ICE JAM FLOOD MECHANISMS ON THE PORCUPINE RIVER AT OLD CROW, YUKON TERRITORY

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Abstract

The community of Old Crow has experienced flooding due to ice jamming on the Porcupine River on a frequent basis. This paper shows several mechanisms which can cause high water levels to occur in the community. These include the formation of an aufeis blockage downstream of Old Crow, surges caused by the release of ice jams upstream, and unusual weather patterns which cause a large disparity in temperatures between the southern and northern portion of the Basin.

The first mechanism by which high water levels can occur is the formation of a large aufeis deposit. This caused the second highest flood of record in 1991 and a smaller flood in 1997. This study undertook the measurements of the aufeis deposit for various years and compared them with meteorological and hydrometric data to determine what parameters cause severe aufeis formation and therefore increased risk of ice jamming.

The second type of flooding mechanism also contributed to the flood of 1991. High water levels can occur as a result of surges caused by the release of ice jams upstream of Old Crow. Several years of surge data have been documented and include hydrographs as well as ice concentrations. Since ice supply as well as discharge is an important parameter for determining the size of an ice jam and therefore the extent of flooding, the hydrographs and ice concentrations were plotted in a superimposed fashion to gain an understanding of the behavior of multi-phase surges and their possible implications when they collide with a stationary jam.

To help forecast the effect of the multi-phase surges on ice jams downstream of Old Crow, the paper also presents multi-variable rating curves generated by the University of Alberta ICEJAM model and HEC-2. The rating curves are a function of the position of the ice jam, ice jam volume, as well as discharge. A rare discharge measurement during break-up using a theodolite was performed in the spring of 1997. This data has shown that the present ice jam rating curves are reasonably accurate but could use some further calibration.

A third type of flooding mechanism was demonstrated in 1989. A weather pattern in that year caused abnormally cold temperatures to occur in the northern part of the basin while the southern portion experienced a warming trend. This caused a rapid increase in discharge with abnormally competent ice in the vicinity of Old Crow producing an ice jam flood.

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Introduction

Background

Old Crow is a small community situated on the banks of the Porcupine River in the northern part of the Yukon Territory and is the central populace of the Vuntut Gwitchin Band (Figure 1 and 2). The population of Old Crow is approximately 350. The village is about 120 kilometers north of the Arctic Circle and lies within the zone of continuous permafrost. The mean annual temperature is -10.1 °C. The permafrost in the floodplain is relatively dominant and ice lenses can be seen in freshly cut river banks. The community is situated on the floodplain approximately 6 meters above normal water level and immediately downstream of the Old Crow and Porcupine River Confluence. The river channel at Old Crow is about 600 m wide and occupies a broad alluvial valley of about 6 to 10 km in width. The drainage area of the Porcupine Basin at Old Crow is about 55,400 km^2. The mean annual precipitation is relatively low, about 210 mm.

The mean annual discharge of the Porcupine River at Old Crow is about 320 m^3/s. Mean peak flows of 4200 m^3/s occur in May or early June. Low flows of about 15 m^3/s occur in April.

The Community of Old Crow has experienced flooding due to ice jamming on the Porcupine River on a frequent basis (Figure 3). A study is being conducted to assess various conditions within the Porcupine Basin which can lead to severe flooding as well as to help develop a flood warning system for Old Crow. The database is updated annually with additional break-up monitoring data. The study includes the monitoring of ice conditions, water levels, discharge, break-up progression, and meteorological data. Areas of study concentrate on break-up and flood forecasting, the effect of an aufeis deposit, the role of the break-up sequence, and flood hazard mapping. This paper will concentrate on three identifiable mechanisms which can cause or contribute to the risk of ice jam flooding. These include the formation of aufeis downstream of Old Crow at the mouth of the Bluefish River (Figure 4), ice jam surges, and unusual meteorological conditions.

Basin Description

A map of the Porcupine Basin is shown in Figure 5. The basin at the Yukon-Alaska Border covers about 60,000 km^2 and is bounded to the north by the British Mountains, to the west by the Richardson Mountains, and to the south by the Ogilvie Range. The lower elevations are covered by coniferous forest, with the higher elevations covered by Taiga and Alpine Tundra. The treeline occurs at about 450-600 metres above sea level. The Porcupine basin lies in the area of continuous permafrost in the north and discontinuous permafrost in the south. The main drainage arm of the basin is the Porcupine River with the major tributaries being the Old Crow, Bell-Eagle, Miner, and Whitestone Rivers. A distance datum in kilometers was selected for the Porcupine River originating at the confluence of the Miner and Whitestone Rivers and is shown in Figures 4 and 5.

Break-up on the Porcupine River is caused by rapid snow melt, usually in May. Tributaries draining the Richardson Mountains to the east seem to have the largest effect on triggering and influencing break-up. This includes the Bell-Eagle Rivers, Driftwood River, and Berry Creek. The predominant slope of these drainages face south-west thereby increasing their response when compared to the north-east orientation of the Upper Porcupine Basin. The Bluefish River and Lord Creek draining the western portion of the basin also initiate and influence break-up on the Porcupine significantly. The highly influential basins are shown as a darker shade in Figure 5.

The Old Crow and Upper Porcupine Basins appear to be less influential to the initial break-up at Old Crow and are shown as a lighter shade in Figure 5. Physical aspects of these basins give them a slightly later break-up date and are discussed in more detail in Jasek (1996).

Break-up Sequence of the Porcupine River

The date on which the ice adjacent to Old Crow first starts to move is considered the break-up date. Since this section of the Porcupine River is steeper and straighter than reaches upstream and downstream of it; it requires a smaller increase in discharge to set the ice in motion. Shortly after this ice starts to move, it typically jams about 2 km downstream of Old Crow. This deeper and milder reach is in the vicinity of the old Water Survey of Canada gauge site, (km 320.0, Figure 4). This short jam remains intact until a more powerful break-up front arrives in Old Crow. Historical observations show that the time difference between the ice moving out adjacent to Old Crow and the arrival of the more powerful break-up front has ranged between 4 and 42 hours with a mean of 20 hours. Break-up in 1997 was an exception; a powerful break-up front initiated the first movement.

Break-up on the Porcupine River does not progress as a single sequential front as is common on many rivers. Several break-up fronts on the Porcupine River are usually triggered by tributaries. Referring to Figure 5, break-up fronts have been observed to commence at the Bell River, Berry Creek, Driftwood River, Lord Creek, and Bluefish River. These multiple break-up fronts complicate the break-up process and can create situations where the risk of flooding is increased.

The first and most active break-up fronts are usually caused by the Driftwood River and Lord Creek. The break-up front which originates at Driftwood River may catch up and combine with the break-up front which originates at Lord Creek with their combined effect proceeding downstream towards Old Crow. In other years, the break-up front from Lord Creek may reach Old Crow prior to the arrival of the break-up front from Driftwood River. It is with the arrival of the first break-up front that a sudden increase in water level is noted. The water level may come up several meters in a matter of hours.

Normally this break-up front proceeds downstream, stalling for short periods at some sections. It generally reaches the Yukon-Alaska border in less than a day, about 90 km downstream. Once the break-up front has travelled about 40 km downstream of Old Crow (beyond the mouth of the Bluefish River), the threat of jamming and severe flooding is significantly reduced.

In an abnormal year, the break-up front stalls downstream of Old Crow in the reach shown in Figure 4 and causes an ice jam to form. If the discharge is sufficiently high and the jam remains in place, a severe flood can occur. During the 1991 flood, the jam was caused by the break-up front stalling at the aufeis deposit at the mouth of the Bluefish River (km 360). During the 1989 flood, the jam occurred at about km 339 and was possibly caused by a thick ice sheet which may have been frozen to the bottom in this shallow area. In 1994 a jam formed at km 326 but released prior to causing a flood. In 1997 another aufeis formation at the mouth of the Bluefish River contributed to a minor flood.

There are basically two factors which can lead to further increasing water levels once a jam forms downstream of Old Crow. These are an increase in discharge and the movement of the upstream end of the ice jam (head of the jam) towards Old Crow. An increase in discharge can occur due to a surge caused by the release of an ice jam upstream of Old Crow and/or an increase in snow-melt runoff. The former being much more sudden than the latter. The head of the ice jam can travel upstream if ice is flowing past Old Crow and feeding the downstream jam. The source of this flowing ice is often a result of an ice jam surge release from somewhere upstream.

By the time the break-up front reaches the Yukon-Alaska Border(during a normal break-up), there are usually some ice jams and solid ice upstream of Berry Creek. The ice immediately upstream of Berry Creek usually starts to release next. A jam usually forms at the tight and narrow bend at km 188, about 18 km downstream of the Bell River. As the discharge input from the Bell River increases, this jam builds and eventually fails. This sends a surge of water and ice towards Old Crow. If there are no ice jams downstream of Old Crow, this surge may cause some minor flooding. However, if there is a jam in place, this surge can cause severe flooding. There are no break-up observations upstream of Old Crow during severe flood years to assess if this type of flooding mechanism has occurred. However, given that the jam at km 188 can release within 1 day after the initial break-up front moves through Old Crow, it is likely that it has been a part of the flooding mechanism in the past. An ice jam has formed at km 188 five out of the five years where observations were made of this reach (known local Salmon Cache).

The ice upstream of the Bell River is usually the last to move out. In 6 years of observations, including the 1991 flood, there was still solid ice and ice jams present upstream of the Bell River after the Porcupine River was free of stationary ice between the Bell River and the Yukon-Alaska Border. Based on a limited amount of observations, this ice moves out anywhere from 1 to 4 days after the release of the last ice downstream of the Bell River.

1991 Flood

The ice in front of Old Crow started to break-up on May 5th. Later that day an ice jam formed at the confluence of the Porcupine and Bluefish Rivers and water levels started rising at an alarming rate in Old Crow. This jam was likely caused by the thicker than normal aufeis deposit at the mouth of the Bluefish River.

By 18:30 on May 7, the head of the jam was 9 km downstream of Old Crow as shown in Figure 6. One fifth of the runway was flooded and some minor flooding in low lying areas had already occurred. It is interesting to note that the jam was not continuous; a 4 km long open water section existed between km 348 and km 352. It is likely that the jam originally formed as a continuous piece but a section of it collapsed as the discharge increased. The water level elevation in Old Crow at 19:10 was about 248.2 m and appeared to be dropping slightly. The dropping water level may have been misleading and was likely due to the consolidation and slight movement of the upstream end of the ice jam rather than a decrease in discharge. The water surface of the Porcupine River was running with about 25% ice in front of Old Crow.

By about 21:00 the water surface of the Porcupine River in front of the village was running with a slight increase in surface ice concentration, about 30%. The downstream segment of the jam was in motion. The increasing ice concentration and ice movement suggests that a surge was arriving at this time.

Sometime after 21:00, the water level started to increase again and reached a dangerous elevation at about 23:30. The levels remained high through the night and knocked out telephone communications with Old Crow at about 04:30 on May 8. The water depth throughout most of the village was greater than 1 m and floating ice blocks posed a threat to many structures. Old Crow RCMP Cpl. Al O'Donnell was interviewed by the Whitehorse Star(1991):

> "We were using the normal big boats with 50-horsepower motors to get around town, so that will give you an idea how deep the water was. Had the water kept advancing for just another four or five hours, said O'Donnell, the damage could have been quite extensive. Large pieces of ice already had started flowing down the closest street to the river. Ice pieces that size, with the potential for even larger pieces to show up in rising water, could easily cause severe damage or even destroy a home, he added."

Aerial photographs of the jam and flood were taken at about 09:30 May 8, just an hour or two prior to the peak water level (Figure 3). Figure 7 shows the extent of the ice jam at 09:30. By this time the lower segment of the jam was gone but the upstream portion remained intact. Figure 7 shows that the head of the jam had advanced about 4 km upstream from where it was the previous day and was within 5 km of Old Crow. The water level peaked at an elevation of 248.8 m. By 11:30 the jam had released and by 12:00 the water level had dropped to 248.1 m. The water levels continued to drop through the day and the threat of further flooding had past.

1989 Flood

The 1989 flood is described here since it was likely caused by unusual meteorological conditions, the third type of mechanism responsible for flooding. Meteorological data indicated that the southern portion of the basin warmed significantly while the northern portion remained relatively cool. This difference in temperatures was the largest recorded for the 15 year period for which data during the break-up period is available.

Break-up occurred on May 3, 1989. The river was flowing clear late on May 3 in front of town. However, the next morning at about 09:30, the river jammed up and stopped moving in front of Old Crow. A description of the events are recorded in the Whitehorse Star(1989) through an interview with Drew Dunn, Yukon Government Emergency measures coordinator:

> "The ice blockage is about 18 kilometres by water downriver from Old Crow. Dunn said chunks of ice as big as a city block and two metres thick appeared to be hung up in a shallow part of the river. At about (16:30 May 4) a surge of water started the ice moving in the part of the river that runs through Old Crow. This in turn put pressure on the blockage downriver. By (17:45 May 4), this movement had worked its way down to the point of the jam-up. "The water started flowing over these big pieces, tipping them over," ,said Dunn, who was flying over the scene in a helicopter. Within half an hour, the largest piece of ice was ten metres across, and the ice was flowing well. By (20:00 May 4), ... the level of the Porcupine River had dropped eight metres."

This description of the jamming location gives the impression of very thick and competent ice. This agrees with the relatively cool temperatures experienced at Old Crow during break-up.

An important feature of this break-up was the location of the toe of the jam was about 18 km downstream of Old Crow (km 339, Figure 4). The Bluefish-Porcupine River Confluence is about 40 km downstream of Old Crow(km 360). This suggests that possible aufeis formation at the Bluefish River was not the cause of the jam as it was in the 1991 flood. Another significant feature is that the flood occurred with the jam right in town. This is unlike the 1991 flood which occurred in the backwater upstream of the jam. This suggests that the water surface slope was much steeper through the village than in the 1991 flood.

Mechanism 1 - Ice Jamming Caused by Aufeis Formation on the Porcupine River due to Winter Overflow Conditions on the Bluefish River

The severe ice jam flood of 1991 was apparently caused by an ice formation at the Porcupine and Bluefish River confluence, about 40 km downstream of Old Crow. The condition was the result of the freeze-up process on the Bluefish River. During freeze-up, the Bluefish River often freezes to the bed in many places. This blocks the flow and forces water to the surface through cracks and near bank edges. This is known as overflow. The overflow quickly freezes and the process can continue throughout the winter creating an extremely thick aufeis deposit.

To assess the severity of the aufeis deposit from year to year, pre-break-up ice surveys were conducted in March 1994, March 1995 and April 1996. Their primary purpose was to measure the icing deposit at the mouth of the Bluefish River. The first survey also measured the aufeis elevations which occurred prior to the 1991 break-up. These elevations were pointed out by Stephen Frost, an Elder of the Old Crow community who often resides at a cabin on the north bank of the Porcupine River at the Bluefish-Porcupine River Confluence. Figure 8 shows the location of the ice and channel cross sections.

Figure 9 shows profiles of the ice surface across the Porcupine River near the mouth of the Bluefish River for 1991 and 1994 (Section A-A Figure 10). The two years show the low and high extremes of aufeis formation. The estimated range of the 1991 aufeis level indicates that the aufeis was between 3 and 4 meters thick. Figure 4 shows the aerial extent of the icings for the 1991 and 1994 observations. The aerial extent of the 1991 icing was obtained from Stephen

Frost and shows that the aufeis extended about 2 km downstream and 5 km upstream on the Porcupine River, a total length of 7 km!

Extensive aufeis also formed in 1997 which caused an ice jam to form and Old Crow experienced a minor flood. The jam stayed intact for a week and was a cause of concern for the community. The aerial extent of the aufeis was similar to the 7 km reach as in 1991. However, lack of resources did not allow the measurement of the aufeis thickness. Local residents suggested that it did not appear to be as thick as in 1991.

The break-up in 1997 was unusual in that a sudden cooling trend occurred during mid break-up and lasted for several days. During this cooling trend, the river discharge decreased and provided a unique opportunity to see how the aufeis may be causing jamming on the Porcupine River. Figure 10a shows the Porcupine-Bluefish River confluence shortly after the formation of the jam. Figure 10b shows it several days later after the discharge had decreased and the aufeis is plainly visible. In Figure 10a, notice the supercritical flow or rapids overtop of the aufeis downstream of the Bluefish River and the subcritical flow (tranquil flow) upstream. This suggests that the aufeis does not create a blockage directly but instead creates a reach of deep slow moving water upstream of it, much like a dam. This deep slow moving water allows for jamming to occur much more easily than if the water was flowing faster along a steeper gradient.

Table 1 rates the severity of aufeis formation for various years for which observations are available. The table also shows meteorological and hydrometric parameters which may be indicators of aufeis severity.

Table 1. Aufeis severity at the Bluefish River and meteorological and hydrometric parameters.

Year	Aufeis Severity	°C-Days of Frost for entire Winter	Total Winter Precipitation (mm)	April 1 snow survey Snow Depth (cm)	Total Precipitation for previous summer (mm)	December Discharge in Old Crow River (m^3/s)
1991	**extreme**	**4620**	**110**	**58**	**98**	**0.125**
1997	**extensive**	**4937**	**101**	**65**	**169**	**4.95**
1996	**moderate**	**4965**	**100**	**77**	**236**	**1.82**
1994	**negligible**	**4315**	**125**	**61**	**142**	**3.49**
1995	**negligible**	**4368**	**101**	**77**	**180**	**1.96**

°C-Days of Frost - It would be expected that a colder winter would cause the ice in the Bluefish River to freeze to the bed more readily and therefore increase the formation of aufeis. Table 1 shows that the mild winters prior to the 1994 and 1995 break-ups matched well with the negligible aufeis formation. However, the trend was not so apparent for the moderate(1996), extensive(1997), and extreme(1991) categories. Apparently the severity of the winter is not the only parameter that determines the extent of the aufeis.

Total Winter Precipitation and April 1st Snow Depth - It would be expected that greater winter precipitation would provide an insulating effect and therefore cause the Bluefish River to freeze to the bed less readily. However, there did not appear to be any relation between the total winter precipitation or the April 1st snow depth with aufeis severity.

Total Precipitation for the Previous Summer - Total precipitation for the previous summer is an important factor in determining the winter flow. A dry summer would cause low winter flows in the Bluefish River and allow it to freeze to the bed more readily. Table 1 shows that out of the five years, 1991 had the lowest previous summer precipitation and also the most severe aufeis formation. The other years show that this factor alone is not enough to determine aufeis severity.

December Discharge in Old Crow River - Since the Bluefish River is an ungauged stream, the Old Crow River was taken as a possible surrogate indicator of the winter flow for the Bluefish River. The years 1991, 1994, 1995, and 1996 seemed to hold a good relation with aufeis severity. However, 1997 seemed to be an outlier. Personal communications with Russ Gregory of Water Survey of Canada indicated that the winter metering section was moved in 1996. Further discussions indicated that winter flow measurement on this particular stream are often difficult and may produce varying results depending on location.

Local Knowledge and Unusual Temperature Events - It appears that winter severity and the previous summer precipitation hold some promise for determining the aufeis severity. However, observations of trappers who have made frequent crossings across the Bluefish River suggest that aufeis formation may be related to daily temperature fluctuations and not just seasonally accumulated variables. There are instances where the Bluefish River was crossed when there was only a small skiff of water on the ice. On the return trip about two hours later, the overflow of water on top of the ice was more than 0.3 meters and made crossing with snowmobiles difficult. The event coincided with an unusually warm winter day. In fact, meteorological records indicated that the winter previous to the 1991 flood had an extreme midwinter warm spell lasting one week. The high temperature occurred on January 25, 1991 with a daytime high of +2.5°C, followed by weeks of temperatures in the -20 to -40 °C range.

Mechanism 2 - Flooding due to Ice Jam Surges

Ice Jam Surge Hydrographs and Ice Concentration Profiles

Observations of the 1991 flood indicated that at least one surge produced by a releasing ice jam upstream of Old Crow likely contributed to the severity of the flood in that year. The surge provided an increase in discharge as well as ice supply. The increased discharge created higher water levels and the ice supply caused the upstream end of the ice jam to move closer to Old Crow. This combined effect caused one of the largest floods in the history of the village. Since surges contributed to the 1991 flood, data was collected during subsequent break-ups which would allow for a better understanding of the behavior of these surges and therefore possibly predict their consequences in the future. McKay and Hicks(1996) have developed a preliminary ice jam surge model which will be incorporated into flood forecasting in the future.

The break-up in 1995 provided some very fruitful data and is described in more detail in McKay and Hicks(1996) and Jasek(1996). In that year the release of an ice jam at km 188 was observed from the air, the hydrorgraph was recorded at a Water Survey of Canada gauge at km 194 and at Old Crow (km 320). See Figure 5 for locations. Additional aerial observations of the surge were made as it travelled towards Old Crow. The percentage surface ice concentration was also estimated at Old Crow at regular intervals. Additional surges from ice jams upstream of the Bell River were also recorded by both gauges. Figure 11 shows the hydrographs at the two gauges and shows that surge A increased the discharge from 2600 m^3/s to 3600 m^3/s, a 40% increase in discharge in 12 hours. If an ice jam had existed downstream of Old Crow in that year, the surge may have caused a flood.

The fact that the release of an ice jam was observed directly and recorded by two gauges allowed for the calculation of different aspects of the surge and ice velocities:

surge front velocity	=	5.4 m/s	km 188 to km 194
surge front velocity	=	4.2 m/s	km 194 to km 320
ice front velocity	=	2.4 m/s	km 188 to km 318
surge crest velocity	=	2.3 m/s	km 194 to km 320

The above velocities show that the discharge from a surge arrives much earlier than the ice. In this case it was six hours. Figure 12 shows that 80% of the surge height had arrived by the time the first ice from the surge reached Old Crow.

Surface ice concentration estimates were also obtained from aerial observations and are shown in more detail in Jasek(1996). The observations show that the peak ice concentration decreases and disperses with the distance travelled; the ice run peak concentration had decreased from 100% to 70% in 120 km of travel and the length of the run increased from 18 km to 100 km.

More surge data was obtained during the 1996 break-up and is shown in Figure 13. The figure shows three surges following the initial break-up. An automatically triggered camera was used to collect the more detailed ice concentration data for that year. This hydrograph and ice concentration data may be useful for developing a model that will help predict water levels in Old Crow when an ice jam surge collides with a stationary ice jam downstream of Old Crow.

Development of Multi-Variable Ice Jam Rating Curves

To help forecast the effect of the multi-phase surges on ice jams downstream of Old Crow, multi variable rating curves were developed using the University of Alberta ICEJAM model (Flato and Gerard(1986) and HEC-2, Hydraulic Engineering Center, US Army Corps of Engineers (1991). The ICEJAM model was used to calculate ice jam profiles and water levels of ice jams of various lengths downstream of Old Crow. The HEC-2 model was used to calculate the open water profile upstream of the ice jams. River cross-sections of the Porcupine River were surveyed to provide river geometry data for the models. The ice jam roughness taken to be 2 meters, and the bed roughness was anywhere from 0.05 to 0.3 m depending on the cross-section. Due to shear volume, the details of this work has been left to a forthcoming report.

The rating curves are shown in Figure 14 and are a function of the position of the ice jam, ice jam volume, as well as discharge. If there is no additional ice feeding the downstream jam, the curves of constant jam volume are useful in estimating how much an ice jam will compress as the discharge is increasing. One has to be careful in using the rating curves if the discharge is decreasing as the ice jam thickness would not be expected to thin correspondingly. The curves would underestimate the water level in the decreasing discharge case. It is hoped that estimates of ice volume from surges can be obtained from ice concentration data and be used with these curves to predict the position of the ice jam head and therefore predict water levels in Old Crow more accurately during future surge events.

A discharge measurement using a theodolite as described in Prowse and Demuth (1991) was conducted during the break-up in 1997. The discharge measured was 750 m^3/s, the ice jam location was at km 330, and the water surface elevation was 242.30. This point is plotted in Figure 14 and appears to agree very well with the curves. However, the discharge was in a decreasing trend during this time and therefore the rating curve should overestimate the water level for this situation. Further investigation may lead to how much the curve should be below the measurement. This would allow further calibration of the ICEJAM model in its application to the Porcupine River.

Mechanism 3 - Ice Jamming due to Differential Temperature Regimes in the Porcupine Basin

Temperature data from Old Crow representing the northern portion of the Porcupine Basin and from Eagle Plains representing the south indicated that the break-up flood of 1989 was an unusual event. Normally, the mean values of °C-days of thaw for break-up to occur at Old Crow is 32 °C-days at Old Crow and 36 °C-days at Eagle Plains. In 1989 the degree-days of thaw were 5 °C-days for Old Crow and 40 °C-days for Eagle Plains. Of the 15 years of record this was by far the largest discrepancy in temperature between the two locations during break-up. This lead to a rapid increase in discharge with strong competent ice in the Porcupine River at Old Crow. The combination resulted in subsequent flooding.

Conclusions

Three types of mechanisms which contribute to ice jam flood potential have been identified and include a blockage due to aufeis formation, ice jam surges, and unusual temperature differences between the northern and southern portion of the Porcupine Basin during break-up.

The formation of the aufeis deposit caused by overflow on the Bluefish River may be anticipated from meteorological data. Cold winters, low previous summer precipitation and unusual winter warm spells can lead to increased and even extreme aufeis formation on the Bluefish River causing ice jamming and possible flooding. An effort should be made to document the aufeis during years where it appears extensive or extreme.

Ice jam surges have been demonstrated to play a role in at least one flood and should continue to be a major concern of any break-up. Important hydrographs and ice concentrations resulting from ice jam surges have been collected and should be useful in predicting water levels in Old Crow should a surge collide with a stationary ice jam downstream of Old Crow. Multi-variable rating curves were developed using ICEJAM and HEC-2 to help predict the effect of surges in the future. More work needs to be done to calibrate these rating curves.

The unusual temperature disparity between the northern and southern portions of the Porcupine Basin prior to the 1989 break-up indicated that temperatures in Eagle Plains as well as Old Crow should be monitored in order to better predict timing and severity of break-up in Old Crow.

Acknowledgments

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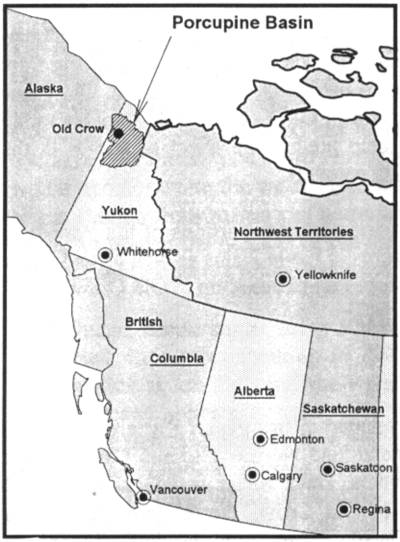

Figure 1. Location of the Porcupine Basin.

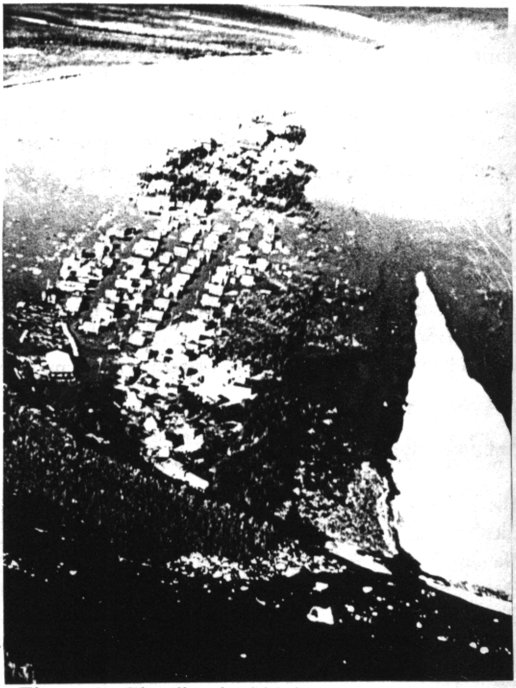

Figure 3. Flooding in Old Crow at 09:30 May 8, 1991 due to ice jam 5 km downstream.

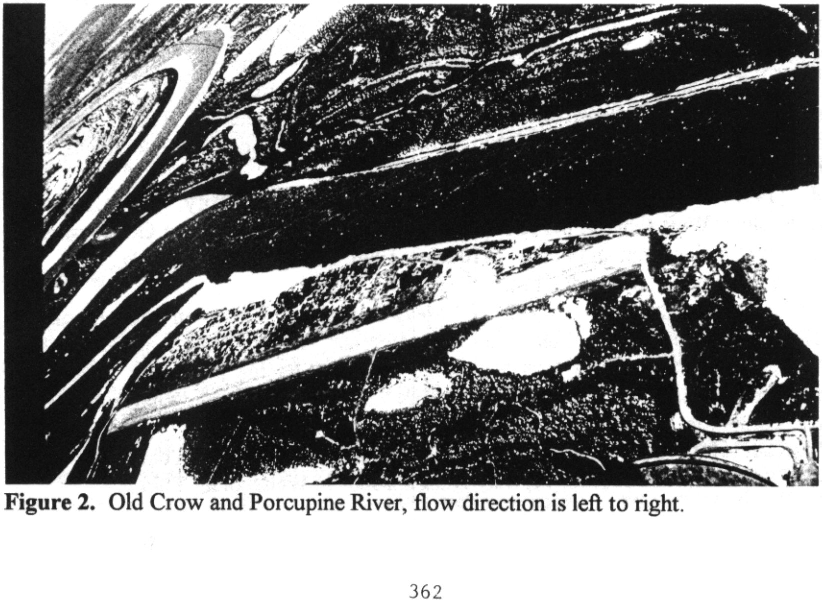

Figure 2. Old Crow and Porcupine River, flow direction is left to right.

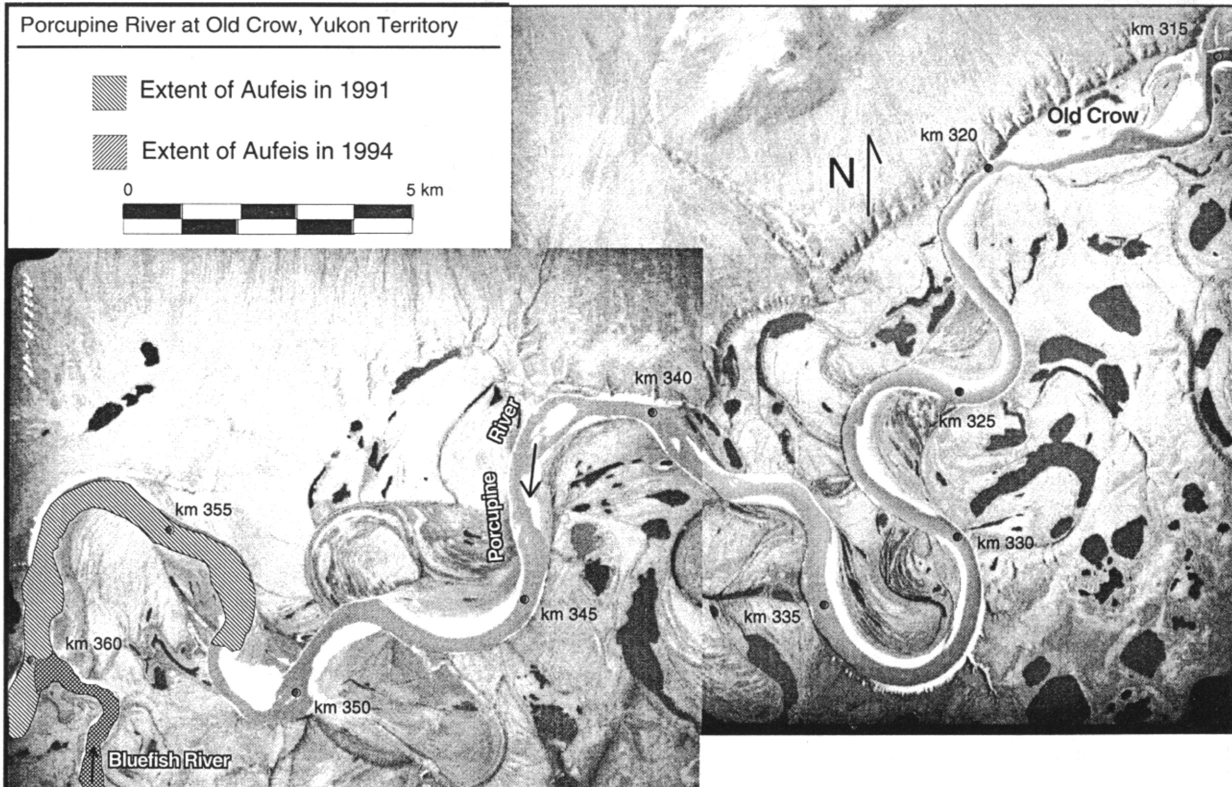

Figure 4. Porcupine River between Old Crow and Bluefish River, distance datum, and extent of aufeis in 1991 and 1994.

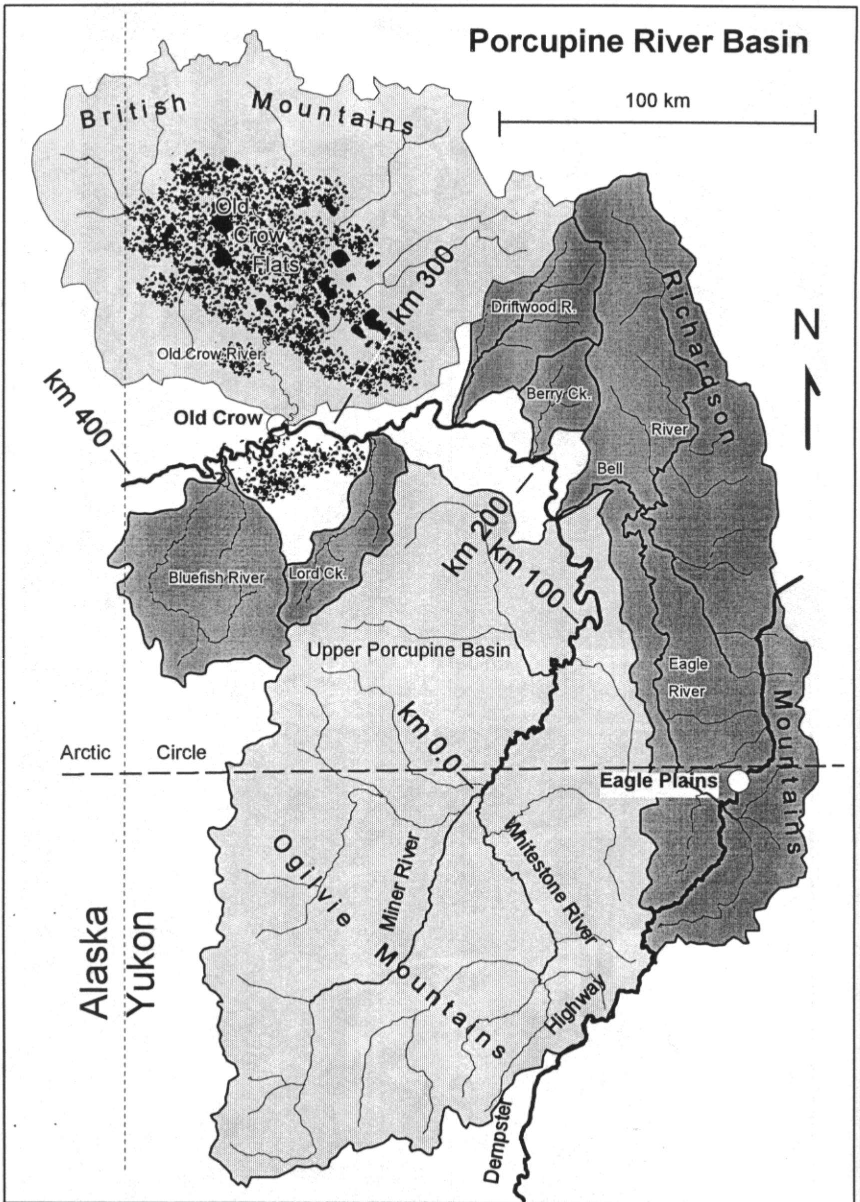

Figure 5. Porcupine Basin, subbasins and distance datum.

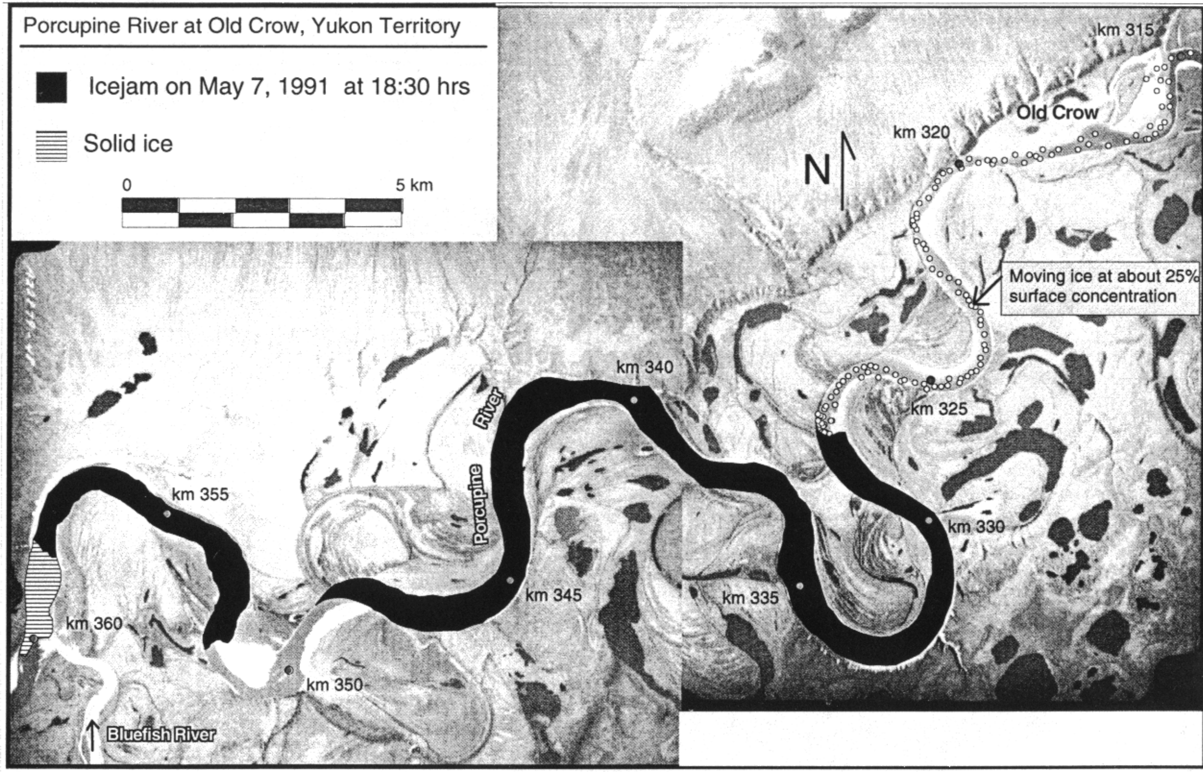

Figure 6. Observations on May 7, 18:30 showing location of the ice jam. Water levels in Old Crow were causing only minor flooding at this time. A portion of the ice jam had collapsed creating an open water section between km 358 and km 352.

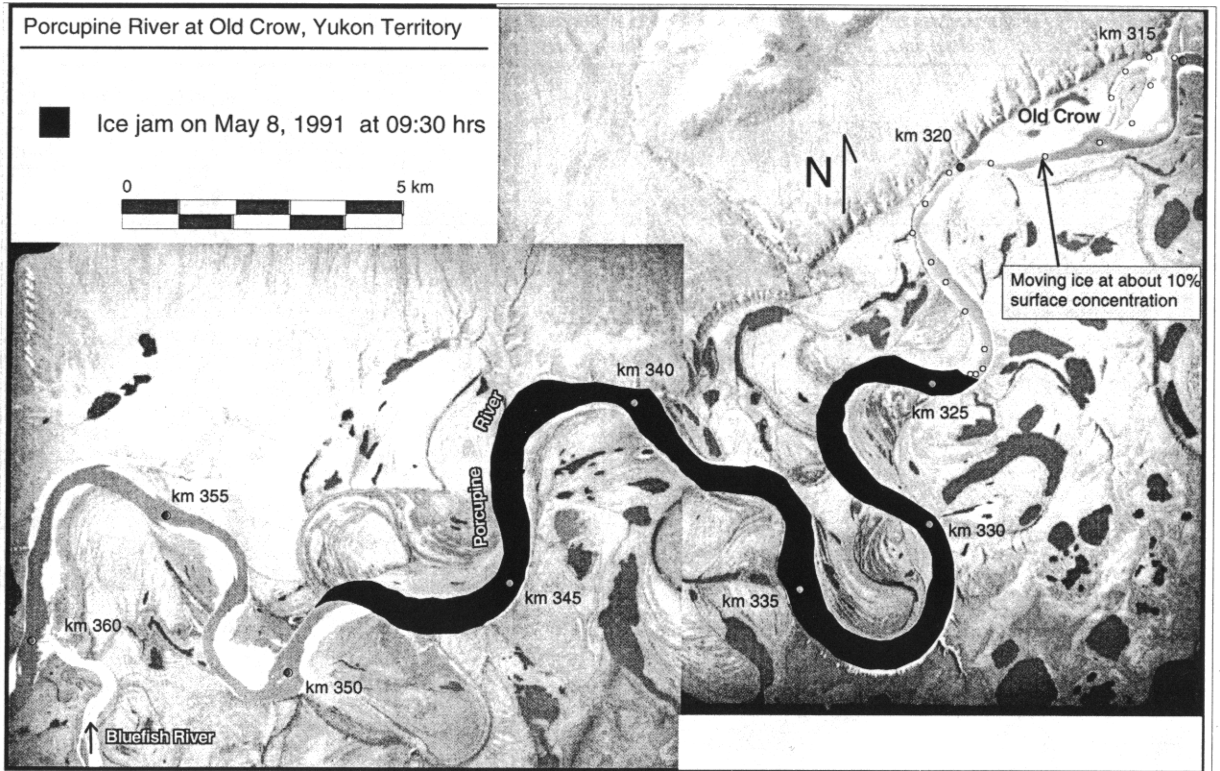

Figure 7. Observations on May 8, 09:30 showing the location of the ice jam just prior to the peak water level in Old Crow. The upstream end of the ice jam was 5 km downstream of the community. The downstream segment of the ice jam had released completly the evening prior.

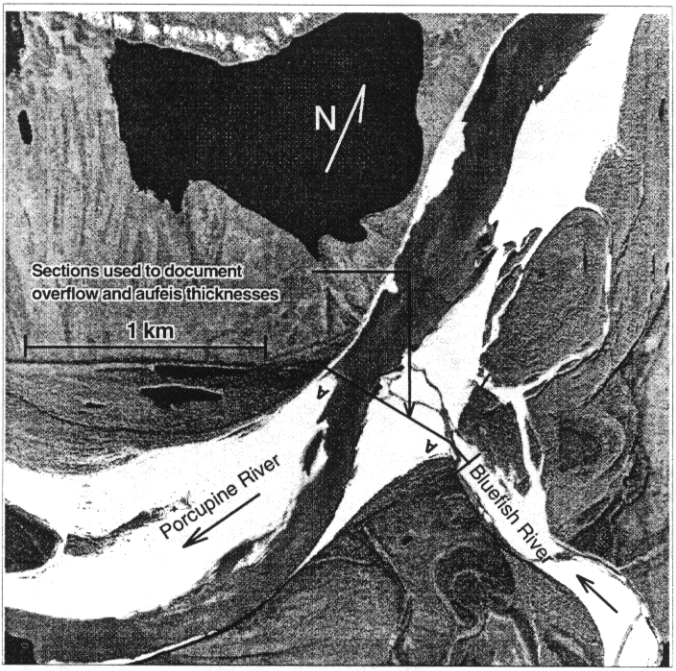

Figure 8. Porcupine River and Bluefish River confluence, and cross-sections at which aufeis was measured.

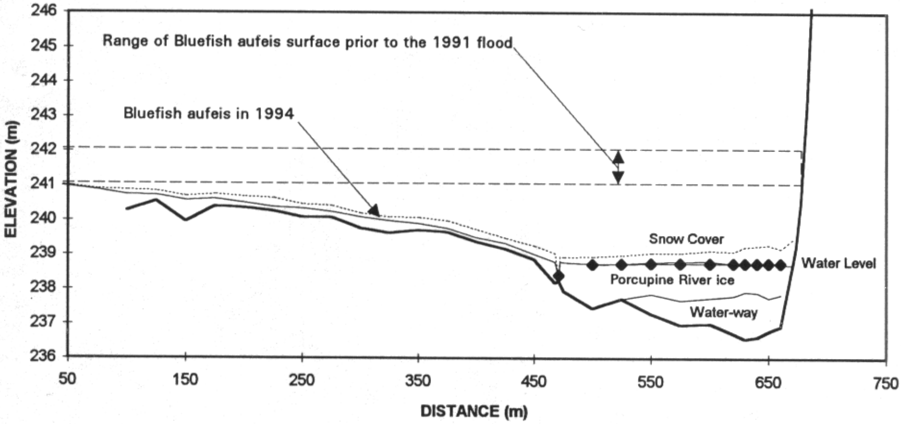

Figure 9. Ice surface profiles on the Porcupine River at the mouth of the Bluefish River for 1991 and 1994 (Section A-A).

Figure 10a. Aufeis causing ice dam on the Porcupine River at mouth of Bluefish River on May 9, 1997. Backwater from this ice dam has caused an ice jam to form several kilometers upstream. Photo taken looking north and upstream on Porcupine River. Bluefish River comes into the Porcupine on the right hand side of the photograph. Note tranquil sub-critical flow upstream of the aufeis and the rapids or supercritical over top of it.

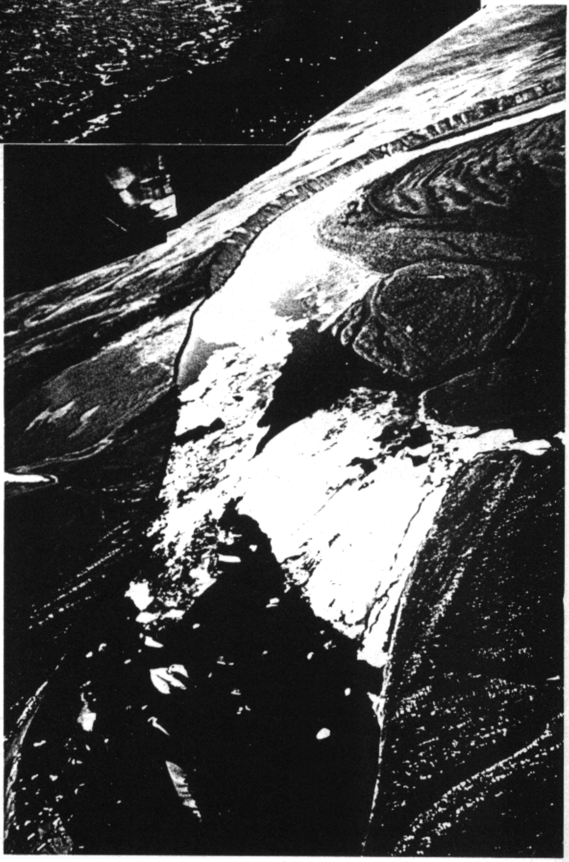

Figure 10b. Reduced discharge on May 11, 1997 provided a clear view of the aufeis formation at the Bluefish - Porcupine River Confluence. Photo taken looking upstream on the Porcupine River.

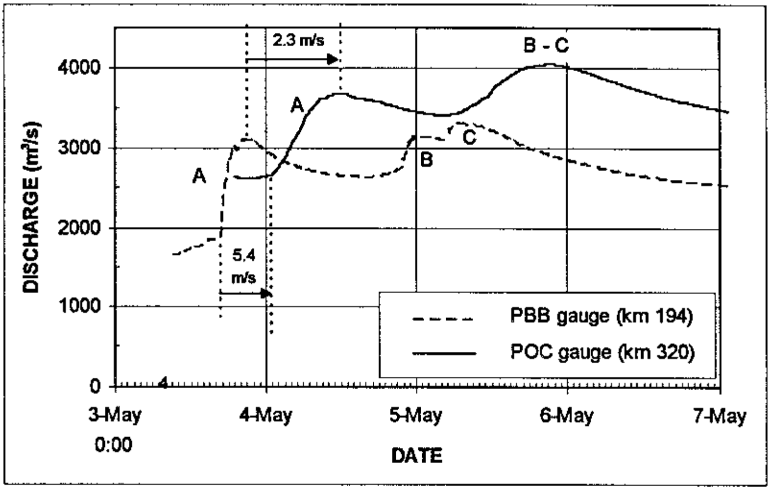

Figure 11. Hydrographs of surge activity at the PBB and POC gauges during the 1995 break-up. Surges resulting from Jams A, B and C are shown (Jasek 1996).

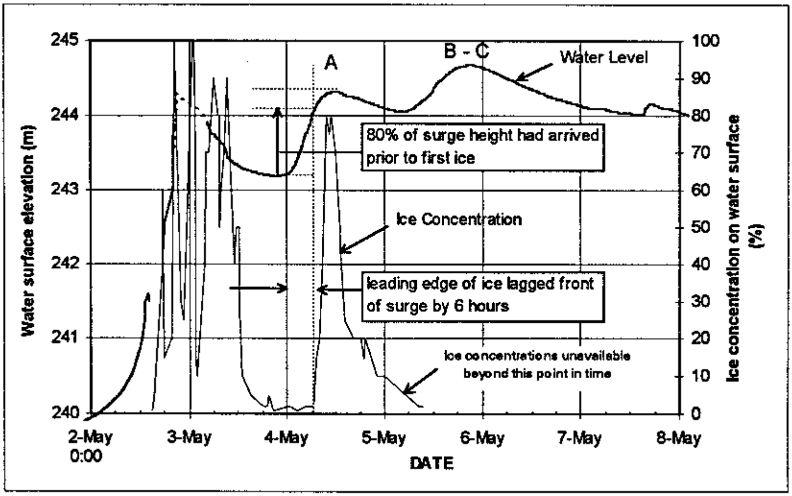

Figure 12. Water surface elevation at WSC gauge at Old Crow in 1995. Water surface ice concentration is also shown.

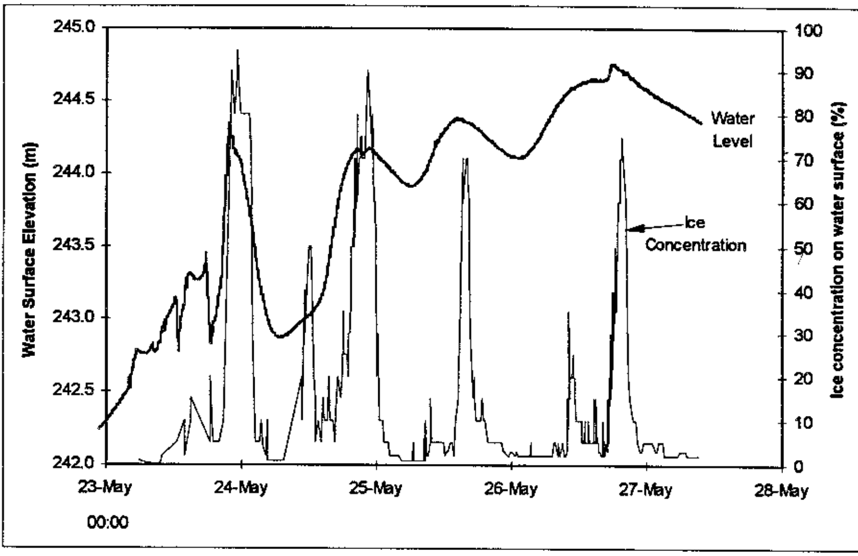

Figure 13. In 1996 three surges following the initial break-up front were documented.

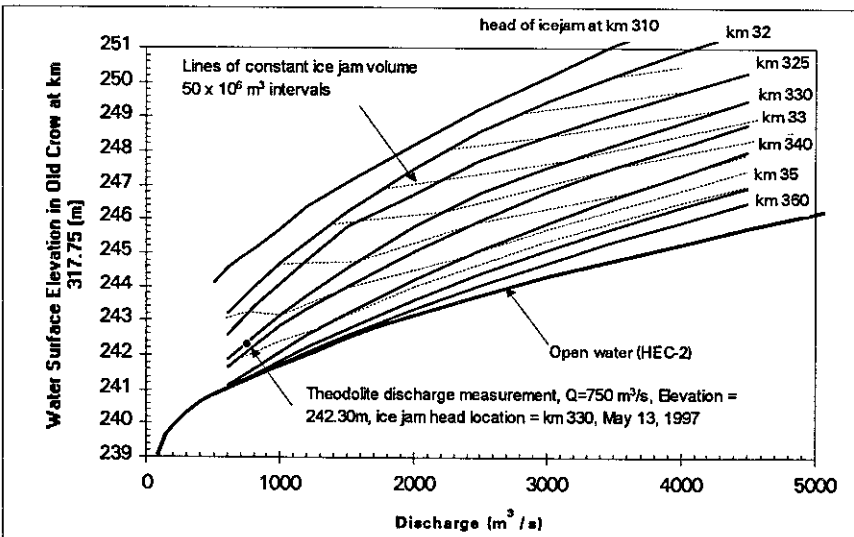

Figure 14. Multi-variable ice jam rating curves developed using the ICEJAM model and HEC-2.