



The 2019 Freeze-up Ice Jam on the Severn River and Flooding of Bearskin Lake First Nation

Lucas Wazney^{1a}, Rick Carson^{1b}

¹KGS Group, 865 Waverley St, Winnipeg, Manitoba R3T 5P4

[^alwazney@ksgroup.com](mailto:lwazney@ksgroup.com)

[^brcarson@ksgroup.com](mailto:rcarson@ksgroup.com)

In November 2019, water levels in the community of Bearskin Lake First Nation (BLFN) rose rapidly due to adverse freeze-up ice conditions in the adjacent Severn River, reaching water levels never before experienced in the 80+ year history of the community. Several roads were flooded, including the only road connecting the community to the airport. Approximately 365 people were evacuated via helicopter and were displaced for several weeks.

The cause of the flooding was a hanging ice dam at White Sand Rapids, located approximately 5 km downstream on the Severn River, just upstream of Severn Lake. High river discharge from late summer and fall precipitation events inhibited bridging of border ice for several kilometres upstream of the rapids, resulting in a continuous supply of frazil ice to the area. The incoming ice was swept under the lake ice cover, and subsequently deposited to create a hanging ice dam in Severn Lake. Surface shoving and collapse of the ice cover further exacerbated the ice accumulation and obstruction of flow through White Sand Rapids. The resulting backwater caused a rise in water levels in the BLFN community, causing several road crossings to experience flow reversal and overtopping.

This paper presents the case study of the 2019 freeze-up ice jam event on the Severn River. The hydraulic and meteorologic conditions contributing to the formation of a large hanging ice dam at the inlet of Severn Lake are reviewed in the context of historical records to explore the probability of a repeat event in the future. The paper also presents ongoing efforts to further understand the river ice processes in the Severn River and potential mitigation measures to reduce the ice jam flood risk in the community of BLFN.

1 Background

1.1 Site Overview

Bearskin Lake First Nation (BLFN) is located in northwestern Ontario, approximately 425 km north of the community of Sioux Lookout. It has an on-reserve population of approximately 484 residents and includes a Band Administration Office, K-8 school, Nursing Station/Clinic, MTO Airport, Distance Education Centre, Community Radio Station, Early Childhood Education Centre, a Northern Store, 180 single family homes, and a Post Office. BLFN does not have year-round road access; the community is accessible via winter road for usually four to six weeks between January and March. Outside of this period, the community is only accessible by air.

The community is situated on the shore of Michikan Lake, which is located on the north side of the Severn River. The Severn River is approximately 982 km long and runs northeast in northern Ontario to Hudson Bay. In the vicinity of BLFN, the Severn River varies in width from approximately 200-800 m with flow splits around islands in multiple locations. Several rapids are situated along the Severn River; notably, Owl Rapids is located approximately 3 km upstream of the community, and White Sand Rapids is located approximately 4.5 km downstream of the community. The total watershed area upstream of White Sand Rapids is approximately 38,800 km². A map is shown in Figure 1.

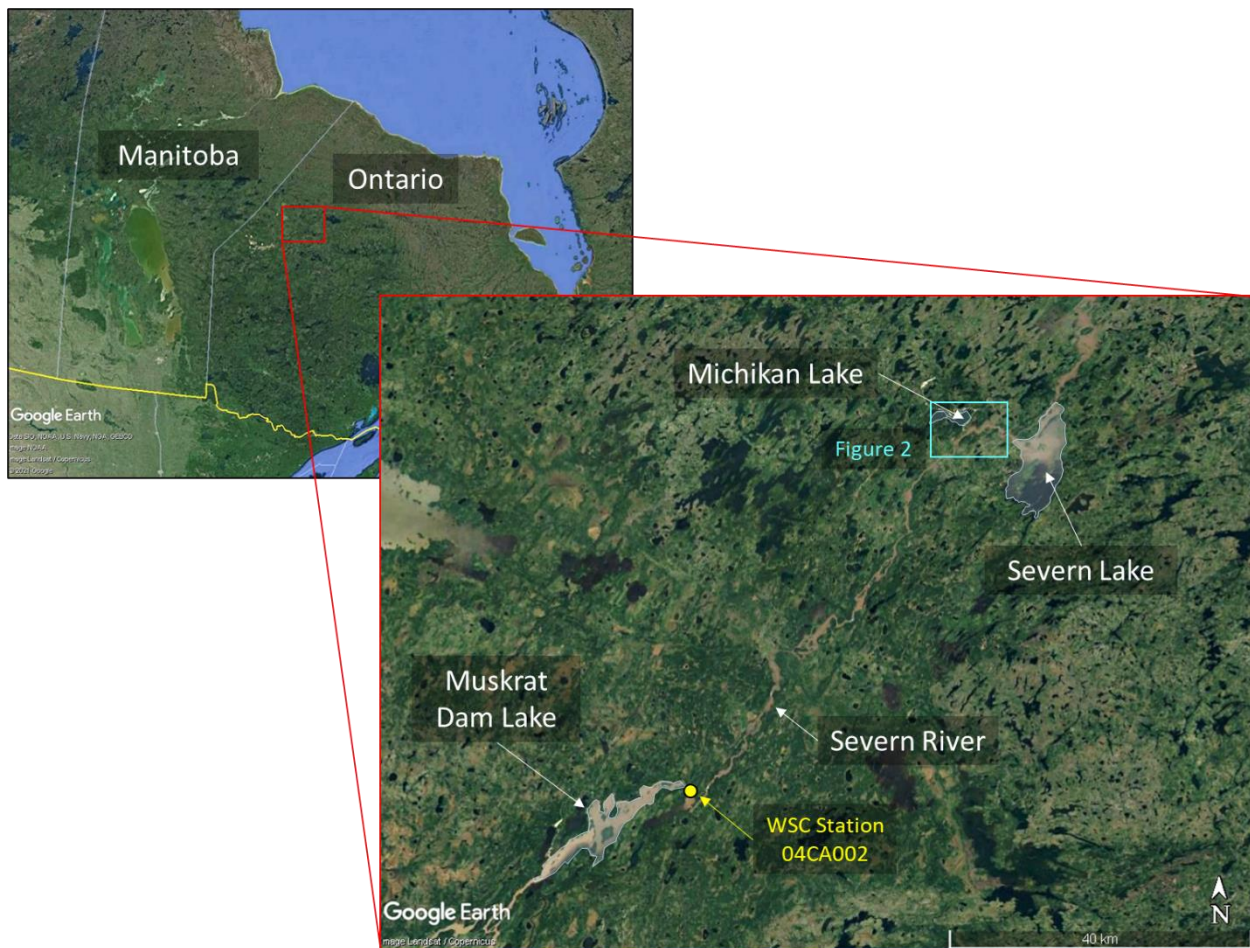


Figure 1. Map of Study Area

A smaller watershed to the north of the Severn River drains to Michikan Lake, which flows into the Severn River through a 1.5 km long channel approximately 50-80 m in width (see Figure 2). The smaller watershed includes Two River Lake and Knife Lake, located west of Michikan Lake, and Moose Lake and Fish Lake, located north of Michikan Lake. The Michikan Lake sub-watershed has a drainage area of approximately 950 km².

There are three main road crossings in the community that convey water through the Michikan Lake system on route to the Severn River. Moose River Crossing and Riverside Creek Crossing comprise roadways with CSP culverts, while Mahan Bridge includes a single span bridge crossing with adjacent CSP culverts. The only road to the airport runs between Moose Lake and Michikan Lake. These sites are shown in Figure 2 and in the aerial photograph presented in Figure 3.

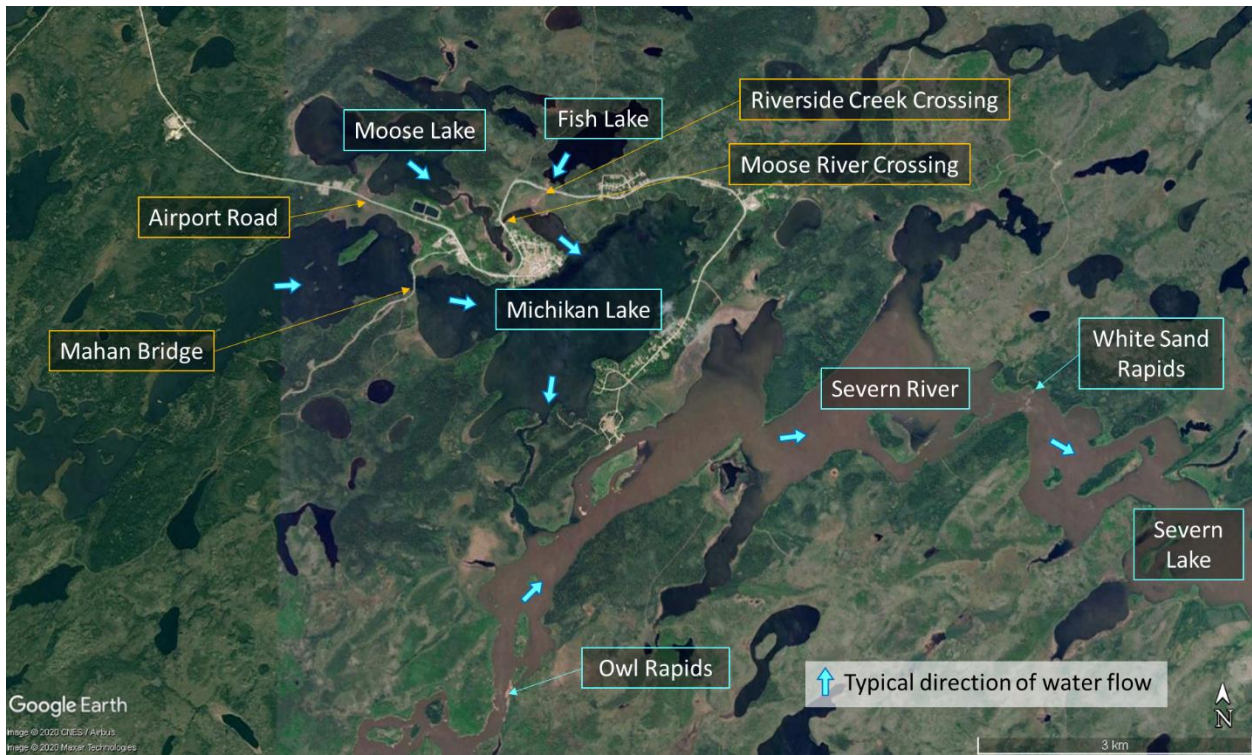


Figure 2. Satellite Image of BLFN Area

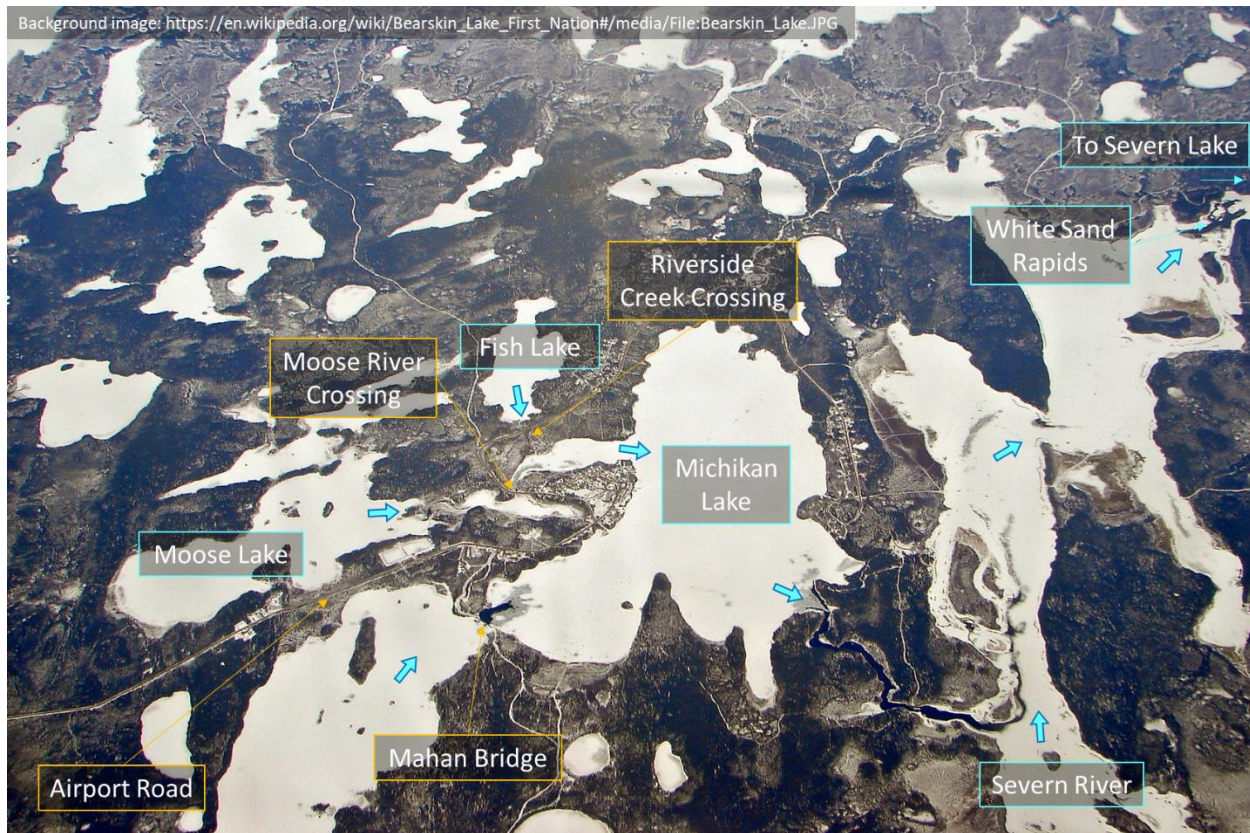


Figure 3. Aerial Photograph of BLFN Community

1.2 Typical Freeze-up Regime of the Severn River Upstream of BLFN

Air temperature has been recorded at Big Trout Climate Station (Environment and Climate Change Canada Climate ID 6010740), approximately 70 km east of BLFN, since 1939. Air temperatures typically drop below 0°C in late October to early November, initiating the generation of an ice cover in the Severn River a few weeks later.

Flow and water level on the Severn River at the outlet of Muskrat Dam Lake (approximately 80 km upstream of BLFN; see Figure 1) have been recorded at Water Survey of Canada gauge 04CA002 since 1965, with a gap in the data from 1995-2006. Prior to 2019, the average discharge in the months of November and December were 275 m³/s and 220 m³/s, respectively.

The Severn River includes several sets of rapids between Muskrat Dam Lake and Severn Lake. In an average year, frazil ice is generated as the river cools at the onset of freeze-up. The frazil ice forms large pans which are transported downstream with the flow. In low velocity areas between rapids, border ice grows and eventually constricts the flow width sufficiently to cause the congestion of frazil pans and the initiation of an ice front. The various ice covers advance upstream through surface packing and consolidation of incoming frazil ice pans. Open water leads can remain downstream of rapids through the entire winter.

The bridging of the ice cover downstream of Muskrat Dam Lake cuts off the frazil ice supply and limits the volume of frazil ice reaching Severn Lake.

2 Freeze-up Flood of 2019

2.1 Overview of Events

In November 2019, water levels in the Severn River near BLFN rose rapidly due to the development of adverse ice conditions in the river. The water level in Michikan Lake rose in response, threatening to overtop the airport road and other crossings within the community. This prompted the community of BLFN to declare a state of emergency on November 9, 2019.

The community was not evacuated immediately, as water levels receded in the subsequent days. On November 11 and 12, the Ontario Ministry of Natural Resources and Forestry (MNR) conducted surveillance flights over the river to assess the ice conditions. The MNR determined the cause of the rising water levels was an ice formation at White Sand Rapids, located just downstream of the community and upstream of Severn Lake. The emergency situation prompted the consideration of various methods to clear the ice obstruction and reduce staging, including the use of explosives or heavy equipment.

On the morning of November 13, evacuation of the community commenced. At this point the flood waters had cut off road access to the airport, which necessitated the use of a helicopter to transport residents to the airport for evacuation. In total, approximately 365 people were evacuated; the evacuees were hosted by Sioux Lookout and Thunder Bay.

In the following weeks, the water levels and flood threat subsided. The evacuees returned to BLFN in late November/early December.

KGS Group conducted a site visit to the community in August 2020 to perform surveys and test pitting to support permanent repair works and to gain first-hand insight from community members on conditions during the flood. Observations from that site visit are presented in the following section.

2.2 Flood Impacts to Community Infrastructure

The high water levels in Michikan Lake resulted in flooding to an extent never before experienced in the 80+ year record of the BLFN community. The airport road reportedly overtopped from the Michikan Lake side, causing water to flow over the road into Moose Lake, as annotated in Figure 4. Based on anecdotal accounts from the joint venture on site during the flood, and corroborated by surveyed elevations of tree scars observed after the flood, the peak water level was approximately El. 226 m.

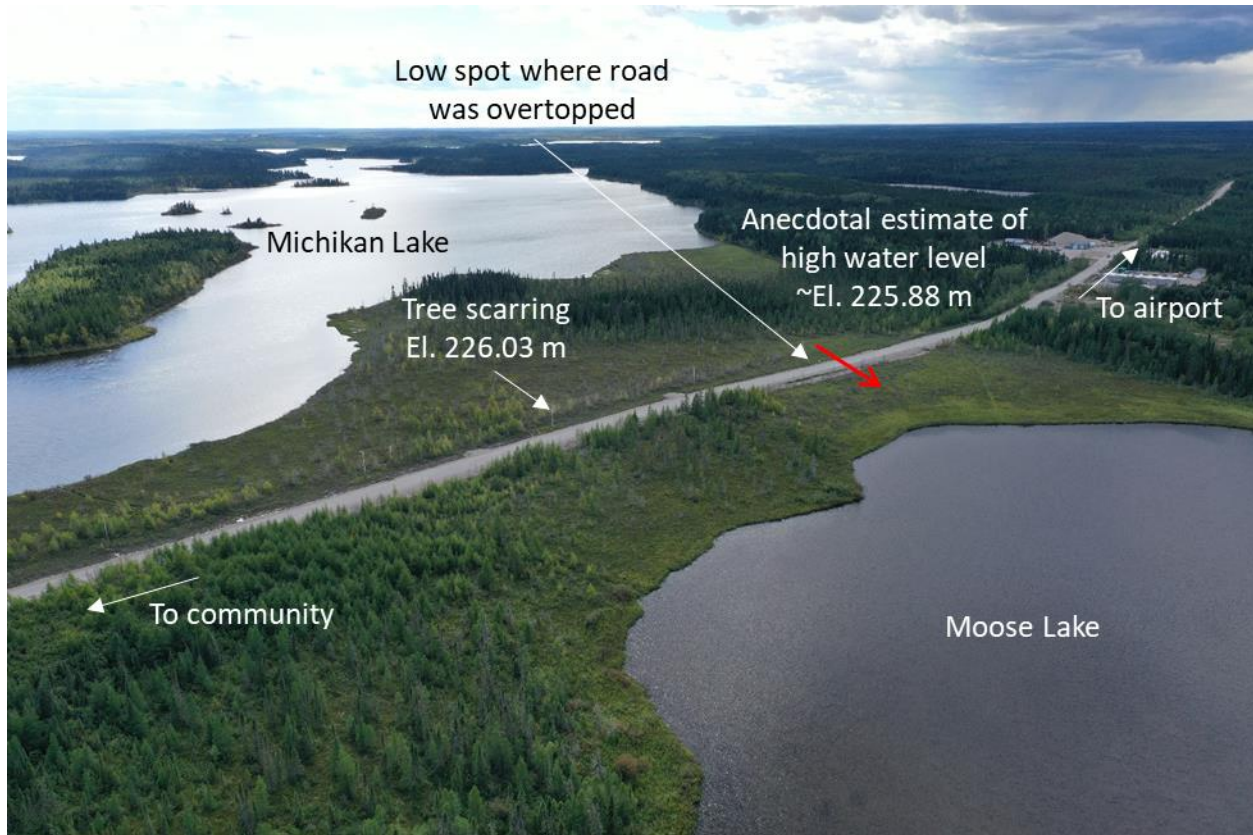


Figure 4. Overtopping of Airport Road

At Moose River Crossing, water was reportedly flowing in the reverse direction through the culverts (i.e. from Michikan Lake to Moose Lake) during the flood peak. The roadway was overtopped to the south of the culverts, as shown in a photograph taken during the flood in Figure 5 and annotated in Figure 6. The velocity of the flow over the road was sufficient to wash out a portion of the road, as indicated by a large pile of deposited material on the Moose Lake side. Small dikes were constructed to protect properties in the vicinity of the crossing.



Figure 5. Photograph of overtopped road at Moose River Crossing

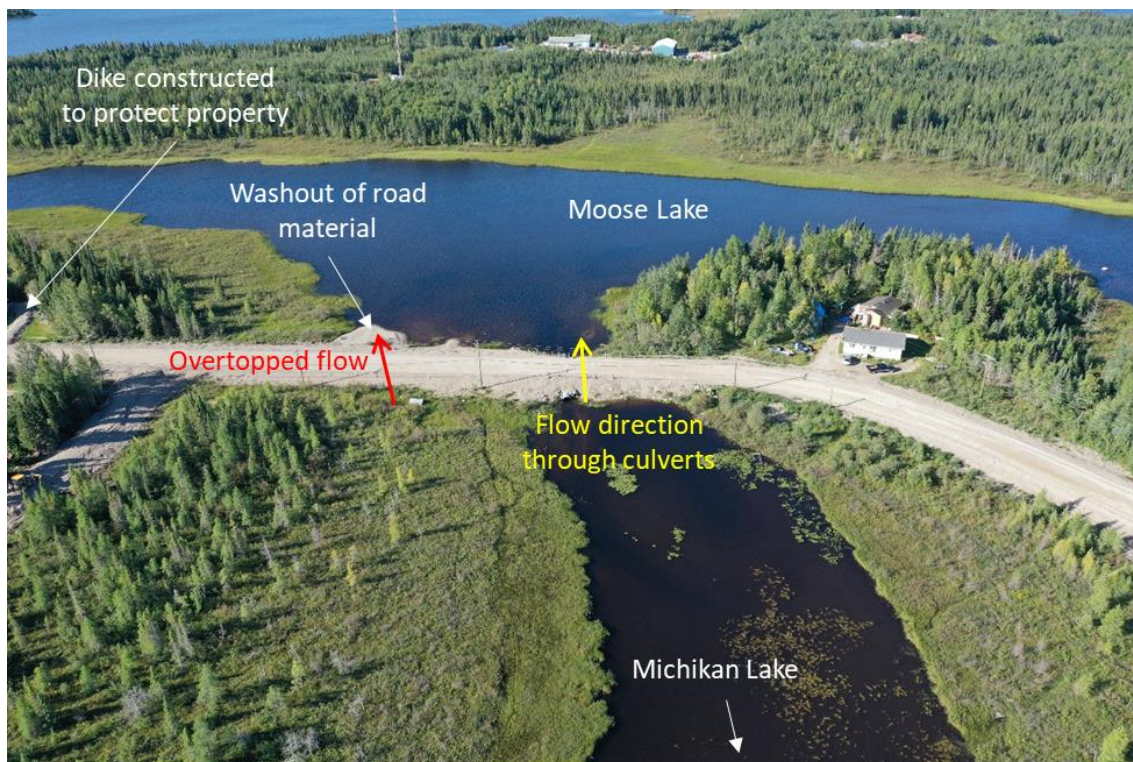


Figure 6. Flood impacts at Moose River Crossing

The culverts at Riverside Creek Crossing were also reported to have been flowing in the reverse direction during the flood peak, as annotated in Figure 7. However, the road did not overtop at this location. Ice scars were observed on trees on the Michikan Lake side of the crossing. The scars were surveyed as El. 225.94 m.

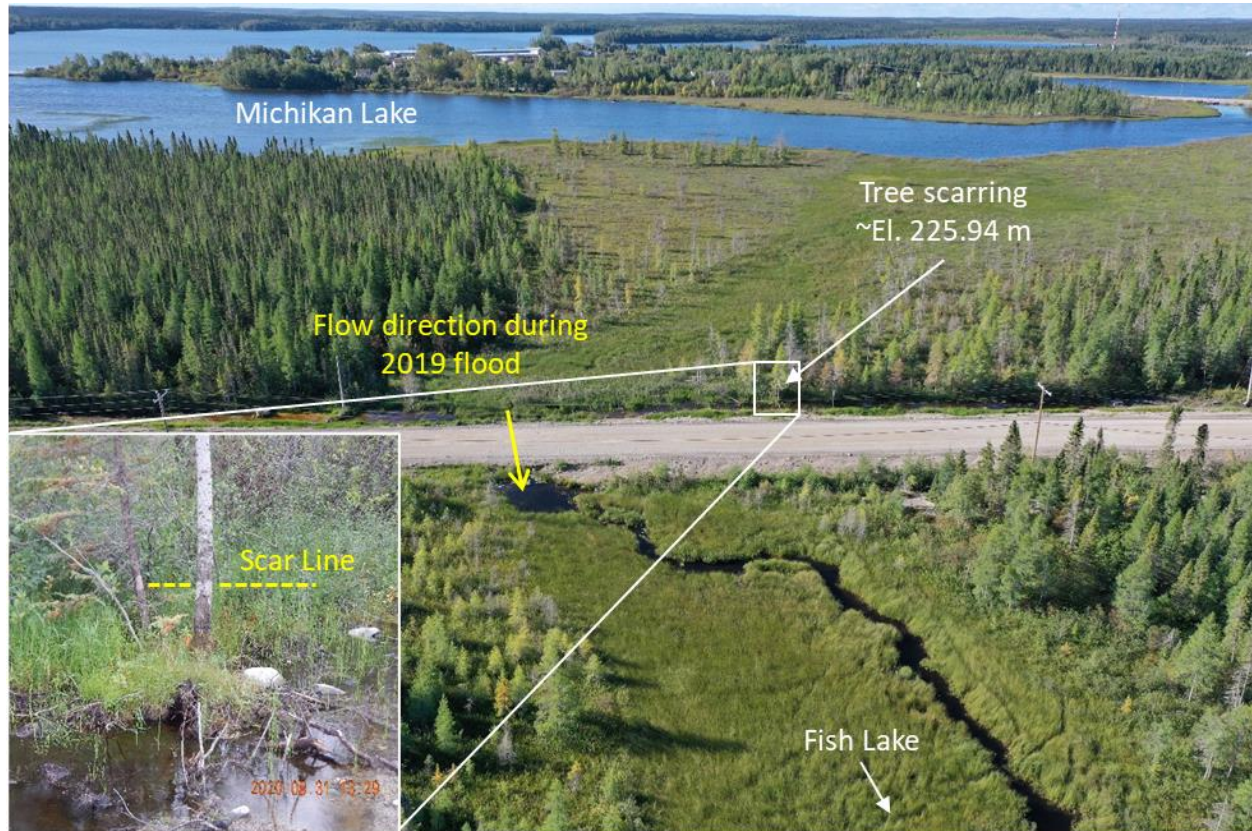


Figure 7. Flood impacts at Riverside Creek Crossing

Flow reversal was also reported at Mahan Bridge, both through the bridge opening and through two adjacent 1800 mm CMP culverts (see Figure 8 and Figure 9). Ice scars were observed on both sides of the crossing, with surveyed elevations ranging from El. 225.94 m to El. 226.05 m. Water overtopped the roadway to the north of the culverts, flowing from “downstream” to “upstream”. The post-flood site inspection identified signs of displaced riprap at the abutments of the bridge, indicating high water velocities through the bridge opening during the flood.



Figure 8. Flood impacts at Mahan Bridge – Photo A



Figure 9. Flood impacts at Mahan Bridge – Photo B

Emergency work conducted by the joint venture on-site during the flood included sandbagging to protect the community's water treatment facility and lift station, which are located on the north shore of Michikan Lake (see Figure 10). The peak water level reportedly came within approximately one foot of the bottom of the sandbag dike around the pump house. An earthen dike was also constructed along the lakeshore just downstream of the Moose River Crossing to protect homes from rising flood waters (see Figure 11).



Figure 10. Sandbag dikes constructed to protect water treatment facility and pump station



Figure 11. Emergency dike constructed to protect homes on Michikan Lake

All in all, the freeze-up flood that occurred in November 2019 had a significant lasting impression on the community of BLFN – both in terms of impacts to infrastructure as well as the emotional and physical toll of being evacuated and displaced for several weeks.

KGS Group is currently undertaking the design and construction of permanent repairs to the affected roads and culvert crossings to protect the community from future ice jam floods.

3 Post-Flood Analysis

3.1 Conditions Contributing to 2019 Flood

In light of observations and information gathered during the site visit, the contributing factors leading up to the 2019 flood were investigated to better understand the flood risk and determine which mitigation measures might be most effective in protecting the community against future floods of this nature.

The root cause of the flood was reported to be an ice jam at White Sand Rapids, which is approximately 4.5 km downstream of BLFN (note that in this context, “ice jam” refers to the general obstruction of river flow caused by ice formations; the exact mechanisms are differentiated later in this paper). At this location, the water level drops several feet in elevation over a short distance near the entrance to Severn Lake. A photograph of White Sand Rapids is shown in Figure 12.



Figure 12. White Sand Rapids – view is looking downstream to Severn Lake

The historical flows recorded at WSC Station 04CA002 at the outlet of Muskrat Dam Lake are shown in Figure 13, with notable recent hydrographs highlighted for discussion. Flow percentiles shown were calculated from the period of record prior to 2019. As shown, the median flow in early November is approximately 290 m³/s. As reported by MNRF in their technical report (MNRF,

2020), the rapid rise in Severn River flow in October 2019 was due to late summer and fall precipitation (rainfall) in the saturated drainage basin. The 2019 hydrograph peaked at 716 m³/s on October 29, and flow remained the highest on record for most of the month of November.

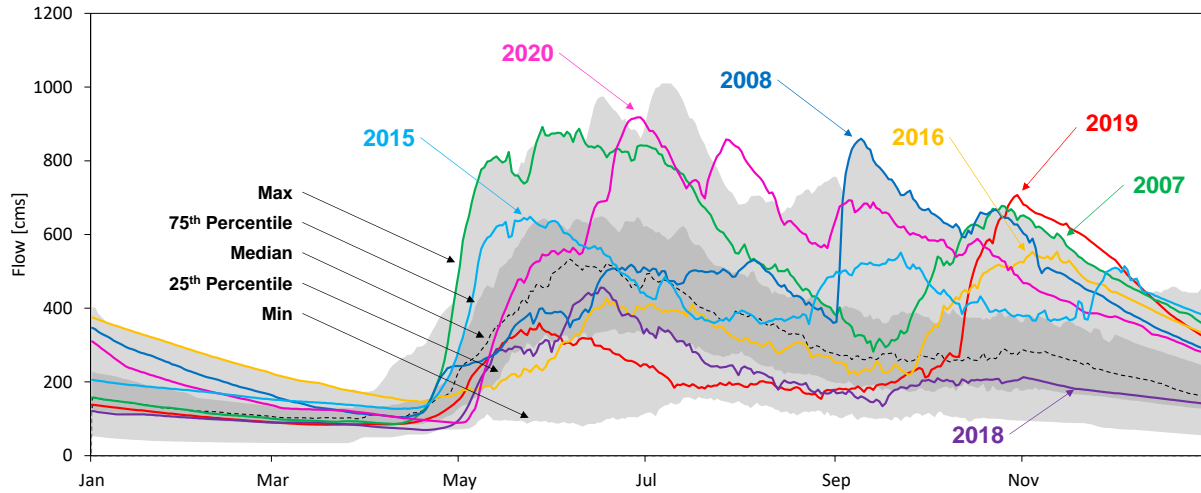


Figure 13. Severn River flow recorded at WSC Station 04CA002

Historical mean daily air temperatures recorded at Big Trout Lake Climate Station are shown in Figure 14. Notable years are highlighted with the same colour scheme as in Figure 13. As shown, the air temperature in 2019 dropped rapidly in November, reaching approximately -20°C on November 11, 2019.

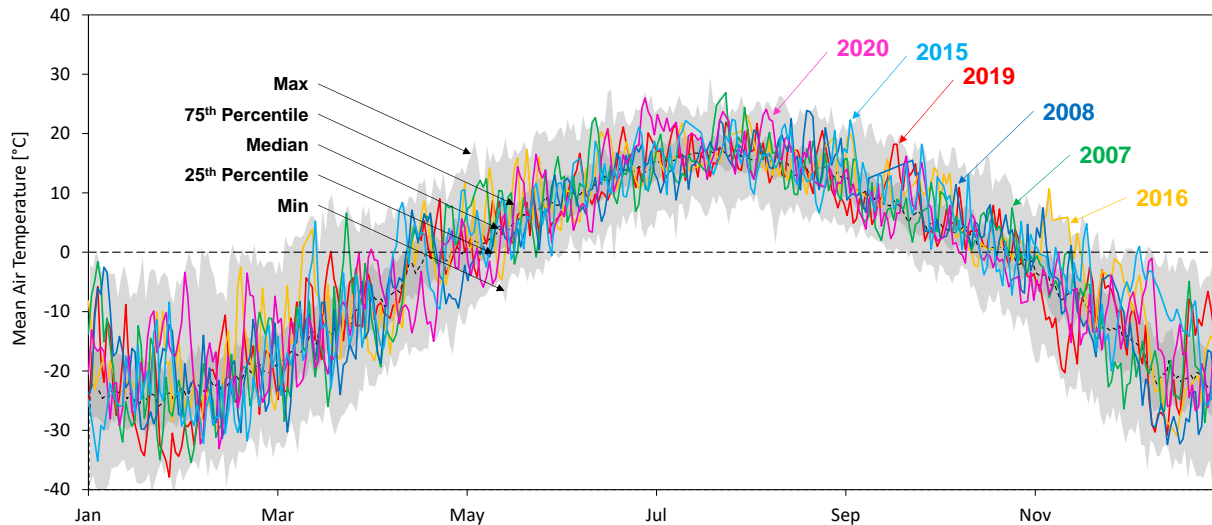


Figure 14. Mean daily air temperature recorded at Big Trout Lake climate station

The mode in which a river ice cover forms is influenced by complex processes driven by hydraulic and meteorological conditions. High flows are associated with increased water velocities, which inhibit the formation of border ice and reduce the likelihood of “bridging” locations (areas that

form an ice cover across the full river width to initiate the leading edge of an ice cover). Instead, the river remains free of an ice cover and continually generates frazil ice, which agglomerates to form larger ice pans that are freely transported downstream.

Examination of Figure 13 and Figure 14 reveals that the sudden drop in air temperature in 2019 was concurrent with unprecedented high flow in the Severn River. The low water velocities in Severn Lake permitted the formation of a thermal lake ice cover in early November. The adverse ice conditions which caused the backwater and flooding of Michikan Lake were likely due to two mechanisms, as described below.

Hanging Ice Dam Formation at Severn Lake

The continual supply of frazil ice pans in the Severn River to White Sand Rapids likely contributed to an ice formation known as a “hanging dam” within Severn Lake. A hanging dam forms when ice pans or slush are transported beneath an ice cover and deposited on the underside in low velocity areas (Beltaos, 2013). Hanging dams can grow to be several metres thick, causing significant backwater effects that can lead to flooding.

Sentinel satellite imagery in early November indicates that a long reach of the Severn River upstream of BLFN had not developed an ice cover. The high water velocity and turbulence at White Sand Rapids likely caused the approaching ice pans to become swept under the leading edge of the ice cover on Severn Lake. The ice pans would be transported with the flow and deposited on the underside of the ice cover some distance downstream of the rapids. As the hanging ice dam grew in size, it constricted flow into Severn Lake, causing the upstream water levels to rise.

This process of ice pan entrainment and deposition can continue until the ice supply is cut off from upstream (e.g. by the formation of an ice bridge), or until the water level upstream rises sufficiently to reduce water velocities and allow incoming ice pans to juxtapose against the edge of the lake ice cover.

Ice Cover Shoving and Mechanical Thickening

An ice cover that forms via the surface accumulation of ice pans will mechanically thicken in response to the forces acting on it. As the cover lengthens, the forces acting in the downstream direction (water shear and the self-weight of the cover) increase. If the forces exceed the internal strength of the ice cover, the cover will “shove” in response. This results in a thicker, rougher ice cover which imposes a greater restriction to flow and raises water levels upstream. An ice jam formed through this process is known as a “wide-channel” jam (Beltaos, 1995; 2013) and its thickness can be calculated via a balance of forces (Pariset et al., 1966; Uzuner and Kennedy, 1976). Due to the high flows in the Severn River, the ice cover likely shoved several times as it formed in the reach from White Sand Rapids to BLFN.

The sequence of Sentinel satellite images shown in Figure 15 illustrate these processes during the freeze-up period in 2019. The first panel (November 9) shows frazil ice pans freely moving down river towards the ice cover in Severn Lake that has progressed upstream and stalled at White Sand Rapids. In the second panel (November 11), the water levels have staged to allow the ice cover to advance upstream of the rapids. The light grey appearance of the ice cover indicates it is relatively thin and has not undergone significant mechanical thickening. In the final panel (November 21), the ice cover in the river appears much whiter, indicating that it has thickened. Open water leads through the ice accumulation at White Sand Rapids are also visible; these form as water cuts paths via preferential melting and erosion of the rough ice surface.

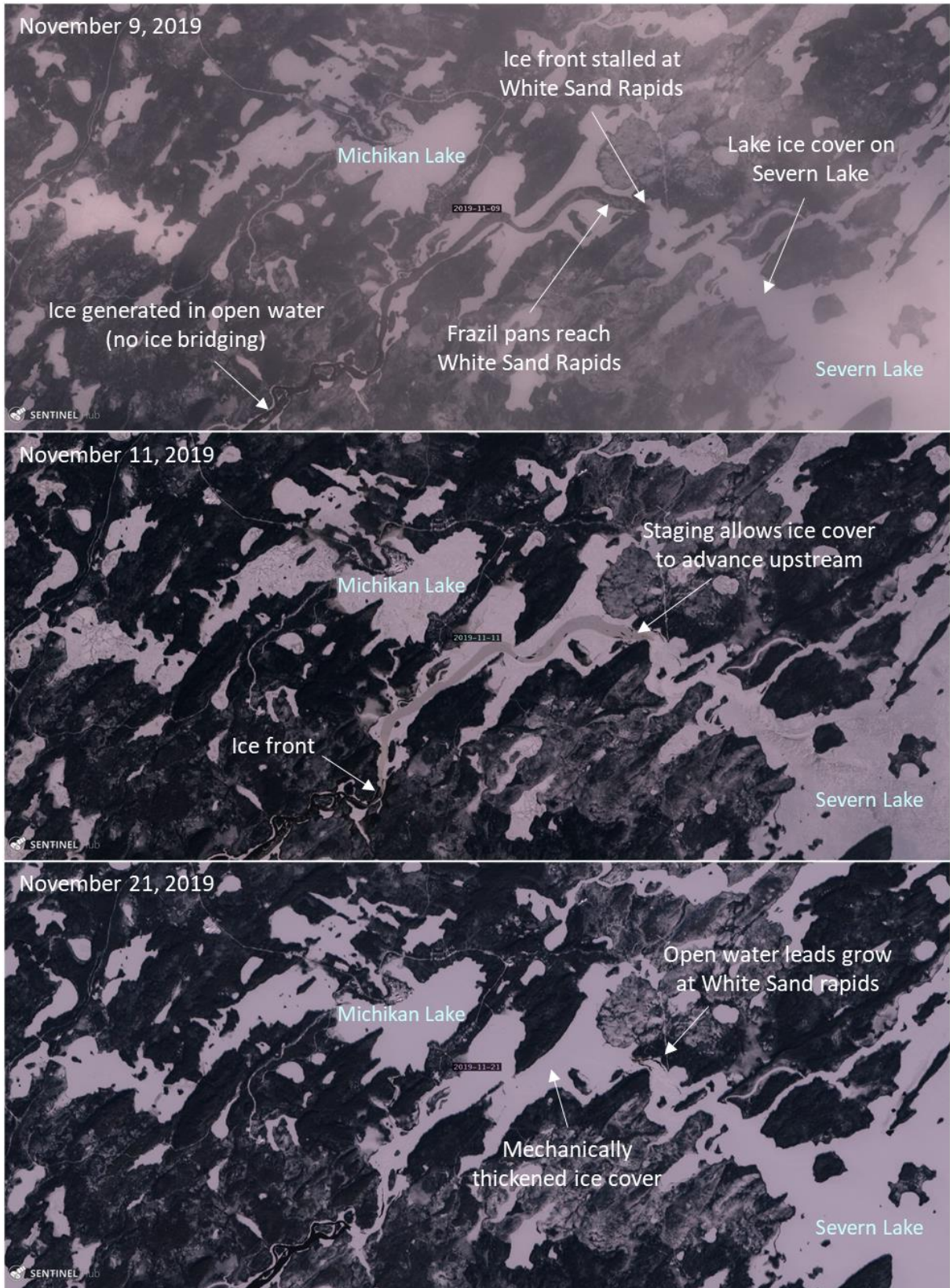


Figure 15. Sentinel satellite imagery showing freeze-up sequence in 2019

3.2 Freeze-up 2020

Flows in the Severn River were well above the 75th percentile in the spring and early summer of 2020, and were the highest on record in August 2020 (see Figure 13). With the unprecedented flooding of 2019 all but forgotten, the community of BLFN was well aware of the potential ice-induced flooding that could occur if flows remained high through the freeze-up season. Flows and air temperatures were closely monitored in October for advanced warning signs of impending flooding and the need to evacuate.

Just one year after the record-setting flood of 2019, BLFN residents again watched water levels in the Severn River rise at the onset of freeze-up in late October 2020. Sentinel satellite imagery again pointed to the cause: a long stretch of open water upstream of Severn Lake producing an unrelenting supply of frazil ice to White Sand Rapids, where the ice cover had again stalled (see Figure 16).



Figure 16. Sentinel satellite image showing onset of freeze-up 2020

Fortunately, the air temperature remained only marginally below freezing in early November as the river discharge continued to decline. This limited the growth of the ice accumulation at White Sand Rapids and ultimately thwarted repeat flooding of the BLFN community.

3.3 Discussion of Ice Jam Flooding Potential

In reviewing the hydrographs in Figure 13, it is evident that, while 2019 included the highest November flows on record, a few other recent years saw flows of a similar magnitude (e.g. 2007, 2008, 2015, 2016, and 2020). Yet, 2019 was the first time the community was consciously aware of ice jamming at White Sand Rapids (due obviously to the extreme water levels experienced in Michikan Lake and flow reversals at the road crossings).

In Figure 14, it is apparent that the onset of freezing air temperatures in the other years with relatively high flows was more gradual and generally occurred later in November compared to 2019. The cumulative degree-days of freezing (DDOF) computed from the daily mean air temperatures recorded at Big Trout Lake is presented in Figure 17.

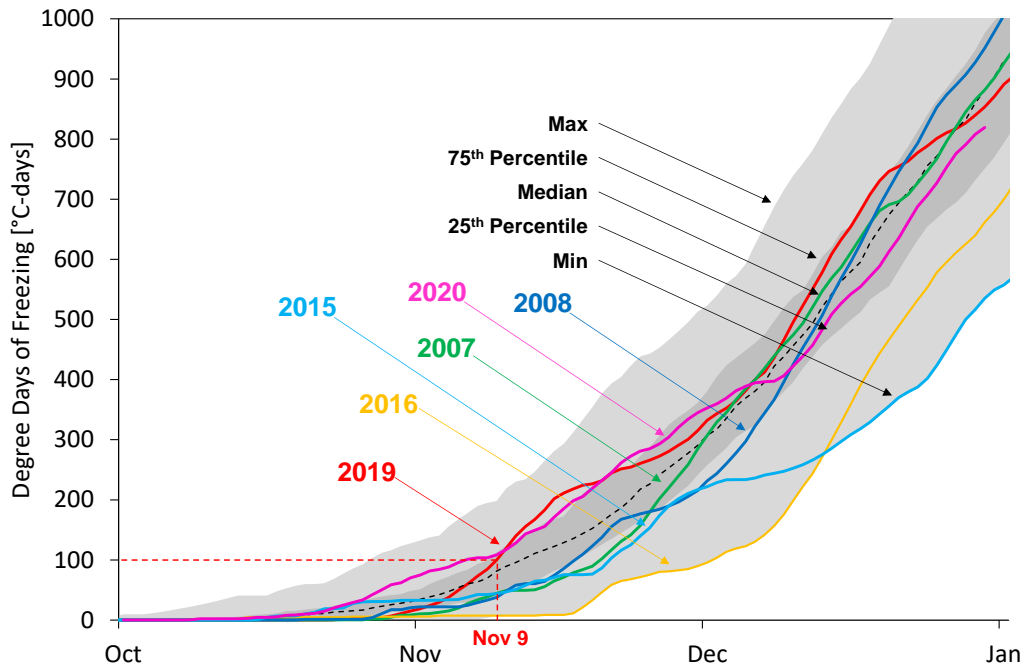


Figure 17. Degree-days of freezing recorded at Big Trout Lake climate station

In 2019, the state of emergency in BLFN was first declared on November 9. At this time approximately 100 °C-days had accumulated, causing enough cooling and ice production to create an ice jam that posed a flood threat. This benchmark of 100 °C-days was used as an indicator to allow a comparison of freeze-up flows for the purpose of highlighting those years where high river flows were concurrent with enough DDOF to potentially cause ice problems.

The maximum Severn River flows concurrent with DDOF > 100 °C-days is plotted in Figure 18 for each year in the period of record back to 1965. As shown, 2019 ranks the highest with a flow of 570 m³/s. However, five other recent years have flows of a similar magnitude: 2007 (536 m³/s), 2015 (514 m³/s), 2008 (470 m³/s), 2020 (447 m³/s), and 2016 (440 m³/s). It is likely that adverse ice conditions developed in these years as well, but not to the point of causing flood conditions at BLFN (i.e. “close-calls”).



Figure 18. Maximum Severn River flow concurrent with DDOF > 100 °C-days

Sentinel 1 satellite radar imagery for the freeze-up periods in 2016, 2018, and 2019 are compared in Figure 19. The bright red and white areas in the images indicate a rough (and presumably thick) ice cover, while dark areas indicate a smooth ice cover or open water.

The freeze-up in 2018 occurred under a relatively low flow condition (see hydrograph in Figure 13), resulting in a relatively smooth and uniform ice cover. In 2016, flows were higher and the formation of an ice jam at White Sand Rapids is evident in the satellite image. The extent of the ice jam is limited to the immediate vicinity of the rapids. There are no signs of a rough ice cover upstream of the rapids or in Severn Lake. In 2019, the extent of the rough ice cover is much greater. The brightly coloured areas extend further into Severn Lake, indicating a roughened ice cover likely due to a combination of shoving and deposition of ice beneath the lake ice cover which could lift the cover and create an uneven surface. Upstream of White Sand Rapids, there are signs of a mechanically thickened river ice cover extending upstream of the confluence with the Michikan Lake channel toward Owl Rapids.

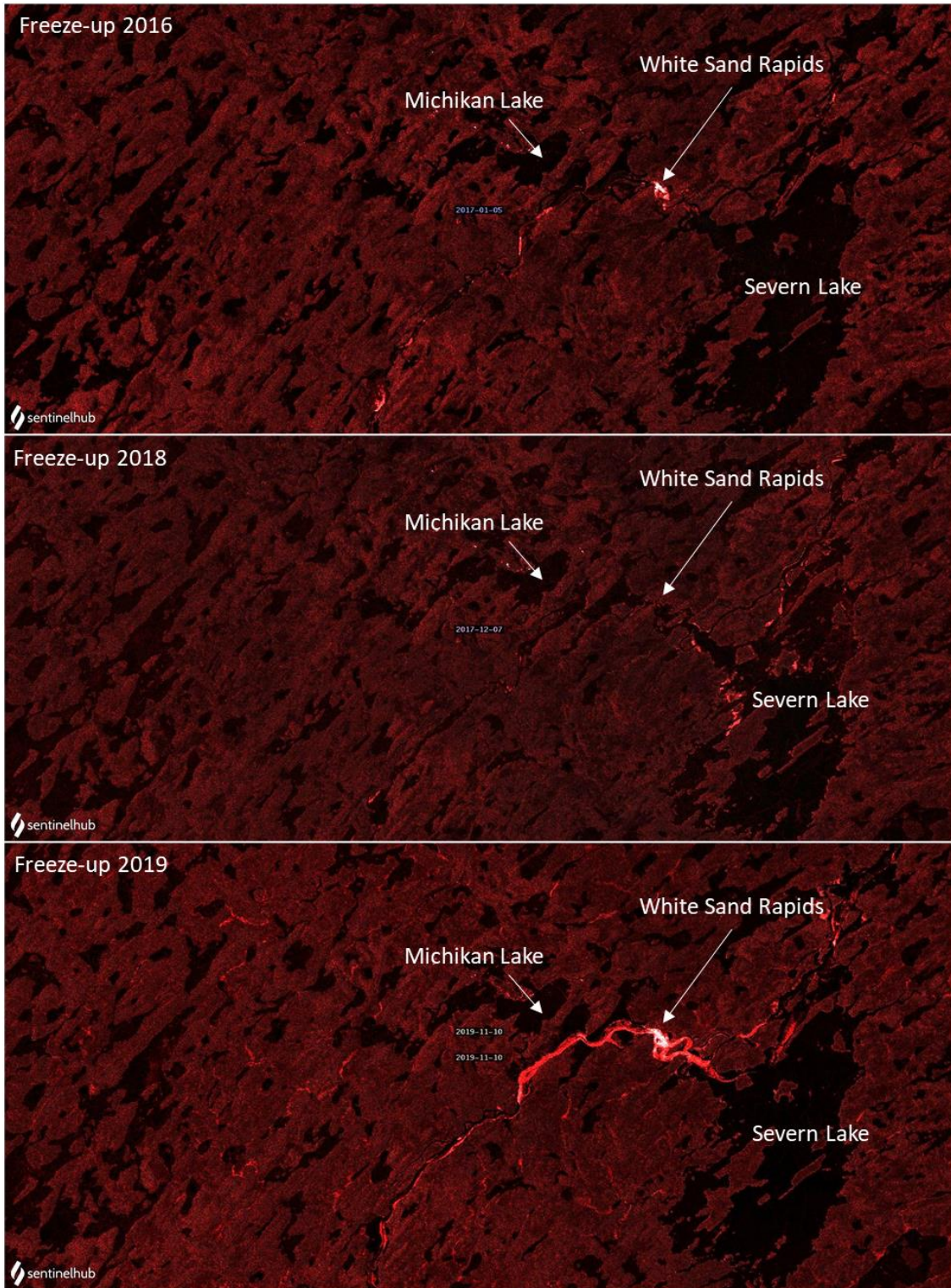


Figure 19. Sentinel radar imagery comparing ice conditions in 2016, 2018, and 2019

The available satellite imagery, historical flows, and air temperatures suggests that ice jamming at White Sand Rapids may be a fairly regular occurrence, despite having only led to flooding of BLFN once in the entire 80+ year history of the community as testified by community members. The size and impact of the annual river ice formations depend on complex interactions of hydraulic and meteorological conditions during the freeze-up period. The points plotted in Figure 18 suggest that the “tipping point” at which adverse ice conditions could progress to the point of creating a flood threat lies somewhere in the range of 450-550 m³/s.

A frequency analysis was conducted on the datapoints in Figure 18 to estimate the approximate annual exceedance probability of freeze-up flows that could result in ice jam flooding. A variety of statistical distributions were trialed, with the normal and gamma distributions providing the most reasonable fits to the recorded data. Results are shown in Figure 20.

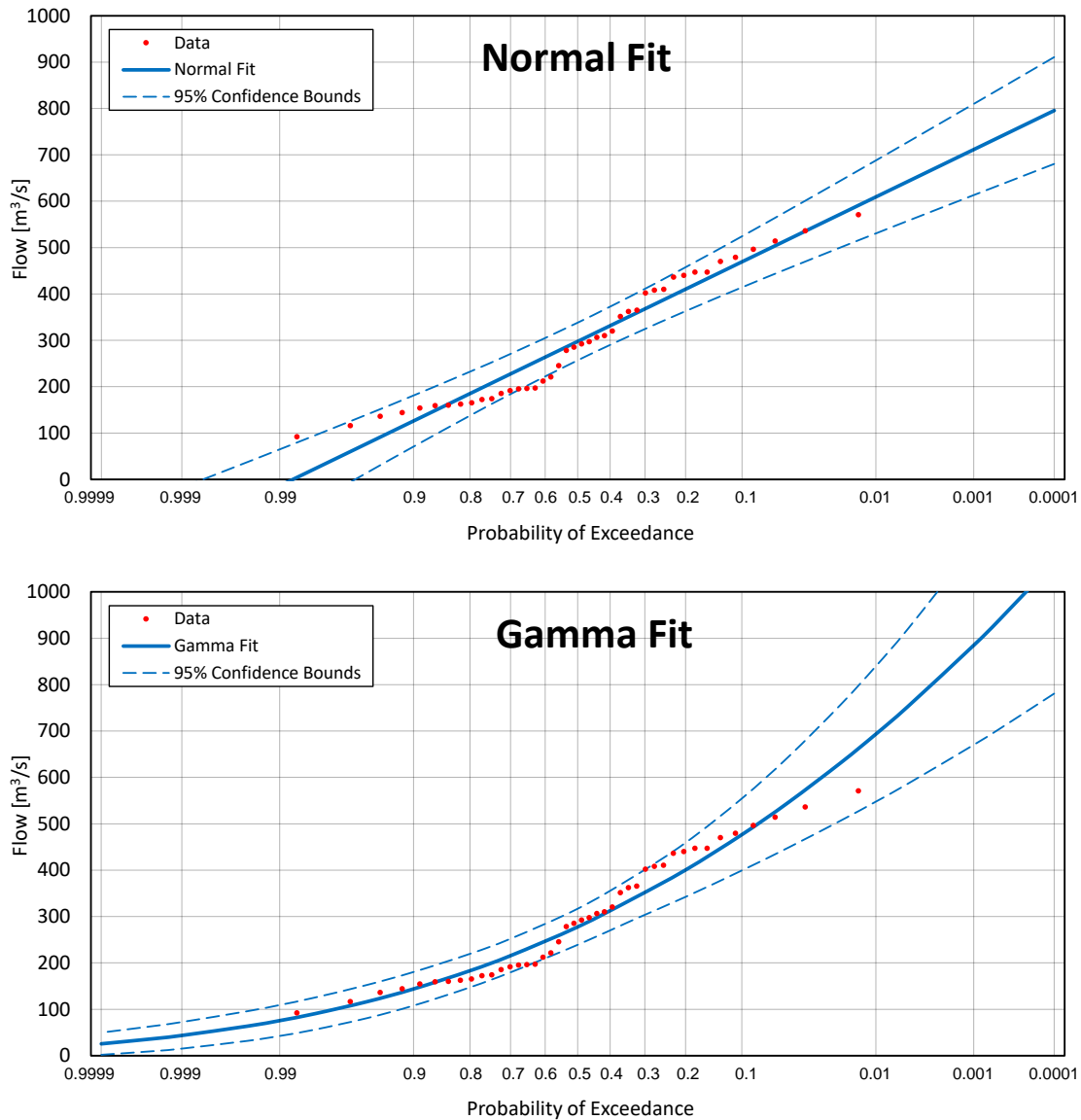


Figure 20. Frequency analyses of Severn River freeze-up flows

Based on these distributions, the freeze-up flow of 570 m³/s experienced in 2019 has an annual exceedance probability ranging from approximately 1:30 to 1:50.

It is acknowledged that these estimated return periods are approximate, and rely on several assumptions that simplify the complexities of freeze-up ice processes. Sophisticated river ice modeling and analysis would be useful in refining these estimates. However, the key message is that the conditions experienced in 2019 may not be as extreme an event as first thought, and that additional studies should be considered to evaluate ice jam flooding potential and mitigation measures to protect the community of BLFN from future events. The complexities associated with climate change may also influence the likelihood of ice jamming and flooding in the future.

4 Future Work

In addition to the design and construction oversight of permanent repairs to community infrastructure resulting from the 2019 flood, KGS Group is working with BLFN to further understand the Severn River ice processes to define the flood risk and potential mitigation options.

A bathymetric survey of the Severn River from Owl Rapids to Severn Lake is planned for summer 2021. The survey will provide necessary information such as river slope and cross-sectional geometry which will be subsequently used to assess river hydraulics at a range of flows. This will allow calculation of various criteria that play a role in hanging dam formation, such as the Froude number criterion for entrainment of ice pans at the leading edge.

A one-dimensional river ice model will then be developed using KGS Group's VARY-ICE software. This will enable simulation of river ice processes under a range of conditions to estimate the probability of a similar, or worse, ice jam flood occurring in the future. Due to the lack of measured data and variability inherent in the various ice processes, a Monte Carlo framework will be utilized to provide an envelope of potential outcomes simulated with a large number of model runs. The model will also be used to evaluate conceptual mitigation options such as the installation of an ice boom upstream of White Sand Rapids or the excavation of a bypass channel.

5 Summary

Key points from this case study are summarized below:

- The cause of the 2019 freeze-up flood that displaced the residents of BLFN was an ice jam that originated at White Sand Rapids near the entrance to Severn Lake.
- Staging of water levels in Michikan Lake occurred due to the growth of a large hanging ice dam and mechanical thickening of the Severn River ice cover.
- The driving factors behind the ice jam were a sudden drop in air temperatures in early November that coincided with high river flows from fall precipitation in the watershed.
- The ice jam flood was the first of its kind in the 80+ year history of BLFN, and prompted the evacuation of the community for several weeks. Several road crossings sustained damage and vital infrastructure such as the water treatment facility and pump station were threatened by the high flood waters.
- A review of historical flows and air temperatures, as well as recent satellite imagery, indicate that ice jamming at White Sand Rapids is a relatively regular occurrence. High

flows during freeze-up keep long stretches of the Severn River open, resulting in continual frazil ice production and supply to the hanging ice dam in Severn Lake.

- Statistical analyses suggest that the combined hydraulic and meteorological conditions that led to the ice jam in 2019 have an annual exceedance probability of approximately 1:30 to 1:50.
- KGS Group is undertaking additional studies to better understand the Severn River ice processes and future flooding potential of BLFN, including bathymetry collection and development of a 1D river ice model which will be run in a Monte Carlo framework to derive an envelope of potential flood stages.

6 References

Beltaos, S., 1995. River Ice Jams. Water Resources Publications, LLC. Highlands Ranch, Colorado, USA.

Beltaos, S., 2013. River Ice Formation. Committee on River Ice Processes and the Environment, Edmonton, Canada.

Ontario Ministry of Natural Resources and Forestry (MNR), 2020. Bearskin Lake First Nation Fall 2019 Flooding Technical Report.

Pariset, E., Hausser, R., and Gagnon, A., 1966. Formation of ice covers and ice jams in rivers. ASCE J. Hydraul. Div. 92, 1-24.

Uzun, M., Kennedy, J., 1976. Theoretical model of river ice jams. J. Hydraul. Div.