stage at which an ice cover can initiate and stabilize. In addition, the greater the flow at formation, the greater would be the rafted ice thickness that becomes the starting point for subsequent thickening during the winter due to frost penetration.
- The initiation of the formation of "hinges" in the ice cover between the river surface and the shoreline at a relatively high elevation. The high water level prevalent during the formation of these hinges would then have to be exceeded in the spring before the stationary ice in the river would tend to release downstream into Lake Melville. The greater the rise required before the hinge is fractured and releases, the longer the ice cover on the river surface will persist without breakup during the rising spring flood. The propensity for the solid ice cover to catch and accumulate broken ice from upstream would persist. This process is described by several authorities, including Beltaos (1996) and Acres Consulting Services on behalf of the Canadian Electrical Association (1984). Essentially, the river ice must rise above the level at which it first formed in the early winter. The higher that water level is, the longer the ice cover will persist in place.
- The flooding of the sand bars in the lower river and the formation of ice over the sand bars. The recorded sharp declines in flow and water levels in the river in late winter would have stranded that ice and essentially grounded it for the majority of the following winter. Frost penetration may also have led to freezing of the ice undersurface to the surface of the sand bars. In addition, the grounded ice would have been isolated from the warming waters of the flow in the central main channels in spring before the full freshet commenced. Reports by local residents support the fact that the snow on the ice stranded on the sand bars remained white and did not show signs of melt before the flood event. The ice formed over the sand bars, and then stranded later in the winter would, in general, have enhanced the potential for delaying ice breakup and delaying the release of ice runs that occurred from upstream.

The record of water level at English Point only extends back to 2009 and only consists of water levels measured to an arbitrary datum. It is therefore difficult to examine how high the water level was at the time of the ice cover formation in early winter near Mud Lake relative to historical conditions. Nevertheless, the record correlates well with anecdotal information from local residents (see Section 4.0). Figure 8.19 shows the fall water levels between October 1 and December 31 for the period of record at the English Point gauge. The data indicates that the water level at English Point in late November 2016 was the highest in the short period of record.

FIGURE 8.19
FALL WATER LEVELS AT ENGLISH POINT

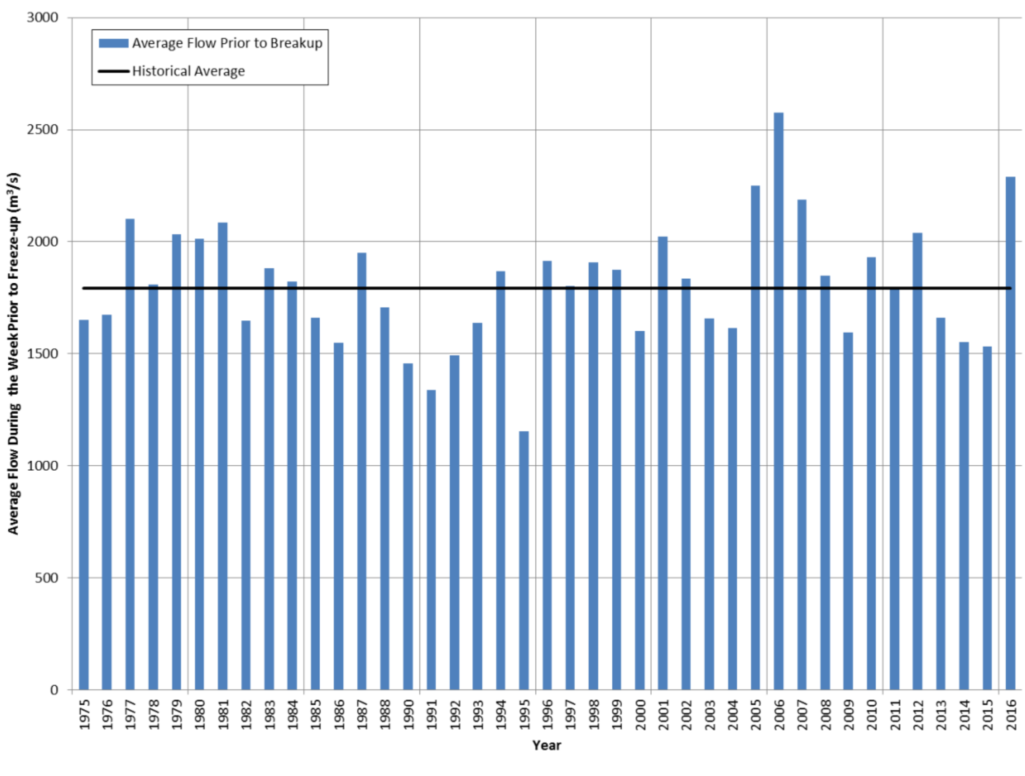


KGS Group recognized that the water levels in the late fall of 2013 were the closest in the short record to that of 2016, and averaged approximately 0.3 m lower than 2016 in the critical few weeks of first ice development. Nevertheless, that 0.3 m is reported to have been significant by the local residents, as it caused the sand bars to be almost totally submerged in the area of Mud Lake, albeit at modest depth. That observation is consistent with the typical surface elevations of the sand bars shown in the bathymetric/Lidar information available to KGS Group.

The average stage at ice formation is estimated from the short record to have been approximately 0.5 m below that of 2016. In the fall of 2016, the high water levels are reported to have caused the formation of an ice cover that spanned the entire river width of more than 2100 m near Mud Lake. That differs from almost all previous years, when the residents report that the sand bars were not submerged and were only snow covered for the entire winter until spring breakup.

The magnitude of river flow at the time of ice cover formation can be measured reasonably reliably against a record of estimated flows at Muskrat Falls extending back to 1975. As summarized in Table 6.1, the residents have kept records of first snowmobile crossing. This information can provide a good indication of the approximate time of river freeze up each year. The critical period of ice formation has been estimated from the recent photographic records and satellite imagery since 2010 to coincide with approximately 2 days before the first recorded snowmobile crossing at Mud Lake. That record of dates of first snowmobile crossing has been used as a milestone to estimate the river flow at the time of ice formation at Mud Lake in previous years. Figure 8.20 shows a comparison of the flows over the week prior to the time of ice formation for the period from 1975 to 2016. The flow in 2016 was the second highest on the 40 years of record.

FIGURE 8.20
LOWER CHURCHILL RIVER FLOWS AT TIME OF ICE FORMATION



It is useful to note that the highest river flow at the time of ice formation was that of 2006, and it was approximately 2,575 m^3/s compared to 2016 at 2,290 m^3/s. But the spring of 2007 (unlike that of 2017) had a near normal flow during breakup that was roughly only 60% of that in 2017.

It appears that the high river flows and river stage in November 2016 were significant contributors to the ice jamming and flooding potential in May 2017.

This was also a position put forward by local residents, and in particular through a thoughtfully written report submitted to KGS Group written by Mr. Dave Raeburn (as listed in Section 4.0). However, their position was that these high river flows were caused by untimely releases from Muskrat Falls. As previously indicated, the climate, flow, and water level data indicate that the high river flows were not caused by the operation of the Muskrat Falls spillway when the reservoir was lowered on November 18 and 19. It was clearly caused by the influx of local runoff that occurred in late November due to excessive rainfall and snowmelt late in the fall. Nevertheless, KGS Group paid particular attention to this, and attempted to approximate what the flows near Mud Lake would have been if the fluctuations in reservoir level at Muskrat Falls had not occurred, or if indeed the development had not been in construction (i.e. pre development at Muskrat Falls).

To this end, KGS Group applied a method of "back-calculation" using the recorded outflows from the Muskrat Falls Spillway in combination with recorded water levels in the Muskrat Falls reservoir. The calculation was directed at identifying what the natural inflows were during this period to the low impoundment at Muskrat Falls. That inflow was considered a reasonable proxy for the flows that would have passed downstream at Mud Lake if there had been no construction activities at Muskrat Falls. Admittedly this approximate method ignores the natural river attenuation that would have been caused by the natural river in the short impounded length of the small reservoir at Muskrat Falls during this time period. However, given the very low height of the reservoir level during this entire period of time that effect is insignificant.

The results of that analysis are shown in Figure 8.21. That figure shows the recorded outflow from Muskrat Falls compared to the estimated flow that would have occurred in the river if the Muskrat Falls Project did not exist. It indicates that, except during the emergency drawdown on November 18^{t} and 19th, the effect of the Muskrat Falls reservoir on river flows was insignificant. Furthermore, as explained in Section 7.0, that short-lived pulse of outflow from Muskrat Falls cleared through the river system well in advance of the start of the ice cover formation in the Churchill River near Mud Lake. Similarly, also shown on Figure 8.21, the spillway operation in spring when the Muskrat Falls reservoir was lowered from El. 22.5 m to 21.5 m between May 11 and May 12 had no significant influence on the river flows during the ice breakup. As previously indicated in Section 7.0, the lowering of the reservoir by 1.0 m in May added only a very small amount of flow to the overall spring flood peak.

It is the opinion of KGS Group that operations at Muskrat Falls had effectively no influence on the flood event at Mud Lake in 2017.

Rather, it is the opinion of KGS Group that, as previously described, the much greater than average rains in November and the resulting runoff in late November that flowed down the Lower Churchill River at the time of ice formation were the primary causes of the high freeze up levels.

The effects of the late November rains and runoff on the freeze up levels at the Mud Lake Crossing were captured on the hourly photographs of the river that were taken at the Mud Lake Crossing climate station. Figure 8.22 shows a compilation of a few of the hourly photographs that show the ice formation between November 26 and December 1. The recorded water levels form the English Point gauge are also annotated on the photos in Figure 8.22 to show the magnitude of water / ice level rise.

FIGURE 8.21
COMPARISON OF RECORDED AND NATURALIZED FLOWS AT MUSKRAT FALLS

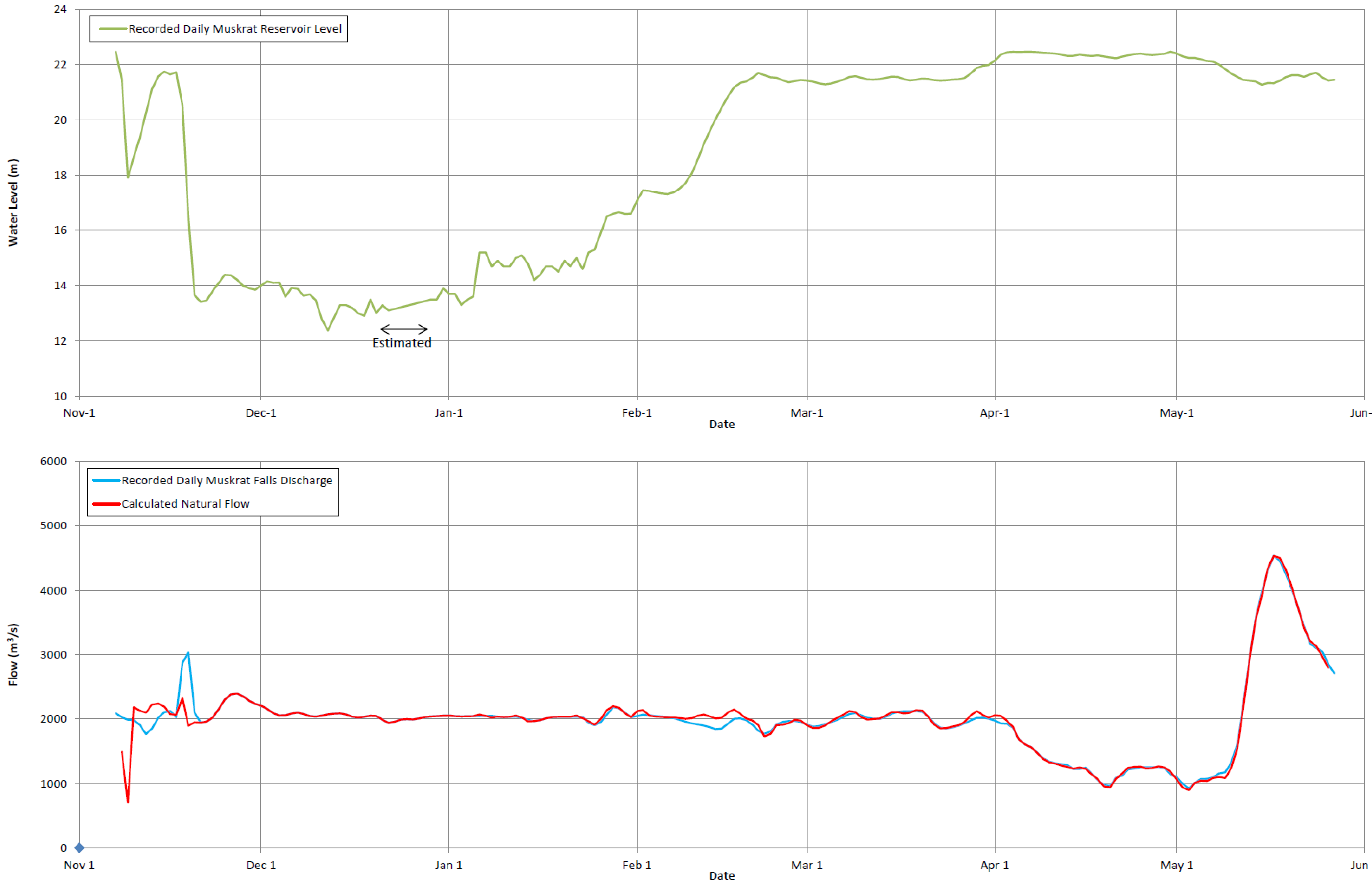
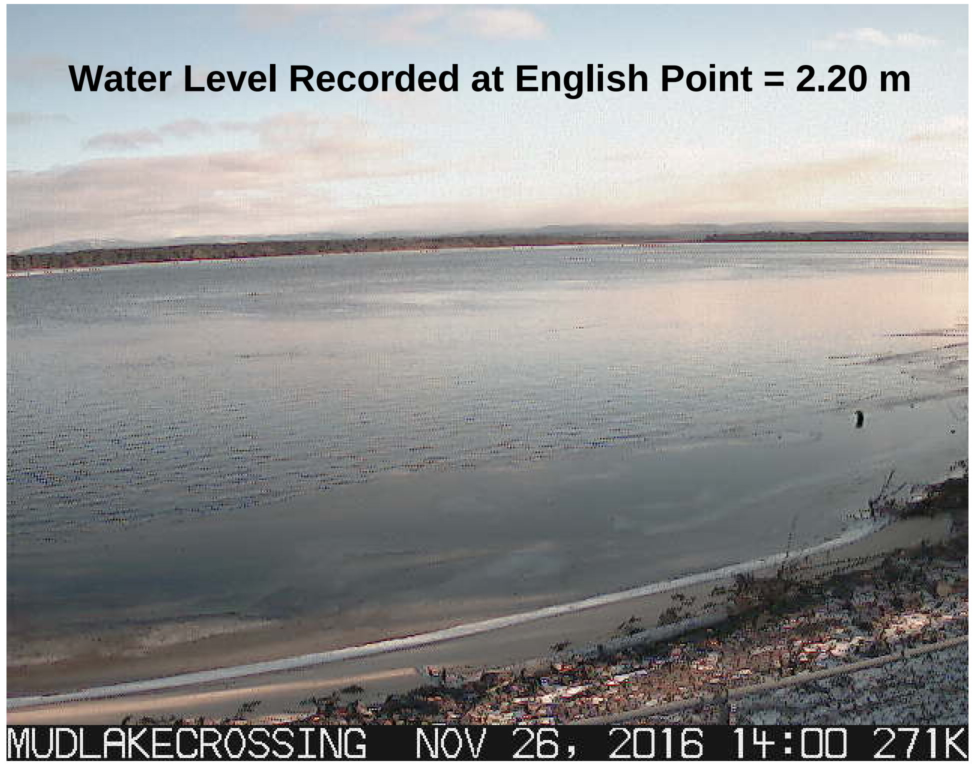


FIGURE 8.22
PHOTOGRAPHS SHOWING FREEZE UP AT THE MUD LAKE CROSSING

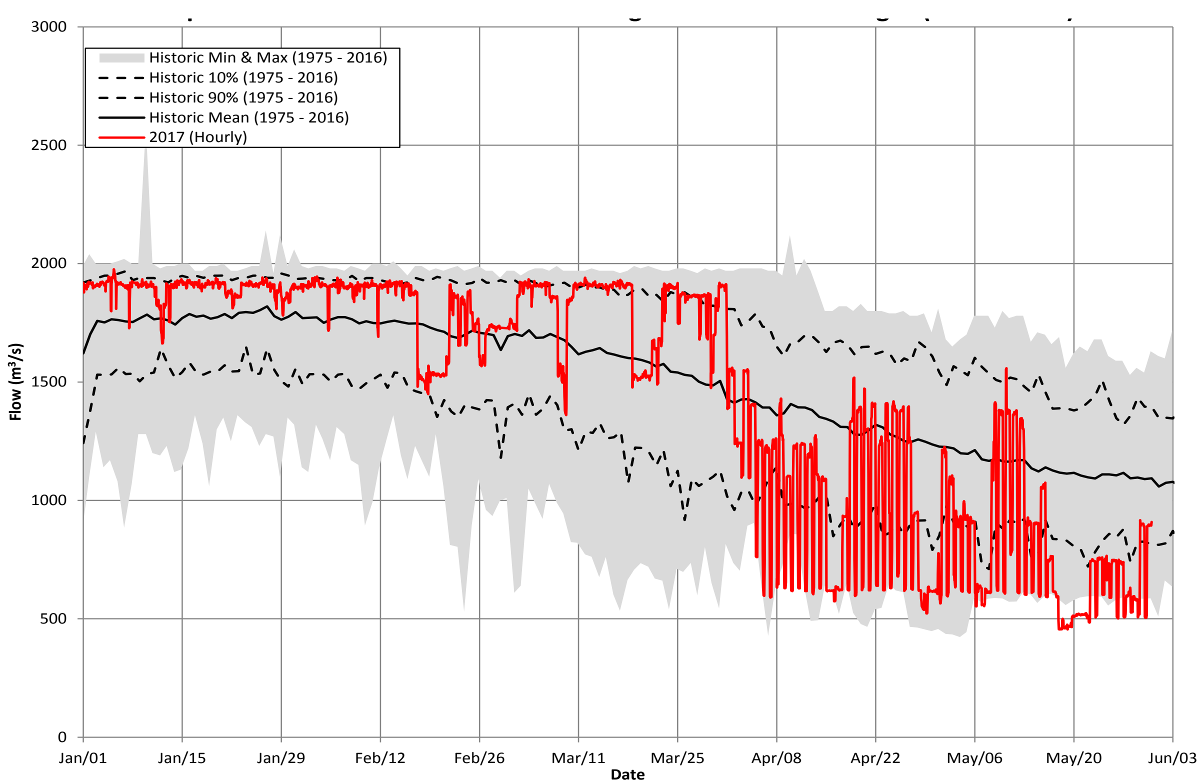


Source: Government of Newfoundland and Labrador (2017)

8.3 HIGH WINTER FLOWS FOLLOWED BY LOW EARLY SPRING FLOWS

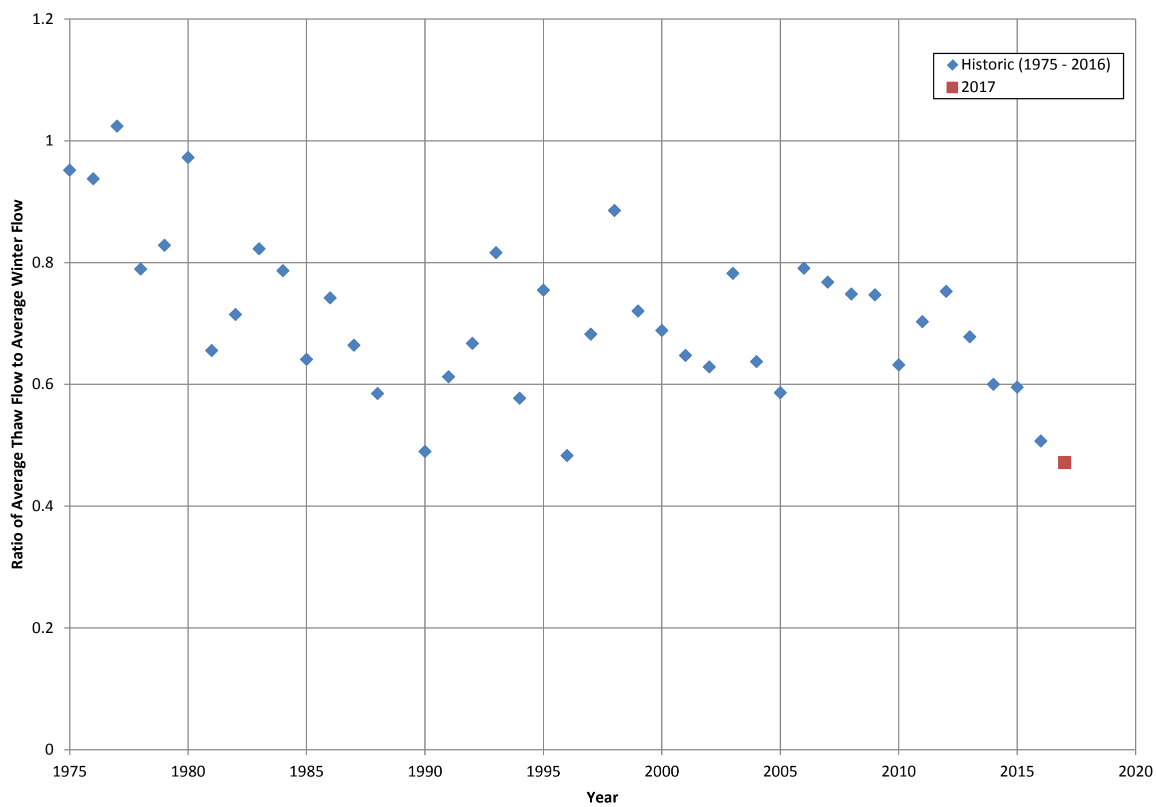
The flow records show that the releases from Churchill Falls during most of the winter were relatively high. Figure 8.23 shows the historical normal outflows compared to the flows in 2017. The runoff between Churchill Falls and Mud Lake is relatively small prior to the spring melt period that commenced in May. Figure 8.23 also demonstrates that the Churchill Falls outflows throughout the winter were higher than normal. They are estimated to have been close to the flows exceeded only 5% of the time in the past, at that time of year. However, starting in late March, and extending through April, the flows decreased substantially and were (on average) near the low flows that are normally exceeded 90% of the time at that time of year. As described in Section 8.2, this would tend to increase the grounding of ice on high points in the river cross sections near Mud Lake. It may also have encouraged frost penetration and freezing to the riverbed until the air temperatures rose consistently above the freezing mark. The extent to which this may have impeded the release of the ice through to Lake Melville is not clear.

FIGURE 8.23
COMPARISON OF 2017 CHURCHILL FALLS OUTFLOWS TO HISTORIC OUTFLOWS



As noted above, the change from winter outflows to spring outflows was shown to be drastic. An analysis was carried out to determine the ratio of spring flow to winter flow for each year at Muskrat Falls that resulted from the change in outflow from Churchill Falls. This was done to investigate how common notable flow reductions in the early spring are. Figure 8.24 shows the ratio of spring flow to winter flow at Muskrat Falls over a period of years. It demonstrates that the ratio in 2016 / 2017 was the lowest on record. This means that since 1975 the outflow from Churchill Falls has not ever been reduced as much as it was in the spring of 2017.

FIGURE 8.24
RATIO OF AVERAGE SPRING THAW FLOW TO AVERAGE WINTER FLOW



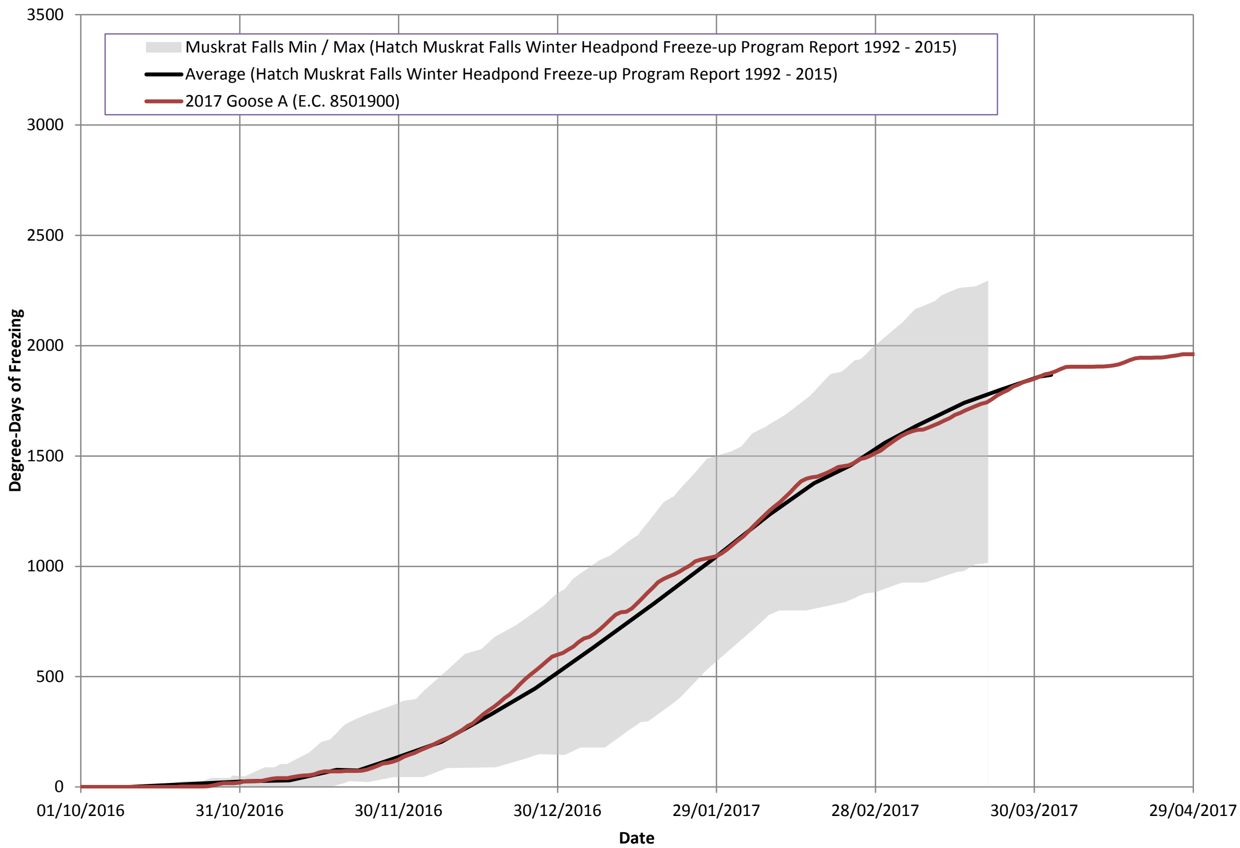
It appears that this sequence of high flow followed by low flow before breakup was a direct result of the sharp reduction of outflows at the Churchill Falls G.S. This may have contributed to the potential for high water levels at Mud Lake during the breakup period that was soon to follow.

8.4 SEVERITY OF WINTER

The severity of winter is a common measure of the growth of ice on water bodies. The most common indicator of the severity is the summation of the number of degree days of freezing over the winter season. One degree day of freezing is a daily average air temperature of -1 degree Celsius for 24 hours. Figure 8.25 shows the typical accumulation of degree days of freezing at Happy Valley - Goose Bay. It suggests that the average total number of degree days of freezing in the Happy Valley - Goose Bay is roughly 1900 degree days of freezing. The coldness of the winter is typically reflected in the ultimate depth of frost penetration and the growth of ice thickness in the river. The severity of the winter of 2016-2017 was almost equal to the average, so it is unlikely that the temperatures over the winter season have been directly responsible for any abnormal influence on the spring flood event at Mud Lake.

On the other hand, as described in Section 8.1, the less than normal snowfall during the winter in the catchment would tend to encourage more intense frost penetration in the river ice and probably lead to greater ice thicknesses. This could result in both the river near Mud Lake as well as on Lake Melville. Unfortunately, ice thickness measurements were not taken in 2017 as they were in the past so comparisons of ice thicknesses to those in previous years could not be done. However, it would be expected that the combination of near normal air temperatures over the winter, as attested by Figure 8.25, with below normal snowfall would result in above normal ice thicknesses. This is also consistent with the reports from the local residents of Mud Lake who noted in the public open houses that the river ice in 2017 was much thicker than normal. This could understandably contribute to a greater potential for ice jamming and enhanced resistance of ice jams to release downriver into Lake Melville.

FIGURE 8.25
DEGREE DAYS OF FREEZING IN HAPPY VALLEY - GOOSE BAY



8.5 ABRUPTNESS OF THE ONSET OF SPRING MELT

The sudden onset of warm temperatures and the extent of warming during the spring melt influence the river ice breakup in two ways:

- A sudden switch from sub-zero temperatures and a rapid consistent rise in air temperature well above freezing can result in abnormally high rates of snowmelt in the local drainage basin between Churchill Falls and Muskrat Falls. This would contribute to abnormally high spring runoff and river flows, which is the subject of Section 8.6.
- A sudden rapid rise in air temperature can result in rapid snowmelt, but there is a thermal inertia associated with the river ice. The ice temperature can lag behind the rise in river flow and result in strong ice that is resistant to breakup and release. This would be particularly true if the river ice and the ice on Lake Melville had been thicker and stronger than normal at the onset of the spring thaw. This phenomenon occurred, for example, in 2009 in Manitoba in the Red River Valley.

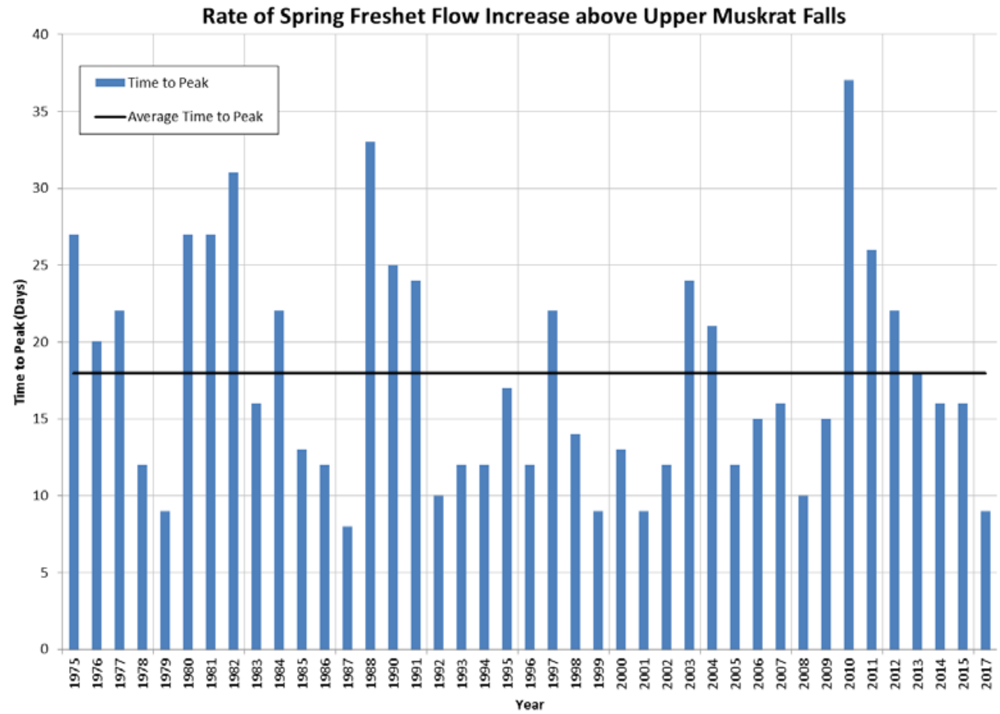
The rate of snowmelt and the rate of rise of the spring flow have been measured for the Churchill River by two methods.

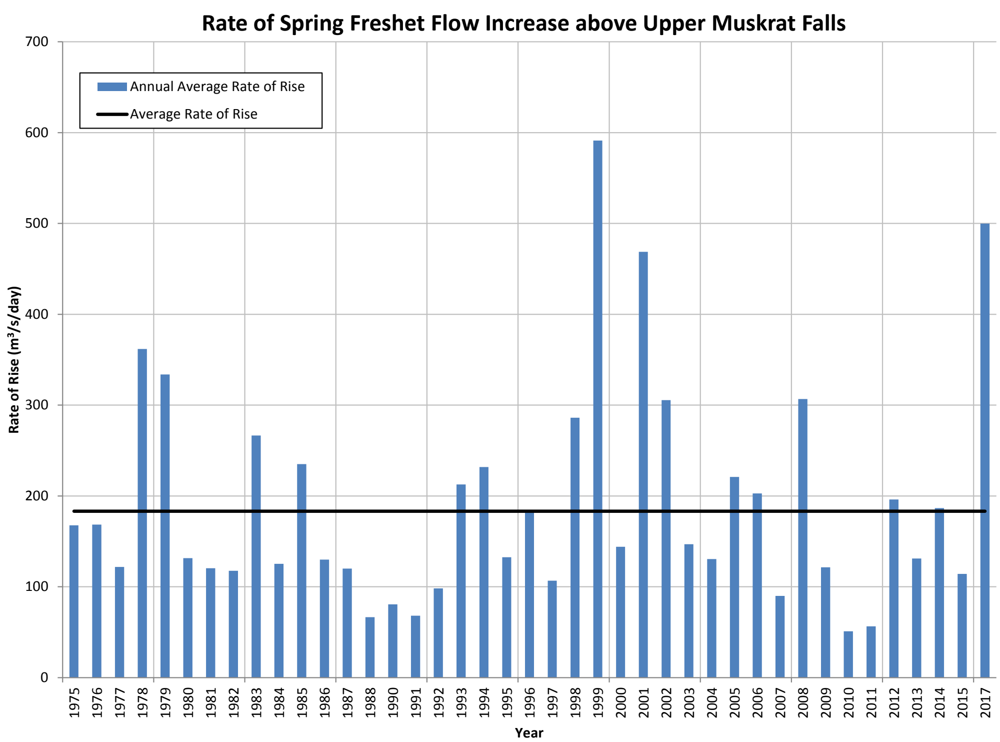
The first method was to investigate the number of degree days of thaw (i.e. the reverse of the degree days of freezing which measures the number of degrees per day above freezing) between the start of the spring thaw and the time at which the ice would be in a critical state of breakup at Mud Lake. This was previously described in Section 8.1 and indicated that the spring melt occurred relatively quickly, as compared to normal.

The second method to assess the abruptness of the onset of the spring melt is to compare the steepness and timing of the rising limb of the river flow hydrographs in the spring. The runoff downstream of Churchill Falls normally increases from a nominal amount before the spring melt commences, to several thousand m^3/s in a short period of time. Figure 8.26 shows a comparison of the time to peak for each spring flood since 1975, as well as the average rate of rise. The time to peak was determined as the time from the initial rise of the flood hydrograph to the date of the peak river flow. The rate of rise was determined as the ratio of the peak flow (minus the initial flow) over the duration of time to reach the peak. The values shown in Figure 8.26 indicate that the time to peak was the second fastest, and the rate of rise of the hydrograph was the second fastest, since 1975.

FIGURE 8.26

COMPARISON OF THE TIME TO PEAK AND RATE OF RISE





The methods to assess the abruptness of the onset of the spring melt both provided consistent findings and suggest that the spring 2017 melt occurred very quickly compared to normal. This sudden melt resulted in a rapid response and rise of the flows in the Churchill River. The abruptness of the spring melt would cause the flows in the Lower Churchill River to be earlier than normal, as compared to the extent of river ice degradation that would have occurred at that time. This is consistent with the testimonies of the local residents that have indicated that, at the time of breakup, the river ice was much more solid than normal.

8.6 RIVER FLOW AT TIME OF ICE BREAKUP NEAR MUD LAKE

The river flow leading up to, and at, the time of temporary accumulations of fragmented ice in the river near Mud Lake is a key factor that can lead to flood potential. As described in Section 6.8, the river near Mud Lake is particularly prone to rises in water level during the formation of temporary ice jams, particularly if they are comprised of large volumes of fragmented ice and extend from shore to shore.

Review of the ice observation reports since 2010 indicates that the time when the river flow would be most critical during the evolution of the river ice breakup is typically 2 days before the reported first boat crossing in spring. Similar to the record of first snowmobile crossing, the residents have also maintained a record of the first boat crossing in the spring of each year, extending back to 1982. Table 8.2 provides the listing of the first boat crossing recorded for each year.

TABLE 8.2
DATE OF FIRST BOAT CROSSING AT MUD LAKE

YEAR	FIRST BOAT CROSSING DAY	YEAR	FIRST BOAT CROSSING DAY	YEAR	FIRST BOAT CROSSING DAY	YEAR	FIRST BOAT CROSSING DAY
1972	05-Jun	1985	28-May	1996	04-May	2007	19-May
1975	30-May	1986	07-May	1997	24-May	2008	07-May
1976	17-May	1987	23-Apr	1998	12-May	2009	18-May
1977	15-May	1988	12-May	1999	10-May	2010	20-Apr
1978	27-May	1989	15-May	2000	11-May	2011	12-May
1979	14-May	1990	22-May	2001	14-May	2012	15-May
1980	17-May	1991	26-May	2002	22-May	2013	01-May
1981	15-May	1992	27-May	2003	17-May	2014	19-May
1982	01-Jun	1993	17-May	2004	18-May	2015	18-May
1983	14-May	1994	22-May	2005	08-May	2016	17-May
1984	15-May	1995	11-May	2006	04-May		

This record has been used as a means to identify the day(s) for which the magnitude of river flow is most relevant each year. The flow at the critical time this year (May 17 2017) is estimated to have been approximately 4,400 m^3/s which is ***the largest flow ever recorded immediately prior to or during breakup***. ***It is clear to KGS Group that the high flow this year was arguably the greatest contributor the ice jamming and resulting high water levels during the ice breakup period that caused the significant and rapid overland flooding***.

8.7 AGGRADATION OF THE RIVERBED

A common comment by the local residents was their perception that the river has aggraded, as attested by the growth of the sand bars. If this were true and the riverbed as a whole has risen due to increased sedimentation, then it would almost certainly be manifested in higher water levels during both open water and ice covered periods.

KGS Group addressed this in a number of ways:

- Google Earth has the capability to show historical photographs, and in the case of the river at Happy Valley - Goose Bay, over a period of over about 20 years however it is difficult to place exact dates on the various air photos as Google Earth builds mosaics of the photos in each year. Nevertheless, examination of these maps did show changes in the sand bar formations over the years but there was no strong evidence of growth of those sand bars overall, nor any indication of accretion of the riverbed in any significant way.

- Examination of recorded water levels at the Water Survey of Canada gauge at English Point. There did not appear to be any significant or noticeable trend towards increasing water levels. However, it is noted that the length of record at the English Point gauge is too short to draw conclusions on long term sedimentation from.

- Discussion with Water Survey of Canada to determine whether they have seen any evidence of riverbed aggradation in the period in which they have operated the water level gauge at English Point. They were not aware of any indications of aggradation, although they admittedly only have familiarity of this area since the inception of the English Point water level gauge.

- Review of isolated photographs supplied by local residents (listed in Section 4.0). No strong evidence of overall riverbed aggradation emerged.

- Review of sediment studies done by others in recent years. Notable points raised by others include:

    - The observation by Northwest Hydraulic Consultants (NHC) in their report in July 2008 that there has been an increase in the areal extent of the sand bars between Happy Valley – Goose Bay and Lake Melville. The following statement about the sand bars (islands) is quoted from their report….”comparison of recent (2006) orthophotos with 1972 satellite imagery reveals that the islands are very stable. The area of the islands has actually increased over this period, a reflection of the reduction in peak flows since completion of the Churchill Falls Dam.”

    - NHC also identified the potential for the Muskrat Falls Reservoir, when fully impounded in the future, to trap incoming sediment and generally reduce the sediment load in the river downstream. That is predicted by NHC to virtually eliminate the long term sedimentation in the river downstream of Happy Valley – Goose Bay, and actually cause a substantial reduction in riverbed levels between Muskrat Falls and Blackrock Bridge.

    - Hatch studied the potential for erosion at the restriction in the river caused by the Blackrock Bridge. This was done using a three dimensional numerical simulation with the software FLOW3D, and proved that there could be substantial local erosion at the restriction, associated with deposition of the eroded material downstream. The short extent of the numerical model of the river near the bridge did not permit the estimation of the aerial extent of sediment deposits downriver.

It appears from these reviews that there is a strong possibility that the riverbed has been aggrading in the reach between Happy Valley – Goose Bay and Lake Melville, and that may have contributed to some extent to the staging that occurred in May 2017. This would possibly be an expected result from:

- Systematic reduction in flood peak flows caused by the reservoir at Churchill Falls.
- Constriction of the river at the Blackrock Bridge causing increased erosion locally at that location, with deposition in the river downstream.
- The natural tendency for development of deltaic deposits where a river with sediment load enters a lake. This would have been occurring for millennia, long before Mud Lake was inhabited.

Quantifying the effects on flooding from each of the influences listed above is not possible with the field data that has been gathered to date, nor from theoretical analyses.

Offsetting the possible trend in deposition in recent decades may be the significant reduction in the future in sediment load in the Churchill River downstream of Muskrat Falls. This would occur due to the trapping effect of the reservoir, as predicted by NHC.

There does not appear that there is adequate measured evidence to quantify the increased recent sedimentation in the river and to firmly estimate what effect it had on the flooding at Mud Lake in 2017. It is also not possible to firmly estimate the future trend and effect that the evolving sedimentation process may have on ice jamming and flooding. Systematic bathymetric surveys of the river would be required over a period of years in the future to permit a credible assessment of the effect, if any, that sedimentation may have on ice breakup and spring water levels.

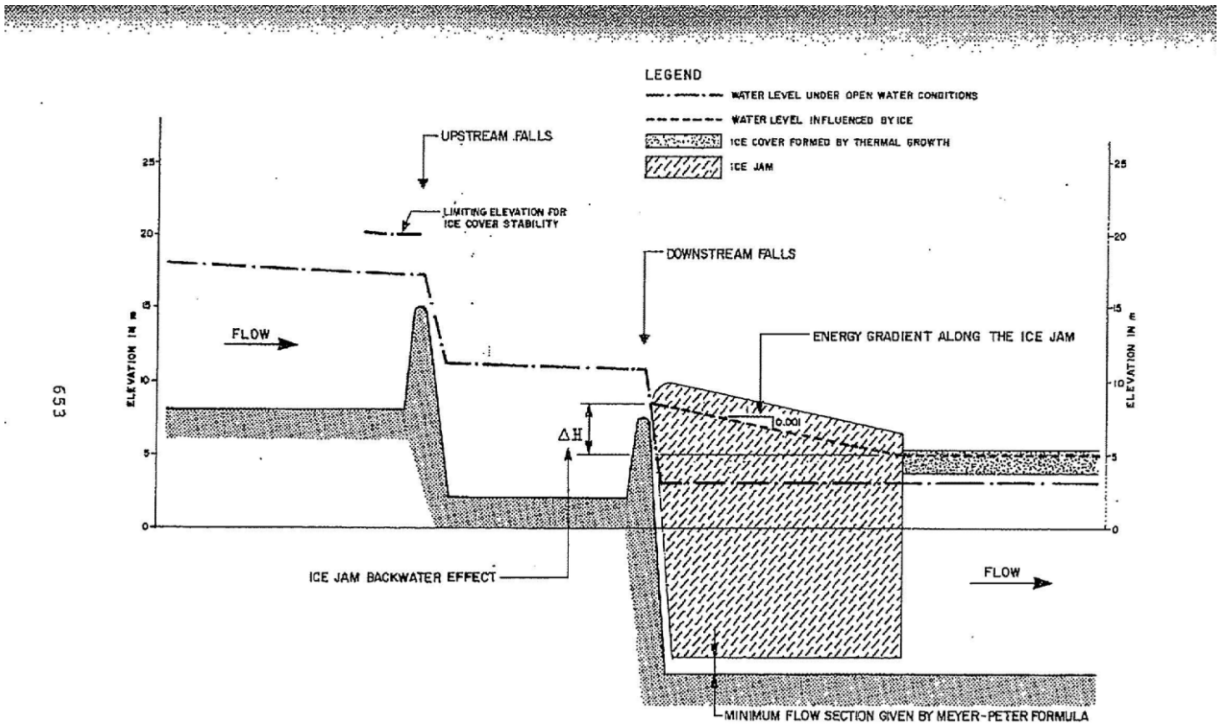
8.8 EFFECTS FROM HANGING ICE DAM BELOW MUSKRAT FALLS

As described in Section 6.11, the advancement of the ice cover from Lake Melville each year has been arrested, at least temporarily, by the high velocities of flow at Muskrat Falls. Incoming ice from the river upstream has been carried to great depths and accumulated in what is termed a “hanging ice dam”. Photos 8-1 and 8-2 show the typical hanging ice dam as it developed in 2009. It typically causes local ice thicknesses downstream of Muskrat Falls to grow to as much as 35 m or more. The phenomenon was aptly described by SNC Lavalin engineers Cheung and Guillaud in their technical paper published in 1981 in the Canadian Society of Civil Engineers.

Figure 8.27 has been extracted from that 1981 paper that conceptually displays the typical profile of this enormous hanging ice dam.

FIGURE 8.27

TYPICAL HYDRAULIC PROFILE AT ICE DAM



MUSKRAT FALLS ICE JAM SCHEMATIC REPRESENTATION FIGURE 5

Source: J. Cheung and C. Guillaud, (1981)

PHOTO 8-1
HANGING ICE DAM DOWNSTREAM OF MUSKRAT FALLS (FEB. 23, 2009)

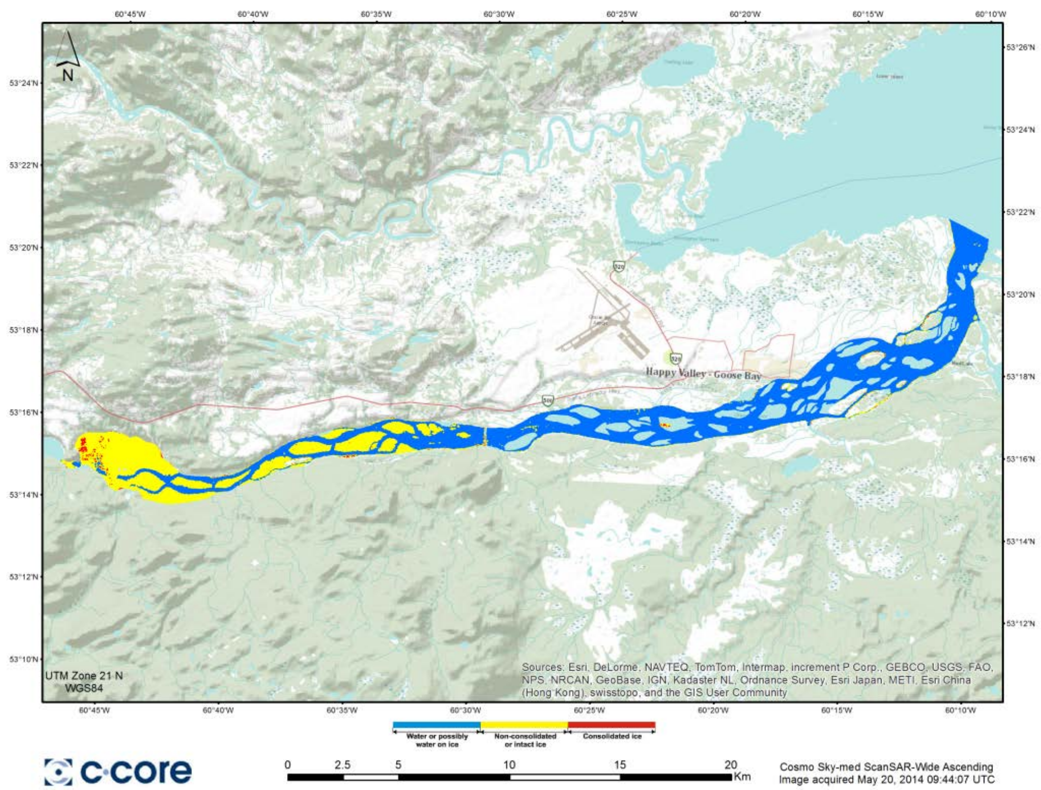
PHOTO 8-2
HANGING ICE DAM DOWNSTREAM OF MUSKRAT FALLS (MAR. 19, 2009)

Cheung and Guillaud (1981) describe surveys of the hanging ice dam that show that the water surface profile created by the fully developed ice dam extends downstream with a hydraulic gradient of 1 m per 1000 m of channel length, as shown in the Figure 8.27. This gradient along the hanging ice dam is consistent with ice dams observed on other rivers (Kivisild, 1958). This would mean that a thick deposition of ice would extend more than 10 km downstream of Muskrat Falls, if the water level rose by 10 m at the falls. In fact, staging well in excess of 10 metres has been recorded frequently in the past (SNC, 2013).

The existence of this massively thick, long ice dam has had a beneficial effect on the river downstream during the spring breakup period. The thick ice has been highly resistant to breaking up and in fact has grounded over large areas and deteriorated in place to a large extent. Figure 8.28 shows the typical extent of ice remaining below Muskrat Falls in 2014, while the downstream ice had already broken and passed downstream of Mud Lake without causing a flood threat. Previous investigators have also noted this characteristic (Guillaud, 1981 and NHC, 2006, for example).

FIGURE 8.28

ICE CLASSIFICATION ON THE LOWER CHURCHILL RIVER (MAY 20, 2014)



Source: 2013/2014 Ice Observation Survey Mud Lake Crossing, Lower Chuchill River LC-EV-107 (Sikumiut Environmental Management Ltd., 2014)

Review of the water level records and the photographs of the hanging ice dam in 2016/2017 indicates that a hanging ice dam did indeed form, although likely not to the extreme extent of some past years. Photo 8.3 shows the hanging ice dam that occurred over the winter of 2016/2017 with the spillway in operation.

PHOTO 8.3
LEADING EDGE OF HANGING ICE DAM DOWNSTREAM OF MUSKRAT FALLS (MAY 14, 2017)

The hanging ice dam that occurred in 2017 was much like it appeared in the past, but only achieved a maximum water level of approximately El 7.5 m downstream of Muskrat Falls. The key reason for this accumulation was that the reservoir was not able to be partially impounded as had been originally planned by the designers/constructors of the Muskrat Falls Development. Incoming ice continued to pass through the structures at Muskrat Falls and build in the hanging ice dam. It appears that the stabilizing effect of the hanging ice dam on the river breakup downstream was similar to previous years and could not be considered to be a significant influence on the flood event at Mud Lake.

In the future, however, when the reservoir at Muskrat Falls is fully impounded, the hanging ice dam below Muskrat Falls will consistently cease to form at all, as has been accurately predicted by Hatch in various reports of the ice processes (for example in Hatch, 2013). There will be an ice cover up to within approximately one kilometre of the structures (Hatch 2013), but that ice cover will be relatively thin (estimated to be less than 1 m by Hatch) and will have little or no tendency to ground as spring breakup initiates. That ice will almost certainly release downriver, and likely early in the breakup process before the ice at Mud Lake has cleared. This may exacerbate ice jamming and flood potential in the future during ice breakup in the river near Mud Lake. This influence has not been reported in any documents reviewed by KGS Group, and may justify further investigation to fully understand the effects of the Muskrat Falls Reservoir in the future.

8.9 LOSS OF RIVER STORAGE EFFECTS IN THE RESERVOIR OF MUSKRAT FALLS

A river has a natural storage effect that attenuates the transmission of floods. As river flows increase, the river stage also increases and some volume of flood water is thereby retained temporarily in the channel. This retention essentially “shaves” off a certain amount of the peak of the flood hydrograph. As the flow recedes, that stored water is gradually released as the river returns to the original lower stage. That type of attenuating effect by the natural channel will be eliminated over the length of the reservoir that will be impounded at Muskrat Falls. The reservoir, however, offers a similar ability, but serves more like a bathtub. Water can be intentionally retained in the bathtub during the rising limb of a flood hydrograph and released later. There will be an attenuating effect that is conceptually similar to the natural river. The EIS for Muskrat Falls has proposed that the storage capacity that will be reserved for exactly this type of reduction of spring flood flows is equivalent to 0.5 m in water level of the reservoir. The stage-storage relationship for the reservoir shows that this proposed reserve would provide a total storage volume of 50,000,000 cubic metres that would be theoretically able to absorb floodwaters during the rising limb of a flood hydrograph.

The relative magnitudes of the natural river attenuation compared to what could ideally be achieved in the proposed reservoir at Muskrat Falls can be computed with detailed numerical analyses. KGS Group has not encountered reports of any such analyses to date for the Churchill River. These are time-consuming calculations usually done by software specifically designed for this purpose, and beyond the scope of KGS Group’s study. However, the relative effects of each attenuation process can be compared in approximate terms using simple calculations as follow:

For the natural river:

i. A change in river flow from say 1500 m^3/s to 4500 m^3/s (similar to the sudden rise in flow that occurred in the spring thaw in 2017) results in a typical rise of at least 3.5 m in water level along the river, based on the shape of the known stage-discharge relationship shown in Figure 6.5 . This rise could be even greater if the river is still fully or partially ice covered.

ii. The surface area of the river has been quoted in the EIS for Muskrat Falls to be 60 km^2. Given the rise in water level described in Point i above, that indicates that a total volume of approximately 210 million cubic metres of water would absorbed into temporary storage during the rising limb of the flood assumed in Point i above.

iii. Over a period of a week, for example, that would result in a reduction of approximately 350 m^3/s from the flood peak.

For the proposed reservoir:

i. If the control of the reservoir would be so precise, and the flood forecasting of inflows so accurate, as to permit the full 0.5 m of the reservoir to effectively serve as a flood reduction measure, then the available 50,000,000 cubic metres would still be less than only one quarter of the storage volume available in the natural river.

ii. This equates to a reduction of only 83 m^3/s.

Clearly, this decline in potential for flood attenuation did not occur in 2017 because the reservoir was not impounded to its full extent. The attenuation of the natural river was still dominant. However, it is a process that should be considered for further studies to determine the extent of loss of river storage, post Muskrat Falls development. Expansion of the live storage capacity available to attenuate spring flood flows may be justified.

8.10 THERMAL INERTIA OF THE RESERVOIR

In their report in 2014 entitled “LCP Ice Formation Environmental Effects Monitoring Plan”, Nalcor accurately pointed out that the thermal inertia of the reservoir will affect the timing of both ice formation and ice breakup. Their report states that:

“*Based on the data collected, Nalcor (2009a) predicted that during Project operation, the ice conditions below Muskrat Falls, including at the Mud Lake Crossing, would be sufficient (i.e.,* *thickness and stability) to form ice roads. However, following Project construction, ice formation near Mud Lake is expected to be approximately two weeks later, and ice break-up is likely to be one week later (Nalcor 2009a; JRP 2009; Hatch 2010a)."*

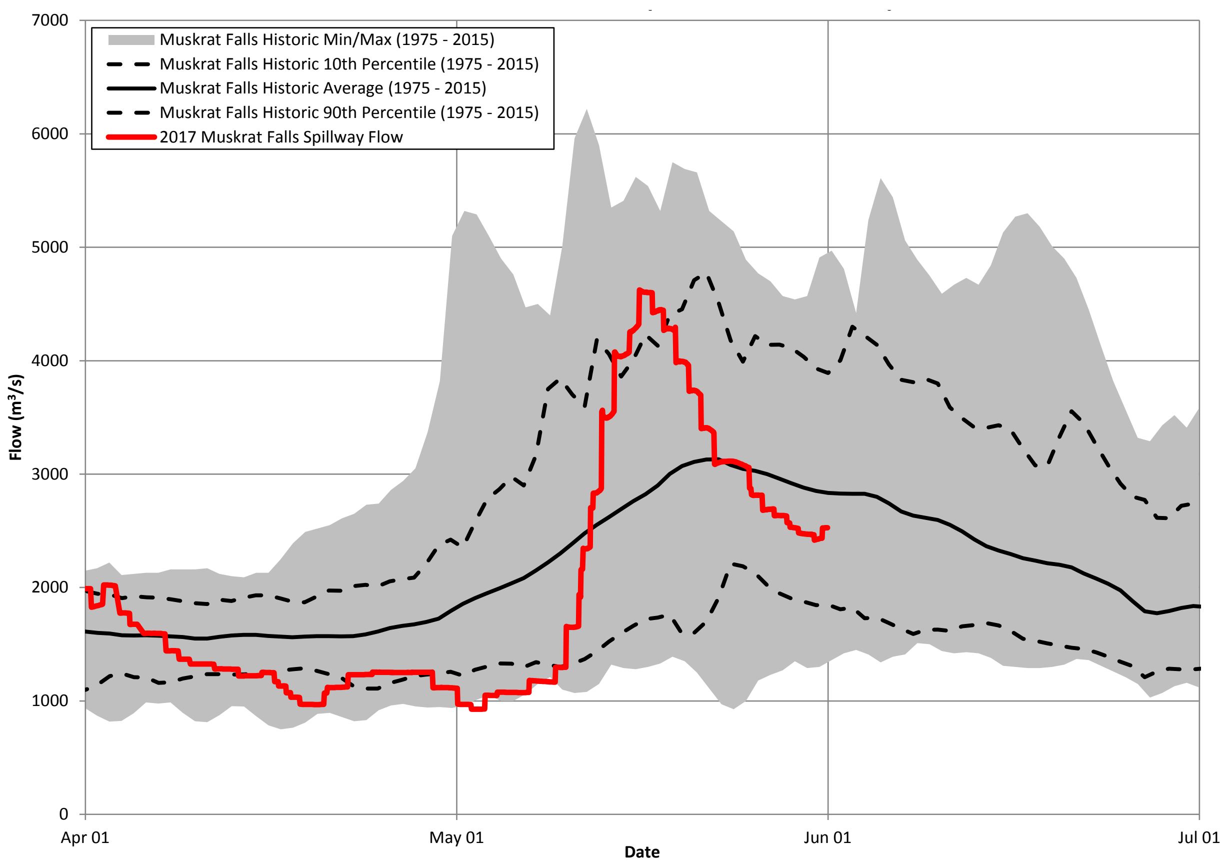
The delay in the breakup was estimated from the fact that the 1500 million cubic metres of water in the proposed reservoir will cool to nearly zero degrees over the winter, and then release that cold water in spring after the start of the spring thaw period. The chilling effect of this late release of cold water on the breakup process was estimated by Hatch (2010) to be a typical delay of 1 week. Clearly that would impede the effect of ice decay in the period leading up to the spring breakup. More ice and stronger ice would be expected to occur when the spring freshet commences.

There appeared to be no recognition that this delay in breakup can expose the downstream reaches of the river near Mud Lake to higher spring freshet flows than would have occurred naturally. The effect could, in some years, result in an increase in potential stages during the spring ice breakup. The vulnerability of this reach of the river to high flows and ice jam flooding was already documented in Section 6.8.

The flood event of 2017 was not affected by the phenomenon described above, as the reservoir has not yet been impounded to any significant extent, and the thermal inertial effect was therefore negligible in 2017. In addition, the flows one week later than May 18 (approximate date of peak of flooding in 2017 at Mud Lake) were actually less than the flow that coincided with the highest water levels at Mud Lake. Thus, had the one week delay actually occurred this year, it could theoretically have resulted in lower stages than actually were observed. This is not a certainty, however, because unbroken ice could still create significant backwater effects (flooding) even if the ice breakup has not occurred. In addition, this fortuitous decline in flow in 2017 is not always the case. In general, the river flows continue to rise in May, and peak in late May. Figure 8.29 shows the typical cycle of flows for April, May, and June in the Churchill River.

FIGURE 8.29

LOWER CHURCHILL RIVER FLOWS IN APRIL, MAY AND JUNE



On the other hand, the same analyses by Hatch have also shown that the slow release of the waters that are warmed in the summer and released in fall may delay the formation of ice on the river near Mud Lake by as much as two weeks. Theoretically, that would delay the ice formation into a period when flows are typically declining after any late-fall rainfall events. It would also reduce the exposure of the ice cover near Mud Lake to two weeks of cold winter temperatures. It may therefore slightly reduce the total growth of the ice in that area. This would have a beneficial effect of resulting theoretically in thinner ice in spring that may clear out more readily without causing severe backwater effects. KGS Group has used the classic empirical equation developed by Stefan (Ashton, 1986) to estimate the effect on the ice growth due to the reduction of exposure to degree days of freezing. Inspection of Figure 8.25, suggests that a delay of two weeks for ice formation in early December would result in approximately (on average) a reduction of 10% of the degree days of freezing. According to the Stefan equation, this would result in approximately a 5% reduction in ice growth over the winter. Given that a substantial portion of the ice thickness is due to the initial formation by juxtaposition, the total expected impact of the delay in ice formation on the ultimate end-of-winter ice thickness would be substantially less than 5%. This small reduction is unlikely to have much impact and almost certainly would not compensate the increase in ice jamming potential due to the effects in spring described above.

To be clear, these thermal inertial effects that were predicted by Hatch did not occur in 2016/17 to any significant extent because the reservoir was not yet fully impounded.

It appears that further analysis of these future thermal effects from the reservoir on spring ice jamming and flooding in the river near Mud Lake should be undertaken and acknowledged.

8.11 ICE BOOM AT MUSKRAT FALLS

The original plan for construction in 2016/17 included the control of the reservoir level at El 25 m, in combination with the installation of an ice boom upstream of the Muskrat Falls structures. The intent was to encourage the formation of a stable ice cover that would minimize the potential for ice generated in the river upstream to pass through the spillway. That would in turn minimize the potential for partially plugging the spillway with ice and also minimize the potential for the excessive growth of a hanging ice dam downstream that could possibly threaten to cause flooding of the downstream side of the construction site.

Complications with the performance of the water retaining structures required that this process be abandoned, and the spillway gates were opened fully. This resulted in the water surface upstream to return to nearly pre-construction levels. This rapid reduction in water level occurred on November 18, before development of an ice cover to any great extent on the river either upstream or downstream.

It is the understanding of KGS Group, through the information offered during meetings with local residents, that the ice boom was not installed at any time in 2016 or 2017. They offered the opinion that the absence of the ice boom resulted in excessive amounts of ice to flow into the river downstream and contribute to the ice jam and flooding event near Mud Lake.

KGS Group believes that:

- The absence of the ice boom did not result in any more significant inflow of ice to the river downstream of Muskrat Falls than would have occurred under natural conditions without the presence of the Muskrat Falls construction site.
- Even if the ice boom could have been installed, it would not have been effective to retain ice or debris under the swift flow conditions that prevailed after the opening of the spillway gates on November 18 and the decline in the river level to near natural levels. In fact, had the boom been in place before the emergency opening of the spillway gates on November 18, it could have failed under the increasing stresses as the water level declined. This could have caused release of whatever ice was retained, as well as debris, all in one massive movement. Plugging of the spillway could have led to rapid flooding of the construction site, possibly with loss of life.

There was also an opinion offered by local residents that the release of a portion of the reservoir from El 22 to 21 on about May 6 caused disruption of the ice upstream. They purported that there was a subsequent release of ice through the spillway that would not have occurred under natural conditions. KGS Group disagrees with this point as well, since almost all of any small amount of released reservoir ice would have been trapped by the hanging ice dam that persisted until late May. It would not have had the opportunity to affect in any way the ice jamming potential in the river near Mud Lake.

8.12 EXCESS DEBRIS

Local residents reported to KGS Group that there was an exceptional amount of debris in the river that was trapped along with incoming ice during the ice cover evolution in November/December 2016. It is possible that significant concentrations of debris could strengthen the ice cover that formed and could potentially add to its resistance to breakup in the spring. However, there were no photos provided to KGS Group that suggested that debris would have occurred in the concentrations that would have been needed to significantly affect the overall resistance of the ice cover to breakup. It is not possible for KGS Group to conclude from the evidence provided that the debris had any significant effect on the flood event.

8.13 TIDAL EFFECTS

The potential influence of the tidal conditions on May 2017 flooding of Mud Lake and Happy Valley - Goose Bay was investigated by evaluating the available data measurements and predictions.

Tidal Conditions in Lake Melville

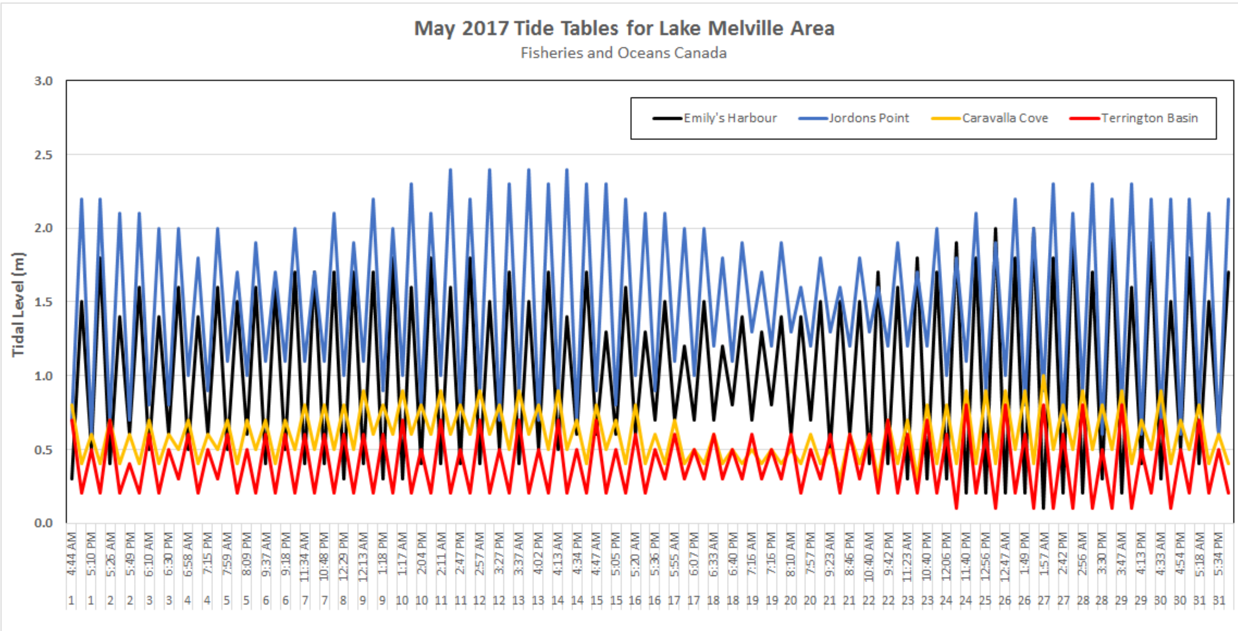
The first question investigated was the degree of tidal influence on the water levels in Lake Melville based on the published tide tables. Since the tables are produced based on the known tidal constituents at the reporting locations, the data is sufficient to look at the tidal effect from the Atlantic coast to the mouth of the Churchill River.

Four reporting locations where evaluated, including:

- Emily's Harbour located along the open coast in the Brig Harbour Island chain.
- Jordons Point which is located in a narrow constriction leading to the channel entrance of Lake Melville.
- Caravalla Cove located near Henrietta Island at the entrance to Lake Melville.
- Terrington Basin which is located just west of the Churchill River Mouth.

Figure 8.30 shows the predicted tidal extremes at the four locations for the month of May, 2017.

FIGURE 8.30
PREDICTED TIDAL EXTREMES FOR THE LAKE MELVILLE REGION



The following observations can be drawn from the tide table data:

- The local tidal range is at its maximum around the Jordans Point station due to the constriction in the shoreline leading to the Lake Melville channel. Consequently, the local tidal forcing is greatest in this location due to the unique coastline morphology in this region. The peak tide for May 2017 was 2.4 m, with a monthly tidal range of 1.8 m.
- Further offshore at Emily's Harbour the tidal range is slightly reduced, since the shoreline orientation does not focus the tidal energy. The peak May 2017 tide prediction was 2.0 m, with a minimum of 0.1 m, for a tidal range of 1.9 m.
- The tidal range decreases dramatically upstream of the channel leading to Lake Melville, in the vicinity of Henrietta Island. At Caravalla Cove, the peak tide predicted for May 2017 was 1.0 m. Refer to Figure 8.30.
- Based on the tidal extremes predicted for the Terrington Basin, the water levels for the southern portion of Lake Melville near the mouth of the Churchill River features a minor tidal signal, with a peak tide of 0.8 m in May 2017. The total tidal range for May 2017 was only 0.7 m.

In summary, Lake Melville features a weak tidal signal compared to the exposed Atlantic Ocean coastline in Labrador. In the vicinity of the Churchill River mouth, the lake featured a tidal range of 0.7 m and a peak tide of 0.8 m for the month of May 2017. In addition, around the flood peak in May the tides were coming off the spring tide cycle and moving into the smaller neap tides, as seen in Figure 8.30. Tidal influenced water level fluctuations were only 0.5 m from May 12 to 20, 2017 at the Terrington Basin.

Potential Storm Surge Influence on Lake Melville Water Levels

While the tide tables were useful to look at gradients in the tidal effects across Lake Melville, since they are predictions based on the tidal constituents and not actual measurements, they can't provide any indication about the actual water levels during the flood. Or, the potential influence of a storm surge on the Lake Melville water level during the May 2017 flood.

In the absence of local measurements, we evaluated the recorded water levels from the Nain tide gauge. The 2017 data is shown in Figure 8.31. The measured data and tide table predictions for week preceding and following the storm are shown in Figure 8.32. The measured (observed) data at Nain closely followed the predictions and there is no evidence of a large storm surge that could impact the local water levels in Lake Melville.

FIGURE 8.31
MEASURED WATER LEVELS FROM THE NAIN TIDE GAUGE (2017)

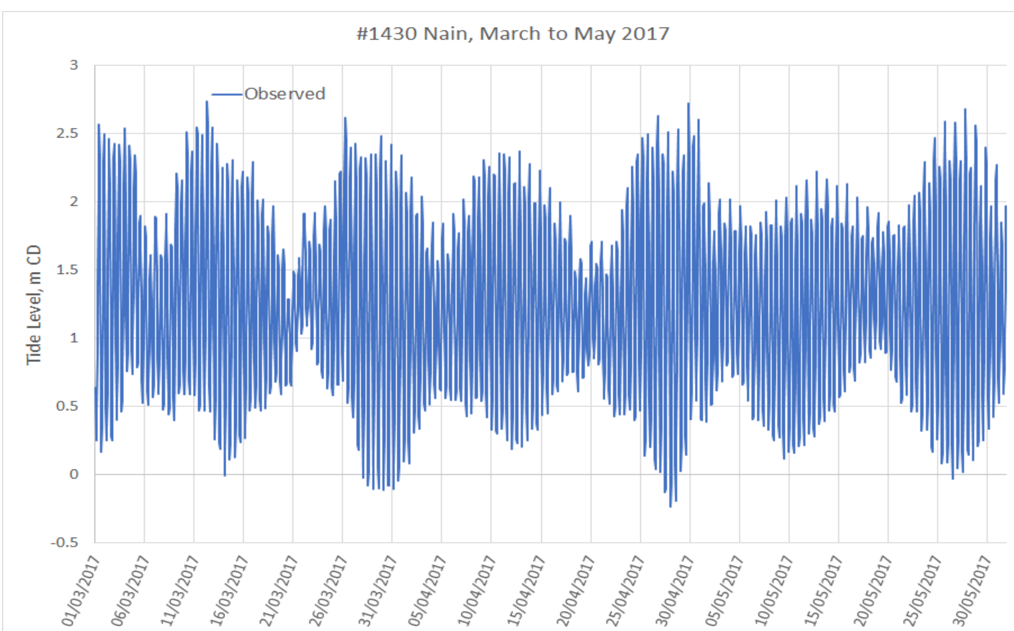
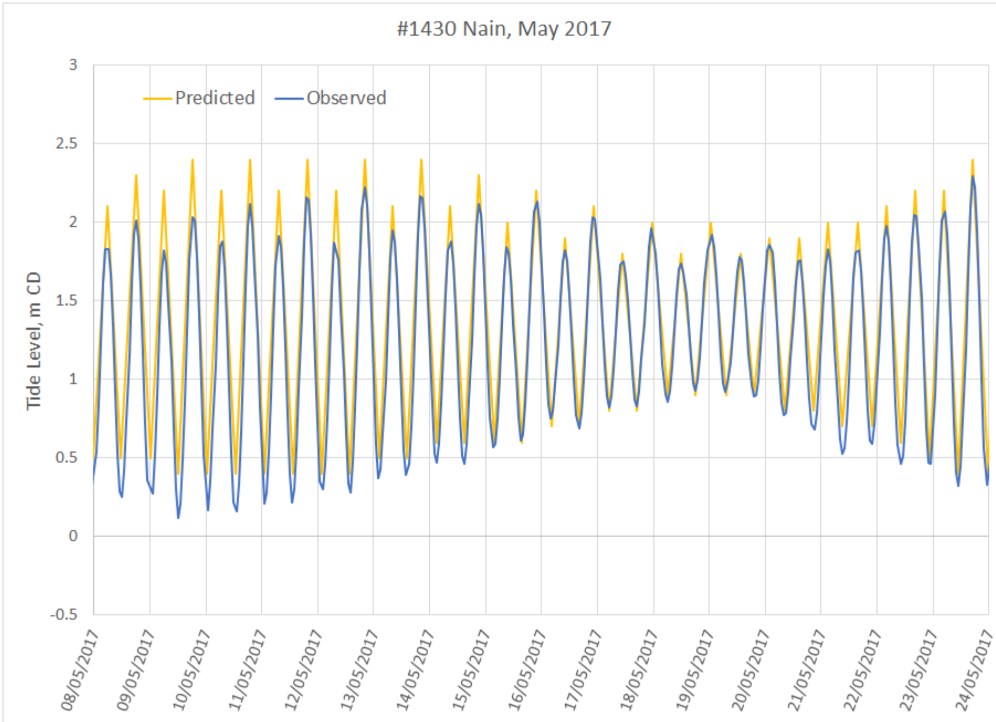


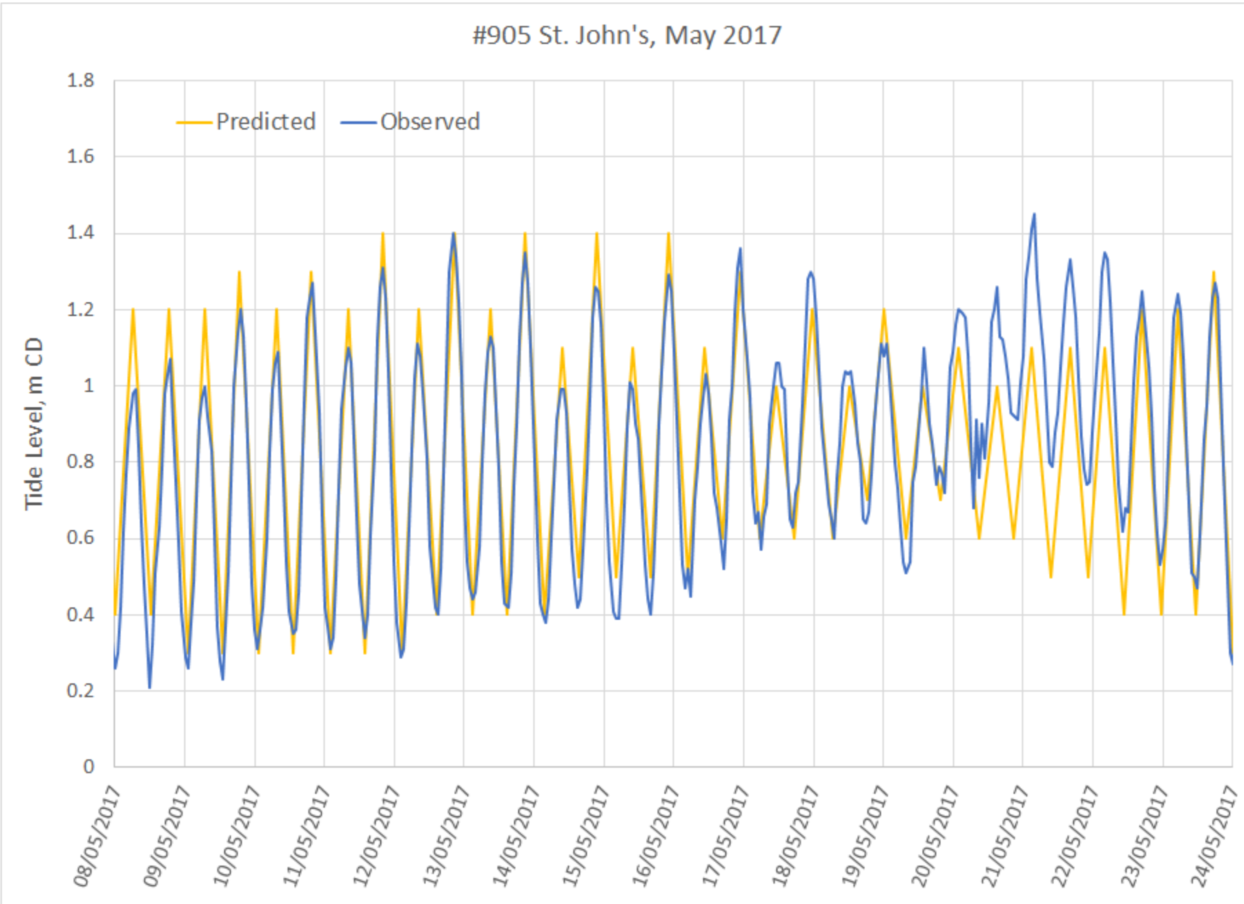
FIGURE 8.32
NAIN WATER LEVELS AND TIDE TABLE PREDICTIONS (MAY 8 TO 24, 2017)



The measured and predicted tides from the St. John's gauge are shown in Figure 8.33. For the days leading up to the flood and immediately following, there was no significant deviation from the predicted and measured tides. Again, these results suggest there were no major storms along the Labrador and northern Newfoundland coastline prior to or during the Mud Lake flood.

FIGURE 8.33

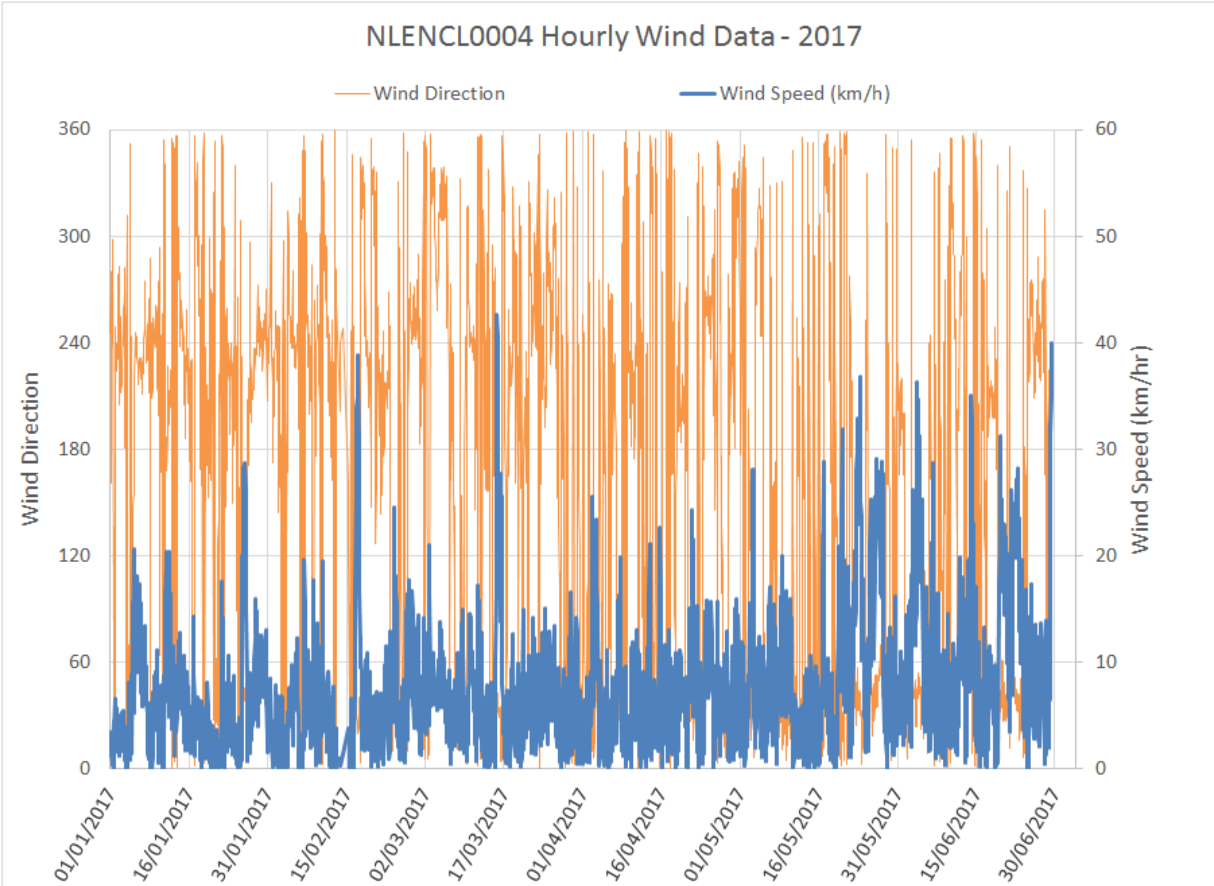
ST. JOHN'S GAUGE MEASUREMENTS & TIDE TABLE PREDICTIONS (MAY 8 TO 24, 2017)



It is interesting to note, however, that the measured water levels at the St. John's gauge do appear to record a storm surge event between the period of May 20 to the 22, 2017. Refer to Figure 8.33. While this event doesn't correspond with the timing of the Mud Lake flood, it does show that the method of comparing measured water levels to the tide tables can be used as a coarse method to screen for storm surge events.

The final piece of evidence that was evaluated was localized wind measurements at Station NLENCL004. The hourly data from January to June 2017, including wind direction and speed, is shown in Figure 8.34. As shown, there are several events with wind speeds of 40 km/hr (approximately 11 m/s).

FIGURE 8.34
HOURLY WIND DATA FOR 2017 AT MUD LAKE CROSSING CLIMATE STATION

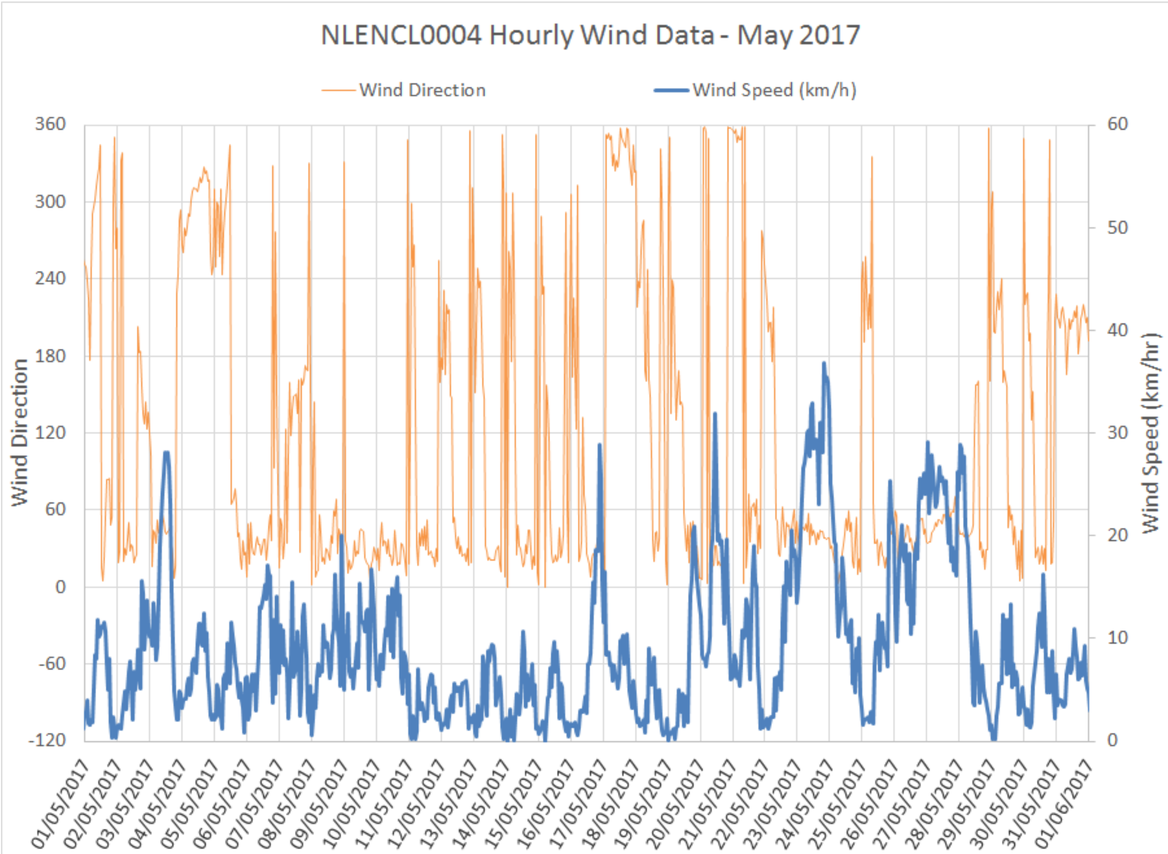


Focusing only on the month of May 2017, there was a peak in the wind speed on May 17, as shown in Figure 8.35. However, while there is clearly a peak in the wind speed during the flooding event, a wind speed of 29 km/hr (8 m/s) is not an extreme condition. Rather, wind speeds in excess of 20 m/s would be typical of a severe storm event capable of propagating an Atlantic storm surge into Lake Melville or creating localized conditions that would elevate the surface of Lake Melville in the vicinity of the Churchill River mouth.

During open water conditions, a sustained northeast wind speed of 29 km/h, acting over the 100 km fetch length along Lake Melville, would result in a wind setup of approximately 0.01 m. However, as the ice on Lake Melville was still in place, any wind setup would have been considerably dampened, and therefore would not have contributed significantly to the flood event.

FIGURE 8.35

HOURLY WIND DATA FOR MAY 2017 AT MUD LAKE CROSSING CLIMATE STATION



Therefore, based on the data available for this analysis, it does not appear that the Lake Melville water levels and tidal conditions influenced the flooding event.

In summary, the data does not suggest Lake Melville experienced abnormally high tides during the Mud Lake flood. In fact, the region was coming off the higher spring tides and transitioning into the smaller need tides. While the Nain and St. John's tide gauges are located a considerable distance from Mud Lake that did not record any abnormal sea conditions surface conditions that could be associated with a large synoptic scale storm surge event that would affect Lake Melville water levels. And finally, the localized winds measured at the mouth of the Churchill River did not feature any extreme wind speed events around the time of the flood that could be associated with an Atlantic storm event capable of propagating a storm surge into Lake Melville.

9.0 OVERVIEW OF THE MOST SIGNIFICANT CAUSES OF FLOODING IN 2017

Consideration of the river characteristics and the evidence available has led KGS Group to conclude that there were a variety of factors that, in combination, conspired to cause flood levels of unprecedented magnitude at Mud Lake. The underlying issue was the ice jam evolution between Happy Valley – Goose Bay and Lake Melville coincident with the peak of the spring freshet. The contributing factors to that main theme were analysed and described in Sections 6.0 and 8.0, and are summarized below.

- The relatively high river stage during the ice formation period in the river between Lake Melville and Happy Valley – Goose Bay. The high stages were due to a combination of relatively high outflows from the Churchill Falls complex (but not uncommon, compared to previous years), and abnormally high runoff from the catchment downstream of Churchill Falls from late November rains/snow/snowmelt. The high stage at formation led to a relatively high resistance of the ice cover to break up in the spring. The wet antecedent conditions in the catchment from October/November 2016 contributed to the potential for intense runoff in the spring.
- High flows coincident with the ice formation period caused an abnormally thick ice cover to form by juxtaposition. This was followed by further thickening during the winter due to the lower than normal insulating effect from the below normal snow depth. Both factors are difficult to quantify accurately, and field measurements are not available to prove conclusively. However, both processes of ice thickening are well understood and experienced elsewhere, and cannot be denied.
- A colder than normal April, which denied the ice cover from early deterioration before the onset of a warming trend in early May.
- Heavy rains in April followed by an intense and rapid warming trend that commenced on about May 7. There was little time for the thick ice cover near Mud Lake to deteriorate before the rapidly increasing river flows developed.
- Once the freshet commenced, it culminated in the highest flow on record at the time of ice breakup in the river downstream of Happy Valley – Goose Bay. It is a well-known fact that the higher a river flow is in coincidence with formation of an ice jam, the higher is the river stage that results.
- The river is wide and shallow between Happy Valley – Goose Bay and Lake Melville, and has a distinct bottleneck near English Point, all of which contributes to a propensity to cause water levels that exceed the river bank elevations in the area. The area has a history of high water levels during both ice formation and ice breakup.

It is unfortunate that the factors listed above all came together in the same year that the construction at Muskrat Falls could appear to have any potential effect on the river conditions. It is understandable that local residents would associate the flooding with the Muskrat Falls development. However, KGS Group has not found any factors that have been significantly influenced by any construction or operation of the Muskrat Falls facilities in 2016 and 2017 and that would have worsened the flood potential at Mud Lake.

There are also factors that could have affected the extent of flooding, but cannot be proven with the information available:

- It is possible that there has been a gradual buildup in sediment in the lower river downstream of Happy Valley – Goose Bay. This could have increased the riverbed elevations to an extent that would lead to increasingly higher stages during the formation of transitory ice jams in spring. However, systematic bathymetric surveys of the riverbed would be required to develop a credible scientific proof that sedimentation is clearly occurring. Furthermore, studies to date have predicted that there will be a net reduction in riverbed levels in the future after the impoundment of the Muskrat Falls Reservoir.
- The abrupt cutback in outflow from Churchill Falls in late March would have caused increased grounding of the ice cover on the sand bars near Mud Lake. This may have led to frost penetration and freezing of the ice to the sand bars prior to the onset of the spring freshet. It would also have stranded the ice over the sand bars and made it less prone to weakening during the short duration of spring melt. Both effects would have enhanced the resistance of the river ice to break up and flush through into Lake Melville.

There are also factors that could further intensify the potential for flooding during river ice breakup ***in the future*** after full impoundment of the reservoir at Muskrat Falls, as discussed in Section 8.0. None of these actually occurred in 2017 because the Muskrat Falls Reservoir contained only an insignificant amount of stored water. These future factors include:

- Elimination of the hanging ice dam below Muskrat Falls. This massive deposit of ice used to extend typically from 3 to 10 km in length below Muskrat Falls and used to mostly decay in place in spring. It usually did not release at the time that ice jams would typically have been prone to occur in the river near Mud Lake. The hanging ice dam will be replaced in the future, after the impoundment of the full reservoir at Muskrat Falls, by a relatively thin ice cover that will almost certainly release and potentially add to the ever-present risk for ice jamming and flooding in the reach from Happy Valley – Goose Bay to Lake Melville.
- Introduction of a large reservoir with a live storage (i.e. storage available to peak shave flood hydrographs in spring) that is considerably less than that of the natural river that it will replace.
- Introduction of a storage volume in the Muskrat Falls Reservoir whose thermal inertia would delay the onset of river ice breakup and potentially shift the breakup period to coincide with more intense spring flows in the river. Essentially, high flows equate with

more violent ice jams and higher stages. As discussed in Section 8.10, this may be offset to some extent by the delay in the formation of the ice cover at Mud Lake in the fall/early winter.

10.0 POSSIBLE MITIGATION FOR FUTURE

KGS Group has developed a list of possible mitigation measures that could reduce the risk of flooding of the magnitude experienced at Mud Lake in 2017. These measures have been developed in concept only and would require further study, economic evaluation, confirmation and prioritization:

1. Consideration of adjusted releases from Churchill Falls so that the total flood flow in the lower Churchill River can be reduced during ice breakup to the maximum extent possible. For example, reduction of outflows in mid-May 2017 by 500 m^3/s would have reduced the flow in the lower river by about 10% during the breakup period and would have reduced the flood levels to some extent. It is recognized that this may adversely affect energy generation from the Churchill Falls complex, and this would require careful consideration.

2. Consideration of cutback in releases from Churchill Falls prior to and during the short period of ice formation near Mud Lake, if local inflows below Churchill Falls are uncommonly high. The objective would be to start the ice cover formation at a level that minimizes the volume of ice in the river that can act as a blockage during spring ice runs. Due consideration of financial impacts from this would be important.

3. Avoidance of drastic cutbacks in outflow from Churchill Falls in the late winter, relative to the flows that had been consistently achieved during the winter, whenever elimination of such cutbacks are practical and cost effective. The objective would be to minimize the grounding of ice on the sand bars, freezing of the ice to the bars and enhancement of the hinge connection of the river ice to the shorelines.

4. Investment in raising the foundations of the affected buildings and roads in and around the community of Mud Lake and along Mud Lake Road so that future flooding in spring does not significantly impact the infrastructure. Such an action was taken in southern Manitoba after the “Flood of the Century” that occurred in 1997. Thousands of homesteads were raised by typically 2 to 5 metres so that future floods would cause minimal damage.

5. Construction of a diversion channel around the flood prone areas near Mud Lake, possibly on the north side of the river. This would be very expensive, but should be assessed in more detail to verify its practicality and viability.

6. Construction of a ring dike or dike(s) at the community to protect against the high water levels that potentially occur in spring. This was also a protection measure undertaken at a number of communities in southern Manitoba after the 1997 flood. The practicality and cost of this option would need to be considered carefully, particularly in comparison with Option 4. The diking would almost certainly require the inclusion of cutoff walls that extend below the dikes into the pervious foundation. This has been used elsewhere to avoid flooding of the protected zone by excessive seepage through the foundation.

7. Development of a more extensive system of hydrometric gauges to assist improved flood forecasting for the catchment below Churchill Falls. This will assist in developing an improved basis of flow cutbacks from Churchill Falls as suggested in Items 1 and 2 above.

8. Consideration of expanding the live storage capacity at the Muskrat Falls reservoir to increase the volume of water that can be effectively used to shave peaks off the annual spring freshet before breakup. Section 8.9 of this report explains that the currently planned live storage associated with the upper 0.5 m of reservoir storage at Muskrat Falls is considerably less than has, under current (natural) conditions, been available to shave flood peaks. An expansion of that range of live storage to approximately 1.5 m (subject to more detailed consideration of what is required to match the natural river storage) would be required.

9. Undertake a systematic survey of the lower river over a number of years to determine whether the channel near Mud Lake is indeed rising due to processes of sedimentation. NHC has predicted that the reservoir impoundment at Muskrat Falls (when fully implemented) will lead to significant degradation of the riverbed upstream of Blackrock Bridge. The effects on the river downstream are less clear, and monitoring in the vulnerable area near Mud Lake would be a wise investment.

10. Improvements to the hydrometric monitoring being carried out on the Churchill River to better understand and verify forecast inflows on the Churchill River, including tributary and local inflow contributions. In particular, the water level gauge on the Churchill River at English Point (i.e. WSC Gauge 03PC001) should be tied in to a geodetic datum such that direct comparisons can be drawn between English Point water levels and other water levels on the Churchill River.

11. Develop more intensive monitoring efforts of the ice formation characteristics and the growth of ice in the Mud Lake area, in an effort to develop a means of better predicting potential flood events like 2017.

KGS Group's review of the considerable amount of available data and the reports from the local residents has allowed KGS Group a strong basis for providing a professional opinion regarding the 2017 flood event. However, it is the opinion of KGS Group that there is a shortfall of data gathering and watershed / ice monitoring in the drainage basin that would be of adequate quality to assist forecasting of future floods and ice jams. This was evident in May of 2017 as the flood and resulting ice jam/flooding appear to have come with complete surprise to downstream residents. The residents were not prepared for the rapid flooding that occurred.

The last two mitigation measures listed above relate to gathering of additional information for forecasting and ice monitoring. Considering that KGS Group's review has concluded that parts of Mud Lake are generally prone to flooding, although perhaps not routinely in the recent history, the general characteristics of the lower river are such that they are favourable for flooding and ice jamming. Considering this, as well as the level of flow control available on the river at Churchill Falls and the when completed Muskrat Falls, it is recommended that a flood management program be implemented. Any such flood management program should include an ice management and detailed ice monitoring program. Each of the mitigation measures noted above should form some aspect of a flood management program.

The flood management program should also include the definition of an effective communication plan between the Government of Newfoundland and Labrador, Nalcor, and downstream residents and stakeholders, as well as possible warning systems. Such a program would help to minimize the sudden flooding, stressful evacuations, and damages that occurred at Mud Lake in May of 2017.

11.0 REFERENCES

The following references were cited within the body of the report. This list of references is not intended to contain a listing of all information that was obtained or reviewed as part of our independent assessment, but rather a listing of known publications that have been cited that support any part of our opinion.

1. "Behaviour of Ice Covers Subjected to Large Daily Flow and Level Fluctuations", by Acres Consulting Service for the Canadian Electrical Association, 1984.
2. "River and Lake Ice Engineering" Edited by G. Ashton, Water Resources Publications, 1986.
3. "Onset of River Ice Breakup" by S. Beltaos, Cold Regions Science and Technology, 1996.
4. "River Ice Jams" by S. Beltaos, Water Resources Publications, 1995.
5. "Hanging Ice Dams" by Hans R. Kivisild, Foundation of Canada Engineering Corporation, 1958.
6. "Formation of Ice Covers and Ice Jams in Rivers" by Pariset, Hausser and Gagnon, Proceedings of American Society of Engineers, Journal of Hydraulics, November, 1966.
7. "Effects of Ice Progression During Construction of Muskrat Falls Hydropower Development" by J.L. Cheung and Ch. Guillaud, Proceedings of Canadian Society of Civil Engineers 5th Canadian Hydrotechnical Conference, 1981.

APPENDIX A

ROUND ONE PUBLIC CONSULTATION ATTENDANCE LIST

AND DOCUMENTATION PROVIDED

HAPPY VALLEY - GOOSE BAY PUBLIC MEETING SIGN IN SHEET

Attendance:

Derek Russell [signature]
Roland Saunders [signature]
Hebert White
INGRIED FELSBERG CROCKER
Donna Best
MELISSA BEST
Claudine Broomfield
GLORIA BEST
CORTLAND BEST
Denise McLean
Germaine McLean.
Rick Burry
Eric Burry
Joe Goudie Tel: (H) 709-896-2623, (C) 709-897-4636
Henry Thevenet
SUSAN FELSBERG
Elizebeth Saunders
ERIN BOBICKI
Vicki Cull
Hobbie Goudie
Richard Felsberg - Born/raised in Mud Lake - Live in Happy Valley

MUD LAKE PUBLIC MEETING SIGN IN SHEET

MELISSA BEST

Duane Dyson

Vyann Kerby

Lester Blake

Ruth Hope

Ingrid Felsberg Crocker

Sevilla Hope

David Davis

Melissa Best email.
melissaebest @ msn.com

Charles Crocker.

Christine Chaulk

CRAIG CHAULK

DAVE RAEBURN

ANN RAEBURN

DEAN CHAULK

Gwen Chaulk

Watson [illegible]

RON HOPKINS

REPORT PROVIDED BY DAVE RAEBURN

THE PERFECT STORM

At a recent meeting between Nalcor officials and Mud Lake residents, we discussed the events that lead to the catastrophic flood of Mud Lake and surrounding areas. Mr. Jim Keating pledged to get to the bottom of what caused the terrible destruction; this was NOT a natural event.

After informal introductions, Mr. Keating read from what was basically a chronological log of the operation of the spillway gates between November 2016 and the present. At that point, a light bulb came on over my head and it suddenly became clear to me the sequence of events that came together to cause the PERFECT STORM. As with most catastrophic events, it is usually a series of problems which combine to produce a final effect.

The flood of Mud Lake in May 2017 was initiated by the release of water from Muskrat reservoir in November 2016. On November 18 and 19 2016, 8 meters of water was released from the reservoir in less than 48 hours. That is a huge amount of water released in a very short time. This was done to enable repairs to be carried out on the coffer dam which was leaking quite severely. I believe the news release at the time said something to the effect that "Water was being released in a slow and controlled manner to enable repair work to be carried out on the coffer dam". In fact, all the spillway gates were fully opened and the entire contents of the reservoir were released in less than 48 hours. The effect of the sudden release of water was to raise the water levels downstream just at the time when the river was freezing over.

At my property in Mud Lake, the ice formed within inches of the top of my river bank. Water levels will normally rise when the river is freezing over but not to the extent of last fall. Because the river froze over so high, all the sandbars were submerged. Ice then formed across the entire width of the river, whereas normally it would form between the sandbars. This became visually evident as the water levels dropped over the winter months and the ice began hinging (breaking off) along the shores and around the sandbars. The cracks in the ice around the hinge points were 3 feet deep in places indicating that there was a huge amount of ice on top of the sandbars. I would estimate that the volume of ice available in the lower reaches of the Churchill River was at least double the norm. Add to that the fact that the ice was one solid sheet from shore to shore and you have the makings of a huge ice dam. Add to that again, we now have an island in the mouth of the river getting bigger every year further reducing the capacity of the river to discharge into Lake Melville.

It is painfully evident to me that Nalcor still does not understand the river and the effect that their operations have. Whether by willful neglect or total ignorance, the release of that water in November 2016 was the catalyst that started the chain of events and decimated the community of Mud Lake.

So, Nalcor, it is time for you guys to step up to the plate, admit you screwed up big time and do what's right by the people whose lives you have turned upside down.

Dave Raeburn

EX Resident of Mud Lake

THE PERFECT STORM PART 2

"The Perfect Storm" is a layman's description of the series of events that led to the flood of Mud Lake on May 17, 2017. Let me first say that I am not an expert on the river, however, I have taken a keen interest over the past 10 or so years on how the river behaves. I also spent some time exchanging photos and information with one of the ice technicians from Hatch, a contractor with Nalcor. I travel the river on an almost daily basis and so I believe I have a fairly good "handle" on what to expect from any combination of influences on the river that might occur.

Further to what I describe in the perfect storm, the warm weather plus the release of more water from the reservoir, in the week prior to the flood, further exacerbated the potential for a catastrophic event. We had four days of exceptionally warm weather during which Nalcor also released a meter of water from the reservoir on top of the already swollen spring runoff. This series of events together with the huge ice dam described earlier brought together all the necessary ingredients to cause a catastrophic flood.

I am absolutely convinced that this was a man-made event. IT MUST NOT HAPPEN AGAIN.

Spring 2017 and Winter 2016 Summary of Stakeholder Updates
Muskrat Falls Spillway Operation

DATE	~WATER LEVEL UPSTREAM OF MUSKRAT FALLS FACILITY	INFORMATION INCLUDED IN STAKEHOLDER UPDATES
May 19	21.5m	The Muskrat Falls reservoir has limited storage capacity. There is no ability to store water upstream of the facility to reduce downstream flows. Nalcor has however decreased production from the Upper Churchill Falls plant to help reduce water flows into the Churchill River. Continue to maintain water levels at approximately 21.5 m. To maintain this level, the spillway gates are regularly adjusted so the amount of water flowing into the reservoir is the same as the amount flowing out. Through our regular stakeholder updates, our spillway pictures have shown all five gates at various heights which can change daily. This is a normal part of spillway operations.
May 17	21.5m	Nalcor and Newfoundland and Labrador Hydro (Hydro) are working together and continue to monitor the situation. Hydro is also working with Fire and Emergency Services (FES) officials to ensure the safety of the public. Updates from Hydro are available on their website: https://www.nlhydro.com/ Water levels have been maintained at a constant elevation of 21.5 metres upstream of the Muskrat Falls spillway since the start of spring thaw last week. Operations at the facility are not impacting downstream water levels and no water has been released from the reservoir. The increased water inflows from upstream as a result of the natural spring thaw are passing through the Muskrat Falls spillway and to the river downstream. Nalcor continues to monitor the increased water flows as well as water levels along the river. Given the lack of storage capacity in the Muskrat Falls reservoir there is no ability to store water upstream of the facility and therefore reduce downstream flows. The amount of water released by the spillway must be the same as the amount of water that flows into the reservoir.
May 16	21.5m	Spring thaw in central Labrador means that water levels upstream and downstream of Muskrat Falls have increased. Nalcor has not released water from the Muskrat Falls reservoir. Water levels have been maintained at approximately 21.5 m since the spring thaw began. The increased inflows from upstream have passed through Muskrat Falls and to the river downstream. The increase in the river is due to natural flow from spring thaw. A graphic was provided that shows water data from the Government of Canada monitoring stations on the Churchill River. The figures showed

		that water levels on the Churchill River upstream and downstream of Muskrat Falls have increased while levels at Muskrat Falls remain fairly constant.
May 12	21.5m	As part of the natural spring breakup, ice upstream of the MF facilities is moving downstream and through the spillway. This is a normal process and water levels are within normal ranges. The elevation of the water in the reservoir has been reduced to 21.5 m to accommodate the changing river flows from the spring melt. The water levels and water flows are consistent with this time of year.
May 11	Reduced from 22.5m to 21.5m	Due to natural spring conditions (snow and ice melt), water flows and water levels downstream of the MF facilities will increase in the coming days. The water flowing through the spillway is being adjusted to match these changing flows. No significant releases of stored water are planned before the end of the spring melt. If carried out before the spring melt, this action could mobilize ice in the river and, if carried out during that period, would further increase flows and water levels downstream of MF. To ensure that water levels upstream of MF do not increase above 22.5 m through the period of higher spring flows, the elevation in the reservoir has been reduced to 21.5 m; a level consistent with water levels in the Churchill River above MF during the spring melt. Changing flows throughout the entire Churchill River in combination with warming weather has resulted in changes to the ice conditions and water levels on the river. Nalcor advises people to avoid the ice and river upstream and immediately downstream of these facilities as the ice cover is unsafe for recreational use.
April 28	22.5m	The water level at the MF cofferdam continues to be held at an elevation of approximately 22.5 m. The water that flows through the spillway is being adjusted to match the changing flows - this means that the river flow upstream and downstream of the MF facilities is the same. Changing flows throughout the entire Churchill River in combination with warming weather will result in changes to the ice conditions and water levels on the river.
April 13	22.5m	Over the past couple of weeks, the water level at the MF cofferdam remains at an elevation of approximately 22.5 m. As we are holding the water level upstream of the temporary cofferdam at a constant level, the water that flows from the spillway is being adjusted to match the natural flow of the river. Essentially this means that the river flow upstream of MF is the same as the river flow downstream of MF. This allows us to keep a constant water level in the reservoir.
April 7	22.5m	The water level at the Muskrat Falls cofferdam is currently at an elevation of approximately 22.5 m.
March 31	Moving from 22m to 22.5m	Over the coming days, we plan to raise the water level from 22 m up to around 22.5 m at the MF cofferdam. This process, which is being done in a controlled and gradual manner, is part of the preparation for the spring runoff levels.

March 27	Moving from 21.5 to 22m	We are in the process of raising the water level at the MF cofferdam. We expect to reach an elevation of approximately 22 m tomorrow. This process is being done in a controlled and gradual manner.
March 3	21.5m	The water level at the MF cofferdam is at an elevation of approximately 21.5 m.
Feb 23	21.5m	The water level at the Muskrat Falls cofferdam is at an elevation of approximately 21.5 m.
Feb 19	21m	We continue to increase the water level in a controlled and gradual manner at Muskrat Falls. The water level at the MF cofferdam is at an elevation of approximately 21 m, with levels immediately upstream of the Upper falls slightly higher. Over the next few weeks, the water level will continue to be gradually and carefully increased, thereby adding to the ice cover that has started to form upstream of the Muskrat Falls site.
Feb 17	18m	We continue to increase the water level in a controlled and gradual manner at Muskrat Falls. The water level at the Muskrat Falls cofferdam is approximately 18 metres, with levels immediately upstream of the falls slightly higher. Over the next few weeks, the water level will continue to be increased to establish an ice cover upstream of the Muskrat Falls site, thereby stopping the further buildup of ice immediately below the Muskrat Falls site.
Feb 3	18m	We continue to increase the water level in a controlled and gradual manner by adjusting the positions of the spillway gates.
Jan 27	16-17m	The water level upstream of the cofferdam is currently around 16-17 m. Over the coming weeks, we will begin to increase the water level in the MF reservoir in a controlled and gradual manner. The water level will be increased to the level necessary to establish an ice cover upstream of the MF site, thereby stopping the buildup of ice immediately below the MF site.
Jan 19	15m	To help minimize ice formation on spillway equipment and to ensure smooth operation of the spillway gates, various gates are continuing to move. We have begun to slowly increase the water levels in the area directly upstream of the temporary cofferdam. At this time, the elevation of the water level remains around 15 m in this area. Over the coming weeks, we will continue to increase water levels in a controlled and gradual manner. The continued operation of the spillway gates and the increase in the upstream water level will not create any safety risks for downstream communities and will not have an impact on the ice cover that is already formed downstream. The ice that has built up in the river below the spillway is as expected and is consistent with what is typical for this time of year. We will continue to closely monitor the ice and cofferdam performance throughout the winter.
Jan 12	15m	To help minimize ice formation on spillway equipment and to ensure smooth operation of the spillway gates, various gates are continuing to move. As noted on January 5, we have begun to slowly increase the water levels in the area directly upstream of the temporary cofferdam. At this time, the elevation of the water level is about 15 metres in this area.

		Over the coming weeks, we will continue to increase water levels in a controlled and gradual manner.
Jan 5	Began to close the spillway gates	Today, we will begin the process to close some of the spillway gates, which will slowly increase the water levels in the area directly upstream of the temporary cofferdam. This will be done progressively in a controlled and gradual manner.
Dec 23	All gates open. Water flowing thru spillway.	We have just started operating the spillway gates. This is done to help minimize ice formation on spillway equipment and to ensure smooth operation of the spillway gates. Over the coming weeks you may see fluctuations in the water levels as well as the slow rising of the water levels in the area immediately upstream of the temporary rock cofferdam. To start to raise the water levels, we will begin to lower and close some of the spillway gates. This will be done in a controlled and gradual manner to ensure that the repair work on the cofferdam is effective in controlling seepage.
Dec 16	All gates open. Water flowing through the spillway.	Work continuing on the cofferdam.
Dec 9	All gates open. Water flowing through the spillway.	Work continuing on cofferdam work.
Dec 2	All gates open. Water flowing through the spillway.	Update on the cofferdam work.
Nov 19	All gates open. Water flowing through the spillway. Water level lowered from 15.5m to 13.5m	All spillway gates remained opened. Water levels in the river returned to normal conditions over the weekend.
Nov 18	Spillway gates opened. Water level lowered from 21.5m to 15.5m	Nalcor opened the spillway gates to lower the water in the reservoir.
Prior to Nov 18	Increased the reservoir level to 21.5m	Operation of the spillway gates to create the reservoir upstream of Muskrat Falls.

APPENDIX B

ROUND ONE PUBLIC CONSULTATION FOLLOW UP

INFORMATION PROVIDED BY RESIDENTS

LETTER FROM RUBY BEST AND JOHN W. MARTIN

July 31, 2017

Attention: Dr. Karl-Erich Lindenschmidt,

RE: *Observations Regarding the Flood of May, 2017*

My name is Ruby Best, and my husband is John W. Martin. We live at 29 Hamilton River Road in Happy Valley-Goose Bay Labrador, on the riverbank side of the road. We have a small cabin on the Mud Lake Road, and my family (family of Mark Best) has a house in Mud Lake. On May 18, 2017, after hearing of the flood in Mud Lake, at home in Happy Valley, we had suitcases packed, fearing an overflow of the riverbank and the destruction that that would result when it did.

The riverbank behind our house generally measures a 15-20 foot drop to the water, and even in the years where we witnessed *extremely* high water levels, there was always an 8-10 foot distance from the top of the bank to the water; this year, on May 18, the water had risen to just 2 feet from the top of the bank, thus prompting us to prepare to evacuate. It is a terrifying prospect to go to bed at night knowing that disaster, literally, is looming on the doorstep.

We observe the river daily, as it constitutes our "back yard". This Winter and early Spring, we had many conversations regarding the fluctuation in water levels, and attributed the anomoly to the obvious new variable - the Muskrat Falls project, and their manipulations of the release and retention of water in the river. In April, for example, a time when the river naturally would be rising, we witnessed the ice on the shore of the small island behind our house breaking off, and falling away, instead of maintaining its level and "making water " due to melting snow and natural Spring runoff.

At freeze-up (late November/early December), a lot of water was released, and along with it, an incredible amount of debris (poles, trees, logs), causing the water level to rise to a high Spring level. When the river actually froze, there was a 50 foot (approximation) square wooden pole (painted in places, seemingly used as a measuring device), that froze into the ice behind our home. The water at freeze-up was unusually high.

At our Mud Lake Road property, my husband's Winter logging harvest floated away in the flood. On May 18, he paddled a canoe to the property, and was barely able to rise the motor of his saw to keep it above the flood waters, and to subsequently save his $10,000 investment. Our family home in Mud Lake was soaked from beneath by the floodwater; the foundation and the floors have been damaged severely, to the point that the house may need to be demolished.

At home here on Hamilton River Road, we live with a very real FEAR of what may become an annual nightmare for those of us who live downstream of the Muskrat Falls mega-project if measures are not put in place to ensure our safety.

We trust that you, Dr. Lindenschmidt, will take our concerns and observations to those who can guarantee our mortal safety. It is an insult to us, who know this river, to dismiss the flood of 2017 as a "natural" phenomenon - there was nothing natural or usual about it.

Please use your influence to help us!

Sincerely,

Ruby Best and John W. Martin

INFORMATION PROVIDED BY SUSAN FELSBERG

PRESENTATION TO THE EARP PANEL for the LOWER CHURCHILL HYDRO PROJECT

Good morning. My name is Susan Felsberg, and I am a first generation Labradorian. I arrived here from Overseas over 50 years ago, to serve the immediate health needs of this pioneer community as a nurse and midwife. I remained here to contribute in elected leadership, and social development, expanding my parameters eventually to include the whole Labrador region. I have lived for 40 years of that time in Mud Lake, and am very familiar with the lower stretches of the Grand-Hamilton-Churchill River. My husband was a skilled artisan, a College instructor, and established a unique enterprise as a metalsmith, while I became a hospital board trustee, an archives volunteer, and an amateur historian and geographer of Labrador. Today I still retain a homestead and an acreage in Mud Lake.

The Panel has heard of the memories and passions of the oldtimers on the river; and now I am a voice from the comparative newcomers, who love this land, call it home, and have paid our dues to do so. You, the Panel, will be well aware that to express one's opinion over a major controversial project in the adjacent polarised population requires courage and conviction on either side of the fence. We have done this time and time and time again, with the military Low-level Flying Environmental Assessment, with uranium mining potential, with health administration, with Parks Canada's arrogance and much else. By and large, Project supporters and critics alike in this town remain good neighbours, but the positions are clearly identified among us, and one lives with the aftermath. I choose to speak with equal courage from yet another position: one of equivocation about this Project, as follows:

Firstly, I have lived and survived on this river daily and weekly, thanks to the river knowledge, good equipment, boat and snowmobile skills usually belonging – though not entirely - to people other than myself. When one lives in sheltered Mud Lake, needing a commute across the river for reasons of employment, grocery supplies, health services or politico-cultural commitments, and the wind is blowing hard, one knows by its direction (especially from the East), plus the sway of the trees, and the distant noise, how the river is behaving, and whether it is navigable. There <u>are</u> people, believe it or not, particularly in the upper reaches of this town, who are quite unaware of the river, and hardly know that it exists, even for their own pollution purposes. Not so, if one lives in Mud Lake. One lives with, and on, and around, the river.

Many years ago, I wrote *"...the river is magnificent, gains one's abiding respect, is ever changeable, and has to be seen and experienced in an autumn gale of ocean proportions, in a solid white mass of swirling snow when visibility is reduced to six inches, in the icy stillness of midwinter, and in the glassy calm of a moonlit summer night. It is under such circumstances that one earns one's place in a country, and in return one feels that a very small piece belongs in one's heart."*

But through the years we Mud Lakers have all watched and struggled with the changes manifest in the lower river that developed after the adulteration from the Upper Churchill: the bank erosions, the shifting sands, the seasonally controlled, reduced water levels, and the solid expanding sandbars spread far and wide – all obstacles for the regular commuter. We have

experienced excess water poured on top of the spring ice during controlled releases upstream, which endangered life and limb. The downstream impacts were not considered in the 1980 EIS.
I respectfully suggest that mitigation is a futile exercise after major damage has been done. It was significant on the third day of these Hearings, to hear Transport Canada declare its mandate towards navigability in recognized bodies of water, and then admit that they have not, and do not, patrol or monitor this stretch of water on a regular basis. Their concerns apparently are exercised for a 30day period related only to a Project launch, and to educated sophisticated public intervention, and thereafter to be shelved.

Along with the beauty and perfection of untouched Muskrat Falls and Gull Island, all of the above explains the practical and aesthetic reasons why I am deeply concerned about this Project. As an aside, if it appears to be hypocritical for anyone receiving Hydro services in a tiny community to be critical of such beneficence, let me explain that when the Upper Churchill was developed, firstly all the power was exported westwards, and then a few years later a fraction was brought eastwards to serve the Upper Lake Melville district. But Mud Lake remained on diesel generation, as the river crossing was deemed too expensive and technically challenging for the hydro alternative. Although the village lobbied vigorously for over ten years, including a cost-benefit analysis for the most labour-intensive diesel plant in the province (the oil supply being hand-pumped into lifeboat drums and towed by speed boat, with no oil tanker being feasible as for coastal plants elsewhere), we were dismissed as unreasonable for a mere population of sixty. Until a new Hydro Chairman arrived on the scene, took a look at the diesel servicing costs across the whole province, realised that Mud Lake was by far the most expensive of all, ordered an experimental submarine cable across the river over the winter months which proved stable and successful, and so the diesel was magically replaced by Hydro. While Mud Lakers appreciate the reduced costs and the convenience and reliability of Hydro services, we would contend that we have paid our price, with the changes made to the river that continue to constantly challenge us.

However, the other side of this equivocation coin for me is the economic future of this region. This Upper Lake Melville society is presently stablilized, after years of fluctuation, by a few factors: its considerable development now as a regional Government and commercial service centre, bolstered by an extraordinarily neglected but superb airport, and also by increasing aboriginal investments and partnerships. We have watched various industrial endeavours wax and wane: military activities of mixed origins, logging, the early tourism efforts, fly-in fish camps, even a new National Park nearby. But I have three grandsons growing up here, and there are hundreds of children in the local schools. This is their home, and their futures must be addressed. At the same time, I am also clearly aware of pro-development voices in this town – of which the Panel should be cogniscent – who do not support this Project unconditionally, but who qualify their endorsement with the caveat that this cannot be yet one more colonial, resource extraction exercise. Labrador must gain substantially from this so-called ‘development’: not with short-term jobs, not with extra training which ultimately takes people to success elsewhere, not with perpetually restrictive remote diesel plants, but with all-inclusive opportunities for our part of the Province. In this day and age to perform otherwise is virtually immoral: a strong word, but one that I use advisedly. It is immoral, in 2011, to be taking, taking, taking, largely for southern benefit, and without local return. And finally, I express this concern for balanced treatment as Progress moves onwards, because I sense a certain political inevitability around the Lower Churchill Project.

Hence I express my equivocation for the Project, which I suspect also represents the voices of many others in this population. Years ago I confronted a vigorous critic of our lively military industry, who was visiting this community. He wondered rhetorically, after a frustrating discussion, who would win, and who would lose, ten years hence, if that industry went ahead? My prompt answer to him was: Everyone. We would all win in economic success, employment, expansion and Allied rapport, and we would all lose in the disappearance of our rural innocence and untouched territory, and with added noise, stress, social turmoil, and other side-effects. The Panel can only listen, study and recommend to both Governments, but we look to you for a quality of input that brings careful judgment and rationality to the advice for the final decisions around this Project.

I would like to thank you and your Secretariat for this opportunity to speak in generalities in your closing days of the Labrador Hearings, and for the efficiency and reliability with which this Assessment is being performed.

Thank you for listening. Susan Felsberg, April 2 2011

PHOTOS PROVIDED BY LOCAL RESIDENTS

PHOTO 1
CINDER BLOCKS SHOVED BY ICE ON MAY 15, 2017

Source: Ingried Felsberg Crocker

PHOTO 2
MAY 15, 2017 ICE BUILDUP

Source: Ingried Felsberg Crocker

PHOTO 3
COMPARISON PHOTO – AUGUST 6, 2017

Source: Ingried Felsberg Crocker

PHOTO 4
COMPARISON PHOTO – AUGUST 6, 2017

Source: Ingried Felsberg Crocker

PHOTO 5
OLD CEMENT SLAB DOCK

Source: Ingried Felsberg Crocker

PHOTO 6
BEACH BUILDUP BEYOND OLD DOCK

Source: Ingried Felsberg Crocker

PHOTO 7
CHURCHILL RIVER FACING MUD LAKE – AUGUST 20, 2009

Source: Ingried Felsberg Crocker

PHOTO 8
CHURCHILL RIVER FACING MUD LAKE – AUGUST 6, 2017

Source: Ingried Felsberg Crocker

PHOTO 9
CHURCHILL RIVER – SUMMER 2007

Source: Ingried Felsberg Crocker

PHOTO 10
CHURCHILL RIVER FACING MUD LAKE – AUGUST 6, 2017

Source: Ingried Felsberg Crocker

PHOTO 11
CHURCHILL RIVER – 2003

Source: Ingried Felsberg Crocker

PHOTO 12
CHURCHILL RIVER – 2003

Source: Ingried Felsberg Crocker

PHOTO 13
CHURCHILL RIVER – AUGUST 6, 2017

Source: Ingried Felsberg Crocker

PHOTO 14
CHURCHILL RIVER – AUGUST 6, 2017

Source: Ingried Felsberg Crocker

PHOTO 15
CHURCHILL RIVER – AUGUST 6, 2017

Source: Ingried Felsberg Crocker

PHOTO 16
ICE ON THE CHURCHILL RIVER

Source: Ingried Felsberg Crocker

PHOTO 17
ICE ON THE CHURCHILL RIVER

Source: Ingried Felsberg Crocker

PHOTO 18
ICE ON THE CHURCHILL RIVER – MAY 2017

Source: Ingried Felsberg Crocker

PHOTO 19
ICE ON THE CHURCHILL RIVER – MAY 2017

Source: Ingried Felsberg Crocker

PHOTO 20
ICE ON THE CHURCHILL RIVER – MAY 2017

Source: Ingried Felsberg Crocker

PHOTO 21
ICE ON THE CHURCHILL RIVER – MAY 2017

Source: Ingried Felsberg Crocker

PHOTO 22
ICE ON THE CHURCHILL RIVER – MAY 2017

Source: Ingried Felsberg Crocker

PHOTO 23
ICE ON THE CHURCHILL RIVER – MAY 2017

Source: Ingried Felsberg Crocker

PHOTO 24

Source: Vyann Kerby

PHOTO 25

Source: Vyann Kerby

PHOTO 26

Source: Vyann Kerby

PHOTO 27

Source: Vyann Kerby

PHOTO 28

Source: Vyann Kerby

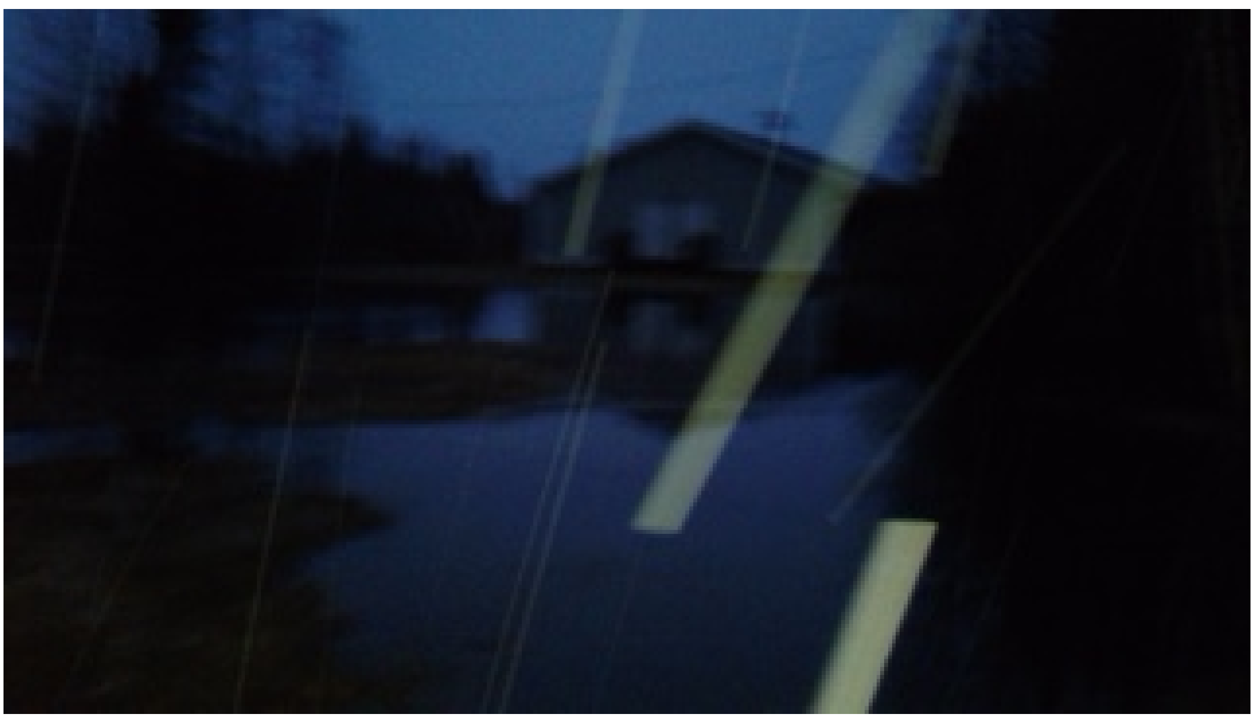
PHOTO 29

Source: Vyann Kerby

PHOTO 30

Source: Vyann Kerby

PHOTO 31



Source: Vyann Kerby

PHOTO 32

Source: Vyann Kerby

PHOTO 33

Source: Vyann Kerby

PHOTO 34

Source: Vyann Kerby

PHOTO 35

Source: Vyann Kerby

PHOTO 36

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PHOTO 48

Source: Dave Raeburn

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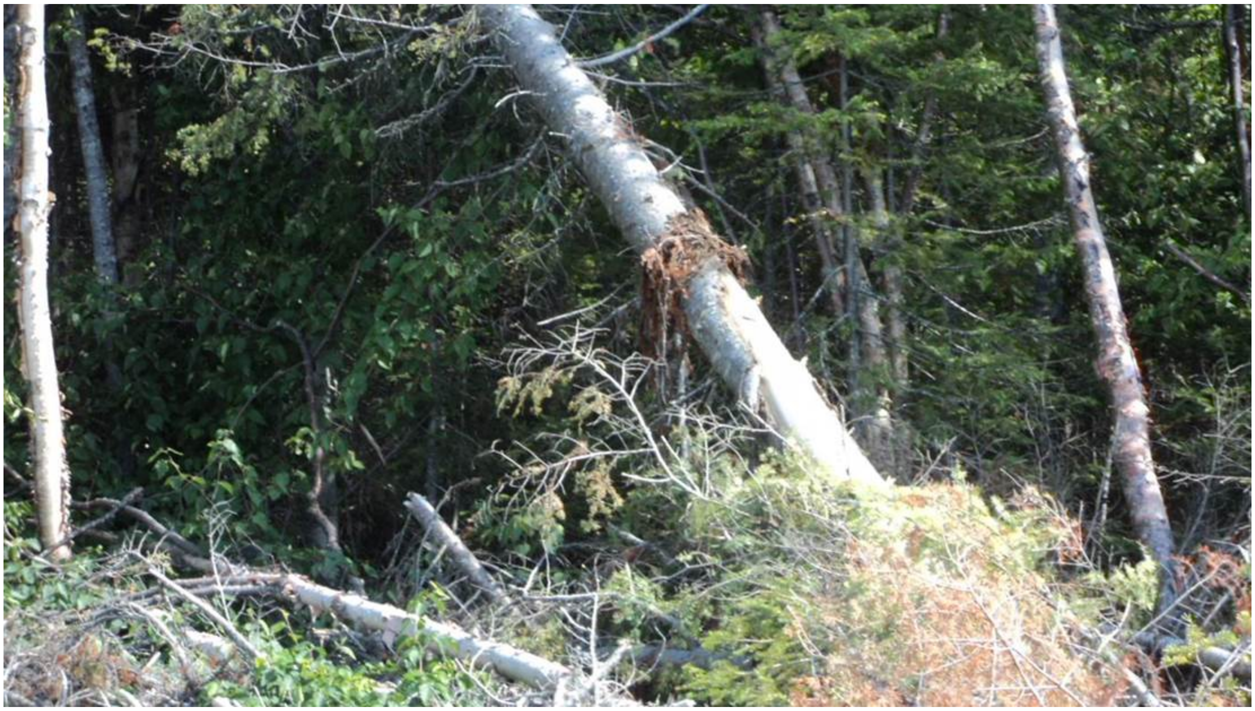
PHOTO 53

Source: Dave Raeburn

PHOTO 54



Source: Dave Raeburn

PHOTO 55

Source: Dave Raeburn

APPENDIX C

ROUND TWO PUBLIC CONSULTATION

ATTENDANCE LIST AND DOCUMENTATION PROVIDED

HAPPY VALLEY - GOOSE BAY PUBLIC MEETING SIGN-IN SHEET

GOOSE BAY MEETING
PRELIMINARY FINDINGS

SEPT 7, 2017

NAME

[illegible] (RUBY BEST)
Susan Felsberg
Elizabeth Saunders
Roberta Benefiel
[illegible]
MILLER DAVID ARNOLD @YAHOO.CA
Gloria Best
Donna Best
JIM PURDY
Michael Mitsuk
Derek Russell
Damien Simms
Kenneth Best
[illegible]
Mary Rumbolt
[illegible]
Marge Goudie
Denise McLean
Patricia Kemuksigak
Bev Thomson
MELISSA BEST
PERRY TRIMPER
Mary Snelgrove
Bonnie Learning
Robin Goodfellow - Baikie
Kathy Michelin
Cora Hamel
Randy Dillon

MARIO BERSHIAOMA
Rick Bury
Robert Way
Jamie Snook
Lori Dyson

MUD LAKE PUBLIC MEETING SIGN IN SHEET

Meeting : Mudlake September 7, 2017
Attendance:
Robert Way
Ron Hopkins
Roy BLAKE "Nunatsiavut Government"
Sevilla Hope
David Davis
Ruth Hope
Jordon Hope
MELISSA BEST.
JIM BROWN.
Christine Chaulk
CRAIG CHAULK
Martha Rumbolt
Lester Blake
Gwen Chaulk
Ann Raeburn
Dave Raeburn
Marjorie Campbell
Vyann Kerby
Marion BROOMFIELD.
Hebert WHite
Dorman. Campbell
Duane Dyson
x TREVOR EDMUNDS

PRELIMINARY RESULTS PRESENTATION

Independent Review of the May 17th 2017 Churchill River Flood Event

Public Open House Presentation on Preliminary Findings

7 September 2017

Karl-Erich Lindenschmidt
Independent Technical Expert Advisor
Associate Professor, University of Saskatchewan

Process (June 2017)

- Independent Technical Expert Advisor (ITEA) appointment
- Initial assessment of 17 May 2017 flood
- Initial data collection
  - meteorological & hydraulic data
  - satellite imagery
  - photos from helicopter flights
  - webcam photos
  - digital elevation maps
  - river cross-sections

Process (July 2017)

- Select an external engineering consultant
  - draft Request for Proposals
  - review proposals and select consultant
- Site visit
  - aerial reconnaissance of Churchill River basin
  - Muskrat Falls Construction Site
  - ground visit of flooded areas
- Public meetings at Mud Lake & HVGB
  - gain insight from local traditional knowledge
  - gain perspectives of the Town of HVGB

Process (Aug. & Sept. 2017)

- Input from local residents
- Review technical work undertaken by engineering consultant
- Site visit
  - boat tour of lower Churchill River
- Presentation at Mud Lake and HVGP
  - comments and feedback from local traditional knowledge
- Final report (end of September) with:
  - synopsis of events leading to the 17 May 2017 flood
  - suggest flood warning measures
  - recommend flood protection measures

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Independent Review of the May 17th 2017 Churchill River Flood Event

Public Open House
Presentation on Preliminary Findings

September 17, 2017

Science | Imagination | Collaboration

KGS GROUP CONSULTING ENGINEERS

Presentation Outline

- **Objectives of Flood Review**
- **Data Collection & Site Reconnaissance**
- **Public Consultation**
- **Generic Factors that Contribute to Flooding**
- **May 17th, 2017 Flood Event - Timeline**
- **Other Possible Contributing Factors**
- **Most Significant Causes of Flooding in 2017**
- **Possible Mitigation for Future**

WINNIPEG | REGINA | MISSISSAUGA | THUNDER BAY

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Objectives of Flood Review

Objectives:

- **Provide a detailed explanation of reasons for May 17th flood**
- **Provide guidance on possible mitigation measures for future**

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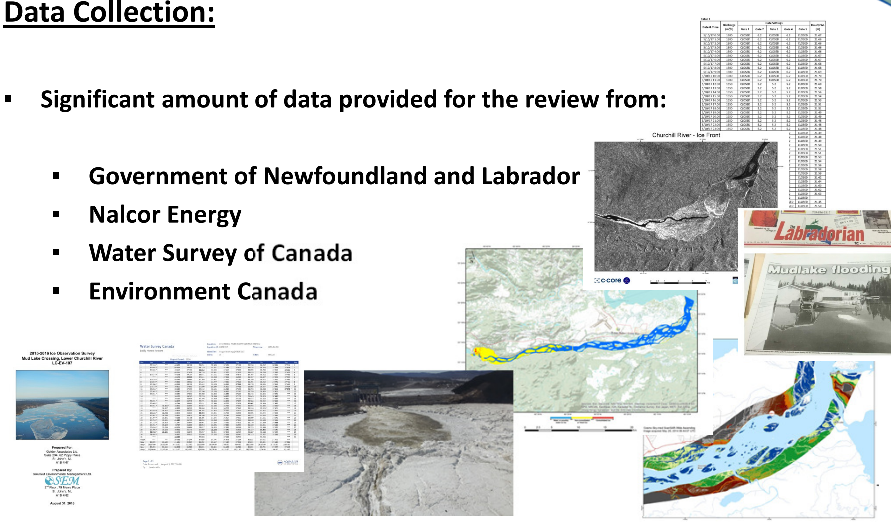
Data Collection & Site Reconnaissance

Data Collection:

- **Significant amount of data provided for the review from:**
  - **Government of Newfoundland and Labrador**
  - **Nalcor Energy**
  - **Water Survey of Canada**
  - **Environment Canada**



Data Collection & Site Reconnaissance

Data Collection:

- Satellite imagery
- Aerial photographs
- Flow and Water level records
- Flow releases from Churchill Falls & Muskrat Falls
- Precipitation Data (Rainfall and snow data)
- Temperature Data
- Wind Data
- Tidal Data
- Blackrock Bridge Drawings
- LiDAR Data
- Survey Data
- Ice Formation and Break-up timing data
- GIS Data (Watersheds, gauge stations, etc.)
- Ice Study Reports
- Muskrat Falls Study Reports
- Sediment Study Reports
- EIS Reports and Information

Data Collection & Site Reconnaissance

Site Reconnaissance:

- **Helicopter Tour (July 26, 2017)**
- **Mud Lake Visit (July 26, 2017)**
- **Mud Lake Road Tour (July 27, 2017)**
- **Muskrat Falls Site Tour (July 27, 2017)**
- **Lower Churchill River Boat Tour (Sep. 7, 2017)**

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Public Consultation

Round 1 – Local Knowledge Gathering:

- Public Meeting in Mud Lake (July 26, 2017)
- Public Meeting in HVGB (July 26, 2017)
- Meeting with Town of HVGB (July 27, 2017)

Extremely Valuable

Round 1 – Follow Up:

- Phone Meeting with Town of HVGB (August 10, 2017)
- Phone Discussion with D. Raeburn (August 14, 2017)
- Numerous photographs & information provided by Residents

Round 2 – Preliminary Results Presentation:

- Public Meeting in Mud Lake (Sept. 7, 2017)
- Public Meeting in HVGB (Sept. 7, 2017)

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Factors that Contribute to Flooding

- ***Low river banks*** – low tolerance for rises in water levels
- ***Wide shallow rivers*** – prone to form ice jams during breakup & ice grounding
- ***High river flows in ice formation stage*** – high freeze up level
- ***Cold severe winters*** – thick ice growth
- ***Modest Snowfall*** – frost penetration and accentuate ice growth
- ***High river flows that rise rapidly before ice deteriorates***
- ***Severe river bends, sand bars, narrowing of channel*** – can impede ice movement
- ***Wet watershed antecedent conditions prior to freeze up*** – increase spring runoff
- ***Large volumes of rain coincident with snowmelt*** – increase spring runoff
- ***Rapid onset of snowmelt*** – increase spring runoff

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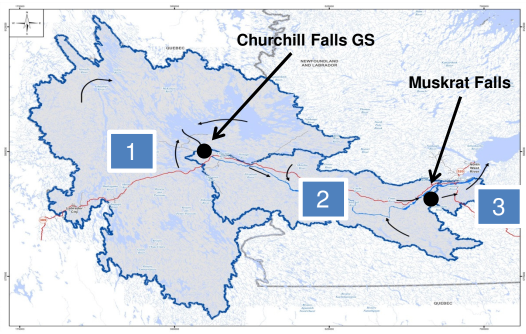
May 17th Flood Event Timeline

Approach:

- Step through the flood based on recorded flows and water levels provided by Water Survey of Canada and Nalcor as well as Muskrat Falls operations
- Review the data and discuss causes of flow and water level changes
- Consider the watershed as three main sub-basins



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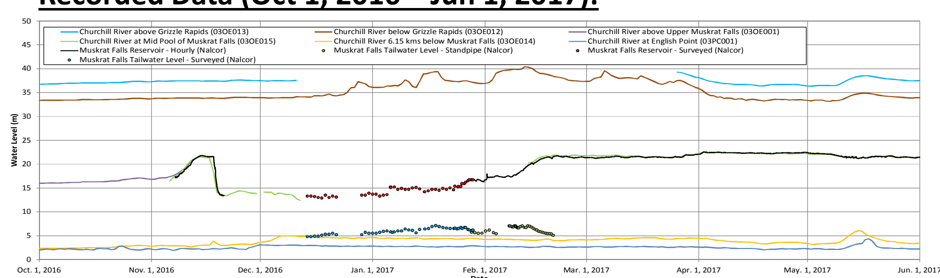
May 17th Flood Event Timeline

Recorded Data (Oct 1, 2016 – Jun 1, 2017):



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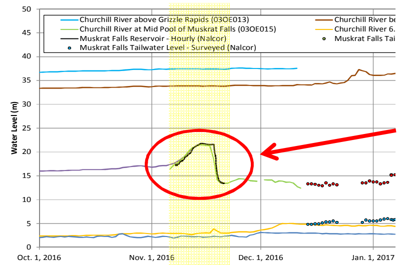
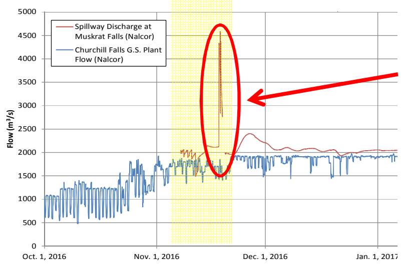
May 17th Flood Event Timeline

Time Frame 1 (Nov. 7 to Nov. 22, 2016):





- Increase of water levels upstream of Muskrat Falls (17.1 m to 21.7 m)
  Spillway gates used to raise reservoir
- Rapid lowering of water levels upstream of Muskrat Falls
  (21.7 m to 13.5 m)
  Spillway gates used to lower reservoir
- Large outflow from Muskrat Falls
  (2,120 m^3/s to 4,590 m^3/s)
  Result of spillway operation

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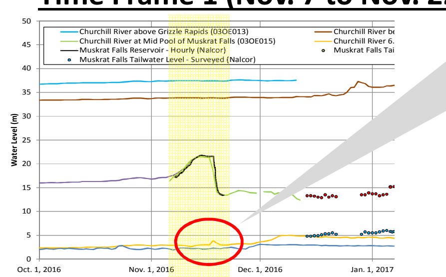
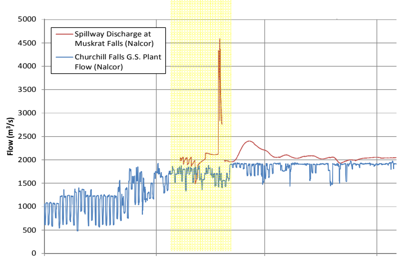
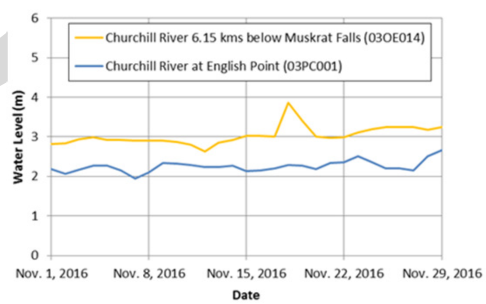
May 17th Flood Event Timeline

Time Frame 1 (Nov. 7 to Nov. 22, 2016):







- Quick rise in water level at 6.15 kms downstream of Muskrat Falls (3.0 m to 3.9 m)
- Relatively constant water level at English Point (~ 2.3 m)
  Minimal response due to Muskrat Falls release

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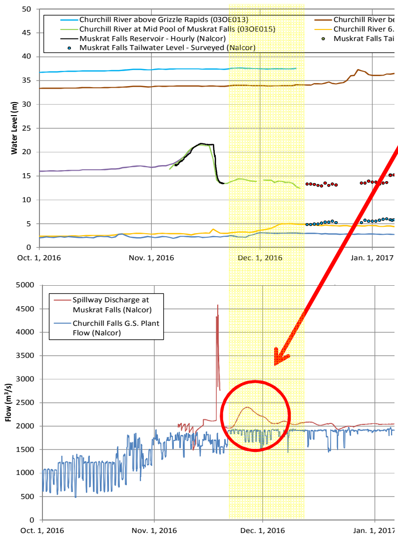
May 17th Flood Event Timeline

Time Frame 2 (Nov. 22 to Dec. 12, 2016):



- Large influx of water passed through Muskrat Falls (1,940 m^3/s to 2,400m^3/s)
- Relatively constant outflow from Churchill Falls
- Spillway gates at Muskrat Falls remained fully open from Nov. 21st though Jan 5th

No spillway operation

What is the source of this large flux of flow?

➔ Look at the basin upstream of Muskrat Falls

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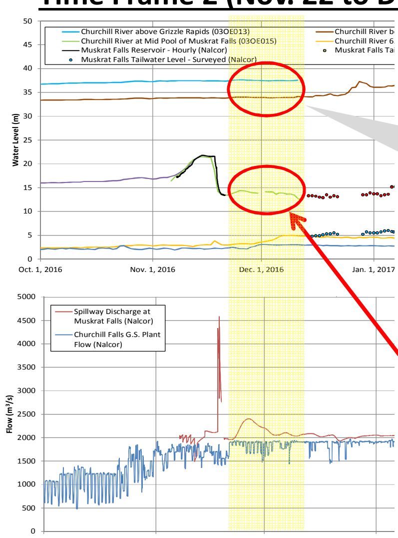
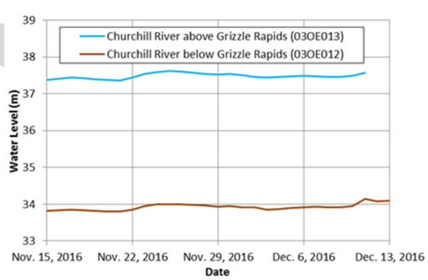
May 17th Flood Event Timeline

Time Frame 2 (Nov. 22 to Dec. 12, 2016):



- Increase in water level at Grizzle Rapids (~ 0.2 m)



- Varying water level in Muskrat Falls reservoir

Reservoir at pre-construction levels

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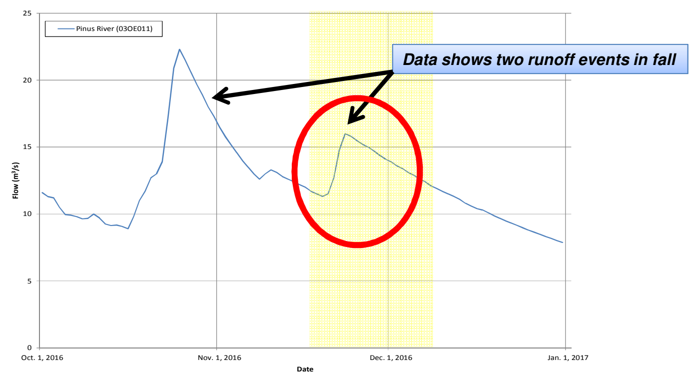
May 17th Flood Event Timeline

Local Tributary Inflow Between Churchill Falls & Muskrat Falls:

- Only one gauged tributary

Pinus River Flows (Oct. 1 to Dec. 31, 2016)



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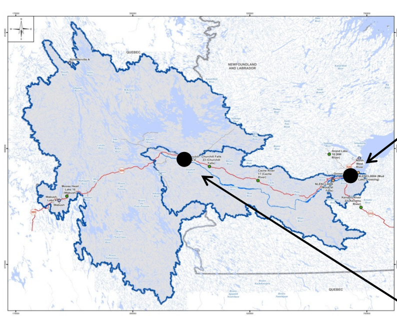
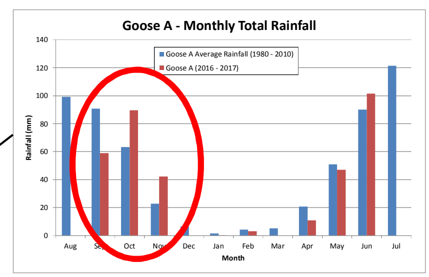
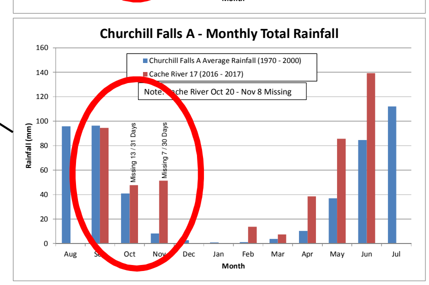
May 17th Flood Event Timeline

Precipitation / Rainfall Data







Data shows significant rainfall in October and November in Middle and lower Basins

2 times normal in Goose Bay

> 5 times normal near Churchill Falls

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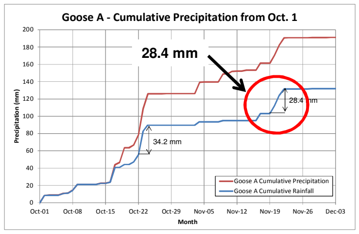
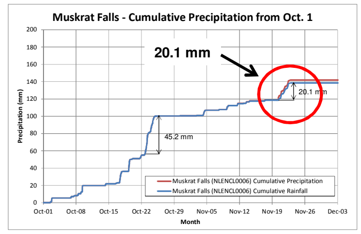
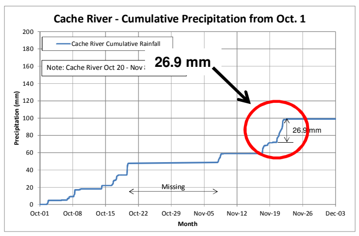
May 17th Flood Event Timeline

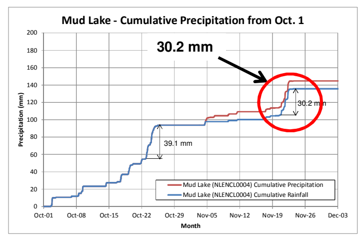
Precipitation / Rainfall Data

Data shows significant rainfall events around October 23rd and November 20th & 21st in Middle and lower Basins









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May 17th Flood Event Timeline

Lower River Freeze Up ~ Dec. 1st 2016

Water Level Recorded at English Point = 2.20 m

Water Level Recorded at English Point = 2.15 m

Water Level Recorded at English Point = 2.67 m

Water Level Recorded at English Point = 3.11 m

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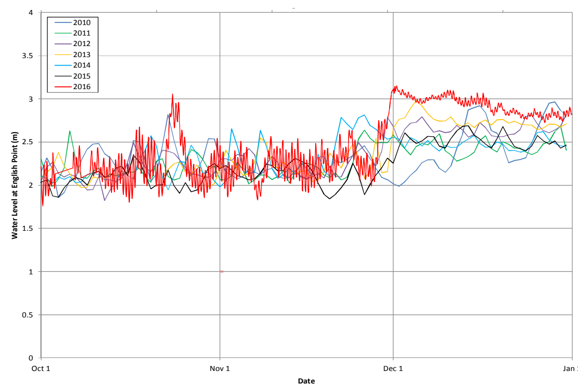
May 17th Flood Event Timeline

Freeze Up Levels

- Reported as highest ever and totally submerged sandbars



Data shows highest freeze up levels since 2010. However, no data prior to 2010.

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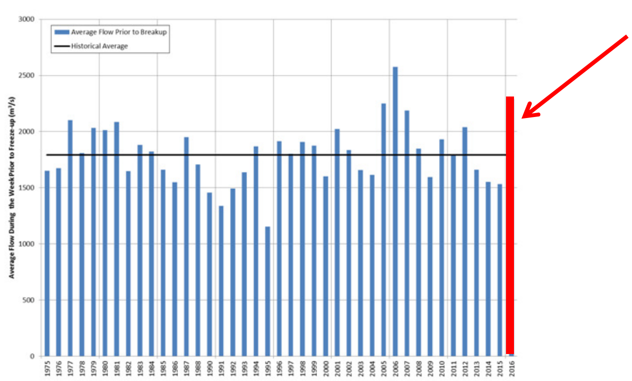
May 17th Flood Event Timeline

Flows at time of Freeze up



Data shows 2016 freeze up flows 2nd highest in 40 years of record.

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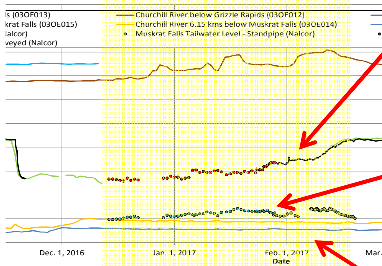
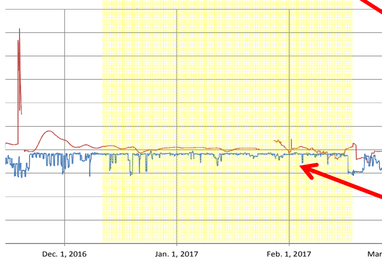
May 17th Flood Event Timeline

Time Frame 3 (Dec. 12, 2016 to Feb. 23, 2017):





- Spillway gates at Muskrat Falls continued to remain fully open until Jan 5th. Between Jan 5th and Feb 20th the spillway gates were operated to increase reservoir levels slowly.
- Tailwater levels at Muskrat Falls increased due to hanging ice dam formation
- Water levels 6.15 kms downstream of Muskrat Falls slowly declined
- Water levels at English Point slowly declined
- Constant outflow from Churchill Falls & Muskrat Falls. Muskrat Falls decrease as reservoir rises.

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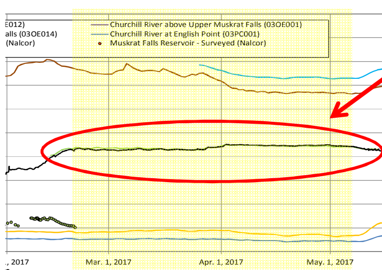
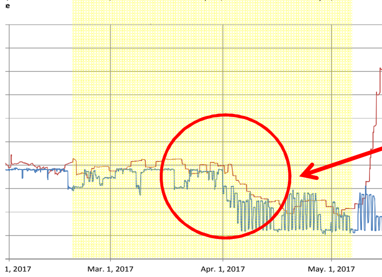
May 17th Flood Event Timeline

Time Frame 4 (Feb. 23 to May 7, 2017):





- Muskrat Falls reservoir levels maintained at 21.5 m until Mar 27th
- Between Mar. 27th and Apr. 7th the spillway was operated to raise the Muskrat Falls reservoir from 21.5 m to 22.5 m.
- Between Apr. 7th and Apr. 30th the reservoir remained at 22.5 m. Between May 1st and May 7th the reservoir was dropped to 22.1 m.
- Outflows from Churchill Falls were reduced in early April (1,900 m^3/s to 900 m^3/s). Correspondingly levels at along the river at Grizzle Rapids, 6.15 km downstream of Muskrat Falls, and English point dropped.

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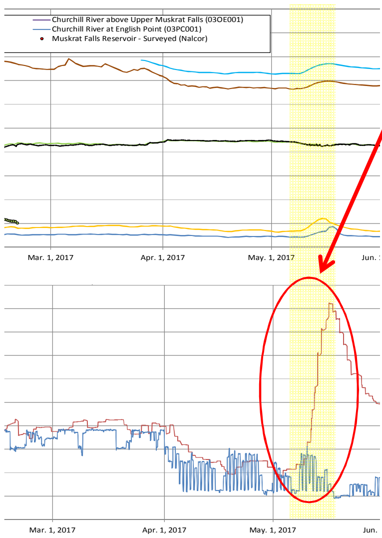
May 17th Flood Event Timeline

Time Frame 5 (May 7 to May 17, 2017):



- On May 10th the flows at Muskrat Falls quickly increased peaking at a maximum of 4,624 m^3/s on May 16th
- At break up at the Mud Lake Crossing on May 17th, the flow was 4,400 m^3/s. Highest ever recorded immediately prior to breakup

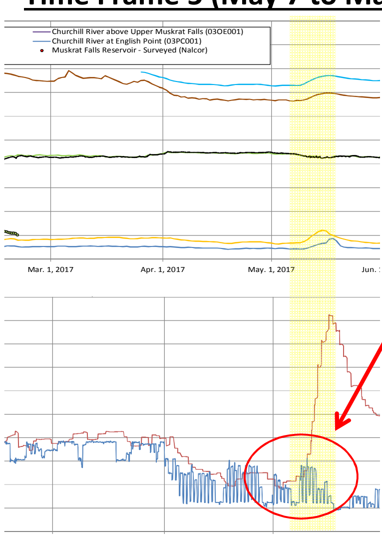
What is the source of this spring flow?

➔ Look at the spring melt conditions and operations at Churchill Falls & Muskrat Falls.

KGS GROUP CONSULTING ENGINEERS

May 17th Flood Event Timeline

Time Frame 5 (May 7 to May 17, 2017):



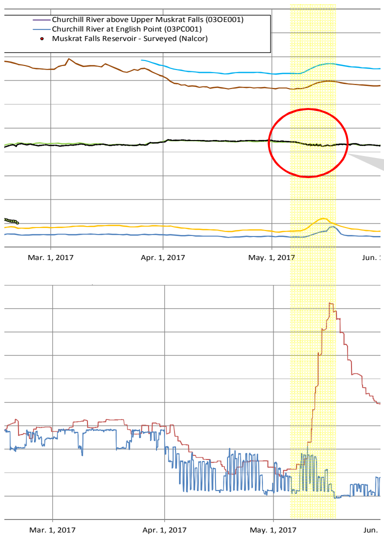
- On May 17th outflows from Churchill Falls were reduced from an average of 900 m^3/s to an average of 500 m^3/s with a narrower range of variation

Data shows no increase of flow from Churchill Falls. Therefore no contribution from Churchill Falls operations

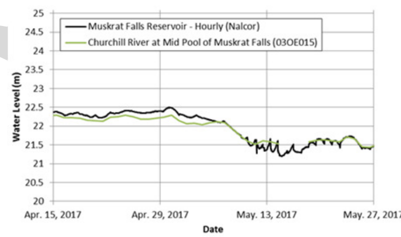
KGS GROUP CONSULTING ENGINEERS

May 17th Flood Event Timeline

Time Frame 5 (May 7 to May 17, 2017):



- Between Apr. 30th and May 12th the spillway gates at Muskrat Falls were operated to lower the reservoir from 22.5 m to 21.5 m.



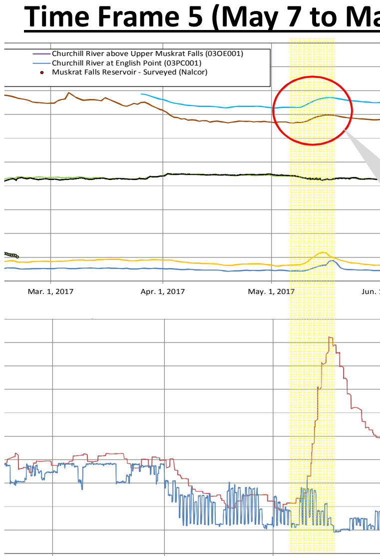
- Reduction of 1.0 m of reservoir over 12 days would mean additional 44 m^3/s (less than 1% of peak)

Data shows minimal flow releases from Muskrat Falls. Flow passed through the spillway would have been the inflow to the reservoir

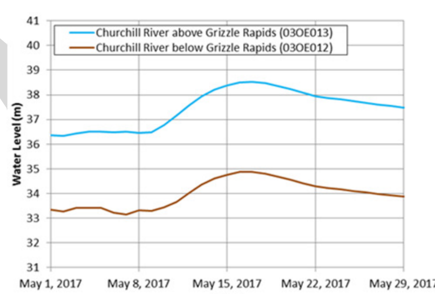
KGS GROUP CONSULTING ENGINEERS

May 17th Flood Event Timeline

Time Frame 5 (May 7 to May 17, 2017):



- Water levels at Grizzle Rapids rose between May 9th, peaking on May 17th (total of 2 m rise above Grizzle Rapids)



Data shows increase in levels upstream of Muskrat Falls. Source → Local Inflow.

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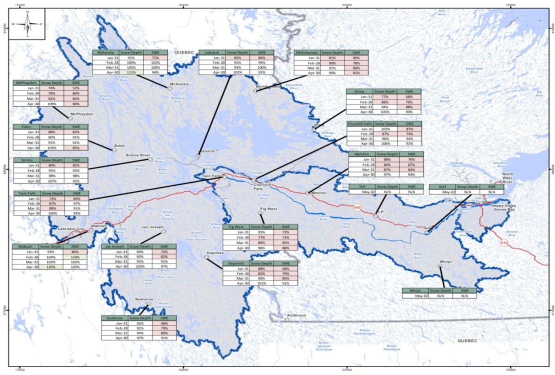
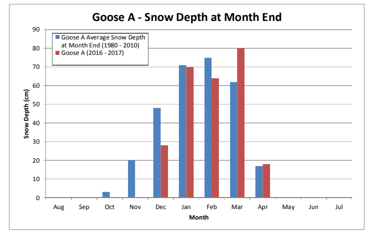
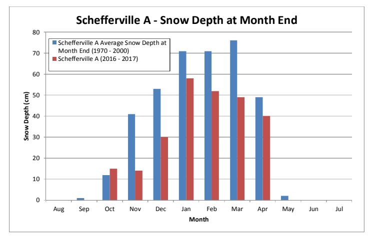
May 17th Flood Event Timeline

Winter Snow Depth & Snow Water Equivalent (SWE)







Data shows normal to less than normal snow depth and SWE

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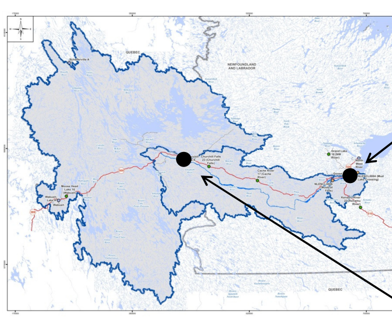
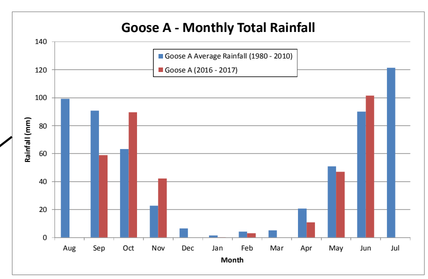
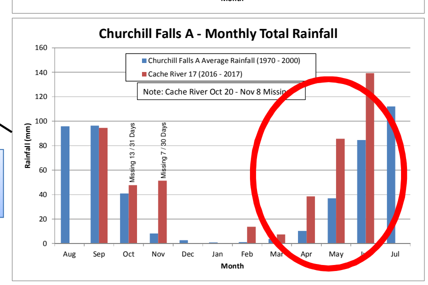
May 17th Flood Event Timeline

Precipitation / Rainfall Data

-







Data shows significant rainfall in April & May in Middle Basin

> 2 times normal near Churchill Falls

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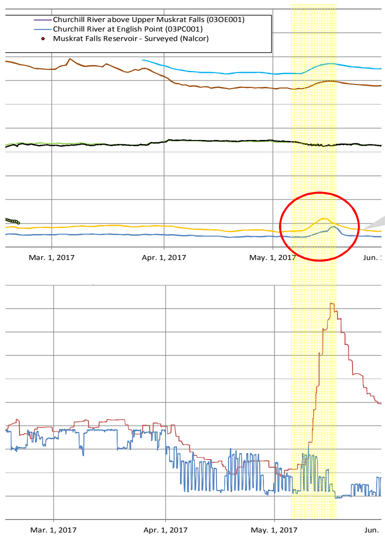
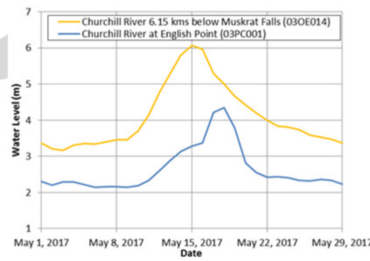
May 17th Flood Event Timeline

Time Frame 5 (May 7 to May 17, 2017):



- Water levels 6.15 kms downstream of Muskrat Falls increased from 3.5 m to just over 6 m between May 9th and May 15th



- Water levels at English Point increased by just over 1.2 m between May 10th and May 16th. Then on May 16th the water levels rose another 0.8 m and peaked on May 18th

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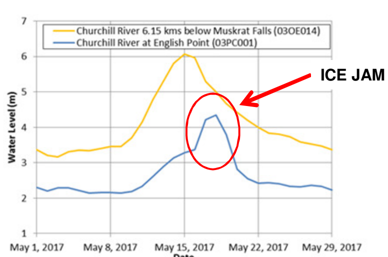
May 17th Flood Event Timeline

May 17th, 2017):



Source: Vyann Kerby

Source: Dave Raeburn

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Other Possible Contributing Factors

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Other Possible Contributing Factors

Increased Sedimentation:

- Reports of increased sedimentation
- NHC study (2009) concludes increase in extent of sand bars between 1972 & 2006
- NHC study (2009) also indicates post Muskrat Falls – less sediment

Data shows suggest strong possibility riverbed aggrading. Difficult to quantify.

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Most Significant Causes of Flooding in 2017

- **Wet fall & high river stage during ice formation period**
  - Created saturated watershed at freeze up
  - Late November rains caused high fall flow at time of freeze up
- **Rapid runoff in Mid-May from local drainage basin**
  - Highest recorded flow in Churchill River during critical ice breakup
  - Runoff caused by abrupt warming and spring rains on melting snowpack
  - Saturated watershed from high antecedent conditions
- **To a lesser extent…but cannot be proven magnitude**
  - Possible gradual sediment build up in lower river
    - Higher stages in fall and increased ice jam potential in spring
  - Abrupt cutback of outflows from Churchill Falls in early spring
    - Grounding of ice cover to sandbars – less prone to ice weakening

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Possible Mitigation for Future

Possible Mitigation Options – Require further analysis & economic evaluation

- Consideration of adjusted releases from Churchill Falls to reduce total flood flow
- Consideration of cutback in releases from Churchill Falls prior to and during ice formation
- Avoiding drastic cutbacks of outflow from Churchill Falls in late winter
- Investment in raising flood prone buildings and roads in Mud Lake and along Mud Lake Road
- Construction of dikes with adequate seepage control
- More extensive system of hydrometric gauges to assist in improved flood forecasting
- Consideration of expanding live storage in Muskrat Falls Reservoir
- Dredging of lower river to increase flow area
- Buyout of flood prone properties

Summary & Going Forward

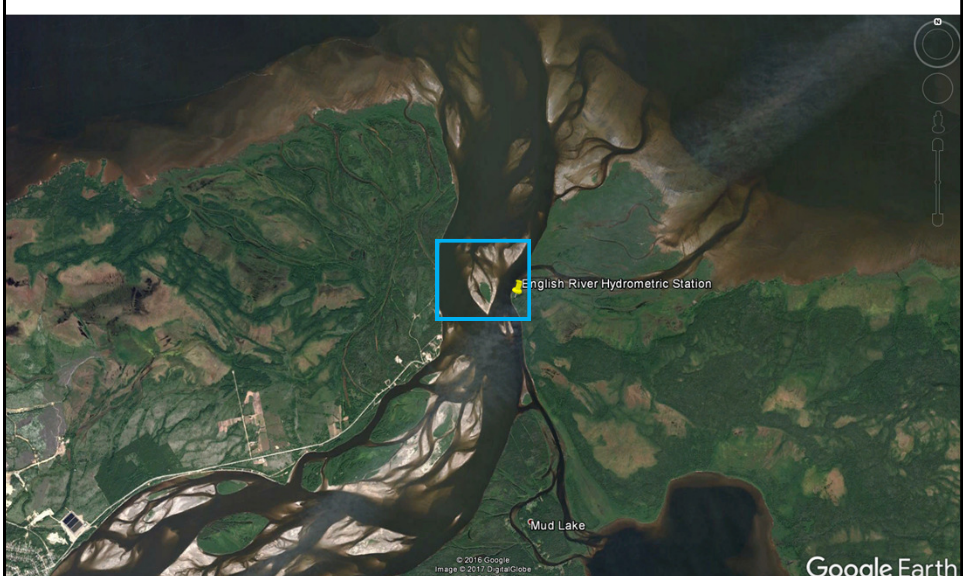
Flood Management Plan

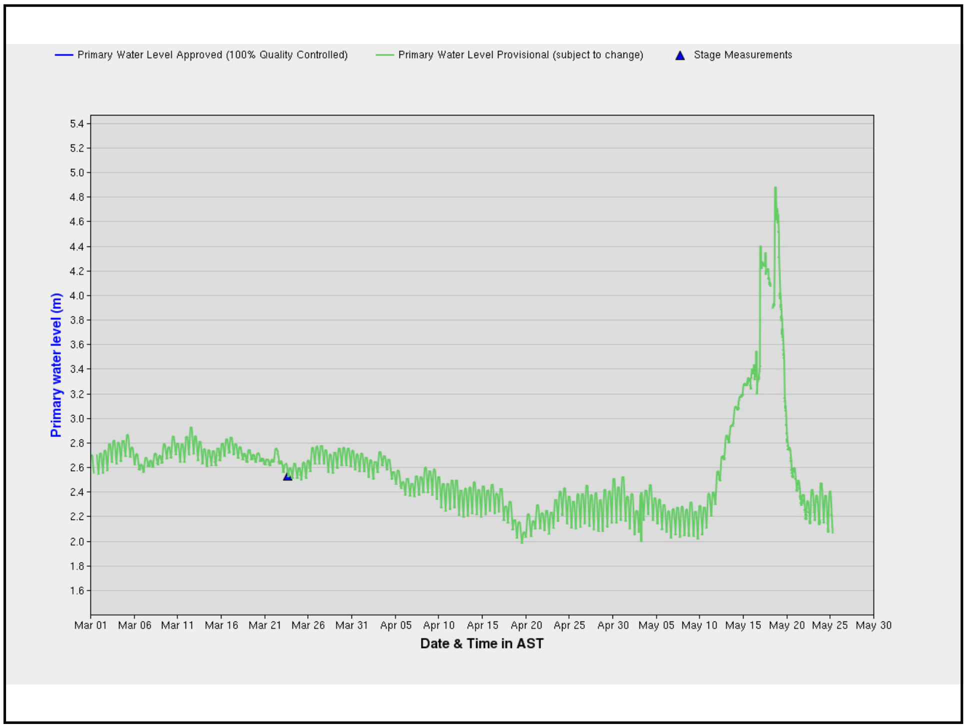
- Forecasting
  - Extend gauge monitoring network
  - Build up modelling capabilities
- Flood preparedness
  - Extend operations to include flood reduction
  - Protect infrastructure and properties at risk
- Flood risk management
  - Flood mapping
  - Cost-benefit analysis of mitigation options
- Emergency response plan

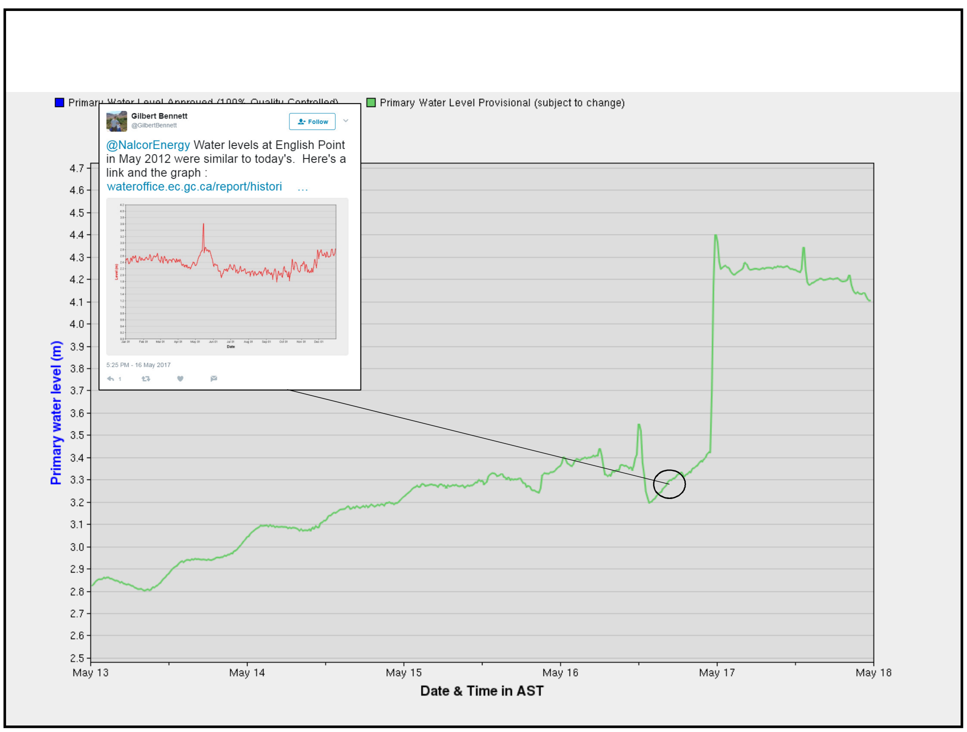
Questions & Discussion

MR. ROBERT WAY PRESENTATION #1


English River Hydrometric Station (~44 km downstream)
Mud Lake, NL
Muskrat Falls Hydrometric Station
Hydrometric Station (~6 km downstream)
Google Earth


English River Hydrometric Station
Mud Lake
Google Earth

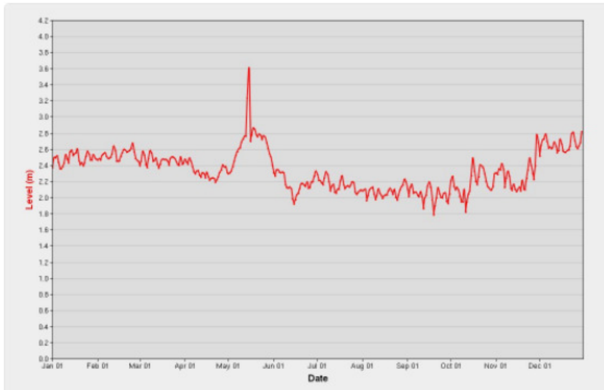

Primary Water Level Approved (100% Quality Controlled)
Primary Water Level Provisional (subject to change)
Stage Measurements
Primary water level (m)
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
Mar 01
Mar 06
Mar 11
Mar 16
Mar 21
Mar 26
Mar 31
Apr 05
Apr 10
Apr 15
Apr 20
Apr 25
Apr 30
May 05
May 10
May 15
May 20
May 25
May 30
Date & Time in AST


Primary Water Level Provisional (subject to change)
Gilbert Bennett
@GilbertBennett
Follow
@NalcorEnergy Water levels at English Point in May 2012 were similar to today's. Here's a link and the graph :
wateroffice.ec.gc.ca/report/histori …
5:25 PM - 16 May 2017
Primary water level (m)
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
May 13
May 14
May 15
May 16
May 17
May 18
Date & Time in AST

Gilbert Bennett @GilbertBennett

Follow

@NalcorEnergy Water levels at English Point in May 2012 were similar to today's. Here's a link and the graph : wateroffice.ec.gc.ca/report/histori …

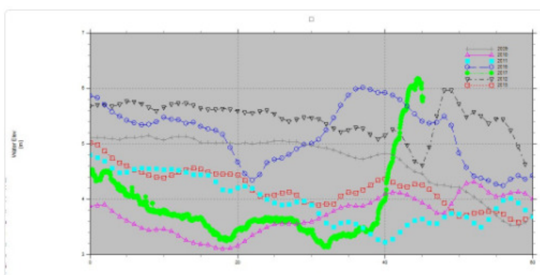


5:25 PM - 16 May 2017

1

Kurt Sullivan @KBS_NL · May 16

I plotted the elevation 6.5km downstream from Muskrat. Only thing I see as unusual is how fast this years level ramped up.



1

Gilbert Bennett @GilbertBennett

Follow

Replying to @KBS_NL @NalcorEnergy

The 2017 & 2012 curves look similar in mid May, but the '17 curve started from a lower value.

5:55 PM - 16 May 2017

1

Kurt Sullivan
@KBS_NL

Follow

Replying to @GilbertBennett @NalcorEnergy

Is there an unusual amount of ice dammed up down stream of Muskrat? Did breakup happen unusually fast or is this year simply bad luck?

RETWEET
1

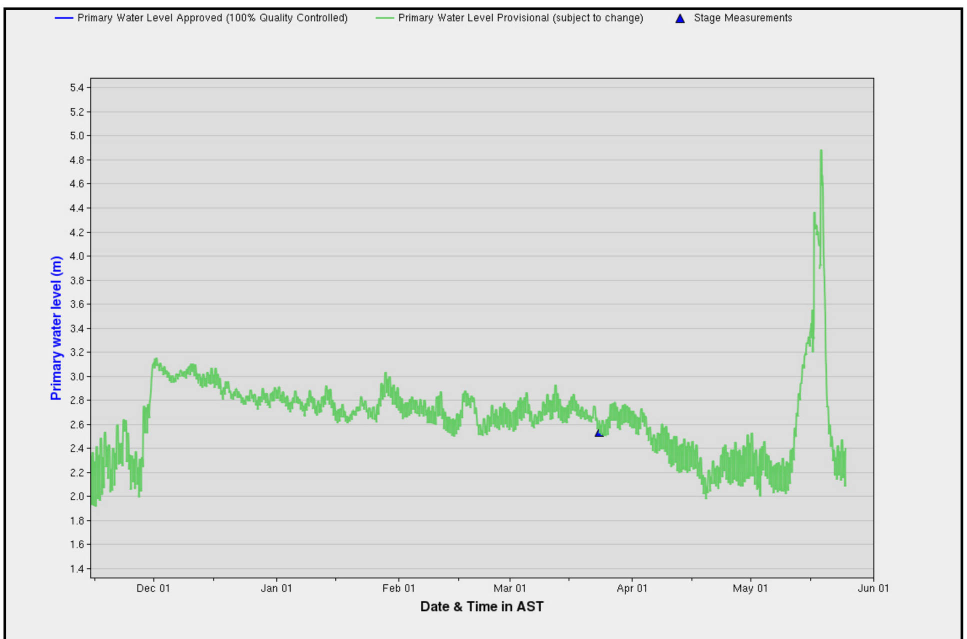
6:14 PM - 16 May 2017

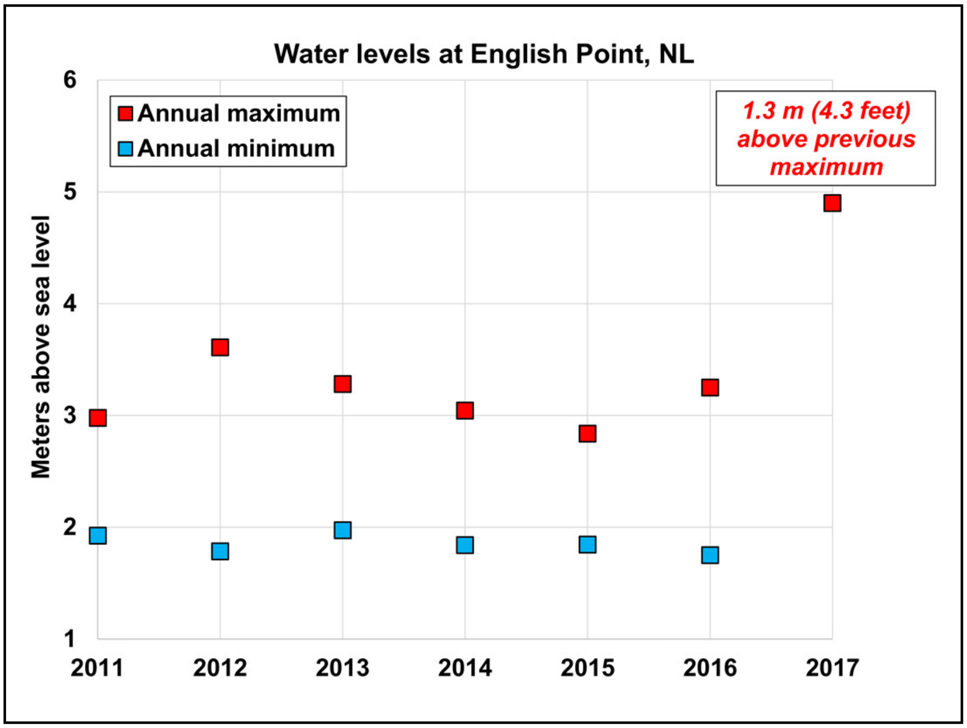
1 1

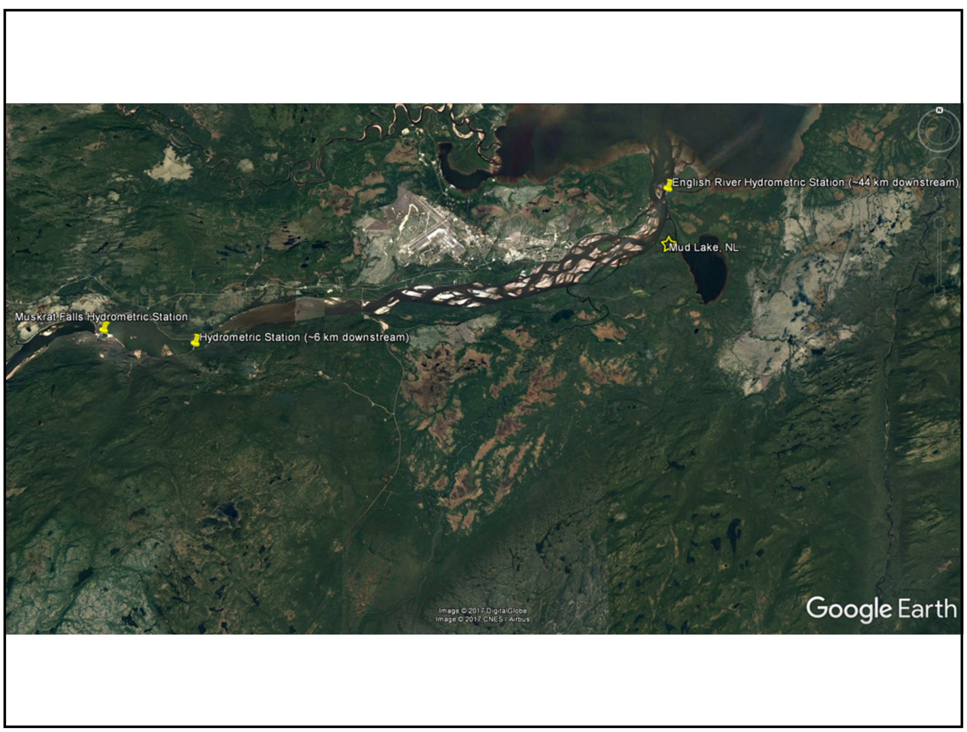
Tweet your reply

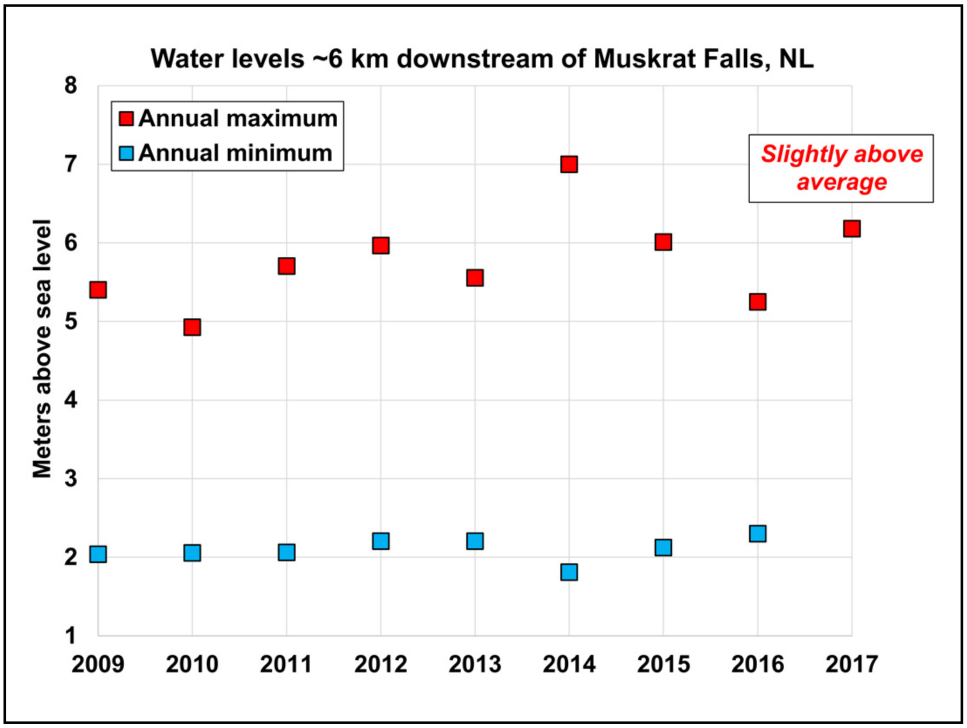
Gilbert Bennett @GilbertBennett · May 16
Replying to @KBS_NL @NalcorEnergy
No and no. Water levels are driven by flow, and snowmelt is major contributor to flow - driven by temps & precip. across the entire region.

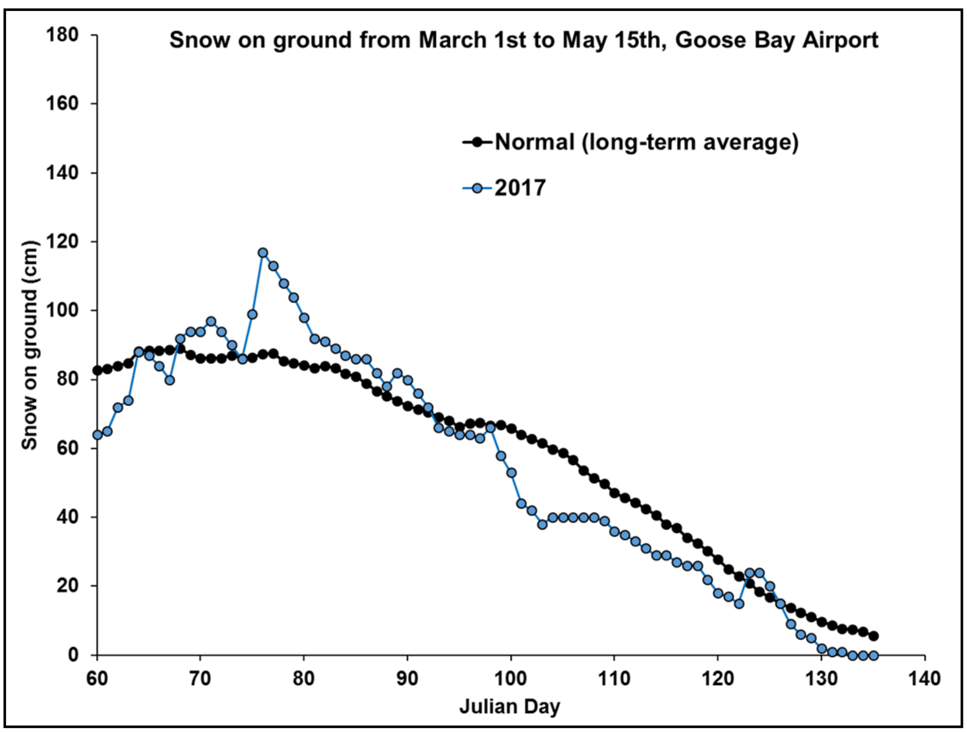
2 2

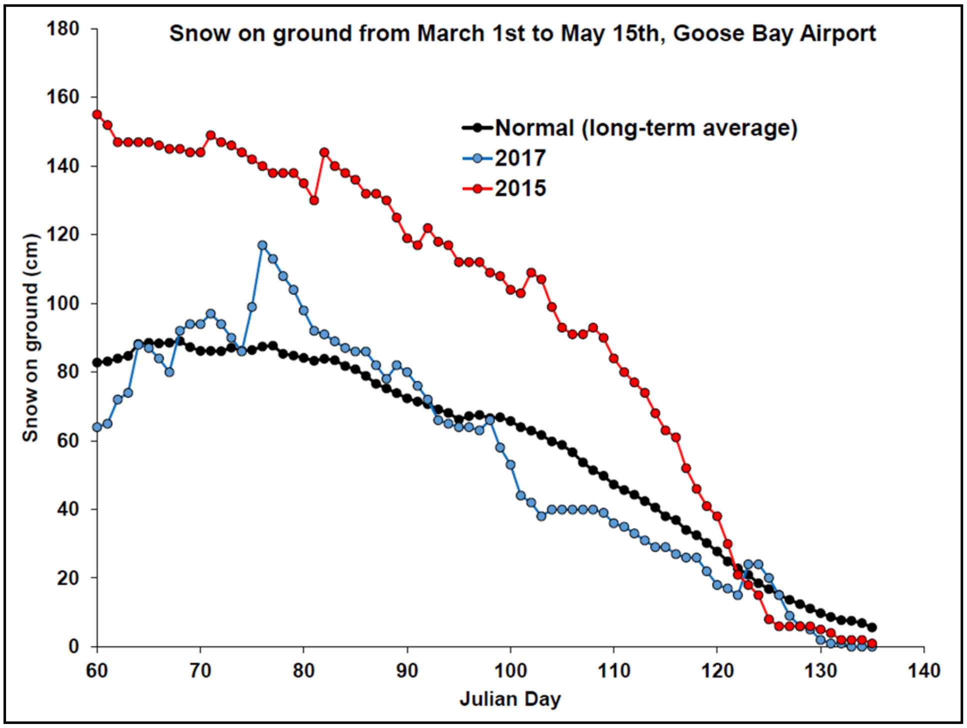


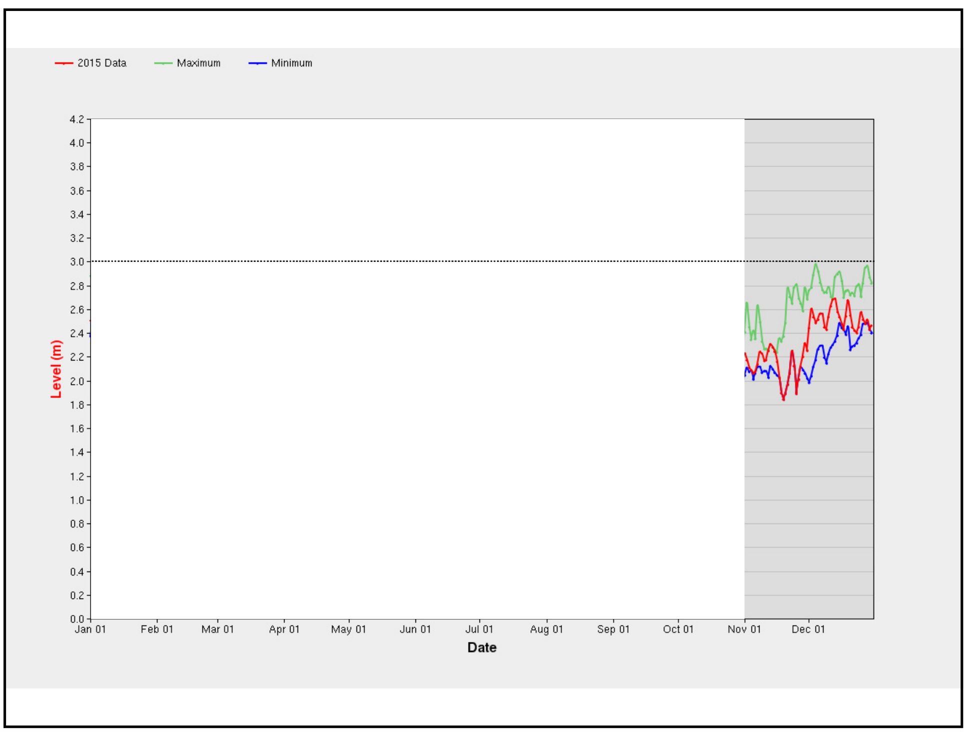

Water levels at English Point, NL
Annual maximum
Annual minimum
1.3 m (4.3 feet) above previous maximum
Meters above sea level
1
2
3
4
5
6
2011
2012
2013
2014
2015
2016
2017

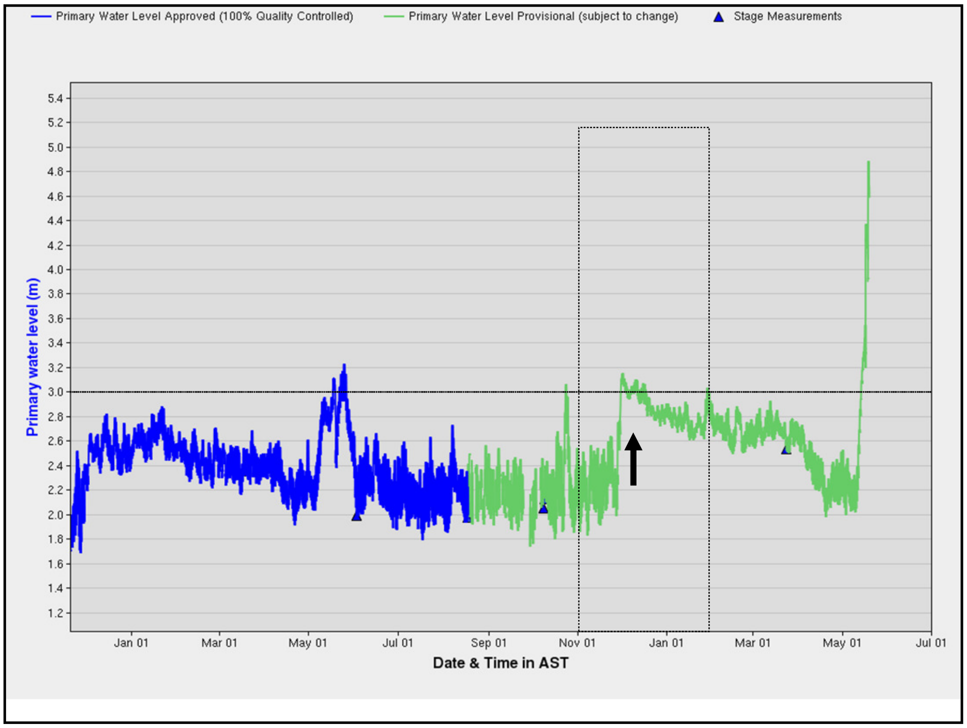

English River Hydrometric Station (~44 km downstream)
Mud Lake, NL
Muskrat Falls Hydrometric Station
Hydrometric Station (~6 km downstream)
Google Earth


Water levels ~6 km downstream of Muskrat Falls, NL
Annual maximum
Annual minimum
Slightly above average
Meters above sea level
8
7
6
5
4
3
2
1
2009
2010
2011
2012
2013
2014
2015
2016
2017


Snow on ground from March 1st to May 15th, Goose Bay Airport
Normal (long-term average)
2017
Snow on ground (cm)
180
160
140
120
100
80
60
40
20
0
60
70
80
90
100
110
120
130
140
Julian Day


Snow on ground from March 1st to May 15th, Goose Bay Airport
Normal (long-term average)
2017
2015
Snow on ground (cm)
180
160
140
120
100
80
60
40
20
0
60
70
80
90
100
110
120
130
140
Julian Day


2015 Data
Maximum
Minimum
Level (m)
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan 01
Feb 01
Mar 01
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Date



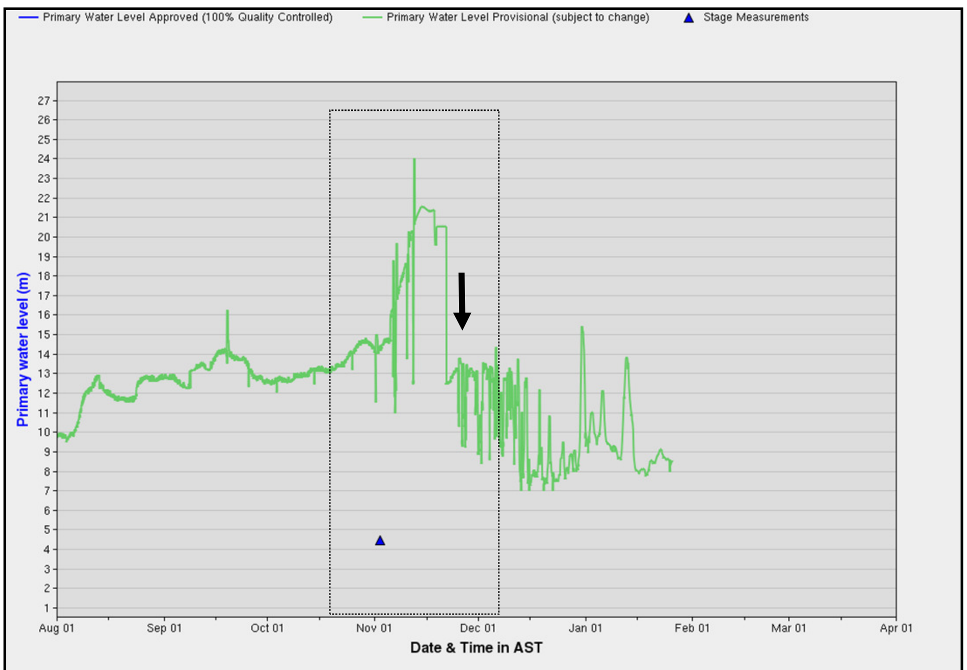
Muskrat Falls reservoir levels reduced due to cofferdam seepage

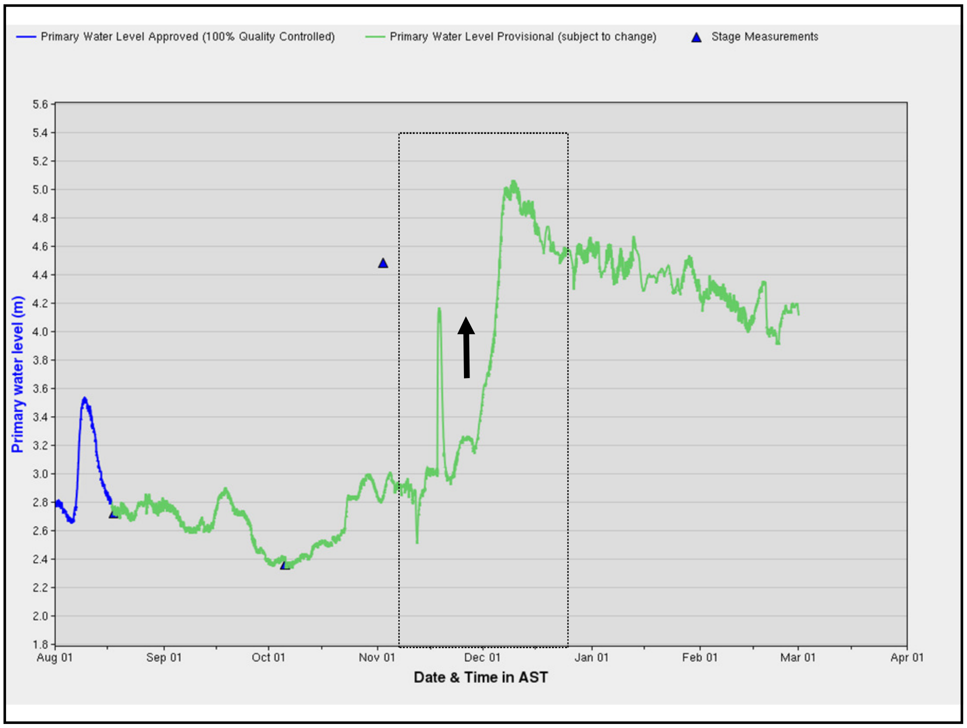
Communities, stakeholders notified, in according with emergency plan, says Nalcor

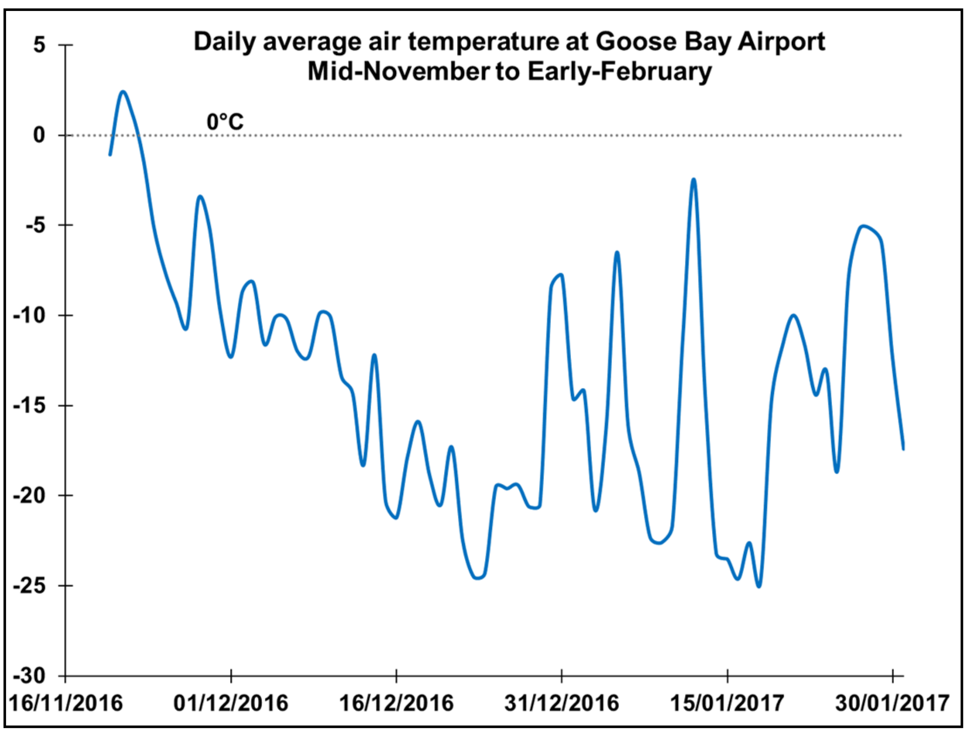
CBC News Posted: Nov 18, 2016 8:33 AM NT | Last Updated: Nov 18, 2016 6:41 PM NT

The Muskrat Falls cofferdam is a temporary barrier, and Nalcor says seepage is common. (Nalcor Energy)


English River Hydrometric Station (~44 km downstream)
Mud Lake, NL
Muskrat Falls Hydrometric Station
Hydrometric Station (~6 km downstream)
Google Earth


Primary Water Level Approved (100% Quality Controlled)
Primary Water Level Provisional (subject to change)
Stage Measurements
Primary water level (m)
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 01
Feb 01
Mar 01
Apr 01
Date & Time in AST


Primary Water Level Approved (100% Quality Controlled)
Primary Water Level Provisional (subject to change)
Stage Measurements
Primary water level (m)
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
Aug 01
Sep 01
Oct 01
Nov 01
Dec 01
Jan 01
Feb 01
Mar 01
Apr 01
Date & Time in AST


Daily average air temperature at Goose Bay Airport
Mid-November to Early-February
0°C
5
0
-5
-10
-15
-20
-25
-30
16/11/2016
01/12/2016
16/12/2016
31/12/2016
15/01/2017
30/01/2017

One person noted an ice jamming problem on Mishta-shipu near Mud Lake. On occasion, ice jams on a shoal near the outlet of the channel flowing from Mud Lake which blocks Mishta-shipu and causes the water to rise in the area, including at Mud Lake. Such ice jamming normally occurs in the spring, so the blockage that occurred in the fall of 2006, as reported in television news reports, was considered to be quite unusual (P2.7.12.06).

downstream of Muskrat Falls will not form during post-project conditions). The pre- and post-project thicknesses in the reach downstream of Muskrat Falls are expected to be comparable.

6.6 Ice Regime

The differences in the existing and post-project ice regimes of the lower Churchill River can be described in terms of timing and ice thickness, as described in the following sections. It should be noted that the timing and ice thickness in Goose Bay and Lake Melville are expected to remain unchanged in the post-project scenario. Therefore, the model was not extended to include this portion of the study area.

A second model limitation is suspected regarding the choking of the under ice flow conduit during conditions of high ice inflow rates. When the inflow of ice to the leading edge exceeds the carrying capacity of the "conduit" through and under the downstream cover, it is expected that the "conduit"

chokes with ice, which results in inflowing water going into storage upstream of the ice front, thereby raising the upstream water levels until the Froude control at the leading edge is drowned out and the ice cover can quickly stage upstream. In ICESIM, the cover will stage upstream only if sufficient energy losses accrue due to flow friction in the downstream channel to achieve adequate water levels at the leading edge to yield a Froude number at or below the critical value specified.

On account of the difficulties described above, the calibration procedure was modified such that each of the five winters was calibrated independently (i.e., input parameters were chosen to achieve the best possible calibration for each year individually). The ice parameter values chosen for each of the five winters were within the accepted range. A pre-project and post-project comparison was then completed for each of these years.

Though this type of calibration is not preferred, the major changes to the ice regime wrought by the proposed hydroelectric power developments have been adequately revealed for the purposes of an assessment of environmental impacts.

winter season. Each winter, however, the observed data show a sudden, unexplained increase in ice thickness at the end of winter, that the model is unable to replicate. It is postulated that this sudden increase in thickness may be due to initial melt of the snowpack lying on top of the ice cover. The melt water would collect and refreeze on the surface of the ice cover, creating an additional layer of ice. Subsequent thickness measurements may have inadvertently included this fresh layer of soft surface ice, resulting in the sudden "spike" in thickness shown.

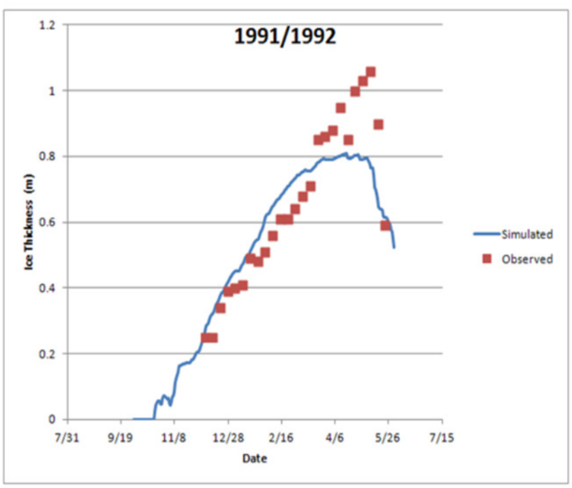
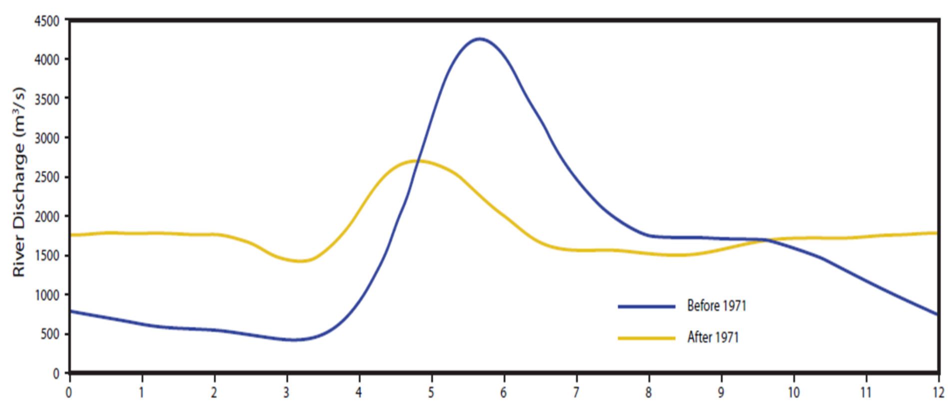


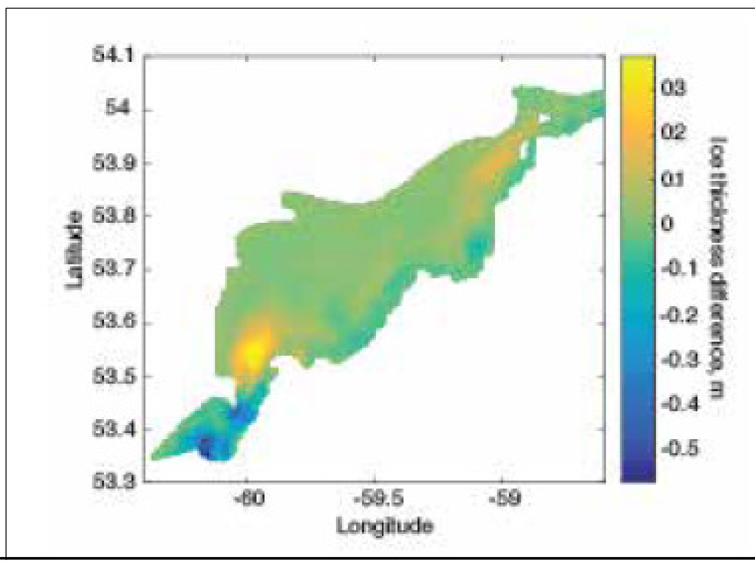
Figure 3-6: Goose Bay Simulation for 1991/1992

In summary, the model setup to simulate ice growth on these northern water bodies appears to work reasonably well. The late season deviation exhibited by the Goose Bay CIS data is likely caused by the initial melt of the snowpack on the ice cover, and is not considered to be important to the assessment at hand. Therefore the model was considered to be ready to simulate the post-project ice regime on the Muskrat Falls forebay.

Recently, a PhD dissertation (accepted in 2017) focused entirely on improving the model used by Hatch Ltd. in the Nalcor sanctioned ice studies (). It was noted that the original model was not able to simulate ice jams during the break-up period effectively. However, the author has seemingly developed new methods to try to improve this with some success.

lower computational cost, permits a longer study reach to be simulated (in the scale of hundred kilometers instead of couple hundred meters in three dimensional simulation). ICESIM model is unable to simulate the break-up period which reduces the model capability in the simulation of the complete cycle of river ice. New subroutines are designed and added to extend the model capability to include simulation of ice processes during the ice cover break-up and finally to calculate the sediment transport under the ice cover. Step 6: As the


River Discharge (m³/s)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
8
9
10
11
12
Before 1971
After 1971


54.1
54
53.9
53.8
53.7
53.6
53.5
53.4
53.3
Latitude
-60
-59.5
-59
Longitude
03
02
01
0
-0.1
-0.2
-0.3
-0.4
-0.5
Ice thickness difference, m

MR. ROBERT WAY PRESENTATION #2

A preliminary look at the factors influencing the Mud Lake flooding of 2017

Prepared by Robert G. Way

PhD Candidate (defended), Department of Geography, Environment and Geomatics, University of Ottawa

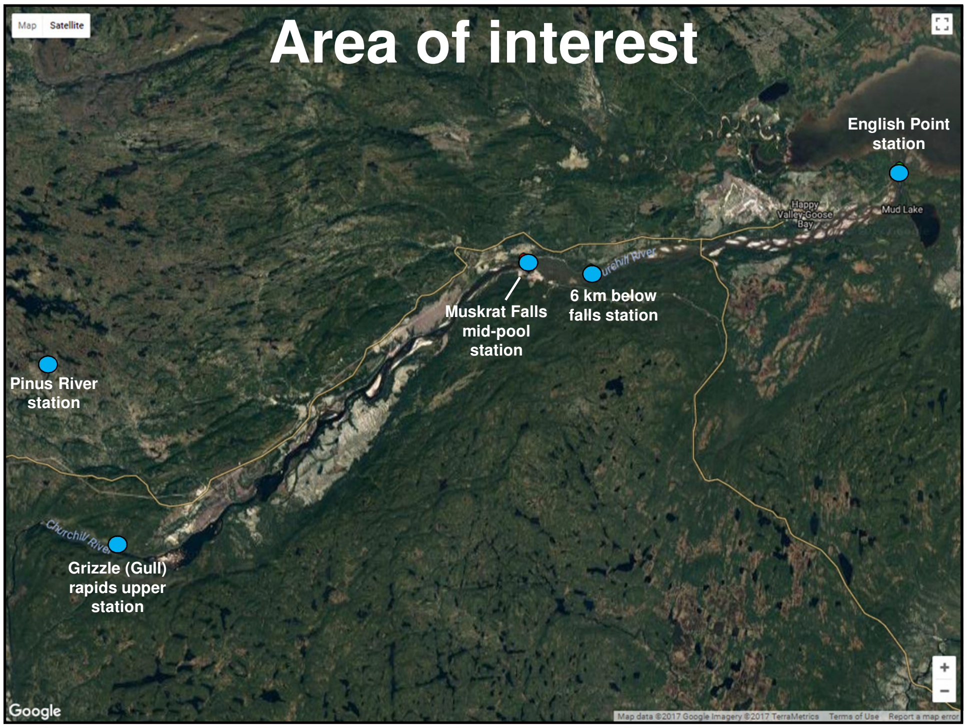
September 2017

Disclaimer

The opinions expressed in this presentation reflect those of the primary author and not those of the institutions to which he is affiliated and/or represents.

Materials provided herein are preliminary and have not be subject to a formal scientific review process. Data and graphical materials may be available upon request.

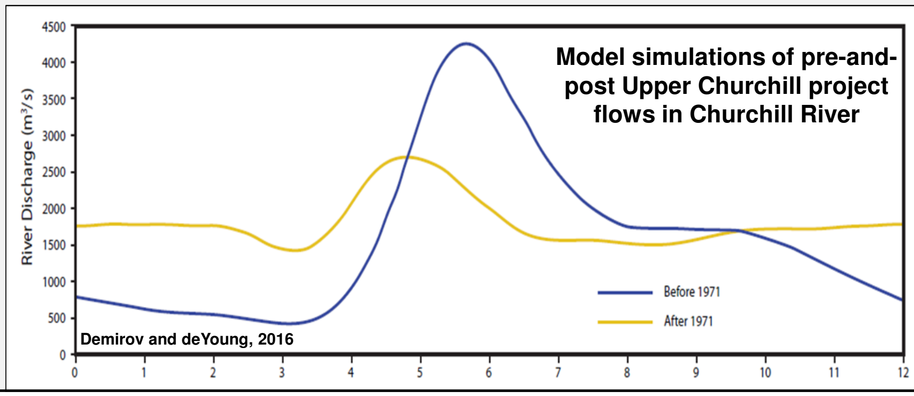
The author is not a Registered Professional Engineer or Geoscientist


Area of interest
English Point station
Muskrat Falls mid-pool station
6 km below falls station
Pinus River station
Grizzle (Gull) rapids upper station
Happy Valley-Goose Bay
Mud Lake
Churchill River


Area of interest
English Point station
Muskrat Falls mid-pool station
6 km below falls station
Pinus River station
Grizzle (Gull) rapids upper station
Happy Valley-Goose Bay
Mud Lake
Churchill River

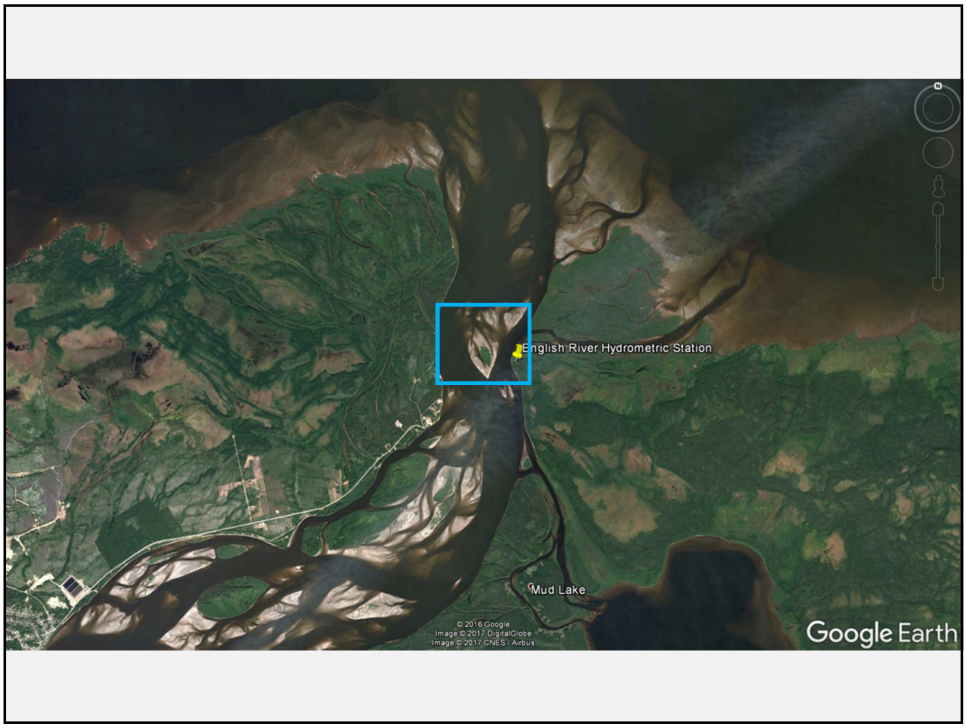
Key reminders

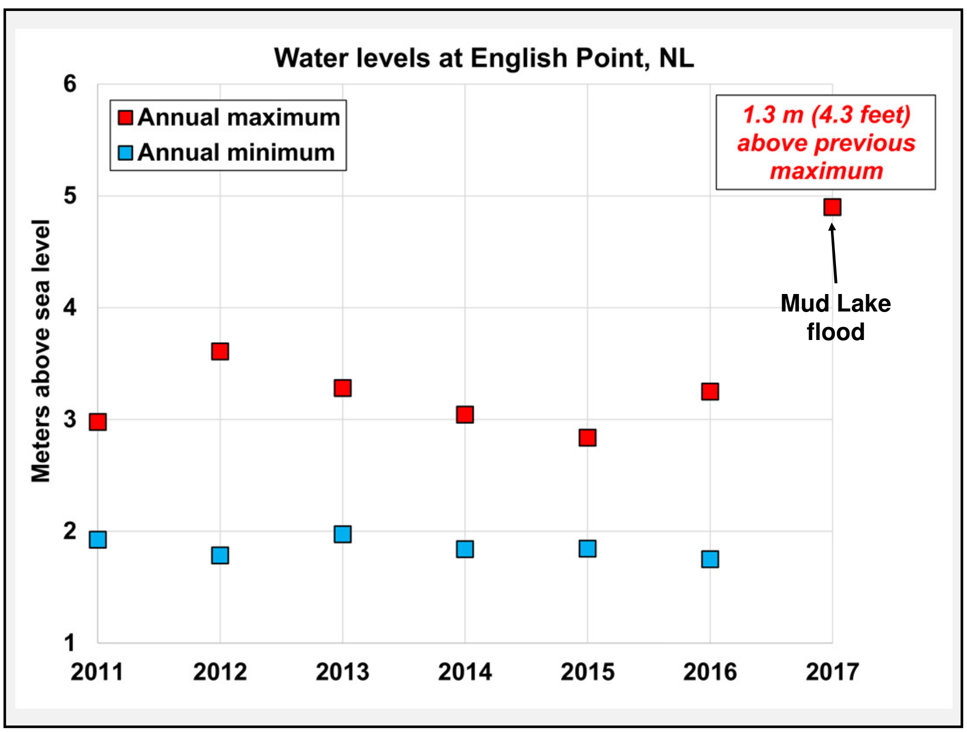
- Nalcor and Hydro Québec (through contractual obligations) control the majority of flow in the Churchill River
- Churchill Falls changed the flow of the river and how ice forms in Goose Bay

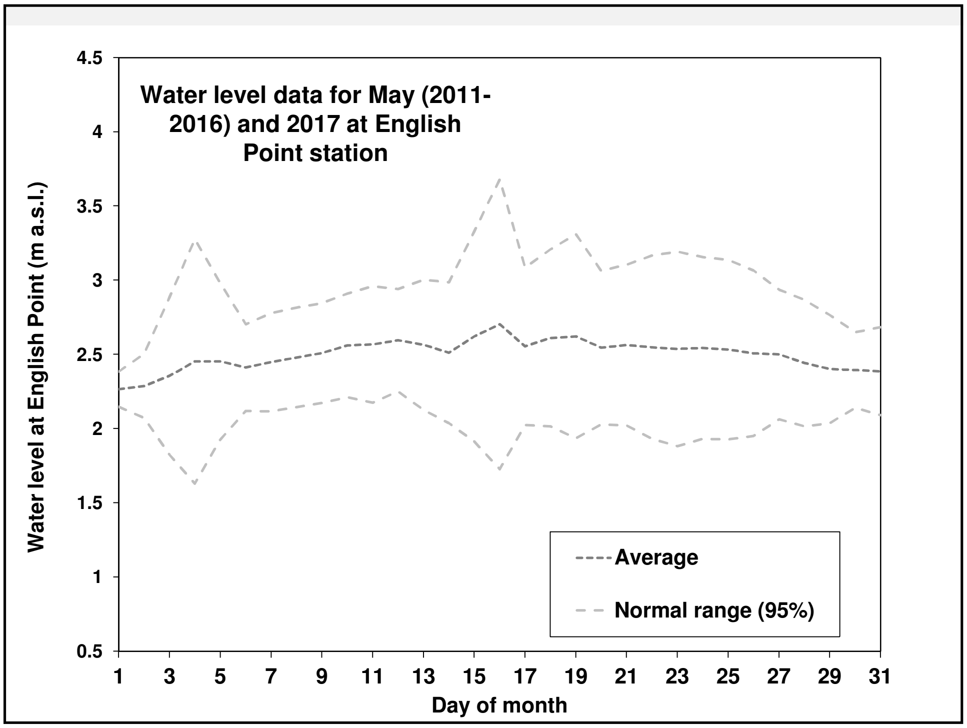


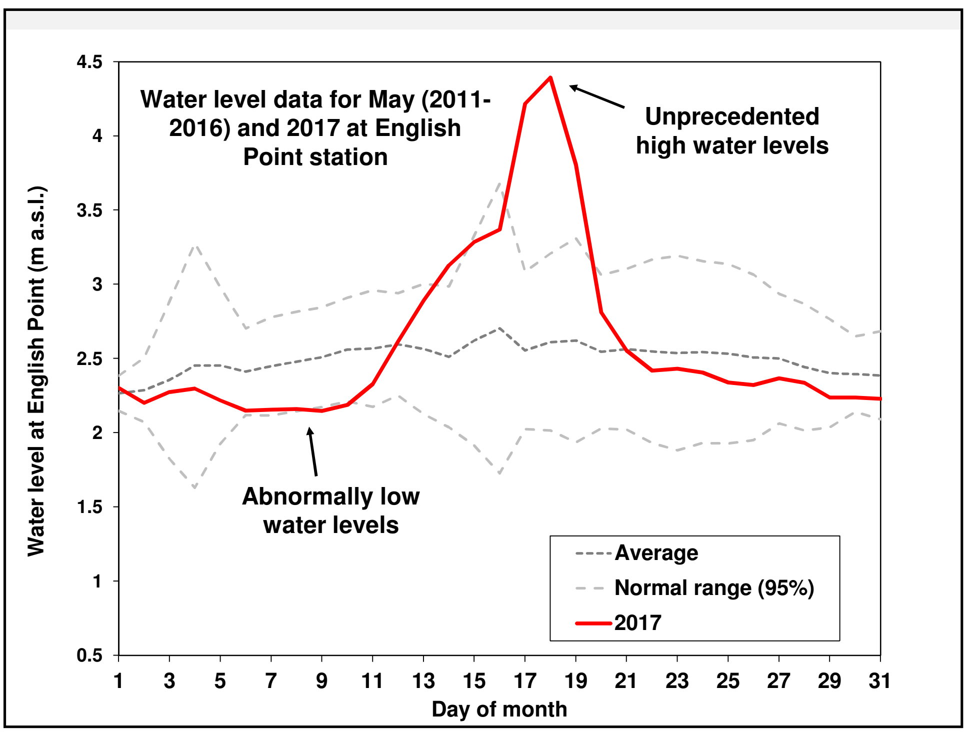
Key reminders

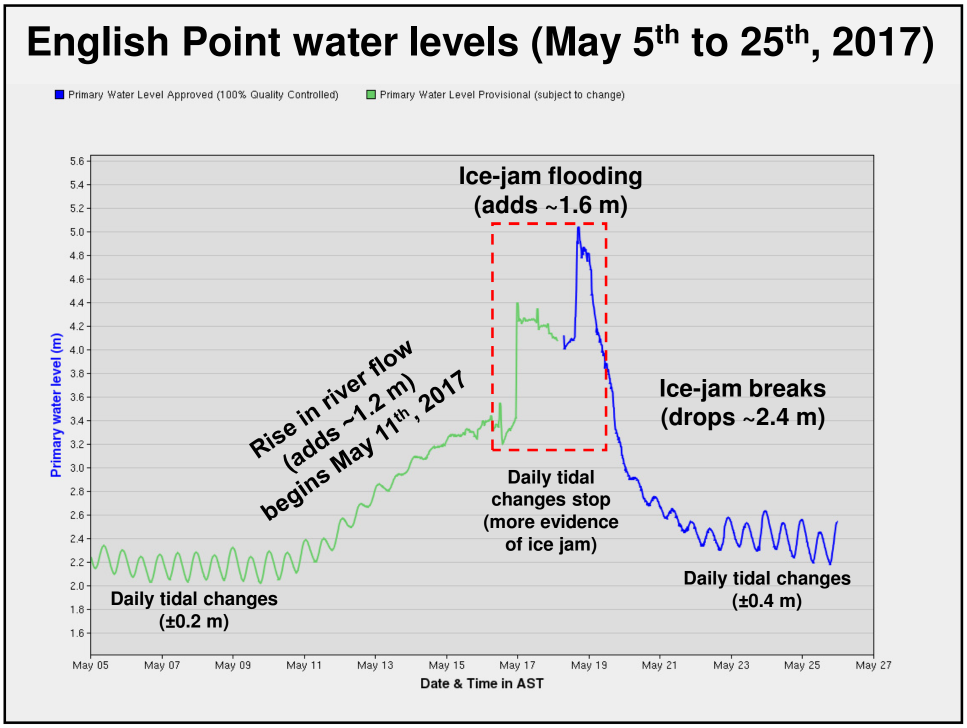
- Nalcor and Hydro Québec (through contractual obligations) control the majority of flow in the Churchill River
- Churchill Falls changed the flow of the river
- Churchill Falls reservoir has massive storage capacity ***(can hold back a lot of water)***
- Muskrat Falls has fairly limited storage capacity ***(can hold back minimal water)***
- Although flooding in portions of Mud Lake occurs relatively frequently – traditional knowledge shows no major floods in the past 100+ years

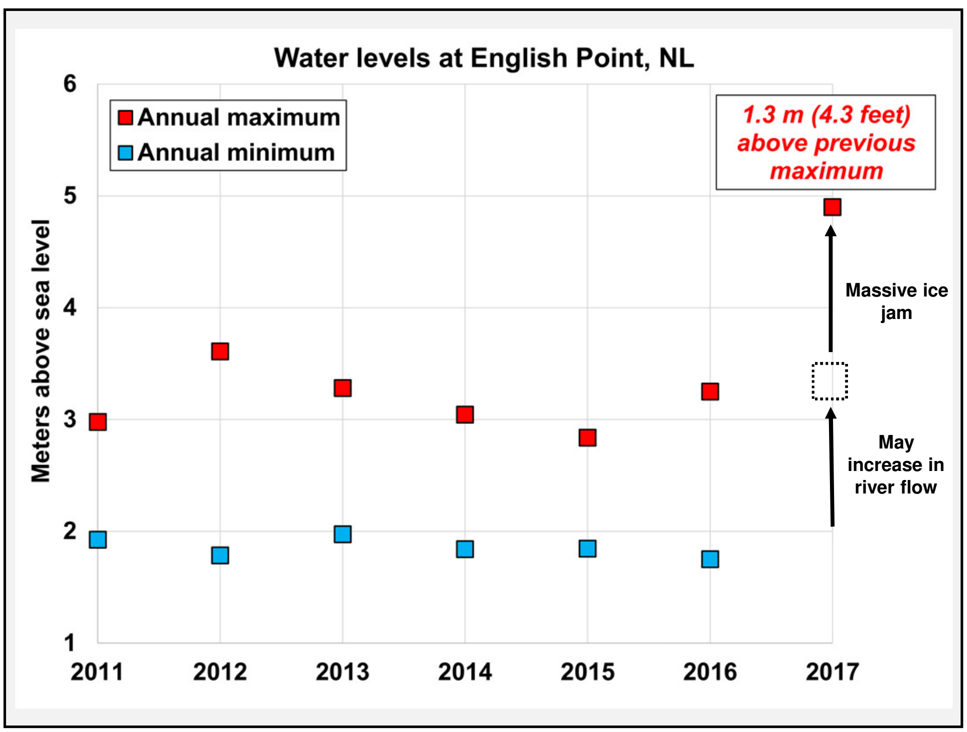

English River Hydrometric Station
Mud Lake
Google Earth


Water levels at English Point, NL
Annual maximum
Annual minimum
1.3 m (4.3 feet) above previous maximum
Mud Lake flood
Meters above sea level
1
2
3
4
5
6
2011
2012
2013
2014
2015
2016
2017

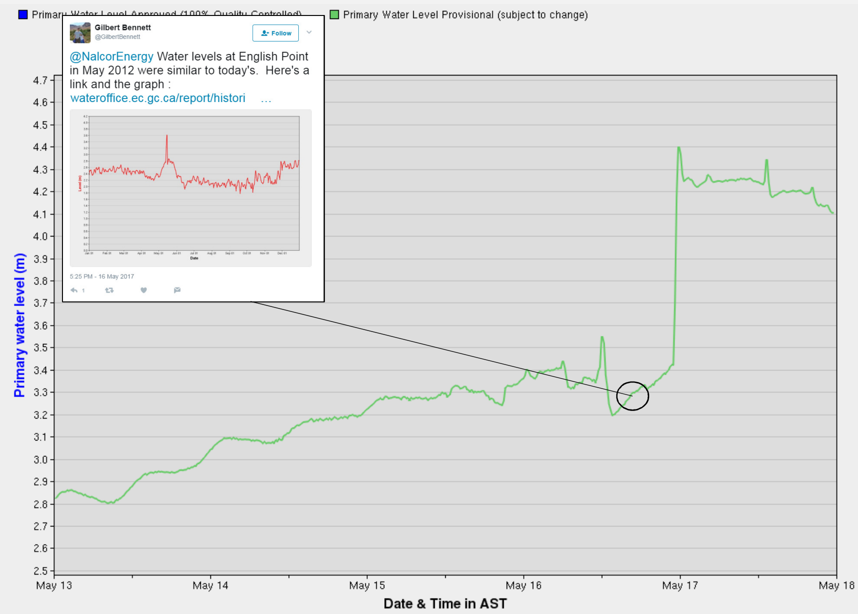

Water level data for May (2011-2016) and 2017 at English Point station
Water level at English Point (m a.s.l.)
Day of month
Average
Normal range (95%)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31


Water level data for May (2011-2016) and 2017 at English Point station
Unprecedented high water levels
Abnormally low water levels
Water level at English Point (m a.s.l.)
Day of month
Average
Normal range (95%)
2017
4.5
4
3.5
3
2.5
2
1.5
1
0.5
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31


English Point water levels (May 5th to 25th, 2017)
Primary Water Level Approved (100% Quality Controlled)
Primary Water Level Provisional (subject to change)
Ice-jam flooding (adds ~1.6 m)
Rise in river flow (adds ~1.2 m) begins May 11th, 2017
Ice-jam breaks (drops ~2.4 m)
Daily tidal changes stop (more evidence of ice jam)
Daily tidal changes (±0.2 m)
Daily tidal changes (±0.4 m)
Primary water level (m)
Date & Time in AST
May 05
May 07
May 09
May 11
May 13
May 15
May 17
May 19
May 21
May 23
May 25
May 27


Water levels at English Point, NL
Annual maximum
Annual minimum
1.3 m (4.3 feet) above previous maximum
Massive ice jam
May increase in river flow
Meters above sea level
2011
2012
2013
2014
2015
2016
2017

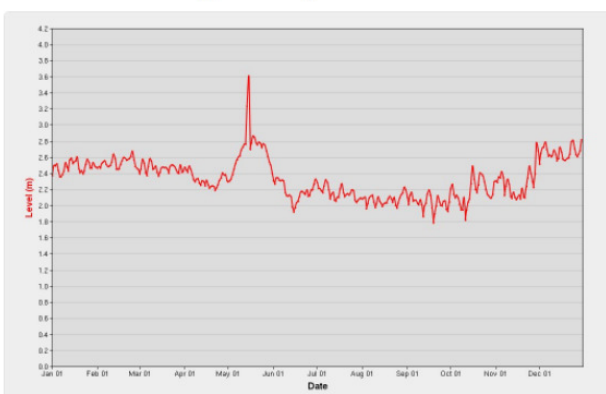
Nalcor unaware of potential for ice jam flooding



Gilbert Bennett
@GilbertBennett

Follow

@NalcorEnergy Water levels at English Point in May 2012 were similar to today's. Here's a link and the graph :
wateroffice.ec.gc.ca/report/histori …

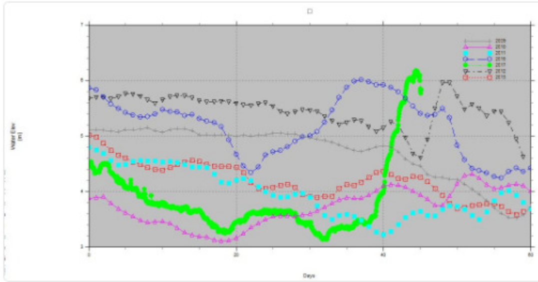


5:25 PM - 16 May 2017

1

Kurt Sullivan @KBS_NL · May 16

I plotted the elevation 6.5km downstream from Muskrat. Only thing I see as unusual is how fast this years level ramped up.



1

Gilbert Bennett
@GilbertBennett

Follow

Replying to @KBS_NL @NalcorEnergy

The 2017 & 2012 curves look similar in mid May, but the '17 curve started from a lower value.

5:55 PM - 16 May 2017

1

Kurt Sullivan
@KBS_NL

Follow

Replying to @GilbertBennett @NalcorEnergy

Is there an unusual amount of ice dammed up down stream of Muskrat? Did breakup happen unusually fast or is this year simply bad luck?

RETWEET
1

6:14 PM - 16 May 2017

1 1

Tweet your reply

Gilbert Bennett @GilbertBennett · May 16

Replying to @KBS_NL @NalcorEnergy

No and no. Water levels are driven by flow, and snowmelt is major contributor to flow - driven by temps & precip. across the entire region.

2 2

Key points

- Extreme flooding caused by an initial rise in river (~43% of increase) waters combined with a large ice jam (~57% of increase)
- Nalcor Energy VP (Gilbert Bennett) was unaware of the potential for an ice jam flood in the lead up to the event
- Ice jams have occurred in the area at various points previously according to local residents - but not to this degree.

One person noted an ice jamming problem on Mishta-shipu near Mud Lake. On occasion, ice jams on a shoal near the outlet of the channel flowing from Mud Lake which blocks Mishta-shipu and causes the water to rise in the area, including at Mud Lake. Such ice jamming normally occurs in the spring, so the blockage that occurred in the fall of 2006, as reported in television news reports, was considered to be quite unusual (P2.7.12.06). **Report of the work of the Innu Traditional Knowledge Committee (2007)**

Did Muskrat Falls or Churchill Falls influence the ice jamming?

- Ice jams can be influenced by many factors including:
  - Large variations in river flow – particularly when rapidly moving from low flows to high flows
  - Development of thick ice at or around potential ice jam pinning locations (buttressing effects)
  - Other factors including accumulation of sediments, ice and debris catching on sandbars and shallow areas
  - Ice jams regularly occur on the Churchill River

Mud Lake residents also raised concerns that changes in channel morphology below Muskrat Falls would affect ice dynamics since they have observed that sandbars play an important role in ice formation by blocking ice coming from upstream. **Joint Review Panel (2011)**

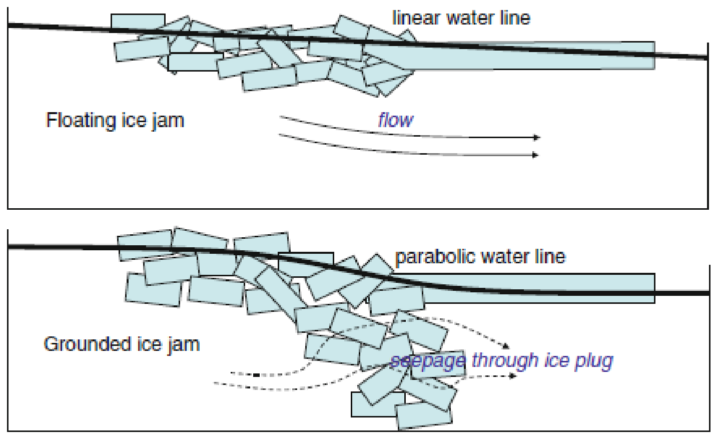


Fig. 9.10 Longitudinal profiles of a floating and a grounded ice jam, the former with a linear and the latter with a parabolic water line (Simplified after Michel 1972)

M.-k. Woo, Permafrost Hydrology,
DOI 10.1007/978-3-642-23462-0_9

Could an ice jam have been foreseen?

- ***Traditional knowledge holders*** indicated the presence of widespread ***unusually thick*** and ***hard ice*** near the mouth of the Churchill River throughout the winter of 2016-2017
- They also expressed concern regarding the potential impacts of abundant blocks of vegetation and trees seen floating downriver in the Fall of 2016
- Unusual river flow variations occurred throughout the Fall and Winter due to construction at the Muskrat Falls site

Could an ice jam have been foreseen?

- Unseasonably thick ice cover present on Lake Melville and Goose Bay in May
- Ice jams can be persistent when there's consolidated ice buttressing the ice jam
- For example, thick ice in Goose Bay restricting ice jam movement in Spring 2017

Did Muskrat Falls or Churchill Falls influence the ice jamming?

- Forecasting ice jams is common practice on many rivers in Canada
  - Requires accurate regular measurements of ice thicknesses in critical areas, complete river flow information and climate data
- The type of ice thickness data required for forecasting ***is not being collected*** by Nalcor Energy
  - Thickness data is collected typically at 5-10 points along the Mud Lake crossing ***once a year*** using an auger
  - 2016-2017 ice study is not yet publicly available and ***was not made available*** for the assessment

Joint Review Panel Report (2011)

If the Project is approved, Nalcor committed to continue to verify ice dynamic predictions for ice progression, thickness and stability through satellite imagery downstream of Muskrat Falls, including near Mud Lake and Happy Valley-Goose Bay and around the mouth of the Churchill River and Lake Melville. Nalcor expected that people would make their own judgments about whether or not ice conditions are safe based on the information provided through monitoring and follow-up programs.

Nalcor also committed to provide information regarding ice thickness and stability of the Mud Lake ice road during the ice formation and break-up period to the Mud Lake Improvement Committee, the Royal Canadian Mounted Police, the Municipality of Happy Valley-Goose Bay, the Town of North West River and the Sheshatshiu Band Council. Nalcor would work in collaboration with communities to develop the details of these public advisories.

Proposed Mitigation Measures and Monitoring

Nalcor's proposed mitigation measures and monitoring related to winter travel included the following:

- provide information regarding ice thickness and stability at select locations on the river, including the ice road to Mud Lake, to local communities and stakeholders and issue public advisories as needed;

Joint Review Panel Report (2011)

Proposed Mitigation Measures and Monitoring

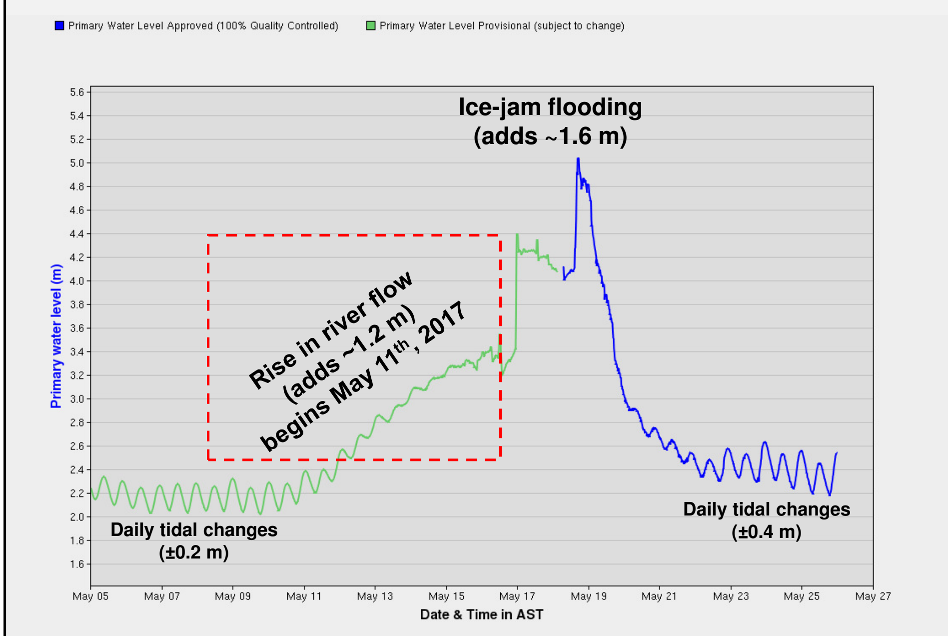
Nalcor's proposed mitigation measures and monitoring related to climate change included the following:

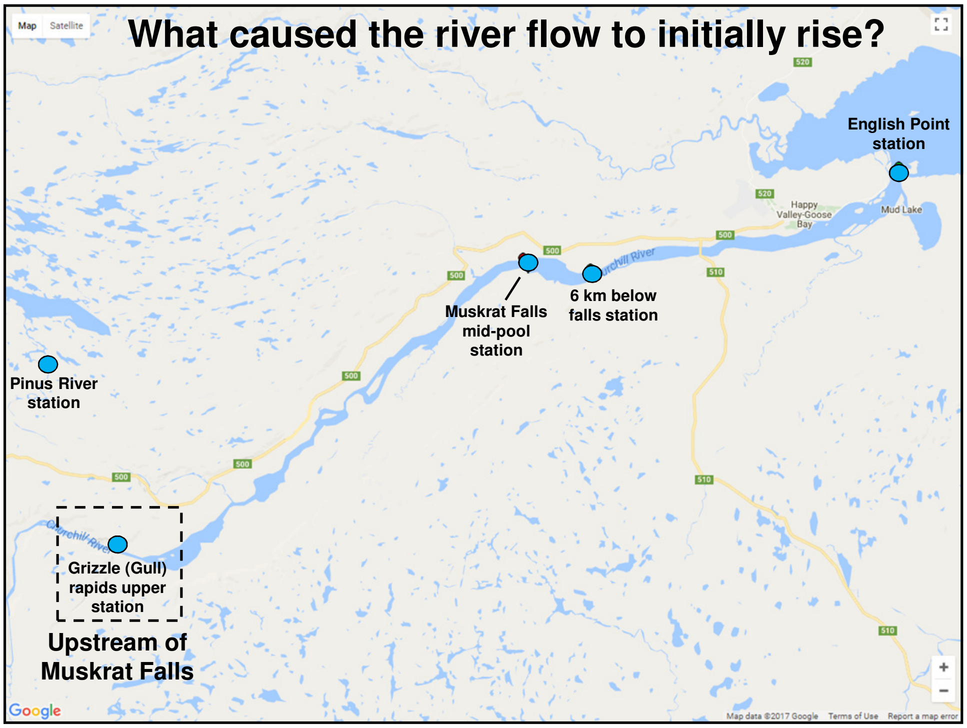
- implement adaptive measures as needed in response to predicted climate change effects on the Project, which could involve new flood procedures, water management practices or increasing spillway capacity;
- continue to work and partner with the Department of Environment and Conservation to determine the optimum approach and Nalcor's role in monitoring for climate change;
- carry out the following monitoring programs for Project-related effects, which would also provide long-term information on climate change effects:
  - remote monitoring systems to measure environmental conditions including: wind, precipitation, temperature, ice, reservoir and trash rack conditions, and tailrace levels;
  - an ice observation program to be carried out throughout the reservoirs, downstream of Muskrat Falls to the mouth of the Churchill River, and Lake Melville, including: timing of ice formation and break-up, area covered, and open water areas including ashkui;
  - satellite-based monitoring of ice progression and stability in the vicinity of Mud Lake and Happy Valley-Goose Bay;
  - monitoring of ice thickness at select locations on the river, including public advisories; and
- carry out research for the period 2009-2012 involving modelling of the effects of climate change on the hydrological cycle of the lower Churchill watershed.

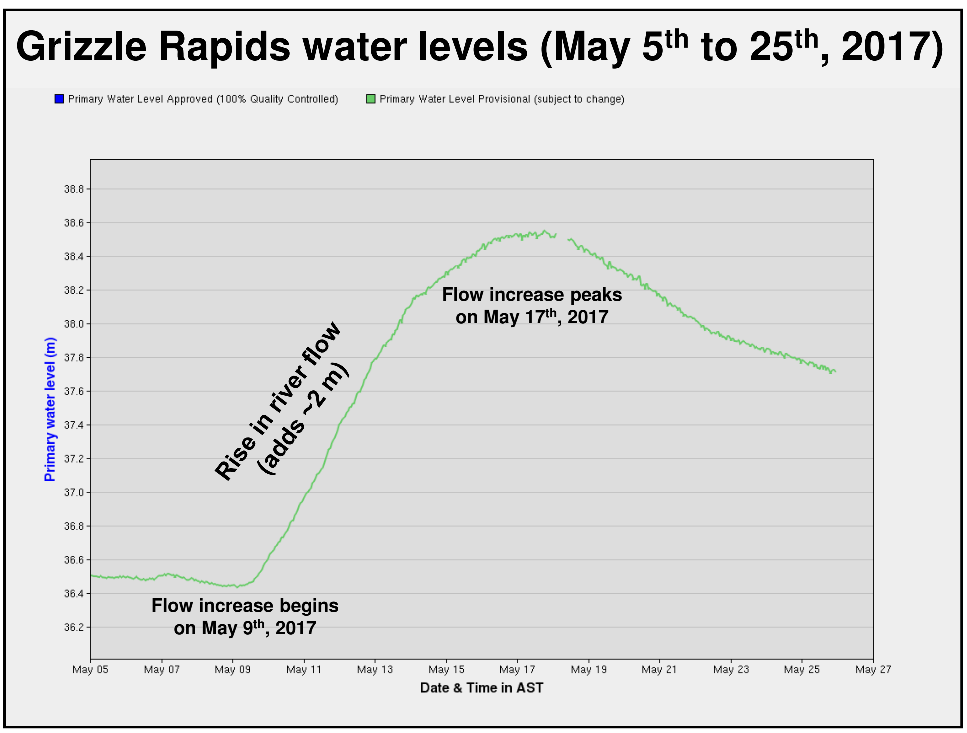
Did Muskrat Falls or Churchill Falls influence the ice jamming?

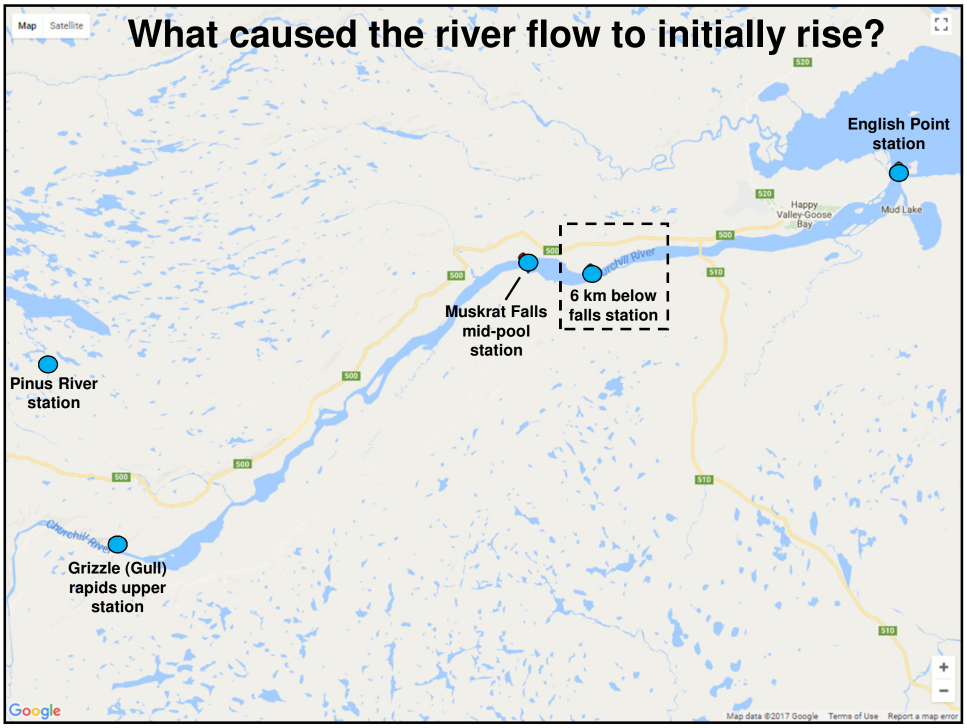
- ***Attributing*** the influence of Muskrat Falls or Churchill Falls on ice thicknesses in Winter 2016-2017 ***requires*** ice jam ***modelling***
  - Nalcor Energy ***does not currently conduct*** flood modelling for the Churchill River or downstream areas
  - Studies contracted for the Environmental Impact Assessment process (Hatch Ltd) were not able to simulate ice jam floods, and struggled with modelling ice thicknesses at the mouth of the Churchill River
  - ***No follow-up study*** on the topic of ice jam flooding was sought by Nalcor Energy
  - Nalcor Energy is not currently collecting the data required to evaluate its predictions on downstream impacts of Muskrat Falls on ice

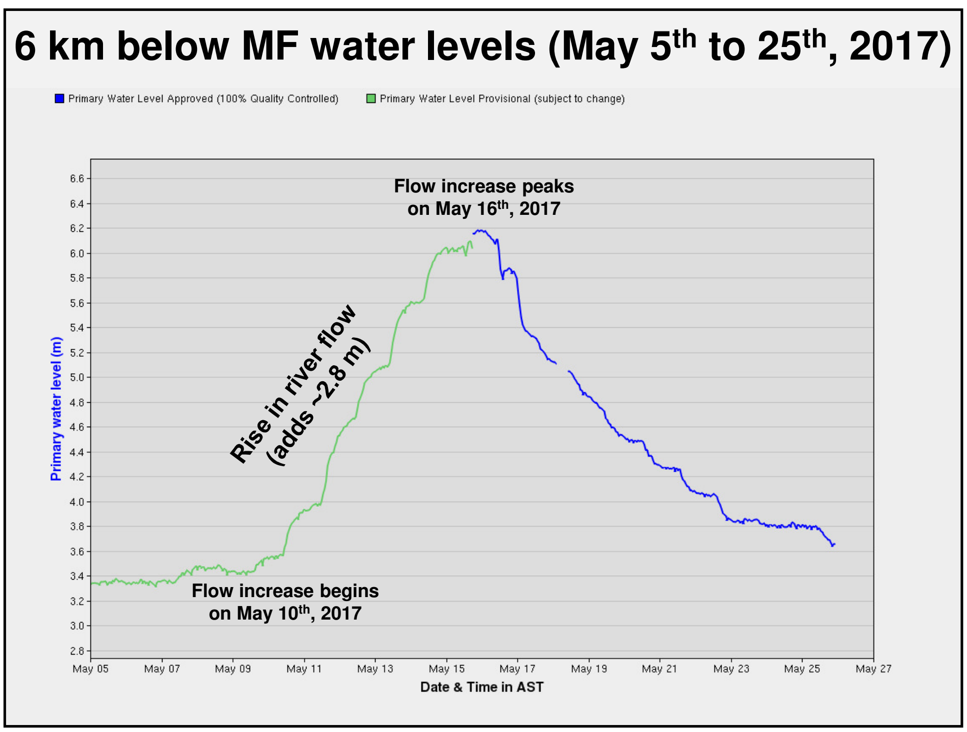
English Point water levels (May 5th to 25th, 2017)

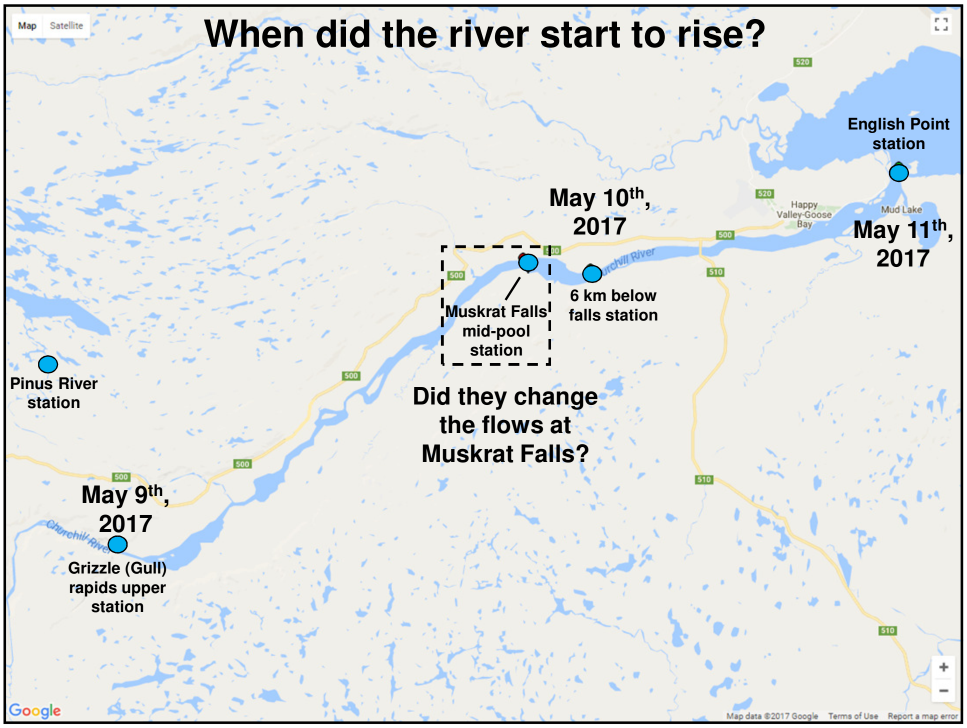


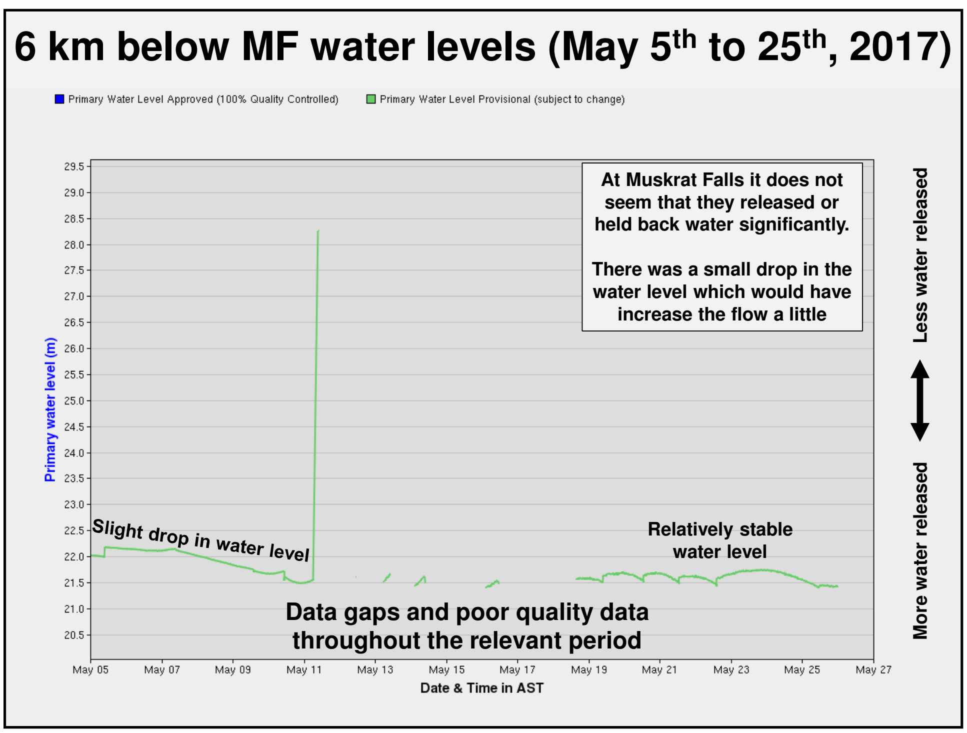

What caused the river flow to initially rise?
English Point station
Muskrat Falls mid-pool station
6 km below falls station
Pinus River station
Grizzle (Gull) rapids upper station
Upstream of Muskrat Falls
Happy Valley-Goose Bay
Mud Lake
Churchill River
Map
Satellite
Google
Map data ©2017 Google
Terms of Use
Report a map error


Grizzle Rapids water levels (May 5th to 25th, 2017)
Primary Water Level Approved (100% Quality Controlled)
Primary Water Level Provisional (subject to change)
Primary water level (m)
38.8
38.6
38.4
38.2
38.0
37.8
37.6
37.4
37.2
37.0
36.8
36.6
36.4
36.2
Rise in river flow (adds ~2 m)
Flow increase peaks on May 17th, 2017
Flow increase begins on May 9th, 2017
May 05
May 07
May 09
May 11
May 13
May 15
May 17
May 19
May 21
May 23
May 25
May 27
Date & Time in AST


What caused the river flow to initially rise?
Map
Satellite
English Point station
Happy Valley-Goose Bay
Mud Lake
Muskrat Falls mid-pool station
6 km below falls station
Pinus River station
Grizzle (Gull) rapids upper station
Churchill River
Google
Map data ©2017 Google
Terms of Use
Report a map error


6 km below MF water levels (May 5th to 25th, 2017)
Primary Water Level Approved (100% Quality Controlled)
Primary Water Level Provisional (subject to change)
Flow increase peaks on May 16th, 2017
Rise in river flow (adds ~2.8 m)
Flow increase begins on May 10th, 2017
Primary water level (m)
Date & Time in AST
May 05
May 07
May 09
May 11
May 13
May 15
May 17
May 19
May 21
May 23
May 25
May 27

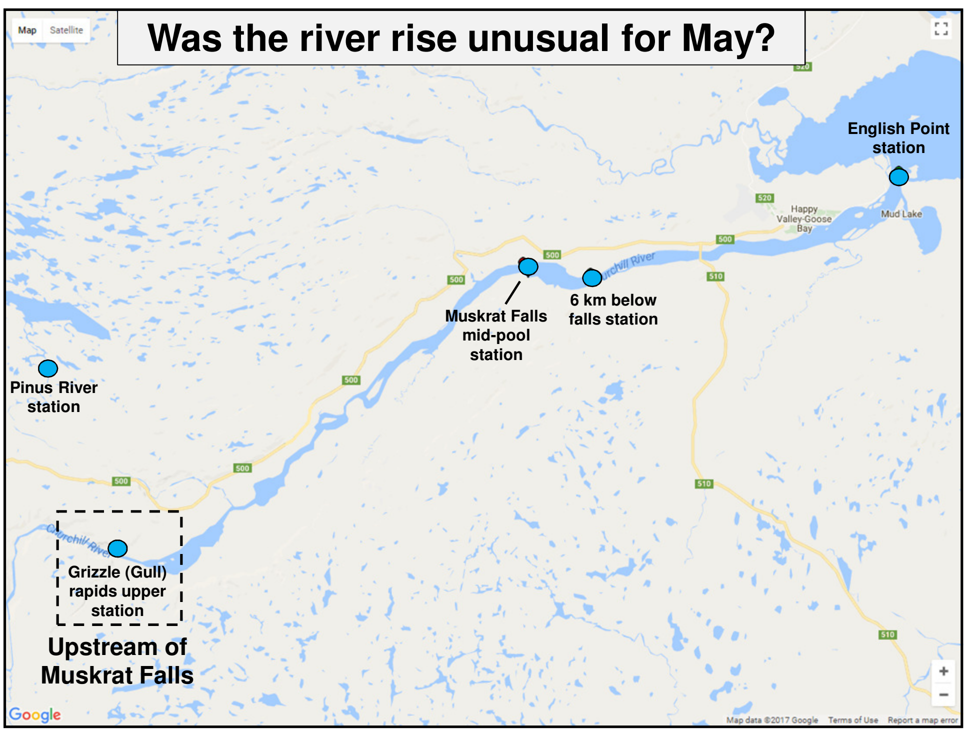

When did the river start to rise?
English Point station
May 10th, 2017
May 11th, 2017
Muskrat Falls mid-pool station
6 km below falls station
Pinus River station
Did they change the flows at Muskrat Falls?
May 9th, 2017
Grizzle (Gull) rapids upper station

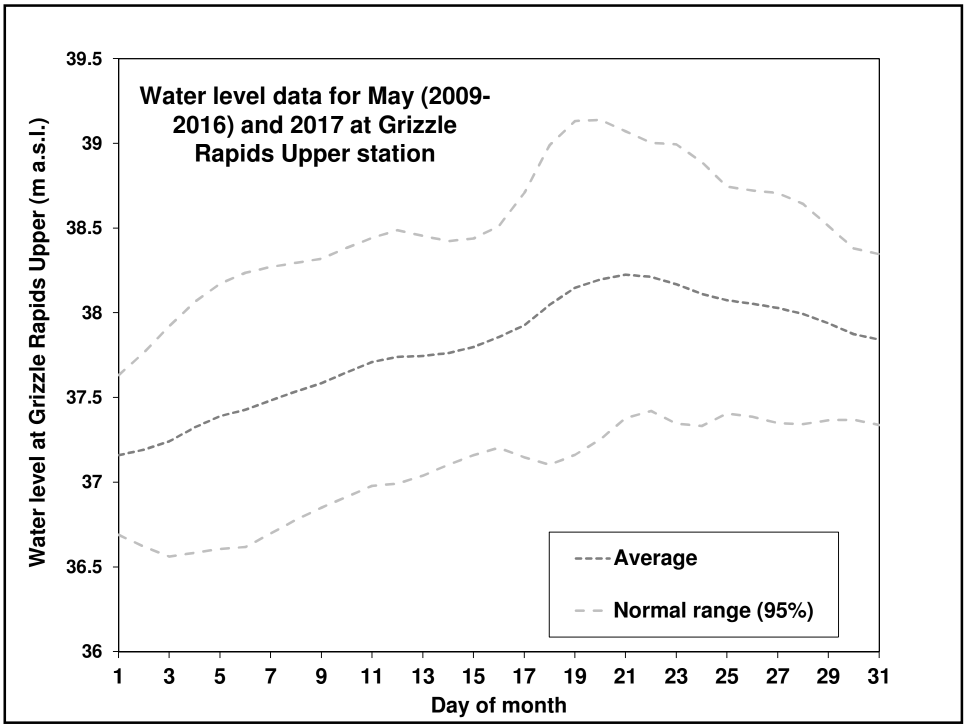

6 km below MF water levels (May 5th to 25th, 2017)
Primary Water Level Approved (100% Quality Controlled)
Primary Water Level Provisional (subject to change)
At Muskrat Falls it does not seem that they released or held back water significantly.
There was a small drop in the water level which would have increase the flow a little
Less water released
More water released
Slight drop in water level
Relatively stable water level
Data gaps and poor quality data throughout the relevant period
Primary water level (m)
Date & Time in AST

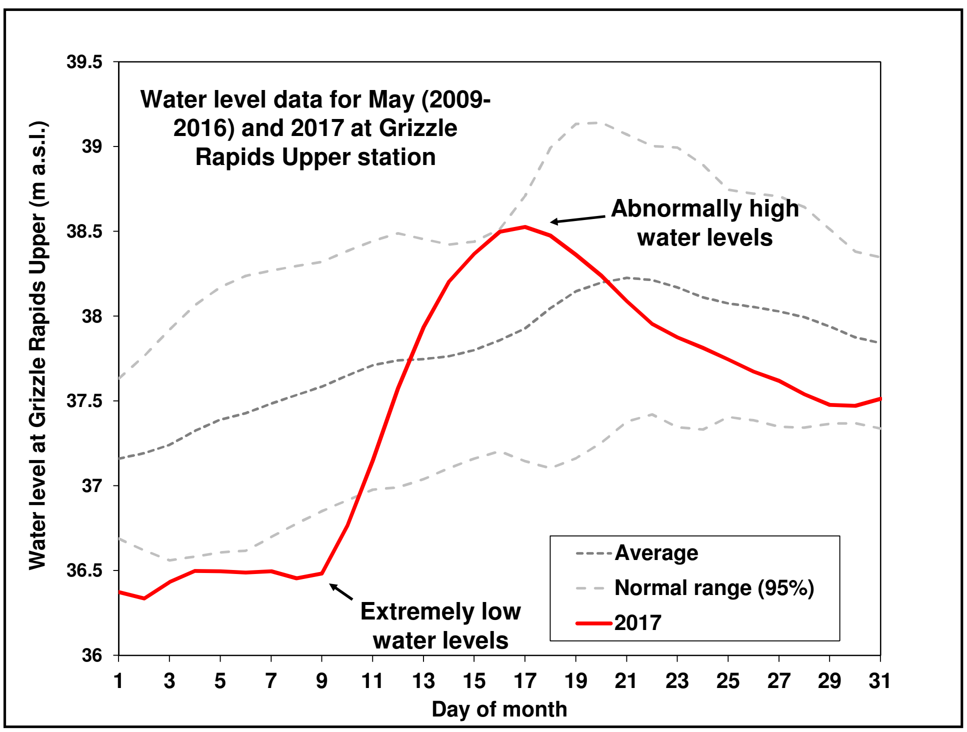
Key points

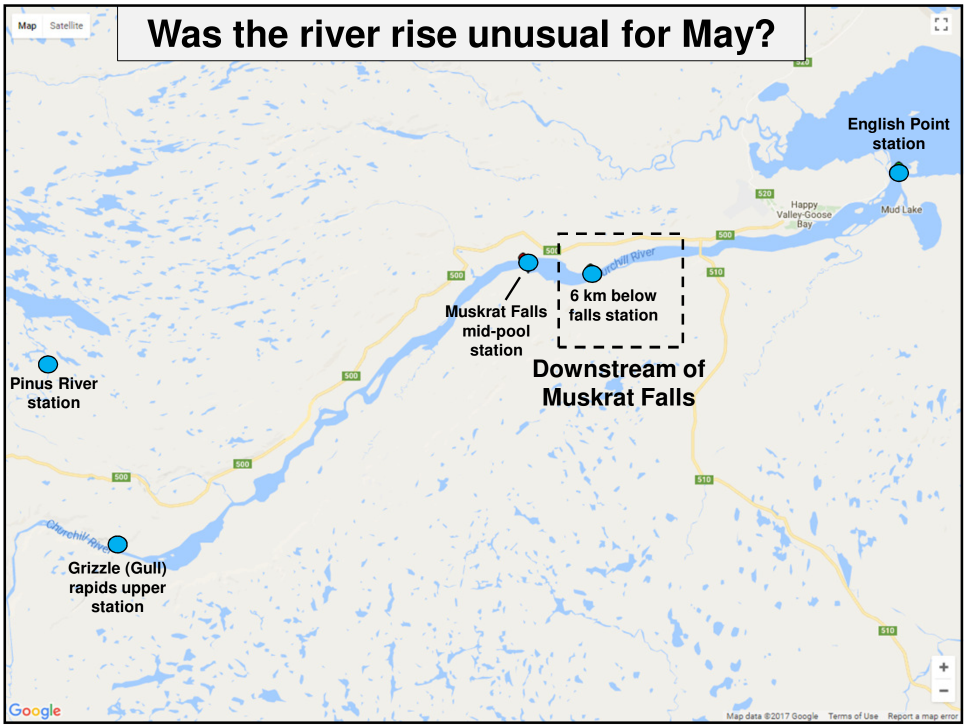
- River flow increased upstream of Muskrat Falls 12-24 hours before the increase was seen below Muskrat Falls
- Data at Muskrat Falls reservoir is ***poor quality*** but does not show any ***significant*** change in water levels
- This means that the big increase in observed flow upstream was allowed to pass through Muskrat Falls and proceed downstream to English Point

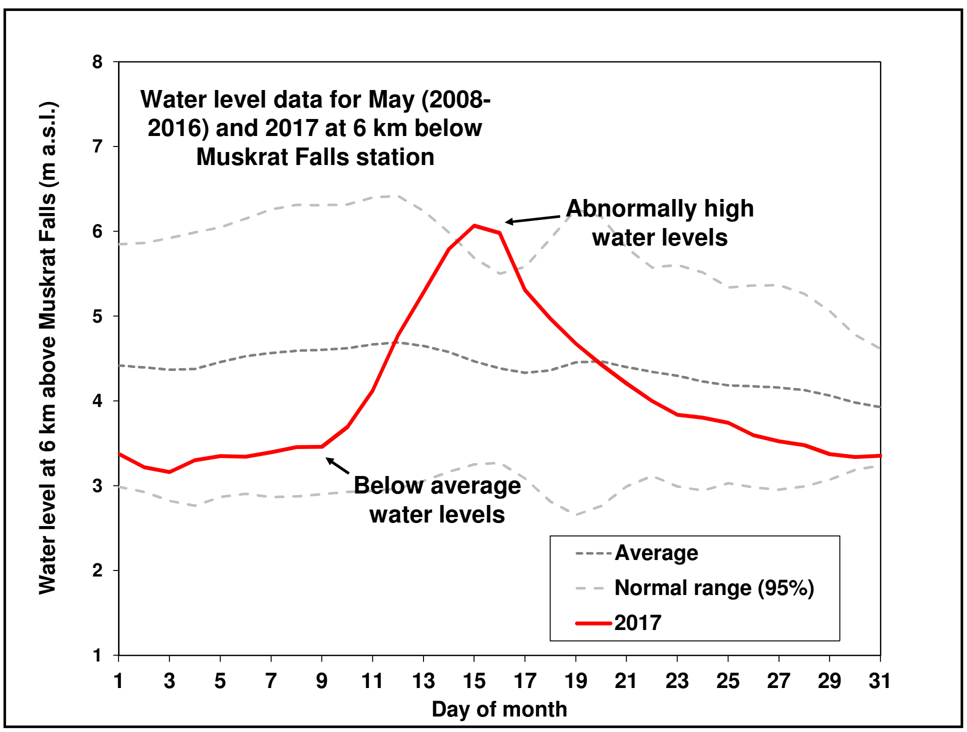
Was the river rise unusual for May?




Water level data for May (2009-2016) and 2017 at Grizzle Rapids Upper station
Water level at Grizzle Rapids Upper (m a.s.l.)
39.5
39
38.5
38
37.5
37
36.5
36
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Day of month
Average
Normal range (95%)


Water level data for May (2009-2016) and 2017 at Grizzle Rapids Upper station
Water level at Grizzle Rapids Upper (m a.s.l.)
39.5
39
38.5
38
37.5
37
36.5
36
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Day of month
Abnormally high water levels
Extremely low water levels
Average
Normal range (95%)
2017

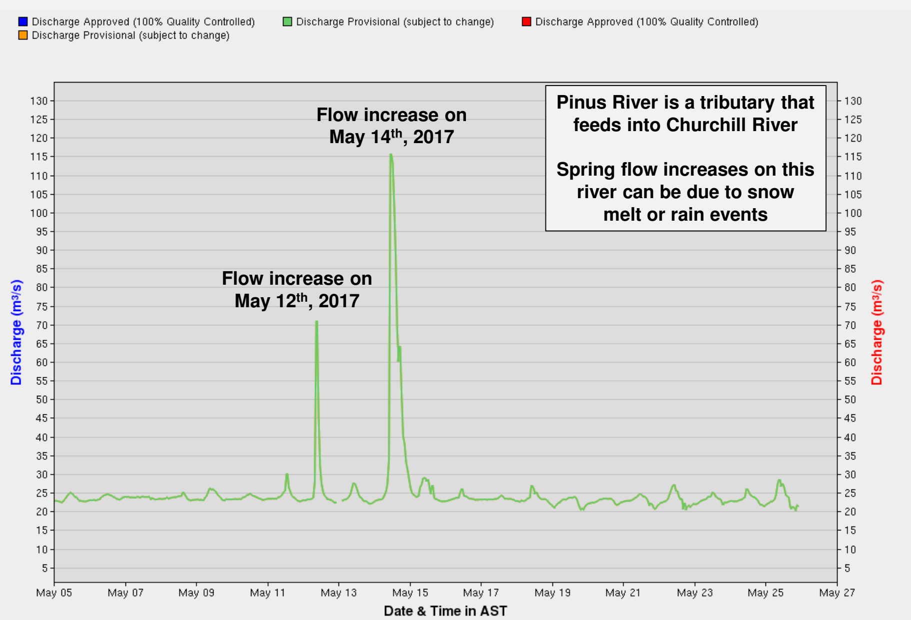

Was the river rise unusual for May?
English Point station
Muskrat Falls mid-pool station
6 km below falls station
Downstream of Muskrat Falls
Pinus River station
Grizzle (Gull) rapids upper station
Happy Valley-Goose Bay
Mud Lake
Churchill River
Map data ©2017 Google

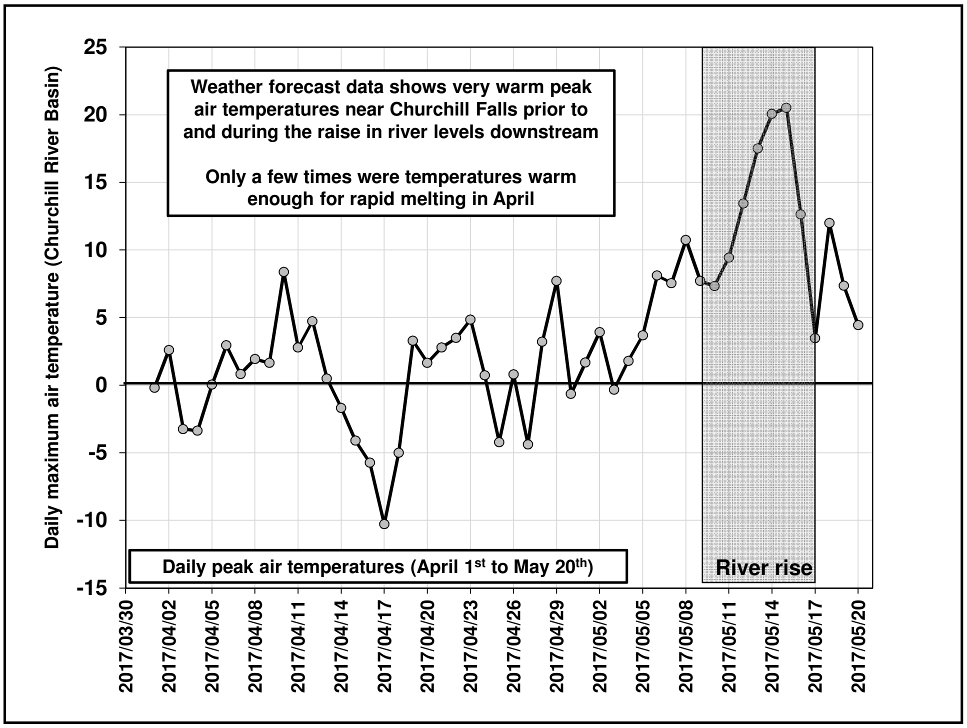

Water level data for May (2008-2016) and 2017 at 6 km below Muskrat Falls station
Abnormally high water levels
Below average water levels
Average
Normal range (95%)
2017
Water level at 6 km above Muskrat Falls (m a.s.l.)
Day of month

What caused the river to rapidly rise in May 2017?

- Water flows upstream and downstream of Muskrat Falls show an extreme rise in water levels
  - Brought water levels from abnormally low to abnormally high in a short period (May 9th to 17th)
- Some potential ***natural*** causes:
  - Rapid snowmelt event?
  - Rainfall events?
- Some potential ***other*** causes:
  - Increase in water flows from Upper Churchill?

Pinus River water flow (May 5th to 25th, 2017)




Weather forecast data shows very warm peak air temperatures near Churchill Falls prior to and during the raise in river levels downstream
Only a few times were temperatures warm enough for rapid melting in April
Daily peak air temperatures (April 1st to May 20th)
River rise
Daily maximum air temperature (Churchill River Basin)
25
20
15
10
5
0
-5
-10
-15
2017/03/30
2017/04/02
2017/04/05
2017/04/08
2017/04/11
2017/04/14
2017/04/17
2017/04/20
2017/04/23
2017/04/26
2017/04/29
2017/05/02
2017/05/05
2017/05/08
2017/05/11
2017/05/14
2017/05/17
2017/05/20

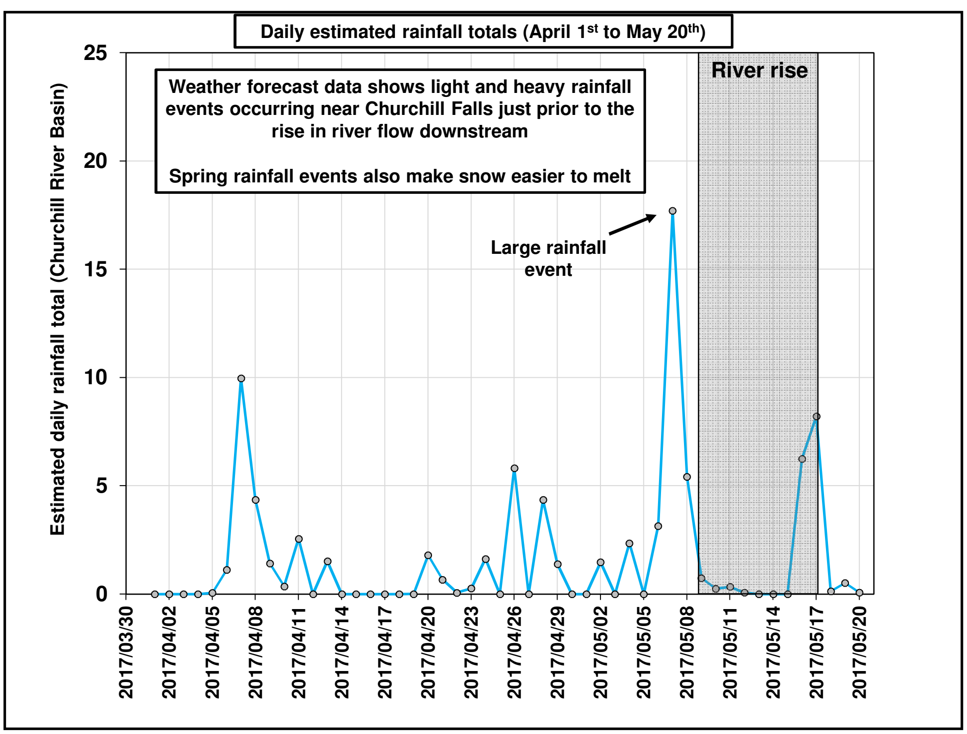

Daily estimated rainfall totals (April 1st to May 20th)
Weather forecast data shows light and heavy rainfall events occurring near Churchill Falls just prior to the rise in river flow downstream
Spring rainfall events also make snow easier to melt
River rise
Large rainfall event
Estimated daily rainfall total (Churchill River Basin)
25
20
15
10
5
0
2017/03/30
2017/04/02
2017/04/05
2017/04/08
2017/04/11
2017/04/14
2017/04/17
2017/04/20
2017/04/23
2017/04/26
2017/04/29
2017/05/02
2017/05/05
2017/05/08
2017/05/11
2017/05/14
2017/05/17
2017/05/20

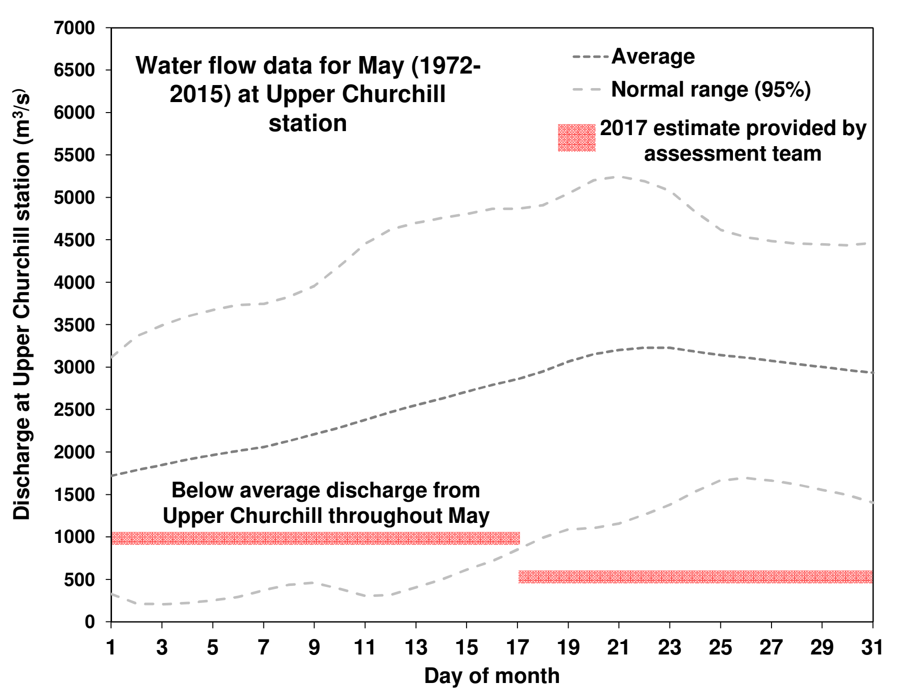
Photo credit: George Way

Key points

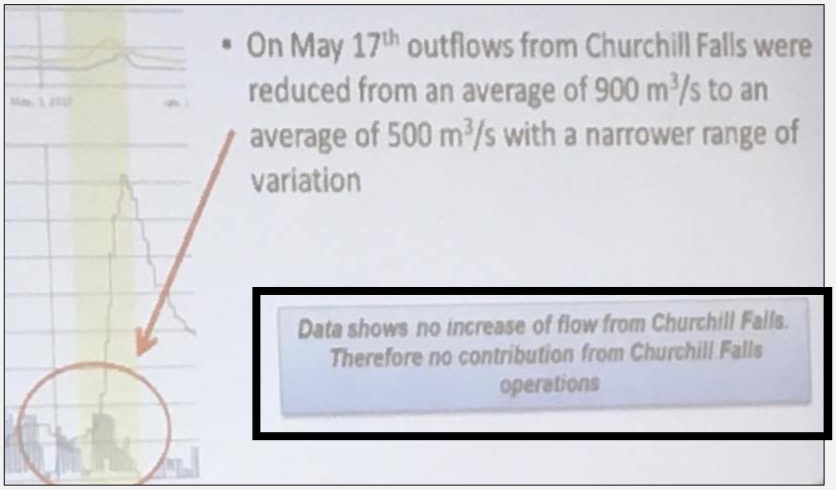
- Daily snow data is ***not adequately collected*** downstream of Churchill Falls
- Peak air temperatures above 7℃ occurred for 11 straight days from May 6th to May 16th)
  - Peak temperatures reached over 20℃ (May 14th and 15th)
- Several rain events totalling almost 30 mm occurred between May 5th and May 10th
- These conditions were ***very*** favorable for a rapid snowmelt event ***(most of the snow probably melted)***
- Rapid snowmelt events can occur ***semi-regularly*** in central Labrador

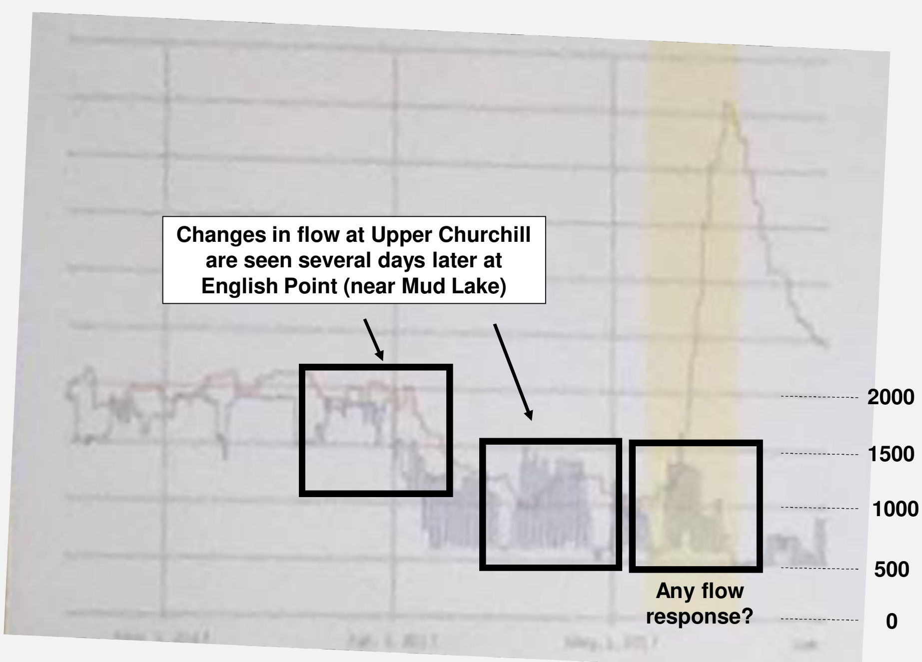
Other causes of river rise – did Upper Churchill contribute?

- Data from the Upper Churchill river monitoring stations are not ***publicly available*** after 2015 through Environment Canada's website
- The preliminary results of the Independent Assessment showed that they did receive access to this data from Nalcor and/or other sources directly
- They concluded that there was no contribution from the Upper Churchill operations



Assessment team conclusion on Upper Churchill contribution





Key points

- Daily flow data for Churchill Falls outflows is ***not available publicly*** for the period of interest *(but is available until 2015)*
- According to Assessment Team the flow was low throughout May
- Small peak in Churchill Falls outflow occurred prior to the rise in river levels at English Point
  - Increases in flow from Churchill Falls are not seen until several days later at English Point
- It is plausible that a ***small*** contribution to increased river flow ***prior to ice jamming*** was due to combined operations at Churchill Falls and Muskrat Falls

Conclusions *(Page 1)*

- The majority of the flooding at Mud Lake was caused by an ice jam formed near English Point
- Water levels rose prior to the ice jam in response to a combination of a ***rapid snow melt*** & ***early-May rain*** events with possibly a small contribution from flows at the Upper Churchill station.
- Data collection by Nalcor on the Churchill River is ***inadequate*** for real-time management of flooding and ice jamming
  - Nalcor has not followed through on its commitments to the Joint Review Panel regarding ice thickness monitoring
  - Nalcor was unaware of the potential for an ice jam flood because even a modest monitoring program was not in place
- Attributing the ice jam component of the flooding to human influences is not possible without more research *(requires complex numerical modelling)*

Conclusions *(Page 2)*

- An elevated risk of ice jamming in May 2017 could have been predicted:
  - Observations of exceptional ice thickness and hardness at the mouth of the Churchill River in late-winter
  - Average to below average snow thicknesses *(deeper freezing)*
  - Below average river flow rates in late-winter
  - High ice freeze up position (Assessment Team result)
  - Numerous flow alterations made during the Fall, the freeze up period and the early winter *(unknown effect)*
  - Observations of grounded ice and trees on sandbars
- The ***extent*** of flood damage at Mud Lake and on Mud Lake road may have been ***mitigated*** with effective management of the Churchill River
  - Nalcor Energy & Hydro Québec now control management of the river in its entirety and can thus control downstream impacts
  - Warnings signs of the potential for extreme flooding were present in the lead up to the event but were not recognized by Nalcor in time to alter flows at Muskrat Falls or Churchill Falls

Recommendations

- Immediate increase in real-time environmental monitoring along the Churchill River and its tributaries:
  - Snow water equivalent and snow depth monitoring
  - Climate and hydrological modelling
  - Implementation of detailed ice thickness surveys on a regular basis throughout key locations downstream of Muskrat Falls
  - Collection of additional traditional ecological knowledge
  - Collected data should be usable for flood risk modelling
- Implementation of an independent flood management program on the Churchill River
  - Independent committee should be formed to oversee scientific data collection & analysis supporting program
  - Must use precautionary principle to inform decision-making
    - i.e. Proponent must prove no adverse effect on downstream flood risk

Data sources

Environment Canada real-time and historical hydrometric data:
https://wateroffice.ec.gc.ca/mainmenu/real_time_data_index_e.html

Climate data:
ERA-Interim Reanalysis (TMAX / PRECIP - Presented)
European Centre for Medium and Long Range Weather Forecasting

Environment Canada (Churchill Falls A / TMAX / PRECIP – Evaluation only)
Environment Canada (Goose A / TMAX / PRECIP – Evaluation only)
Global Precipitation Climatology Centre (PRECIP – Evaluation only)

The Preliminary Assessment of Mud Lake Flooding Event
Directed by Dr. K-E Lindenschmidt

Photos used:
Elizabeth Saunders, George Way, Trent Davis

PHOTOS PROVIDED BY LOCAL RESIDENTS

PHOTO 1

Source: Melissa Best

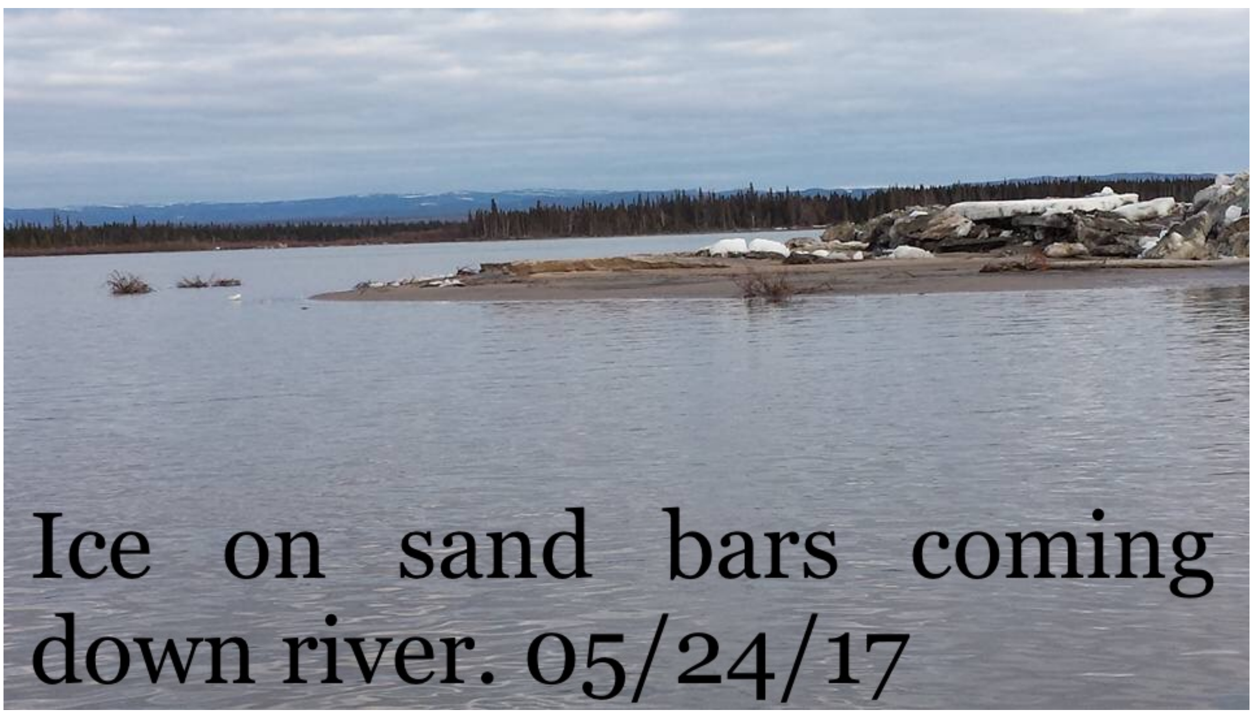
PHOTO 2

Source: Melissa Best

PHOTO 3

Source: Melissa Best

PHOTO 4



Source: Melissa Best

PHOTO 5

Source: Melissa Best

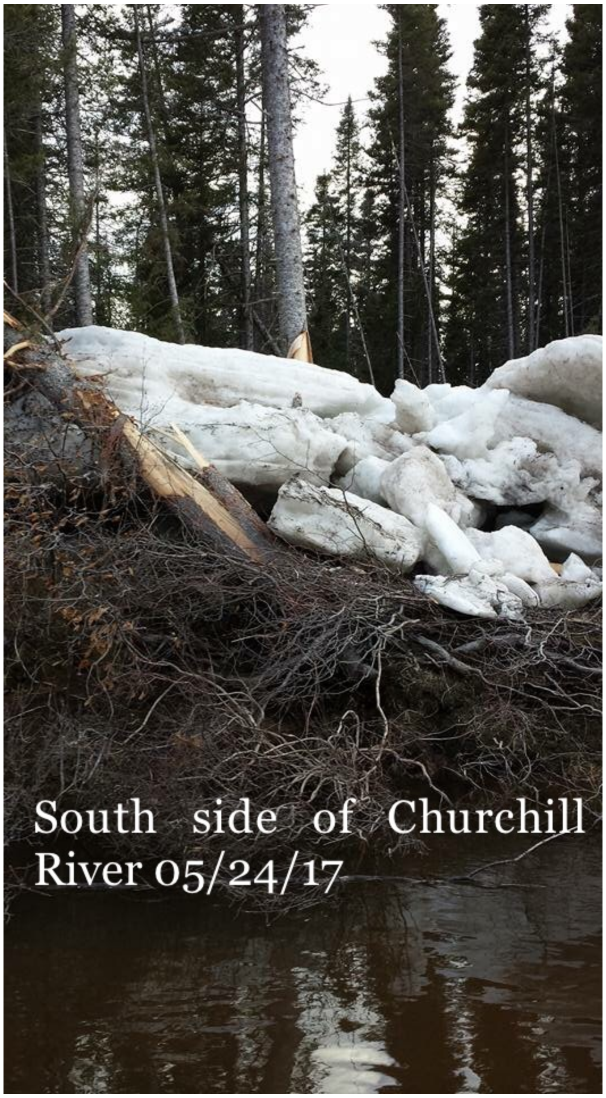
PHOTO 6

Source: Melissa Best

PHOTO 7

Source: Melissa Best

PHOTO 8



Source: Melissa Best

PHOTO 9

Source: Melissa Best

PHOTO 10

Source: Melissa Best

PHOTO 11

Source: Melissa Best

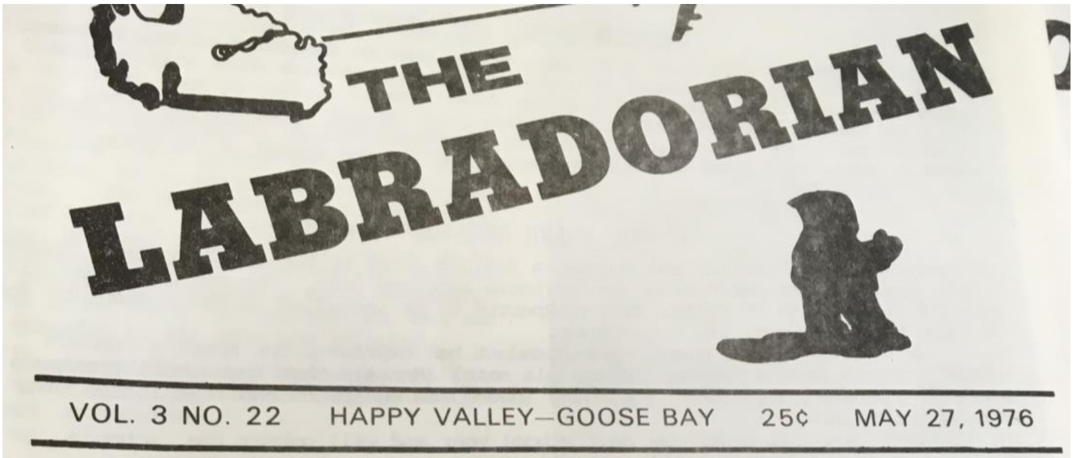
APPENDIX D

NEWSPAPER CLIPPINGS FROM 'THE LABRADORIAN'

PROVIDED BY THE GOVERNMENT OF NEWFOUNDLAND AND LABRADOR

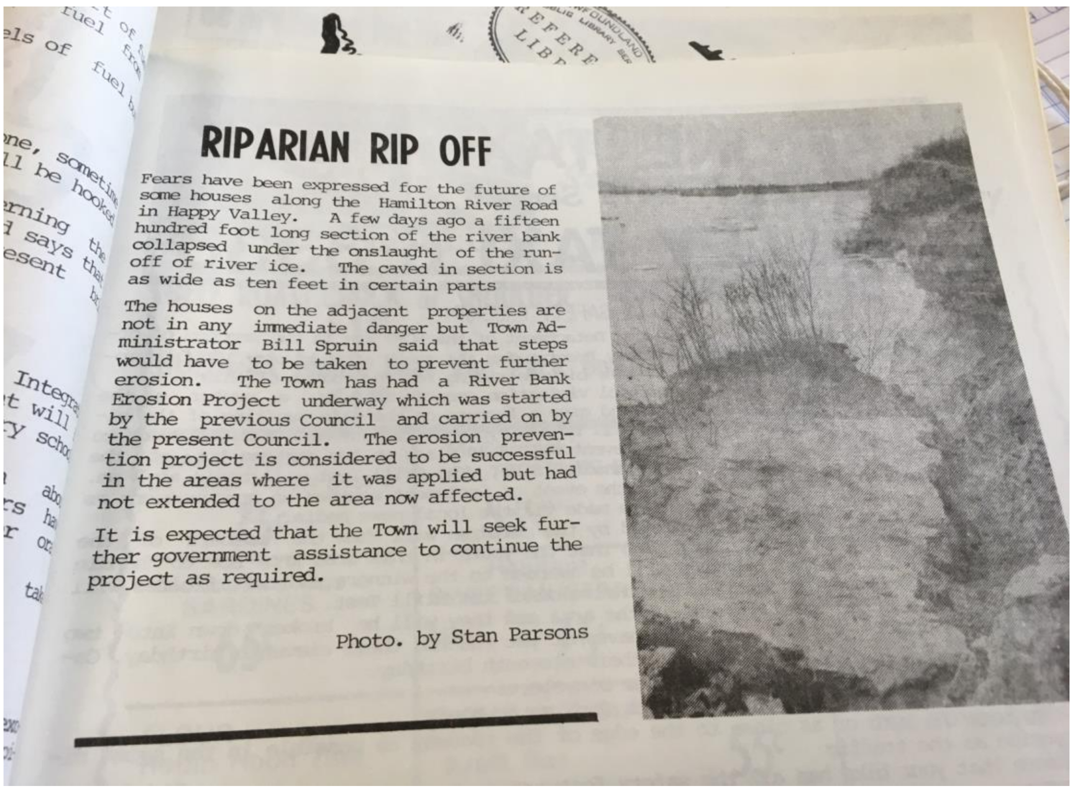
HISTORIC REVIEW OF ICE JAMS ON THE LOWER CHURCHILL RIVER AND THE GOOSE RIVER

1. THE LABRADORIAN - MAY 27TH, 1976



THE LABRADORIAN

VOL. 3 NO. 22 HAPPY VALLEY—GOOSE BAY 25¢ MAY 27, 1976



RIPARIAN RIP OFF

Fears have been expressed for the future of some houses along the Hamilton River Road in Happy Valley. A few days ago a fifteen hundred foot long section of the river bank collapsed under the onslaught of the run-off of river ice. The caved in section is as wide as ten feet in certain parts

The houses on the adjacent properties are not in any immediate danger but Town Administrator Bill Spruin said that steps would have to be taken to prevent further erosion. The Town has had a River Bank Erosion Project underway which was started by the previous Council and carried on by the present Council. The erosion prevention project is considered to be successful in the areas where it was applied but had not extended to the area now affected.

It is expected that the Town will seek further government assistance to continue the project as required.

Photo. by Stan Parsons

Riparian Rip Off

In late May of 1976, a fifteen hundred foot long section of the river bank along Hamilton River Road in Happy Valley collapsed because of the movement of the river ice.

Prior to the event, the town had implemented a river bank erosion prevention project which had been successful in the areas where it was applied however the program had not been extended to the area that collapsed. Fears were expressed for houses along Hamilton River Road however there was no damage to the properties adjacent to the collapsed section of the river bank.

2. THE LABRADORIAN – MAY 25TH, 1978

THE LABRADORIAN

Vol. 5 No. 21 Happy Valley-Goose Bay, Labrador 25¢ May 25, 1978

RIVER BANKS FLOODED

Spring run-off and ice congestion resulted in flooding conditions along the banks of the Churchill River in Happy Valley the past weekend and, up to Tuesday evening, the conditions still existed.

The Birch Island road from the area of the Town Garage to the Pump House on the Island was completely under water and has washed away. The road to the MOT Pump House at the bottom of the hill was also mostly under water and the exact damage to the road could not be determined.

There were several boats located on Birch Island and some were apparently, swept away by the flood. Other boat owners were able to get to the Island in boats and rescue their craft.

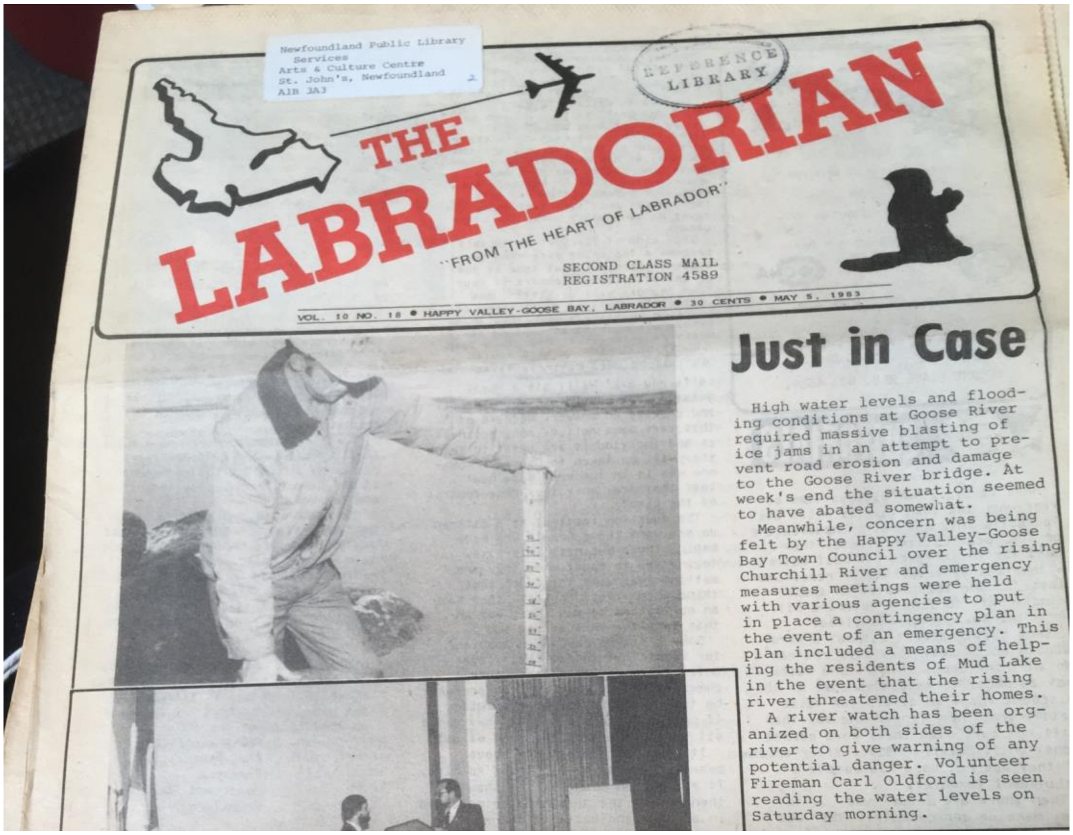
The Telecommunications Branch of MOT have a transmitter building down this road and the water reached a depth of 14 to 15 inches inside the building. Area maintenance Supervisor, Gerry Croucher said that most all of the equipment was kept "on the air" despite the flooding but technicians had to use a canoe to get to the site. He said that the marine transmitters had not yet been turned on for the navigation season but had they been in use, they would have been forced out of operation by the flooding. The water level in the building had receded by Tuesday but a canoe was still required to get to the building.

It was reported that a boat also had to be used for men to get to the MOT pumphouse, also down the same road. The exact extent of the flood damage, cannot be determined until water levels drop. It is expected that the erosion of the river bank will be even more extensive than anticipated because of the unusually high water levels.

River Banks Flooded

In late May of 1978, the river banks along the Churchill River experienced flooding conditions which lasted several days due ice build-up and spring run-off. An area along the Birch Island Road was completely underwater and had washed away, while the Communications Branch of the MOT experienced 14 to 15 inches of water inside of the transmitter building and was only accessible by canoe. Several boats were swept away by the flood. Water levels had not yet dropped and the extent of damage was undetermined on the date that the article was printed. The erosion of the river bank was expected to be extensive because of the unusually high water levels.

3. THE LABRADORIAN – MAY 5TH, 1983



THE LABRADORIAN

"FROM THE HEART OF LABRADOR"

SECOND CLASS MAIL
REGISTRATION 4589

VOL. 10 NO. 18 • HAPPY VALLEY-GOOSE BAY, LABRADOR • 30 CENTS • MAY 5, 1983

Just in Case

High water levels and flooding conditions at Goose River required massive blasting of ice jams in an attempt to prevent road erosion and damage to the Goose River bridge. At week's end the situation seemed to have abated somewhat.

Meanwhile, concern was being felt by the Happy Valley-Goose Bay Town Council over the rising Churchill River and emergency measures meetings were held with various agencies to put in place a contingency plan in the event of an emergency. This plan included a means of helping the residents of Mud Lake in the event that the rising river threatened their homes.

A river watch has been organized on both sides of the river to give warning of any potential danger. Volunteer Fireman Carl Oldford is seen reading the water levels on Saturday morning.

Just In Case

In early May of 1983, flooding conditions were observed at Goose River which required massive blasting of the ice jam to prevent damage to the Goose River Bridge and erosion of the road. Emergency measures meetings were held by the Happy Valley-Goose Bay town council and various agencies to put in place a contingency plan which included a means of helping residents of Mud Lake if flood conditions threatened their homes.

The Labradorian – May 5th, 1983 Continued.

RIVER WATCH CONTINUES

No drastic changes had occurred in flooding conditions on the Churchill River up to Tuesday evening. The River is at a fairly high level, higher, many people say, than they've ever seen it before the river ice breaks up.

Four homes at Mud Lake have been evacuated because of the high water, and the residents of these homes have been taken in elsewhere in the community. Interestingly enough, the first house to be evacuated experiences similar problems just about every year, but the other three, each about five or six years old, have been evacuated for the first time since they were built. This might confirm the belief that the river is a good bit higher than is normal for this time of year.

Meanwhile, the Disaster Operations Committee in Happy Valley-Goose Bay remains alert to the situation and are ready to assist the residents of Mud Lake if that becomes necessary. This concern by a neighbouring community has been met with appreciation by the residents of Mud Lake who feel reassured that in the event of a serious problem, help is only a call away.

Both communities are maintaining a close watch on water levels in the river and a reporting system has been set up in the case of emergency.

A two-way radio, supplied by the R.C.M.P., has been set up in Mud Lake as a back-up to the telephone system and this has given added assurance to the citizens of Mud Lake.

long road closure was the lack of a mail delivery (which even delayed a municipal election) and the shortage of fuel in the community.

Despite damages to pavement and road shoulders on the North West River road, traffic quickly resumed its normal pattern and fresh fuel supplies were trucked in and the mail started to move again as soon as the road re-opened.

IS THIS FAIR?

An interesting bit of information was brought to our attention recently which we believe deserves some comment.

Everyone will recall the public hearings a while ago in connection with Electoral Boundaries at the Federal level. Everyone will also recall that there were two hearing locations in Labrador; Labrador City and Happy Valley-Goose Bay.

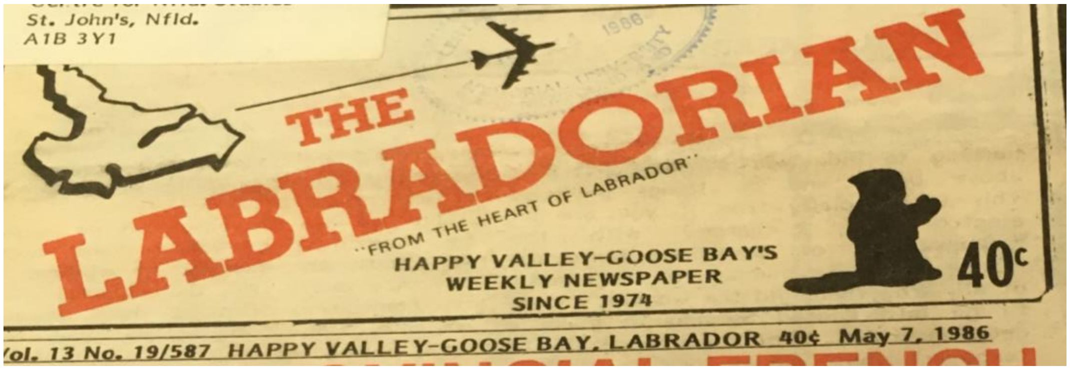
However, when similar hearings were held in the Northwest Territories (which already has TWO federal representatives), they were held in every community in the region. In other words, there were about thirty or so hearings or hearing locations in the Northwest Territories but the Commission dealing with this Province obviously felt that just two locations were fine for Labrador. Obviously, this would somewhat limit the quantity of information input from Labrador on questions vital to our future.

It would appear that this apparent disparity might bear some looking into, and perhaps some explanations would be in order.

River Watch Continues

Flooding conditions were believed to be higher than ever seen before the river ice breaks up. In Mud Lake, four houses were evacuated due to the increased water levels. The first house evacuated experiences similar problems just about every year. The other three houses had been evacuated for the first time since they were built about 5 or 6 years prior. A Disaster Operations Committee in Happy Valley-Goose Bay maintained a close watch on the water levels in the event that Mud Lake required assistance.

4. THE LABRADORIAN – MAY 7TH, 1986



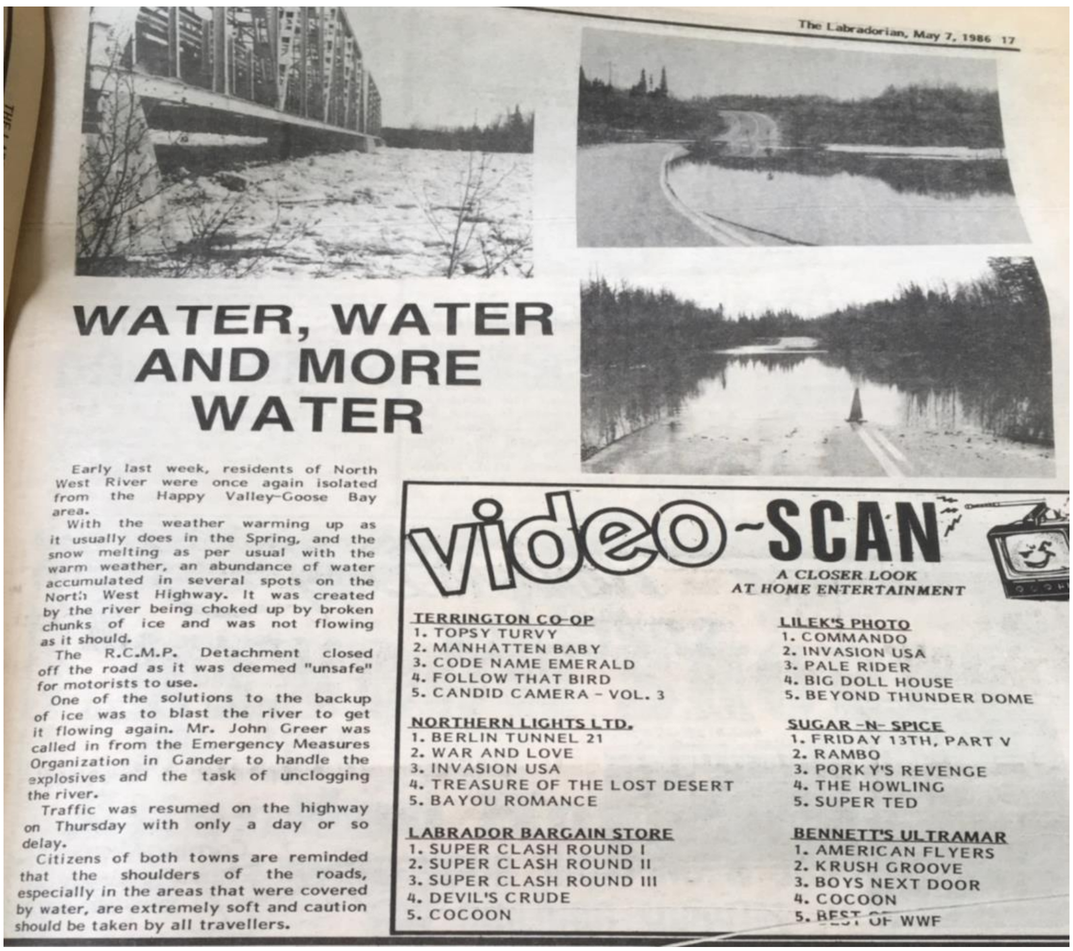
St. John's, Nfld.
A1B 3Y1

THE LABRADORIAN

"FROM THE HEART OF LABRADOR"
HAPPY VALLEY-GOOSE BAY'S
WEEKLY NEWSPAPER
SINCE 1974

40¢

Vol. 13 No. 19/587 HAPPY VALLEY-GOOSE BAY, LABRADOR 40¢ May 7, 1986



The Labradorian, May 7, 1986 17

WATER, WATER AND MORE WATER

Early last week, residents of North West River were once again isolated from the Happy Valley-Goose Bay area.

With the weather warming up as it usually does in the Spring, and the snow melting as per usual with the warm weather, an abundance of water accumulated in several spots on the North West Highway. It was created by the river being choked up by broken chunks of ice and was not flowing as it should.

The R.C.M.P. Detachment closed off the road as it was deemed "unsafe" for motorists to use.

One of the solutions to the backup of ice was to blast the river to get it flowing again. Mr. John Greer was called in from the Emergency Measures Organization in Gander to handle the explosives and the task of unclogging the river.

Traffic was resumed on the highway on Thursday with only a day or so delay.

Citizens of both towns are reminded that the shoulders of the roads, especially in the areas that were covered by water, are extremely soft and caution should be taken by all travellers.

video-SCAN

A CLOSER LOOK AT HOME ENTERTAINMENT

TERRINGTON CO-OP
1. TOPSY TURVY
2. MANHATTEN BABY
3. CODE NAME EMERALD
4. FOLLOW THAT BIRD
5. CANDID CAMERA - VOL. 3

NORTHERN LIGHTS LTD.
1. BERLIN TUNNEL 21
2. WAR AND LOVE
3. INVASION USA
4. TREASURE OF THE LOST DESERT
5. BAYOU ROMANCE

LABRADOR BARGAIN STORE
1. SUPER CLASH ROUND I
2. SUPER CLASH ROUND II
3. SUPER CLASH ROUND III
4. DEVIL'S CRUDE
5. COCOON

LILEK'S PHOTO
1. COMMANDO
2. INVASION USA
3. PALE RIDER
4. BIG DOLL HOUSE
5. BEYOND THUNDER DOME

SUGAR -N- SPICE
1. FRIDAY 13TH, PART V
2. RAMBO
3. PORKY'S REVENGE
4. THE HOWLING
5. SUPER TED

BENNETT'S ULTRAMAR
1. AMERICAN FLYERS
2. KRUSH GROOVE
3. BOYS NEXT DOOR
4. COCOON
5. BEST OF WWF

Water, Water and More Water

In early May of 1986, the North West Highway experienced areas of water accumulation due to the warmer temperatures and the river being choked with large pieces of ice. The RCMP deemed the North West Highway as 'unsafe' and closed the road, which isolated residents of North West River from Happy Valley-Goose Bay. Explosives were used to blast the backup of ice in the river. The Emergency Measures Organization was called in from Gander to handle the explosives and unclog the river.

5. THE LABRADORIAN – MAY 18TH, 1998

The Labradorian

VOL. 25 NO 20 MONDAY, MAY 18, 1998 $1.25 (HST included)

Churchill overflows banks

- Tense Moments For Convenience Store Owner -

Ramsey White, owner of T&R Marina at 1 Hamilton River Road, waits patiently to see if the shore of the Churchill River will rise, and cause any further damage to his business. Within 24 hours, the river went back down to normal levels. See more photos on Page 4.

(Keats photo)

By BRAD KEATS
The Labradorian

The T&R Marina convenience store/gas bar was still located at 1 Hamilton River Road at press time Thursday.

The threat that the Happy Valley-Goose Bay business might be submerged by a rising Churchill River subsided last Tuesday, as the mighty river's shoreline receded gradually from the store's parking lot.

While owner Ramsey White was still concerned Thursday, it looked as if the river was continuing to drop.

"It looks like it's keeping on going back, but it could start to rise again," he said.

There was an echo of White's sigh of relief from the owners of some nearby houses- several basements were flooded.

But it was a different story on Monday. Ice blockages at narrow locations down river inched the water up the front steps of the business. Only the garage, which sits flat on the shore and is nearer to the water, had a few feet of water in it. Store staff managed to move the equipment in the garage to higher ground. Meanwhile, in the adjacent lot, there was a rush to move some piles of logs that had already started to float away. This, along with the added attraction for kids to ride their bicycles in two feet of water, drew many spectators.

"I haven't seen the water as high as this in 15 years," said one man to a group of others.

"The store's going to be floating away this time tomorrow," said another.

Many in the crowd, including White, questioned what was being done to help the situation.

"I'd like to know if they're going to blast that'll get the river going again," White said.

"At the time, there was nothing that could be done - we just had to let nature take its course," explained Bob MacAulay, local representative of Emergency Measures Organization, noting the situation was still being monitored Wednesday. "It's a bit of a different year for the ice. Usually, the ice that comes down the river piles up on top of the bay ice. This year, the river ice seems to be going underneath the bay ice."

MacAulay said the reason might be that this year the river ice is softening up sooner than usual, and by the time it hits the bay ice it's turned to slob - forcing its way underneath.

Section A Page 4 The Labradorian, Happy Valley-Goose Bay, May 18, 1998

Close call

Continued from page 1

"Setting charges wouldn't have done much - the river is too wide."

The biggest concern during the situation was that there was a chance the Mud Lake channel could be blocked off, preventing residents from getting to Happy Valley-Goose Bay in case of an emergency. Also, there was one house that had a significant amount of water totally around it - it looked like a little island by itself.

"Human lives was our main priority," said MacAulay. "Not saying we're not concerned about property damage. But we felt the main concern should be on human lives. So we made sure the Mud Lake residents knew where to call in case they needed to be evacuated."

However, Mother Nature acted gracefully. The threat of flooding at T&R Marina turned out to be the climax.

White said wishes the crowds that turned up would have meant an increase in sales, but said he's relieved to have gotten away so lucky from such a close call.

T&R Marina owner Ramsey White, and a few bystanders, wait around to see if the Churchill River would rise any further. This was about as high as it got.

The road leading to Birch Island disappears last Monday.

KEATS PHOTOS

looks calm, but the river is clearly in control, as ice blocked narrower sections fur-

Logs piled up across from the T&R Marina are moved further up the shore - a handful floated away overnight. The process attracted many a spectator.

Churchill Overflows Banks

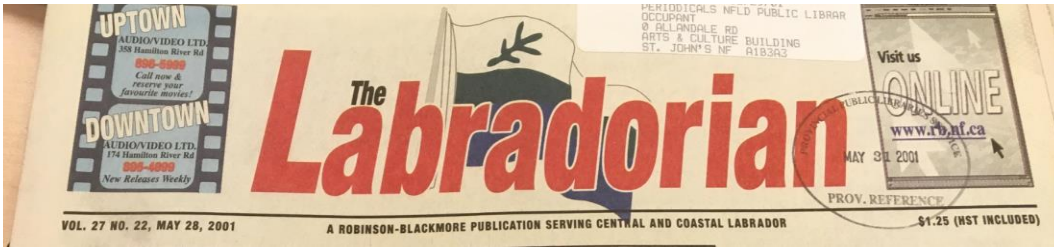
In Mid-May of 1998, a convenience store located on Hamilton Road expressed concern of becoming submerged by the rising water levels of the Churchill River on a Thursday. Several nearby houses had basements that were flooded. By that Monday, ice blockages down river had increased water level to the front steps of the business and flooded the business owner's garage in a few feet of water. Children in the area were riding their bicycles in two feet of water. One man stated "I haven't seen the water as high as this in 15 years". The Emergency Measures Organization local representative said there was nothing that could be done to clear the blockage, referring to the use of explosives.

6. CBC NEWS – APRIL 24TH, 2000

https://www.youtube.com/watch?v=cLlEDoeq1zw&t=22s

During late April of 2000, high winds caused a build-up of ice on the Churchill River at Mud Lake and toward the mouth of the Churchill River, which in turn caused flooding of the Mud Lake Road when the water levels increased by five feet. Mud Lake Road resident Eugene Mesher stated flooding like this was unusual for the time of year (i.e. April). Residents of Mud Lake expressed concern over the possibility of flooding in the basements of their homes. There was a fear that flooding in the spring would completely wash away the already flooded section of Mud Lake Road. Once wind speeds subsided the water level receded several inches but was still several feet above normal at the time of the media coverage. The CBC reporter stated people were concerned because “historically, this area does flood in the spring time”.

7. THE LABRADORIAN – MAY 28TH, 2001



Jordan Hope of Mud Lake sits in his canoe in 44 inches of water that had flooded his basement May 13. Mr. Hope said this was the worst flood he's seen since 1985.
(Submitted photo)

Canoeing in the basement

By BONNIE McLEAN
The Labradorian

You know your basement is flooded when you can go for a canoe ride. That was the scene in Jordan Hope's house in Mud Lake recently.

"The water rose to 44 inches in the basement and about six inches from the main power switch," said Mr. Hope. "That was the highest it rose since 1985."

Mr. Hope lives about 100 feet away from the channel that runs from the Churchill River and empties into Mud Lake. The water came right in over the bank.

Mr. Hope's basement started to flood on the afternoon of May 13, and by that evening, the water had risen dramatically.

"We had a pump on it to try to get the water out, but we couldn't gain — it was just coming in through the door," said Mr. Hope.

REGULAR OCCURRENCE

Mr. Hope said that his house, along with two others next to his, regularly flood every year, with the exception of last year.

"The ice jams out to the mouth of the river and as soon as the ice moves, the water drops back down," said Mr. Hope.

Mr. Hope said there wasn't much damage done to his house, but he did lose some caribou meat before he was able to move his deep freeze into his shed.

The water stayed high until May 22, when it gradually started to drop back down.

"The water still has to go down about another foot-and-a-half before everything is back to normal," said Mr. Hope. "but it's good compared to what it was."

Mr. Hope said there will also be a lot of cleaning up to do.

"There's a big mess around the door," said Mr. Hope. "If you have wood in your basement, everything is floating around. Cleaning up the basement after the water goes back is a couple of days work.

Canoeing in the Basement

On May 13th, 2001 Mud Lake resident, Jordan Hope, had flooding in his basement that rose to a depth of 44 inches of water. Mr. Hope stated "That was the highest it rose since 1985". Mr. Hope's house and two other houses next to his regularly flood. The ice jams at the mouth of the Churchill River and once the ice moves, the water level drops off. The water level stayed high until May 22nd when the levels eventually began to drop back down.

8. **CBC NEWS – MAY 17TH, 2012**

http://www.cbc.ca/labradormorning/episodes/2012/05/17/flooded-homes-in-mud-lake/

In Mid-May of 2012 Mud Lake residents experienced flooding of their homes as the water levels on the Churchill River increased over the river banks when there was an ice blockage along the river that would not let go.

9. **THE LABRADORIAN – MAY 28TH, 2012**

709-896-5317

Noon-1:30 pm

RECEIVED JUN 0 4 2012

Labrador's top cop
See Page A3

The Labradorian

Mud Lake flooding
:More pictures on A5

Vol. 38 No. 23, May 28, 2012

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Mudlake flooding

For the first time in recent memory, Mud Lake has spilled its banks with record flooding into the community. Photos courtesy of Claudine Broomfield of Mudlake

Mudlake Flooding
For the first time in recent memory, Mud Lake has spilled its banks with record flooding into the community.

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