



Towards a Rights-Based Ice Monitoring Trigger

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The Mikisew Cree First Nation and the Athabasca Chipewyan First Nation operate Community-Based Monitoring (CBM) Programs and have collected ice, snow and weather observations for over 9 winter seasons. This work started in response to their Elders' concerns about ice-quantity and quality changes. Data has been collected to understand the impacts of climate change, oil sands water withdrawals and hydro-electric development and how cumulatively these impact their traditional rights.

The Nations have developed a culturally and scientifically relevant monitoring methodology which includes Environmental Effects Monitoring-type triggers. These triggers are being used to give context for any future observed change.

Maximum seasonal ice thickness and snow depth has varied at sites across the region and over time, with differences falling within expected ranges and no statistically significant temporal trends. Average monthly ice thickness however,

has decreased in January but increased in March, while average monthly snow depth has increased in February, perhaps a reflection of climate change.

The Nations have also developed a field-data-parameterized model, to predict ice-thickness growth from weather data. The Nations undertook a historical retrospective using the model, which has shown a decreasing trend and approximately 8 cm of lost maximum thickness over the last 100 years, reflective of Elders' Indigenous Knowledge.

In addition, the model calculates ice-travel duration (Arp et al. 2020), which is the predicted number of safe-travel days each season. This metric has implications for regional winter-travel safety. The Nations are exploring 'Ice-travel duration' as a rights-based management trigger. This index can be used to track cumulative impacts on Section 35 Aboriginal and Treaty rights. Harvest activities are predicated on safe travel to traditional harvest areas and the CBMs can track how changing conditions impede the ability to safely access traditional territory.

1. Introduction

The Peace Athabasca Delta (PAD), located in northeastern Alberta, Canada, is the largest freshwater delta in North America. The Delta was designated as a wetland of international importance under the RAMSAR Convention, and is also listed as a UNESCO World Heritage Site.

For the Mikisew Cree First Nation and Athabasca Chipewyan First Nation (here after referred to as MCFN and ACFN respectively) this is their traditional territory and they have witnessed vast changes to this homeland. There has been rapid development of the oil sands in the lower Athabasca Region, ongoing hydro-electric development along the Peace River, environmental stressors in the Peace and Athabasca watersheds such as agriculture, urban growth, the legacy of pulp and paper, mining, waste incineration, and climate change. Cumulatively, this has led to negative ecological changes in the PAD. ACFN and MCFN, downstream from oil sands operations and the Peace River hydroelectric development, are increasingly concerned about magnifying contamination and decreasing water levels, as well as changes to winter conditions, including ice quality and quantity.

The ACFN and MCFN established community-based monitoring programs (MCFN in 2008 and ACFN in 2010) to track changes in the environment and relate these to their lost potential to safely continue to access their Section 35 rights.

1.1 Context

First hand observations by Indigenous Knowledge holders of declines and changes in the water levels of the PAD rivers, declines in water quality, fish health, wildlife numbers and ice quality and subsequent overall decline in the ecological health of the PAD prompted the Elders to initiate a Community-Based Monitoring program to understand the implications.

The PAD itself is drying: Satellite imagery analysis of the PAD shows ~1450 km² of temporarily inundated regions that support critical habitat have diminished by ~10 km²/yr over the past 46 years; a decline of ~32 percent over the last half century. This environmental change corresponds to the severe decline of culturally and economically important wildlife populations such as muskrats (Ward and Gorelick 2018).

Ice-jam flooding and subsequent flood-induced recharge of perched water basins in the PAD has been decreasing since the 1970s (AECOM 2010, Beltaos 2016, Beltaos et al. 2006, Beltaos et al. 2008, Candler 2013, Carver 2013, Carver 2016, Davidson and Hurley 2007, Dubé and Wilson 2013, MCFN 2017, 2018a, 2018b, Peters and Buttle 2010, Peterson and Courtorielle 1992, Prowse and Conly 1998, Prowse and Conly 2002, Prowse et al. 2006, The PAD Project Group 1972, Wrona et al. 1996). This was also the conclusion of a 2018 Strategic Environmental Assessment (SEA) of Wood Buffalo National Park (Independent Environmental Consultants 2018). The SEA found the main causes of this ice-jam decline to be a combination of higher winter flows and ice elevations due to flow regulation on the Peace River, exacerbated by decreased snowpack runoff from tributaries to the Peace River due to climate change.

Indigenous Knowledge Holders and scientists noted in the SEA report and interviews, that poor quality and thin ice cover, in combination with the lower strength of the Peace River flows in the

spring, prevents the large ice jams that are needed to flood the PAD in the spring and replace water in lakes and channels in order to keep the PAD healthy (ACFN 2018, MCFN 2018a, 2018b).

The loss of ice has widespread ecological concerns, however Elders and land users are also concerned with access to the land for traditional rights, recreation, harvesting and spiritual activities. In particular in the winter season, access to traditional territory and travel safety is a concern which is determined by ice thickness and the timing of freeze-up and break-up. Elders are concerned with changing ice conditions which translates into a concern about the conditions for safe travel. Dangerous ice conditions involve thin ice, weak or brittle/candled ice, overflow and hanging ice.

Since hydro-electric regulation of the Peace River has altered the natural flow patterns, hydro-electric operations are blamed by many Elders and active land users for creating worse ice formation. The artificial high freeze-up levels leads to dangerous hanging ice, where the ice is not touching the water, and a fall hazard for snowmobile travel. Overflow from hydro-electric flow regulation, unusual climate-driven winter melting, or early seasonal snows before full ice formation can bring as much as 20 cm of water overtop of winter roads and snowmobile trails; - cumulatively this is deemed too much weight for such ice to be safe. Elders have observed that the freeze and thaw on the Peace is unpredictable due to a combination of hydro-electric operations and a changing climate and creates rough, sharp ice that makes travel challenging. Many Elders mention that the ice seems to erode from the bottom up on the Peace River. Community-monitoring crews have observed unexpected ice loss in the height of winter on the Peace River, coinciding with winter flow fluctuations resultant from hydro-electric operations.

Higher flows at freeze-up coupled with irregular winter flows is also leading to sediment in ice. Increased sedimentation in both the Athabasca and Peace River systems are blamed for lack of good ice formation. The sediment content creates a darker ice which does not freeze as well, melts more quickly in the sun and creates slushy conditions even if decent ice thickness remains.

We had open water this winter. Saw this back in '96 or '97. This year, crossings on the river are okay, just bad close to Fort Chip. Currents from the lake are moving around sediment, which makes it not freeze. If weirs were fixed, it would help ice form. – Land users advocates network (LUAN) Elder

A consensus among Elders and active land users is that the spring melt has become too fast for safe traditional hunting activities in late spring. Ice ‘rots’ far quicker and even the most experienced land user can get caught stranded as ice gives way to open water.

Elders and land users have observed negative trends for Indigenous Knowledge indicators such as ice colour; - used to be black and sometimes blue in the past and now is described as white or even brown, while ice quality was formerly solid and now is considered of less suitable quality and is more brittle or slushy. Less ice and ice of weaker quality, more overflow and a more rapid melt have been described in detail. Elders have shared that ice no longer forms as well, or as thick, as Elders recall from decades ago. Elders have noted on caribou hunting trips much farther to the

northeast into Saskatchewan (Ivanhoe Lake) that they encounter ice like they used to see in the PAD; -consistently over a metre of thick hard blue ice (Courtoreille 2016).

Winter roads and ice crossing maintenance have become far more challenging. The winter road is the main artery for fuel, food and social contact. Ice timing and quality also impact annual construction of the Fort Chipewyan winter road. As observed in the winter of 2019-20, ice conditions were unusual and included open water at the outlet of Lake Athabasca into the Des Rochers River. Despite very solid, thick ice on the southern Athabasca River and the upper Peace River, PAD ice formation was well below expectations for some regions of the Delta. This forced the relocation of the winter road for the community of Fort Chipewyan. Unsafe ice conditions were also responsible for at least one vehicle and one experienced snowmobile operator going through the ice. That winter season, open water persisted at the winter road crossing location into February.

It does something to a person. This is safety. We're scared to let the kids go out. We are travelling with the windows rolled down because we are scared to cross the winter roads. Our lives are on the line. – LUAN Elder

The road conditions are scaring people away. People are not coming to visit us because of the story of the ice. – LUAN Youth representative

Given the changing conditions, people often need to travel longer, using land-based routes which have financial implications. Overflow and hanging ice are deemed very dangerous to travel, and raise fears in the community that the Athabasca River, its tributaries and the PAD, will no longer support the safe passage so important to traditional Indigenous lifestyles.

1.2 Elder direction for Community-Based Monitoring Program

To address some of these concerns and assess changes over time in the PAD, the Community-Based Monitoring (CBM) winter work includes regular visits to sites of interest to collect weather data, ice thickness, snow depth and water-quality and quantity parameters under-ice. The knowledge Elders have shared with CBM program developers and staff has in turn shaped the CBM program.

Interviews with Elders have resulted in ice quality indicators (colour and quality) that are tracked weekly by the CBM program. The Indigenous Knowledge indicators for CBM inform us that blue, black and clear coloured ice is good quality ice, while a white colour represents weaker ice. Ice density is important and ice of high quality is solid, while poor ice is described as slushy or brittle.

The Athabasca Chipewyan First Nation recently undertook Indigenous Knowledge interviews with their Elders and found that 59 of 61 interviewees stated that ice quality has changed in their lifetime. Elders describe “brown ice”, ice that is “slushy and dirty”. Fifty-one of 59 Elders stated that ice quantity has been reduced in their lifetime. Ice is now described as “brittle”, “thinner”, and with “more open holes”. Elders also note that snow falls earlier in winter and is heavier than it once was. Conditions are deemed “unpredictable,” and one interviewee was very concerned to have noted rain in January. Because of these winter changes, 54 respondents (out of 63) have

altered at least some percentage of their travel routes. Overall Elders note that winters are less cold and are shorter.

Elders have directed the development of the CBM, in particular to track ice changes and winter conditions and identified many of the locations to monitor. Therefore, the Community-Based Monitoring program seeks to understand, within the PAD, whether snow and ice conditions are changing over time and if there is an impact of climate change on the winter conditions. The CBM has undertaken Indigenous and scientific methodology development to support a long-term winter monitoring program. The intent with this work is to set monitoring and management triggers that can be used going forward. This now forms the basis of the Winter Program and will integrate with ongoing efforts of the existing CBM program. Practically, information on winter-travel safety in the PAD can also be derived from this program including periods of safe travel on ice, predictions of ice-thickness growth. Finally, the CBM ice work has the potential to provide valuable information on spring ice-jam potential, important in evolving Federal Action Plan work to guide ecological flow needs.

While the Community-Based Monitoring program combines Indigenous Knowledge and western science to understand environmental conditions and trends, the purpose of this paper is to focus mostly on the scientific findings of the last 9 winter seasons of data collection.

2. Methods

Since 2012, MCFN and ACFN monitoring crews have been collecting data about ice thickness and snow depth measurements as well as Indigenous Knowledge indicators of ice colour and quality at sites throughout the PAD. They also collect under-ice water-chemistry samples (similar to the open water season water-quality monitoring), weather conditions such as air temperature, wind speed and direction, barometric pressure, and humidity. Data collection methodology has evolved over time but the current program has received reviews from experts in the field and is consistent with other winter programs.

2.1 Sampling Sites

Data collection involved crews travelling to sites on a regular basis throughout the winter season starting after freeze-up when the ice is safe to walk on, and continuing until break-up or when the ice becomes unsafe (Government of Canada 2005). Sampling sites were chosen by Elders along with the assistance of Kevin Courtoreille and Jocelyn Marten (MCFN), Johnathan Bruno (ACFN) and Ronnie Campbell (Parks Canada). Sites reflect both local knowledge from frequent lake and river users, as well as Traditional Knowledge from ACFN and MCFN members. Sites' locations have evolved across the seasons. Sites currently included in the program and prior sites can be seen in Figure 1. Winter monitoring sites are listed in Table 1.

Table 1. Wintering monitoring sites. Water Intake site is a duplicate site for both crews for comparative Quality Control.

Nation	Site	Latitude	Longitude	Date started	Date discontinued	Notes
ACFN	Water Intake	58.710765	-111.145046	2014-15	-	
ACFN	Buoy's Channel	58.450695	-111.106541	2019-20	-	near Jackfish
ACFN	Athabasca River	58.433244	-110.999792	2013-14	-	
ACFN	Jackfish Creek	58.418221	-110.918850	2012-13	site moved close to AR in 2018-19	by Graveyard - called Maybelle
ACFN	Steamboat Channel	58.601883	-110.842783	2012-13	site used to be Goose Island Channel right at mouth of GIC on Steamboat	
ACFN	Fisherman's Channel	58.661951	-110.771037	2013-14	-	
ACFN	Lake Athabasca by Old Fort	58.646655	-110.643761	2019-20	-	
ACFN	Embarras by Canoe Portage	58.566035	-111.096407	2012	2018-19	ice wasn't safe - too much overflow and hard to get to
ACFN	Big Eddy on Athabasca River	58.473333	-111.126167	2013	2016	moved to cut above island (current AR site)
MCFN	Lake Athabasca	58.717338	-111.147388	2012	-	unsafe in 2019-20
MCFN	Quatre Fourches	58.772467	-111.439936	2012	-	
MCFN	Moose Island	58.948298	-111.708670	2016	-	
MCFN	Water Intake	58.710985	-111.144864	2014-15	-	
MCFN	Lake Mamawi	58.629793	-111.535942	2012	-	
MCFN	Hay River	58.627288	-111.697139	2012	-	
MCFN	Carlson's Landing	58.978716	-111.818920	2019-20	-	
MCFN	Lake Claire by Cowapak	58.628715	-111.894062	2019-20	-	

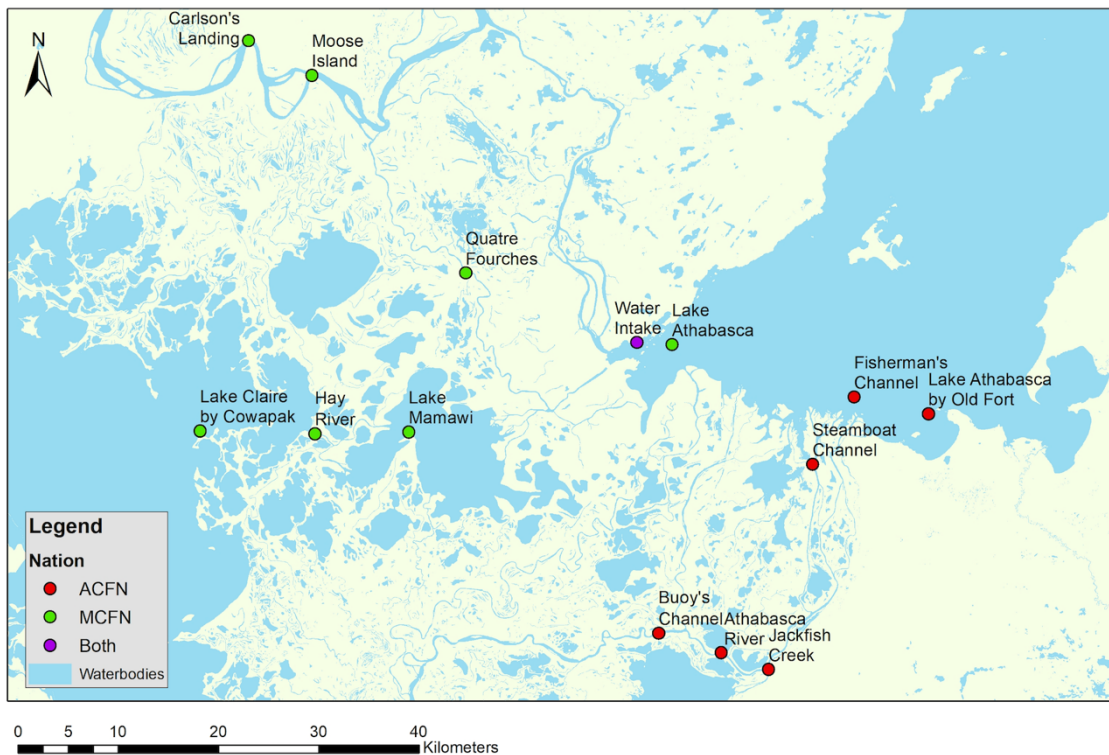


Figure 1. Sampling locations for MCFN and ACFN, 2020 winter season.

2.2 Field Methods and Procedures

At each site, for early measurement years, only one ice thickness measurement was taken each time in undisturbed areas. During the 2019-2020 winter season, three ice-thickness measurements were recorded across the water course or body. This methodology change was based on feedback from Federal Government scientists. Starting in the 2020-21 winter field season, extra effort will be taken in March to sample more sites and to complete 7 measurements per transect (up from 3). Humidity readings will also be taken.

Snow depth measurements are taken concurrently with ice-thickness measurements by firmly inserting a graduated (cm) metal or wooden stake into the snow until it hits ice, and then a measurement can be taken to the nearest cm. Ice thickness is measured using a cm-divided measurement stick or tape measure. For every visit to each site, new drill holes are made at previously undisturbed places in the same spot as the snow depth measurement. The ice is measured for its thickness (the total thickness of ice, including the black ice, the snow ice (white ice) and the water layers between ice layers) to the nearest cm. Holes are located at a distance of at least 50 m from the shore when possible. (Finnish Environment Institute 2018). Water depth is measured from the upper surface of the hole cut in the ice (in cm) to the bottom. Depth measurements are taken with a depth sounder.

Water-quality measurements are taken using an YSI Pro DSS water-quality device. These parameters are temperature, dissolved oxygen, conductivity, salinity, pH, and turbidity. A Secchi tube is also employed to get a measurement of water clarity. Weather conditions are taken from observations by crews. These parameters are wind direction, wind speed, air temperature and barometric pressure at each site. Measurements are taken using a Kestrel anemometer (wind meter) and GPS compass.

Indigenous knowledge indicators of ice colour and ice quality are recorded at each site. Elders are frequent participants in the CBM field work and help refine these indicators and educate the younger staff.

2.3 Data Quality Assurance and Quality Control

During each field trip, data collected at the sites is uploaded into the GeoKeeper database (custom database). Any photographs taken are also attached to the GeoKeeper database record and uploaded. When outside of wireless or cellular range, uploads are done back at the office. The raw data is then merged at the end of each winter season and reviewed for data quality. For parameters with multiple measurements such as ice depth, snow thickness, water depth and Secchi disc, an average value is calculated.

Observations or recordings were reviewed in the context of seasonal and historical data for each site and for the PAD as a whole. Blanks or zero data entries were reviewed to ensure they were correctly attributed. For parameters with minimum or maximum reasonable values, data outside of these ranges were reviewed and addressed as necessary. Erroneous data was removed from further analysis.

Once a clean data set was created for each winter season these were merged with previous seasons. Data analysis was then carried out on the cleaned data.

2.4 Data Analysis Methods

Ice thickness observations were analyzed and the maximum ice thickness for each site for each winter season was extracted. The number of observations and the date of each maximum were also recorded.

Snow depth observations were analyzed in a similar way to ice thickness, with the maximum snow depth for each site for each winter season extracted. The number of observations and the date of each maximum were also recorded.

In order to place observations in context, a region-wide (for all ice seasons) mean maximum ice-thickness and snow-depth value was calculated along with a standard deviation. For sites with sufficient observations over multiple seasons, trends were analyzed to understand how variable ice thickness and snow depths have been over the period of record.

In order to understand changes in the timing of ice formation, break-up and snow accumulation, the monthly trends in ice thickness and snow depth were also analyzed (for the most recent decade only). These may indicate seasonal changes caused by climate change or hydro-electric regulation or both for some sites. For climate-driven variables, often data of 30 years or more is required.

2.5 Modelling Approaches

To investigate whether maximum ice thickness and seasonal growth could be predicted from climate variables, such as temperature and snow accumulation, a mathematical model was developed based on the established Stefan equation but parameterized using local PAD-specific data.

3. Results

3.1 Maximum Ice Thickness

A total of 123 maximum data points were generated considering each site and each ice season of observations. For sites with more than 50 observations over all ice seasons, temporal trends were evaluated. The results are shown in Figure 2.

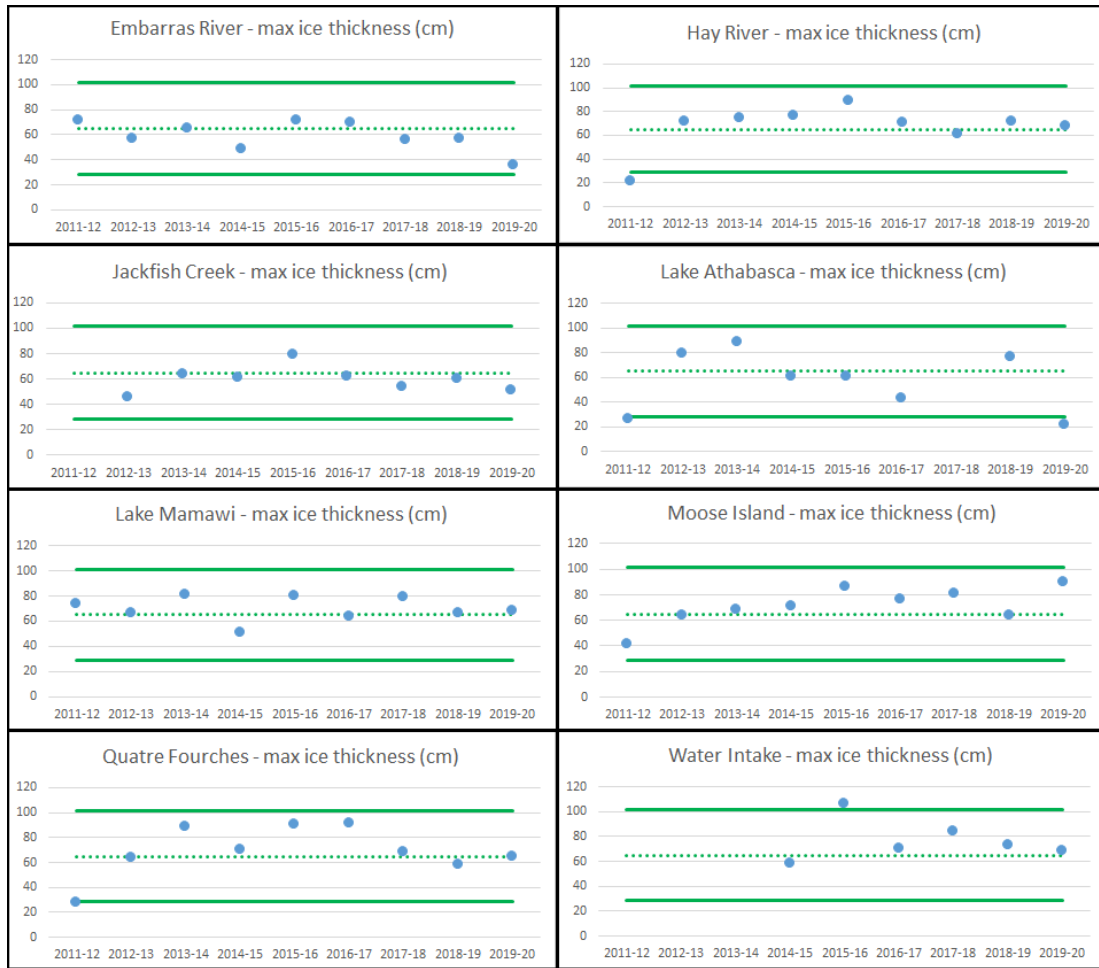


Figure 2. Variation of maximum ice thickness across ice seasons at sites throughout the PAD. Blue circles indicate maximum ice thickness for each ice season. Green dashed lines indicate regional mean maximum ice thickness for all ice seasons. Solid green lines indicate $mean \pm 2 * standard_deviation$. 95% of observations are expected to fall between the solid lines.

There are some ice seasons where the maximum ice thickness falls outside of the solid lines (see Figure 2), but these occur mostly for ice seasons with single observations often taken early in the ice season before ice has had time to build up. The only site with multiple visits within an ice season with a point outside of the solid lines is the Water Intake site for 2015-16. There are no obvious trends in maximum ice thickness over the period of record, which is not unexpected given the short-term nature of the data collected to date. Note that due to logistics, crew constraints and safety considerations, the timing of ice thickness measurements is variable depending on the site and year. A limitation of the data for maximum ice thickness at a site is that the final measurement may occur anytime between January and April. For dates earlier in the ice season, measured ice thickness may not be indicative of actual maximum ice thickness, so this should be taken as an assumption of any analysis work.

3.2 Maximum Snow Depth

A total of 123 maximum data points were generated considering each site and each ice season of observations. For sites with more than 50 observations over all ice seasons, temporal trends were evaluated. The results are shown in Figure 3.

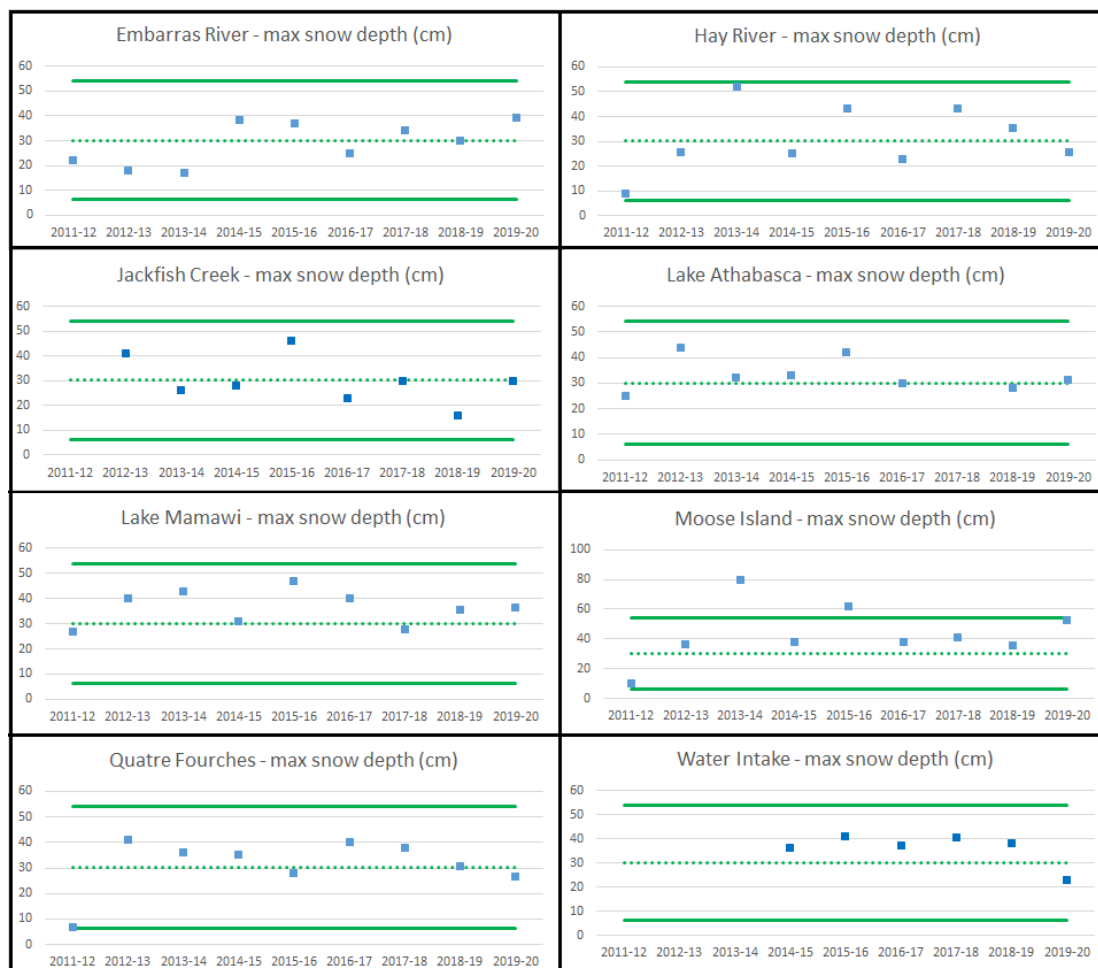


Figure 3. Variation of maximum snow depth across winter seasons at sites throughout the PAD. Blue squares indicate maximum snow depth for each winter season. Green dashed lines indicate regional mean maximum snow depth for all winter seasons. Solid green lines indicate $mean \pm 2 * standard_deviation$. 95% of observations are expected to fall between the solid lines.

There are some winter seasons where the maximum snow depth falls outside of the solid lines (see Figure 3), but these occur mostly for winter seasons with single observations often taken early in the winter. The only site with multiple visits within a winter season with a point outside of the solid lines is Moose Island for 2013-14 and 2015-16. There are no obvious trends in maximum snow depth over the period of record.

3.3 Monthly Trends over Winter Seasons

In order to investigate if the timing of ice formation, freeze-up and break-up is changing over time, the average monthly ice thickness across all sites for each ice season was obtained from averaged daily values collected within a month (see similar approach for snow depth by Liu et al 2019). The results are shown in Figure 4 (left hand column).



Figure 4. Linear regression of average monthly ice thickness (left hand column) and snow depth (right hand column) for entire region for each ice season.

As can be seen in Figure 4, the average January ice thicknesses have decreased significantly, while the average March ice thicknesses have increased significantly over the past 9 winter seasons. This could indicate that freeze-up is happening later in the ice season and also break-up is happening later in the ice season. Thus, based on the last decade of observations, the period of ice cover may have shifted. This may have implications for the condition of ice, especially towards the end of the ice season when temperatures get warmer, and in particular on the establishment of the winter road.

Similarly, the average monthly snow depths were calculated for each winter season to determine if there was a trend over time. The results are shown in Figure 4 (right hand panels). The only month with a significant trend over time was February with increasing snow depths. The increased

snow depths have implications for insulation of the ice under the snow and potentially reduced ice formation under the snow.

3.4 Modelling Maximum Ice Thickness

In order to investigate whether maximum ice thickness could be predicted from climate variables, the data observations for maximum ice thickness was analyzed as a function of accumulated degree days of frost (ADDF - this is the accumulated average temperatures below zero from the start of the winter season until the date of the maximum) and the measured snow depths. We use the Stefan ice-growth model (Stefan 1891), in this instance, the model is a simple mathematical equation tailored to the specific conditions of the PAD. The equation used is: $\text{max ice thickness} = f(\text{snow depth}) * \text{sqrt}(\text{ADDF})$. A linear form of the function f was considered but there was strongest evidence for using a constant term for f . The resulting equation, parameterized using field data had the following form:

$$\text{Max ice thickness} = a * \text{sqrt}(\text{ADDF}) \quad [1]$$

where a varies by site. Models for individual sites were all significant with $p < 0.01$ and $R^2 > 0.87$. The range of a values was between 1.359 and 1.726 which is comparable to results from other northern lakes and rivers (Michel 1971). Some example comparisons between field observations and modelled output are shown for Embarras River and Lake Mamawi sites below in Figure 5.

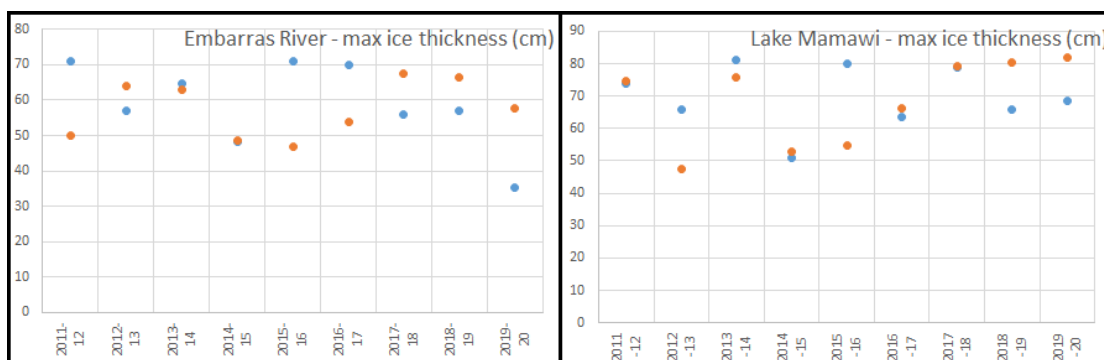


Figure 5. Comparison between field observations (blue symbols) for maximum ice thickness and model predictions (orange symbols) for Embarras River and Lake Mamawi sites, $R^2 = 0.937$ and 0.969 respectively.

While there are some discrepancies, the model is a useful approach to be able to predict maximum ice thickness using climate variables.

3.5 Predicted Regional Ice Growth and Decay

Another way to compare across winter seasons, and integrate the weather and climatic conditions in terms of their impact on ice thickness in the region, is to use a regional model of ice growth within an ice season. We used all the regional data for ice thickness as it evolves throughout each season from all sites and climate data from the Fort Chipewyan RCS weather station (ID 3072659). A regional model for ice thickness on any day of the season included a growth component with

input variables of accumulated temperatures and snow accumulation and a thawing contribution (ice decay when temperatures are above zero). This approach is consistent with other northern lakes and river systems (Arp et al. 2020 and Bilello 1980). The regional ice growth model was used for analysis going forward in this paper and in particular to calculate maximum ice thickness and ice-travel duration for each season as follows:

$$\text{Ice thickness} = a*\sqrt{\text{ADDF}}-b*\text{snow accumulation}*\sqrt{\text{ADDF}}-c*\text{ADDT} \quad [2]$$

where $a = 1.24$, ADDF are the accumulated degree days of freezing, $b = 0.0008$, $c = 1$, ADDT are the accumulated degree days of thawing. ADDF and ADDT are calculated from October 1 for lake sites and November 1 for river sites. If ice thickness falls to zero, then ADDF and ADDT are reset to zero for that date and then accumulation continues once ice thickness is predicted to be positive again.

Examples of ice growth during a season at a site and comparison with the model predictions can be seen in Figure 6. Here the pattern observed is followed closely by the model predictions, although the predicted ice thickness appears to slightly underestimate the observed ice thickness. Results can be interpreted as conservative estimates.

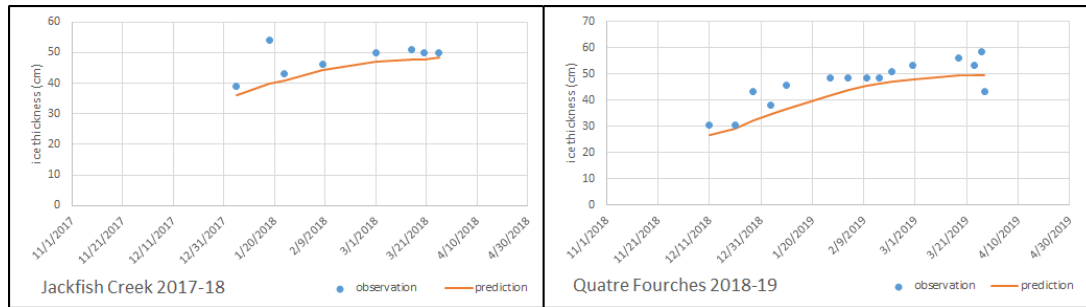


Figure 6. Comparison between field observations for ice thickness throughout an ice season and model predictions for Jackfish Creek 2017-18 season and Quatre Fourches 2018-19 season, $R^2=0.921$ and 0.904 respectively.

This approach means that the seasonal maximum ice thickness can be estimated even if crews are not able to visit sites on the exact date of maximum thickness due to safety or other constraints. This metric allows better comparisons between winter seasons and across time. The approach also enables a prediction to be made about ice-on/ice-off dates which are inherently difficult to estimate from the ground in the field (distant field sites cannot be reached safely until at least 30 cm or 12 inches of ice). An example winter season (using regional data) with ice thickness growth is shown in Figure 7.

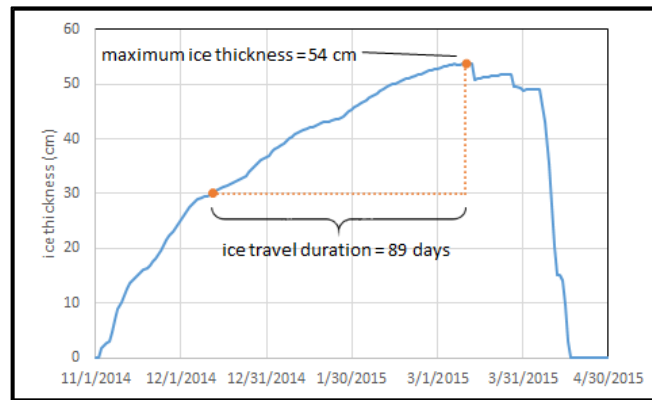


Figure 7. Example ice growth and decay curves for the 2014-15 winter season, the time when maximum ice thickness (MIT) is reached and the period representing ice-travel duration (ITD).

The results for modelled regional maximum ice thickness for each season are shown in Figure 8. There is a slight decrease in maximum ice thickness over the years, but this is not significant.

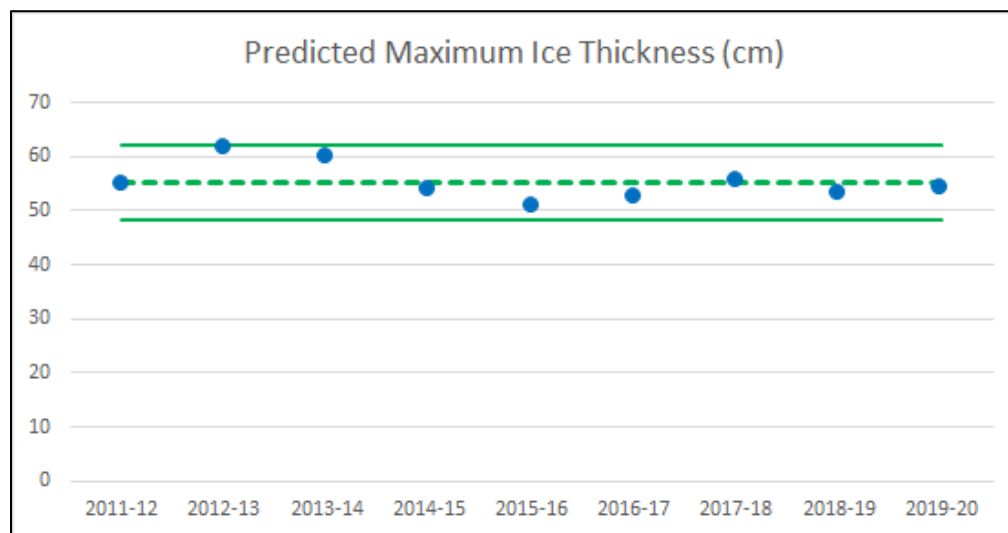


Figure 8. Regional maximum ice thickness (blue circles) calculated by using a model that uses daily temperatures and snow accumulation across an ice season to describe ice growth and decay. Mean predicted maximum ice thickness is displayed (dashed line) and upper and lower triggers representing $mean \pm 2 * standard_deviation$ (solid lines), calculated over the period of record.

3.6 Ice-Travel Duration – Rights-based management trigger

Another metric of interest is the period of time when it is safe to travel on the ice due to sufficient ice thickness, known as Ice-Travel Duration (ITD; Arp et al, 2020). This is estimated from the modelled ice growth from an ice thickness of 30 cm to the day of the winter season when the maximum ice thickness is reached. Even if safe travel is possible, once the ice starts to decay, this is difficult to estimate, therefore a conservative approach is to use the date of maximum ice thickness. Once decay begins, the ice loses strength and bearing capacity rapidly; and cannot be trusted for safe travel even if its thickness is still near the maximum value. This is corroborated by the Elders and CBM-team experiences on the ice.

The ITD metric allows comparison between locations, winter seasons and over time. The graphical interpretation of ice thickness duration for a season can be seen in Figure 7. The results across winter seasons are shown in Figure 9. There is a very slight decrease in ice-travel duration over the years, but this is not significant.

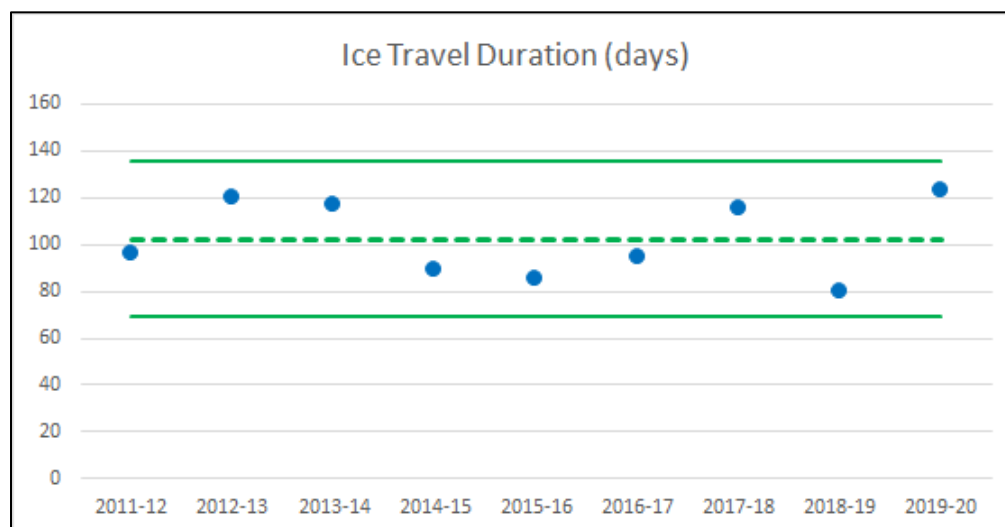


Figure 9. Regional ice-travel duration (blue circles) calculated by using a model that uses daily temperatures across an ice season to describe ice growth. The period of travel duration is calculated from the day the ice reaches 30 cm until maximum ice thickness is reached. Mean predicted maximum ice thickness is displayed (dashed line) and upper and lower triggers representing $mean \pm 2 * standard_deviation$ (solid lines), calculated over the period of record.

This index is furthermore useful for exploration as one potential way to track the combined impacts of hydro-electric development, industrial water withdrawals and climate change on the function of Section 35 Aboriginal and Treaty rights. Harvest activities and other traditional rights are predicated on the ability to safely access traditional areas.

The MCFN and ACFN CBM programs are designed to track environmental changes against management triggers, or rights-based triggers (Sec 35 triggers). The Nations already formally employ one Section 35 Rights policy to track open-water navigation. They have established an 'Aboriginal E(x)treme Flow' (AXF) policy/trigger which links flow rates on the Athabasca River to safe navigational depths at known pinch points (known shallower locations which are the first to become impassable as water depths decline). By monitoring changes to water depth in the PAD, the ACFN and MCFN are able to point explicitly to the oil sands water withdrawals as having negative impacts to their navigation rights below 500 m³/s. Now, long-term monitoring of an Ice-Travel Duration (ITD) index will allow the communities to show how rights-based activities are compromised by the cumulative loss of ice quantity.

Additionally, access to a safe, functional winter road in a remote, fly-in community is critical for the safety, food security, family connections and a myriad of other reasons. Erosion of this critical resource may be tracked against the index and may lead to useful management considerations for

hydro-electric flow regulation and potential adaptations to climate variations. CBM can therefore track how changing conditions impede the ability to safely access traditional territory.

3.7 Historical Retrospective on Ice Thickness and Travel Safety

Using the models for regional maximum ice thickness and ice-travel duration as tools, estimates for historical ice conditions were investigated. Historical weather station data was collated from Fort Chipewyan Station ID 3072657 (1920 – 1940 and 1962 - 1967), Fort Smith Station ID 2202200 (1940-1962), Fort Chipewyan A Station ID 3072658 (1967 – 2005), Fort Chipewyan AWOS A Station ID 3072662 (2006 – 2011), Fort Chipewyan Station ID 3072655 (2011 – 2012) and Fort Chipewyan RCS Station ID 3072659 daily (2012 – 2020). Using weather station information as input, ice thickness and ice-travel duration were estimated for the past 100 years. The results for regional maximum ice thickness are shown in Figure 10.

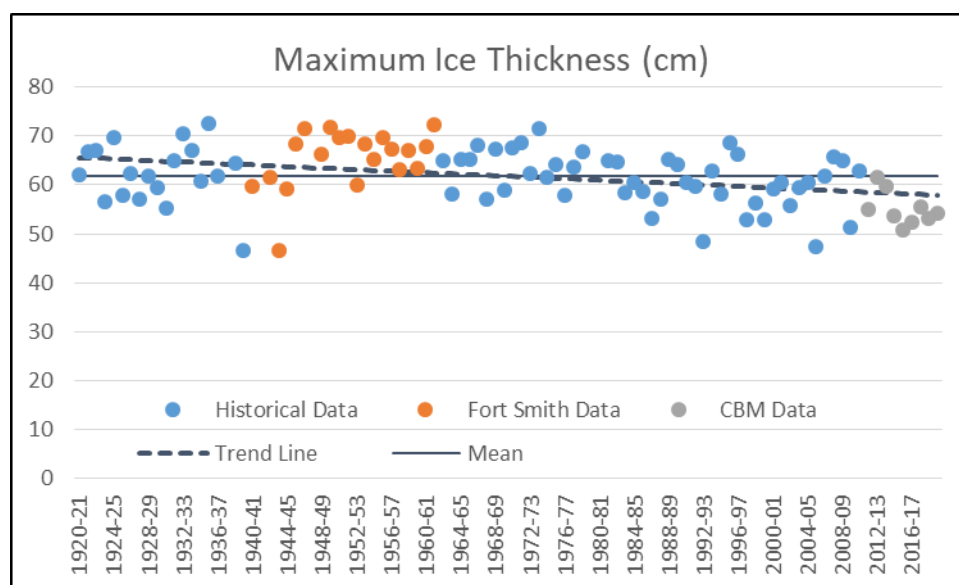


Figure 10. Regional maximum ice thickness calculated for the last 100 years using daily temperatures across an ice season to describe ice growth. The period of CBM data indicates the period which was used to build the model. The decreasing trend in thickness is statistically significant ($p < 0.05$).

As can be seen in Figure 10, there is a significantly decreasing trend over the 100-year record. This decrease is equivalent to approximately 8 cm over the 100-year period. It is also notable that the values in the last decade appear much closer to the trend line than previous decades, likely due to using the period of the CBM records to parameterize the model. This decline in ice thickness is consistent with Elder observations and was the driving rationale for the winter monitoring program.

The results for regional ice-travel duration are shown in Figure 11. As can be seen in Figure 11, there is a decreasing trend over the 100-year record, equivalent to approximately 8 days over the period, but this trend is not statistically significant. There is much more scatter in the ice-travel

duration metric than in maximum ice thickness. This is to be expected, since this metric involves more uncertainty in the timing of reaching 30 cm and peak thickness.

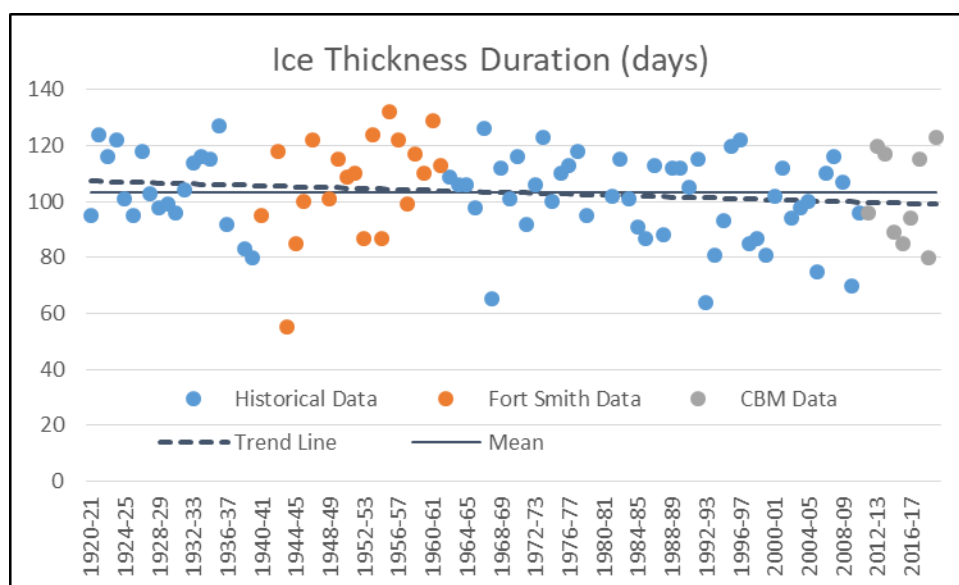


Figure 11. Regional ice thickness duration calculated for the last 100 years using daily temperatures across an ice season to describe ice growth. The period of CBM data indicates the period which was used to build the model. The period of travel duration is calculated from the day the ice reaches 30 cm until maximum ice thickness is reached.

There are some assumptions and limitations to this method. There are gaps in temperature data for the Fort Chipewyan weather station for some periods. To fill these gaps, the Fort Smith station was used as a proxy. Both stations show very high correlation for mean daily temperatures (with $R^2 > 0.94$). There are model uncertainties based on parameterizing the model using 9 seasons of data (although the R^2 is high at 0.88). It should also be noted that the estimates are for the PAD as a region and not for a specific location.

4. Discussion and Conclusion

The Mikisew Cree and Athabasca Chipewyan are concerned about the changing health of the Peace Athabasca Delta as well as travel safety, access to traditional territories, exercising traditional rights, impacts of hydro-electric regulation, industrial water uses by oil sands development and climate change. Due to these concerns, a Winter Monitoring Program was established in 2012. This has evolved over the past 9 winter seasons, and collects ice thickness, snow depth and climate information as well as water-quality parameters at several sites throughout the PAD.

The program now has sufficient information to guide robust program design and development of triggers to watch for changes to winter conditions. The triggers can be used to give context to future observations and support monitoring for change.

Individual sites across the PAD show variability in observed maximum ice thickness and observed maximum snow depth with no consistent trends across the period of data collection. The majority

of observations fall within the expected ranges. When the timing of ice thickness and snow depth within an ice season is considered, the average monthly ice thickness in January has decreased while the March thickness has increased. This may indicate the period of ice cover is shifting later in the winter season which has implications for travel safety towards the end of the winter as warmer temperatures impact break-up. Snow depth has increased in February which has implications for insulating the ice.

A model has been developed to predict ice thickness, growth and thawing using climate information from the Fort Chipewyan weather station. This can be used if sites cannot be visited due to logistics and also towards the end of the winter season as break-up occurs and travel safety is a concern. The model can be used to predict maximum ice thickness, ice-travel duration (length of the safe-travel season) and ice-on and ice-off dates. Predicted maximum ice thickness integrates weather data (accumulated temperatures and snowfall) across the entire season and is not dependent on crew visits to a site. A regional estimate can then be compared across seasons. This has shown a slight decrease as has ice-travel duration (safe-travel days). If this trend becomes significant and continues it may have implications on traditional rights.

A historical retrospective to estimate ice thickness and safe winter navigation has shown decreasing trends over the last 100 years. This is a co-validation of Traditional Knowledge, where Elders' reflections have shown accuracy in noting environmental change. Future projections of climate change and their impacts on ice formation indicate that ice thickness is likely to decrease by between 18 to 28 cm by the 2080s (Beltaos and Bonsal 2021), indicating more change is to come in the region with corresponding impacts on traditional use and activities.

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