HYDROMETEOROLOGIC CONDITIONS PREVAILING DURING THE 1984 RIVER ICE BREAKUP, FORT SIMPSON REGION, N.W.T.

by

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ABSTRACT

Observations were made of the progress of river ice breakup and ice jamming on the Liard and Mackenzie Rivers within a 30 km radius of Fort Simpson, NWT. The 1984 breakup was an overmature or thermal event, characterized by: a) extensive melt and thermal weakening of the ice sheet prior to ice clearance, and b) the absence of a large spring flood wave. An ice jam formed at the Liard River mouth raising the stage to 122.2 m (amsl) at the Liard River gauging site. This water level included 3.9 m of ice jam backwater and translates into a mean flow depth approximately 2.3 times greater than that which would occur with equivalent discharge under open water conditions. Breakup of the Mackenzie River, including the portion upstream of the Liard confluence, was concomitant with the release of the Liard River ice jam. The resulting ice temporarily jammed at a bend 20 km downstream of Fort Simpson island, but released before water levels at Fort Simpson rose above 118.9 m (amsl). The 1984 breakup water levels on both rivers are the second lowest on record since detailed breakup observations began in 1978.

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March 15, 1985

Mr. A.R. Waroway
Head, Engineering and Planning Section
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Dear Mr. Waroway

Attached is a copy of a report on the breakup of the Liard and Mackenzie Rivers near Fort Simpson, in April-May 1984. The report is primarily a descriptive chronology of breakup observations made during the 1984 event. The field information obtained from this and previous events forms the data base for a detailed analysis of breakup and ice jamming conditions in the area. A paper which focuses on ice jamming at the Liard River mouth is in final preparation and will be forwarded to you when complete.

Sincerely,

T.D. Prowse
Research Scientist

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1. INTRODUCTION

This study is a continuation of work begun in 1982 by the National Hydrology Research Institute (NHRI) under the auspices of the Department of Indian Affairs and Northern Development. The primary objective of the study continues to be: to investigate the timing and characteristics of river ice breakup on the Liard and Mackenzie Rivers within a 30 km radius of Fort Simpson, NWT. Previous reports include Anderson (1982) and Prowse (1984) which provide descriptive chronologies of the 1982 and 1983 breakups, respectively. Prowse (1984) also details the hydrometeorologic conditions which lead to river ice breakup and ice jamming, and reviews the history of flooding in the area. As part of a larger regional study for the Mackenzie River Basin Committee, NHRI has also investigated the progression of breakup along the Liard River over a three year period 1978-1980. Sherstone (1981) chronicles the breakup in these years, and Anderson and Fogarasi (1981) discuss the hydroclimatic factors which lead to the generation of spring floods on the river.

This report is primarily a descriptive chronology of the 1984 river ice breakup. The information obtained from this and previous events forms the data base for a detailed analysis of breakup and ice jamming conditions on the Liard River. The 1984 observational results are presented in two sections. The first describes the general climatic and hydrologic conditions which prevailed during breakup. The second section is an abstraction of detailed field notes referenced to hydrometric station data. A brief conclusion summarizes the 1984 conditions and compares them to those of other recent years.

2. STUDY SITE

Fort Simpson (61°53'N, 121°22'W) is located on an alluvial island near the confluence of the Liard and Mackenzie Rivers, approximately 520 km south of the Arctic Circle in the District of Mackenzie, NWT. Draining an area of approximately 280,000 km^2, the Liard River is the second largest tributary of the Mackenzie River. Much of the upper Liard River basin lies within the relatively steep terrain of the Western Cordillera while the lower portions are located in the flat plains of the Interior Plateau. The slope of the lower 500 km stretch of the river, from its headwaters to the confluence with the Mackenzie River, is shown in the inset of Figure 1.

For approximately half the year, the rivers near Fort Simpson are ice covered, freezing over in November to mid-December and breaking up in late April to mid-May. The Liard River, which flows from the warm more mountainous regions to the west, usually acts as a `trigger' to breakup on the Mackenzie River downstream of Fort Simpson. In most years, the Mackenzie River from Fort Simpson to Fort Good Hope clears of ice before the lower or upper reaches of the river (MacKay and Mackay 1973). Spring flow in the upper Mackenzie River is dependent on runoff from southern tributaries, such as the Athabasca, Hay, Peace and Slave Rivers, although discharge from these basins is heavily damped by the stabilizing effects of Great Slave Lake. Normally, the stretch of the Mackenzie River between Fort Simpson and Great Slave Lake remains intact approximately two weeks longer than the section immediately downstream of Fort Simpson and consequently experiences a much more mature type of breakup.

There are three sites prone to ice jamming within the study area. Firstly, the Liard River mouth is known to be a site of almost annual ice jam formation. The combination of change in slope, widening of the channel and the presence of intact Mackenzie River ice cover leads to the accumulation of large quantities of ice at the river mouth. Release of these jams usually initiates breakup of the Mackenzie River ice cover. On the Mackenzie River there are two ice jam prone sites: the shoals just downstream of Fort Simpson Island (MKP* 340) and the sharp bend in the river approximately 20 km downstream of Fort Simpson (MKP 355). Both of these latter two sites pose the greatest hazard of backwater flooding for the town of Fort Simpson.

Flow on the Liard and Mackenzie Rivers is monitored by two hydrometric stations operated by the Water Survey of Canada. The Liard River station (No. 10ED002) is located approximately 17 km upstream of the river mouth and the Mackenzie River station

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* *MKP and LKP refer to kilometer positions on the Mackenzie and Liard Rivers respectively.*

(No.10GC001) is located on Fort Simpson island. The Atmospheric Environment Station operates one station in the area at the Fort Simpson Airport (Fort Simpson 'A').

3. GENERAL HYDROMETEOROLOGIC CONDITIONS

River ice breakup near Fort Simpson was preceded by a prolonged period of above normal temperatures (Fig. 2). Maximum daily air temperatures at Fort Simpson were over +12°C at the beginning of April, although the normal maximum temperature for the month is only +3.8°C (A.E.S. 1982). Moreover, during the entire month, the maximum temperature fell below the freezing mark for only two days. In the seven years that NHRI has monitored spring breakup on the Liard River, only the 1980 event was noted to have a comparable degree of pre-breakup warming. This is evident in Table 1 which contains the number of melting degree days (AMDD) accumulated from April 1 to the time of breakup in each year (breakup at the Liard River ferry crossing). All years registered highly negative values (-56 to -174) except for 1980 and 1984 in which AMDD reached +149 and +71 respectively.

YEAR	DATE	AMDD	Q
1978	MAY 03	-61.7	2270
1979	MAY 11	-174.2	900
1980	MAY 02	+149.1	1700
1981	MAY 07	-73.0	2800
1982	MAY 09	-55.7	1000
1983	APR 29	-48.3	1450
1984	APR 29	+70.8	1460

Table 1. ACCUMULATED MELTING DEGREE DAYS (AMDD) All data refers to the Liard River ferry crossing site. Degree days are accumulated from April 1 to time of breakup. Q is daily discharge.

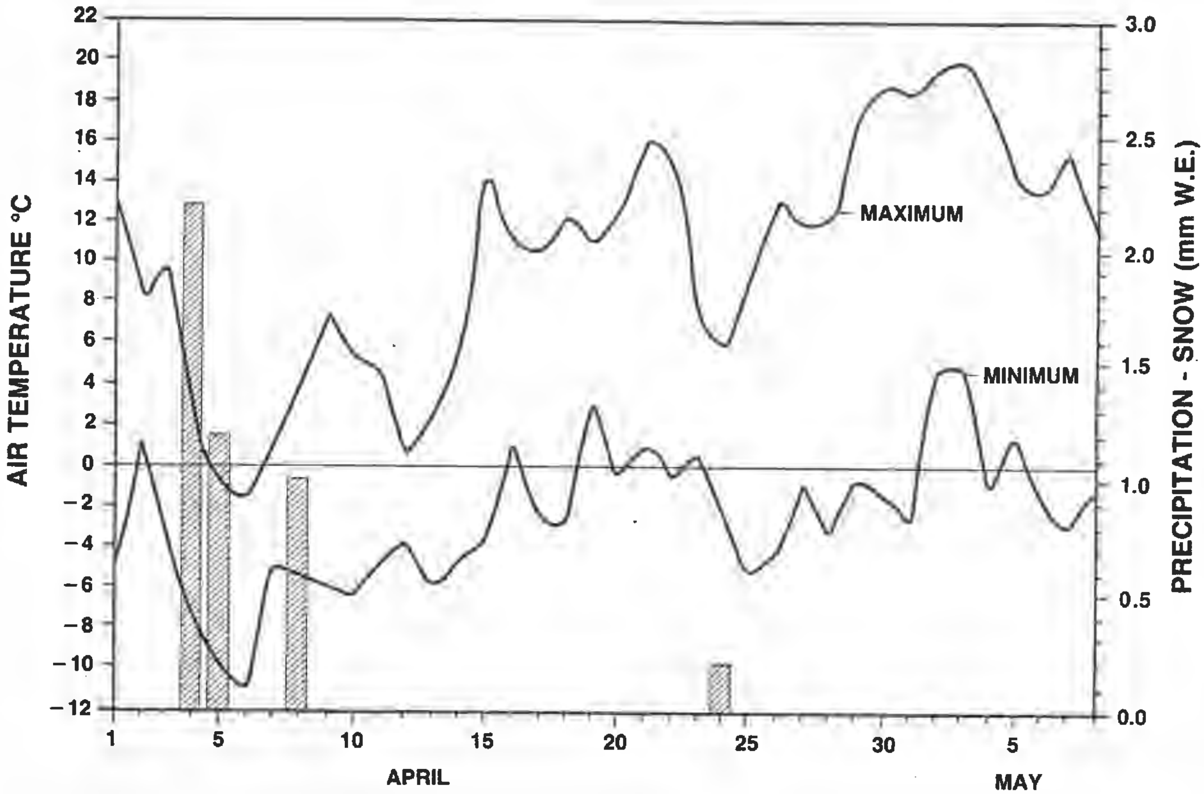

Figure 2. METEOROLOGIC CONDITIONS. Atmospheric Environment Service Station: Fort Simpson 'A'.

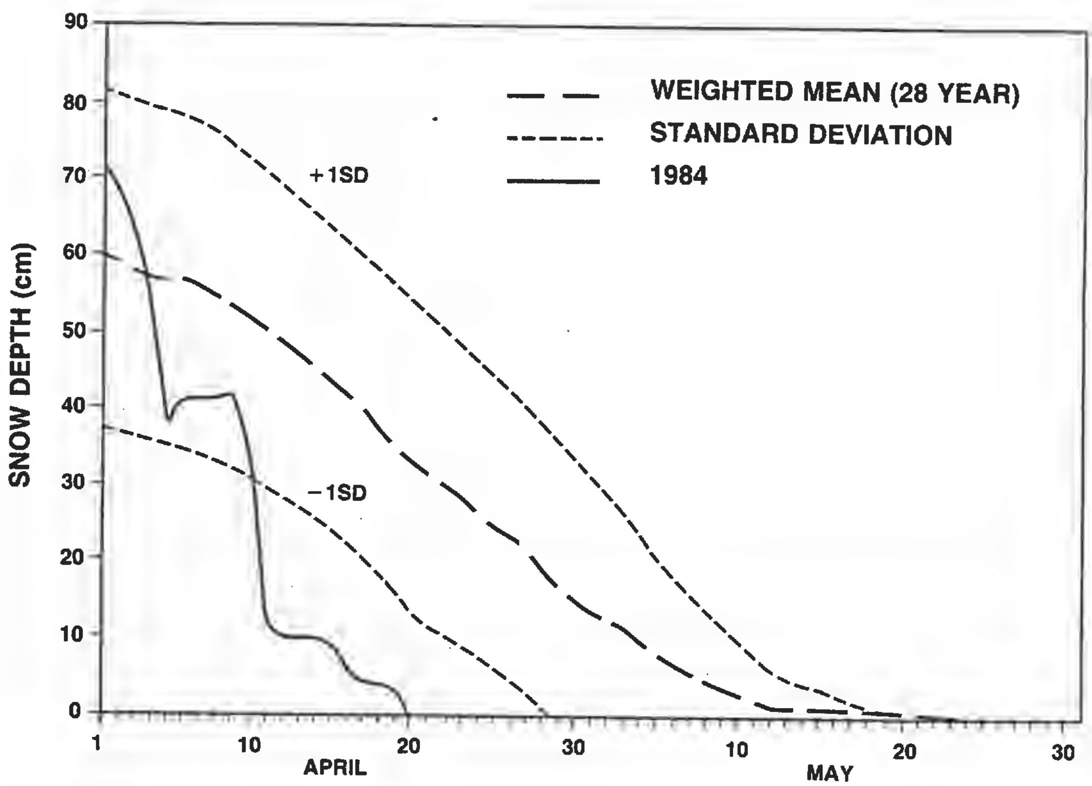

Figure 3. SNOW COVER DEPLETION. Atmospheric Environment Station : Fort Simpson 'A'.

Snow depths were slightly above normal at the beginning of April, but warm conditions rapidly depleted the snowpack to below normal levels within a matter of days (Fig. 3). Snowmelt was interrupted by the brief cold period, mentioned above, and a light snowfall (4.4 mm W.E.) in the middle of the first week of April (Fig. 2), but with a return to warm conditions, snow depth was reduced to only a trace by April 20 - over 20 days earlier than the long term average date.

On April 20, flow on the Liard River was 36% above normal at 658 m^3/s (Fig. 4) and near normal on the Mackenzie River at 2600 m^3/s (Fig. 5). Until the main breakup period (April 30-May 4), discharge remained above normal on the Liard and below normal on the Mackenzie River. Notably, discharge on the Liard River on the day before breakup was almost exactly the same as that in 1983, a year of spectacular ice jamming. (The date of breakup was also the same in both years: April 30). During the main breakup period, however, the Liard River discharge remained relatively constant, rising at maximum rates of only 150 $m^3/s/dy$ to 1810 m^3/s and never producing a true spring flood wave. In contrast, during the 1983 breakup, discharge rose very quickly at rates of 600 $m^3/s/dy$ to a much higher maximum of 4200 m^3/s. Despite below normal discharge on the Mackenzie River, breakup of the river upstream of the confluence was almost concomitant with that of the lower Liard River. More detailed

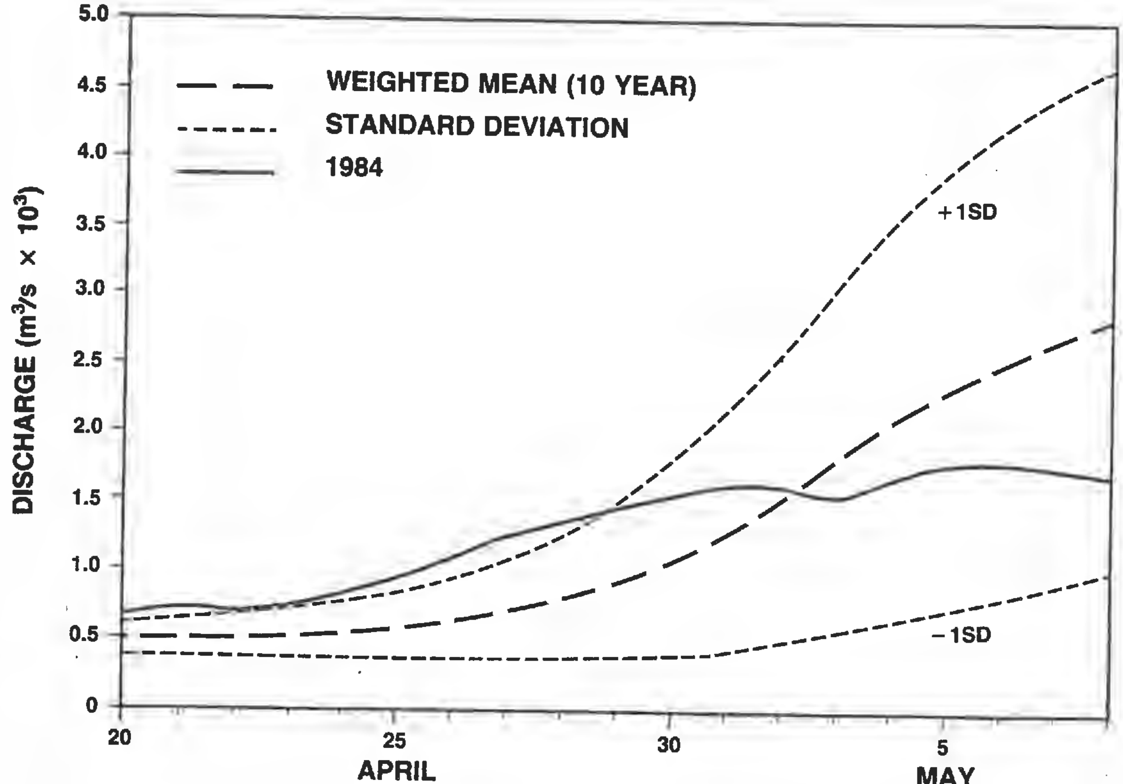

Figure 4. DISCHARGE OF LIARD RIVER NEAR THE MOUTH. Weighted mean derived from record 1973-1982. Source: Water Survey of Canada.

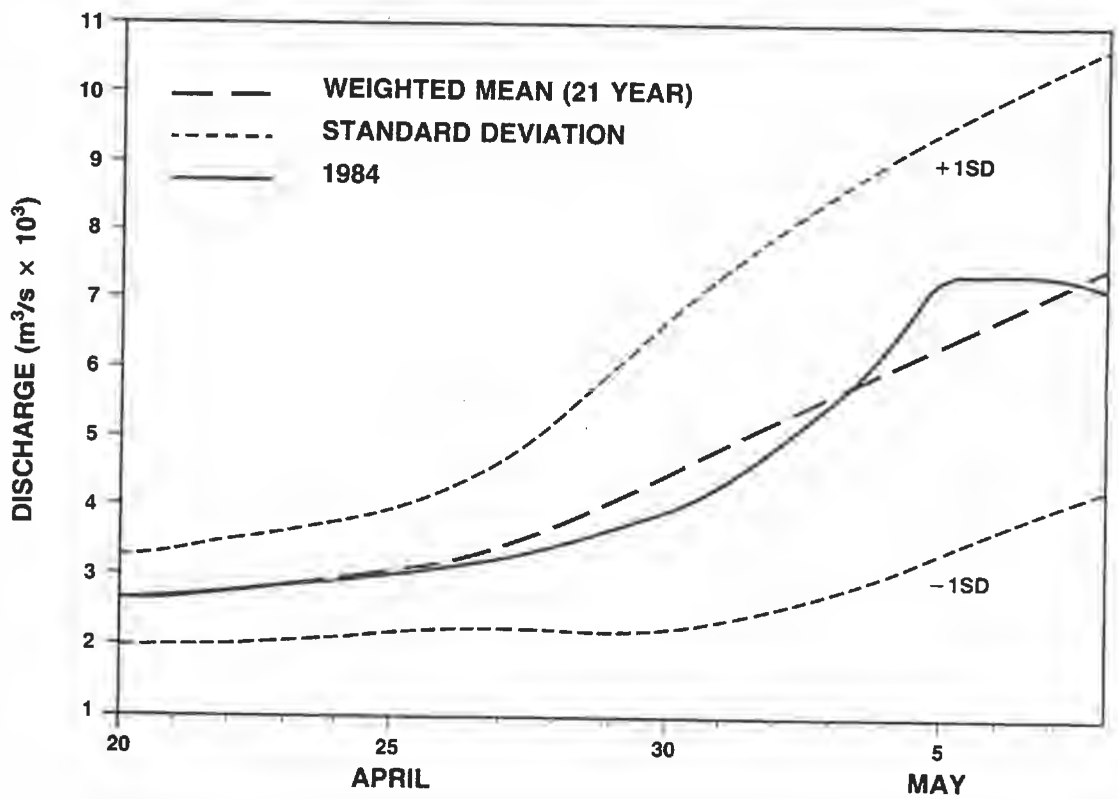

Figure 5. DISCHARGE OF MACKENZIE RIVER AT FORT SIMPSON. Weighted mean derived from record 1960-1982 (excluding 1961). Source: Water Survey of Canada.

discussion of discharge and water levels related to the progress of breakup is included in the next section.

4. BREAKUP CHRONOLOGY

Daily on-site monitoring of ice conditions on the Liard and Mackenzie Rivers near Fort Simpson began on April 20. By that time, the ice cover on most small upstream tributaries had broken up and released into the Liard River. A single breakup front, such as that which dominated the 1983 breakup, did not develop. Instead, breakup was very non-sequential with a number of breakup fronts forming at tributary mouths and in high velocity reaches.

By April 20, the ice cover on both the Liard and Mackenzie Rivers near Fort Simpson was already in an advanced state of decay. Although the ice sheet still remained frozen to the banks, open water leads, up to 1.5 m wide, overlaid the shore-fast ice. Extensive melt of the river snow cover had produced large zones of surface slush, 10-30 cm deep. In other locations, black ice (thermal ice) was exposed at the surface.

The following details some of the more important daily changes in river ice conditons. Water levels are illustrated relative to ice phases in Figure 6. In the text, stated water levels and rates of rise refer to those recorded at the Liard and Mackenzie River hydrometric stations.

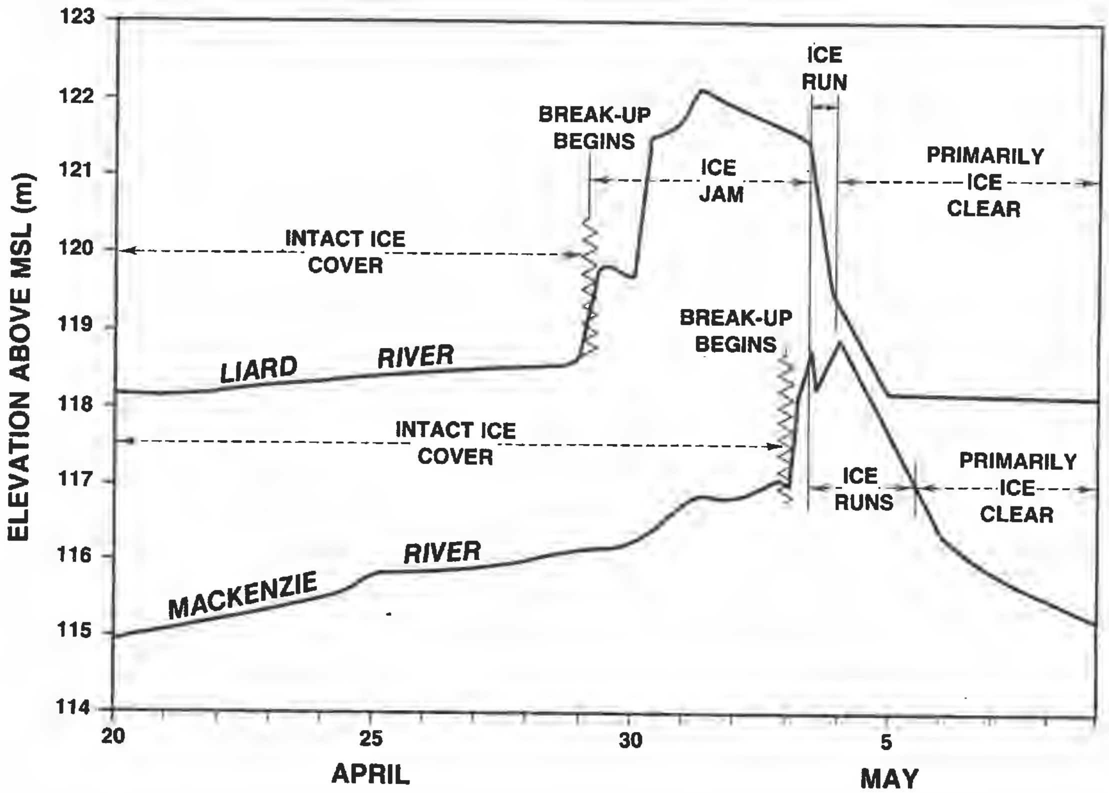

Figure 6. **WATER LEVELS DURING BREAK-UP. Source: Water Survey of Canada and site surveys.**

April 24: Water levels on the Liard River were rising on average 5 cm/dy, and water was beginning to upwell along hinge cracks (cracks running generally parallel to the shore and separating the shore fast ice from the main ice sheet). The Mackenzie River at Fort Simpson was rising at a much higher rate of over 16 cm/dy.

April 25: Large sections (10-20 m long) of shore fast ice began to lift near the Liard ferry crossing. Shore leads had now grown up to 15 m wide. Late in the day, the ice began to lift and a considerable amount of meltwater which was ponded on the surface drained into the river.

April 26-27: Zones of open water continued to grow at many locations near the centre of the ice sheet. Typical river ice conditions are shown in Photograph 1. Velocity experiments were discontinued and meteorological instrumentation was removed from the Liard River because the ice surface was considered unsafe for travel. Photograph 2 shows the degree of hydrothermal melt which had already occurred at the bottom of the ice sheet. Water was now beginning to flow in the shore leads.

A reconnaissance flight upstream revealed that ice was beginning to fracture below a number of open water sections. The Liard River ice cover at Fort Liard appeared to be more competent than that near Fort Simpson, although the Petitot River had already run clear of ice.

April 28: Ice just upstream of the Liard River ferry crossing shifted downstream and formed a pressure ridge (3-4 m high) running normal to the flow. The ice sheet was almost completely free floating with little attachment to the banks.

April 29: Large sections of ice on the lower portions of the Liard River began to separate from the main ice sheet (Photo. 3). In many areas only black ice was exposed at the surface and was beginning to show the effects of candling to a considerable depth (Photo. 4).

Large pans of ice began to shift at the Liard River ferry crossing. Water was spilling out in front of the pressure ridge on to the intact downstream ice cover. Water levels continued to rise at an average rate over the day of approximately 13 cm/hr. At 17:10 the ice began to push in and consolidate near the ferry crossing. By 18:40 a small jam of large pans had formed with the toe just downstream of the ferry crossing. The first large rise in Liard River water levels in Figure 6 is associated with this period of breakup and ice jamming.

Downstream of the jam, the ice cover remained relatively competent. Shore leads continued to grow and a considerable number of open water areas dotted the river mouth near Truesdell Island.

April 30: Overnight water levels on the Liard River slightly decreased (Fig. 6). Figure 7 illustrates the situation in the early morning. During the day, ice began to fracture further downstream as far as LKP 8. Water levels later in the day began to rise and in the evening new ice, released from upstream, began to accumulate behind the existing jam. At 21:43 the toe was near LKP 08 and the head near LKP 19.5. The downstream section was largely comprised of large pans, while the upstream portion was mostly small, brash ice.

May 01: By early morning, a considerable amount of new ice had been added to the Liard River jam (Fig. 8). The toe, still comprised of large ice pans, had moved further downstream to Franklin-Clarke Island (Photo. 5). The position of the jam head continued to fluctuate during the day with further additions of upstream ice, although the jam did not appear to compact and thicken.

Breakup water levels at the Liard River gauge peaked at 122.15 m in the early evening (17:18). By this time the head of the jam had moved down to a point just downstream of Sawmill Island. The jam length and area at the time of maximum water level was 13.1 km and 11.0 km^2 respectively. At a discharge of 1680 m^3/s, the jam produced approximatley 3.9 m of backwater at the Liard River gauge and a mean depth of flow 2.3 times greater than that which would occur with equivalent discharge under open water conditions.

A number of elevational profiles were taken through the ice jam reach, using previously established bench marks, but no discernible change in slope was observed, even at the ice jam toe. The slope closely mirrored that recorded during a pre-breakup survey.

Beginning at approximately 14:00 the Mackenzie River ice cover near Fort Simpson began to extensively fracture, producing some large transverse cracks and leads. Considerable amount of open water was present around the shoals downstream of Fort Simpson island. Notably, sections of open water developed in the bend at MKP 355 and in the upstream reach near Green Island. Some evidence of small ice shoves, produced by large scale shifting of the ice sheet, was apparent on the right bank.

May 02: The ice conditions illustrated in Figure 9 for early morning of May 2 are very similar to those described above for late on May 1. The Liard River jam remained stationary, and water levels and discharge continued to decrease. The influx of ice from upstream had almost totally ceased. A reconnaissance flight further up the Liard River revealed that most of the intact ice cover had now been removed although a considerable amount of ice had accumulated within a number of small jams.

May 03: The head of the Liard River ice jam began to move downstream. The toe of the jam, however, remained at Franklin Clarke Island, despite the presence of a large open water zone at the Liard mouth (Fig. 10; Photo. 6).

At 11:40 large sections of the Mackenzie River ice cover began to shift downstream and cover over some of the open water zones downstream of Fort Simpson island. The Mackenzie River ice cover continued to shift throughout the day in small ice runs (Photo. 7). Water levels steadily increased throughout the day, by as much as 50 cm/hr. Upstream of the confluence, open water now reached as far downstream as MKP 328 (Photo. 8 and 9).

At 21:58 a major ice run started and continued throughout most of the night. The initial part of this run was fed by ice from the Liard River jam, and in later hours by ice from upstream reaches of the Mackenzie River. Clearance of the ice jam is reflected in the dramatic decrease in Liard River water levels

(Fig. 6). Although a considerable amount of ice remained stranded on the shoals and along the banks of the Liard River, the thickness of these accumulations was usually less than 2 m - evidence that the ice jam was also relatively thin.

May 04: Mackenzie River water levels temporarily decreased during the night, but by the morning of May 4 the stage was again rising. Although the river opposite Fort Simpson was only partly ice covered (brash ice accumulation), a jam had formed downstream near the bend at MKP 355 (Photo. 10; Fig. 11). At 11:15 the Mackenzie River breakup water levels peaked at 118.89 m. At a discharge of 6300 m^3, over 3.9 m is attributable to backwater.

The Mackenzie ice jam was only short lived and water levels began to decrease for the remainder of May 4. By 17:00 the Mackenzie River was clear of most floating ice as far downstream as MKP 365. As in the case of the Liard River, no large ice jam shear walls remained along the banks.

May 05: Large concentrations of brash ice flowed past Fort Simpson, but water levels continued to drop until the river was entirely clear of ice several days later.

5. SUMMARY

The 1984 river ice breakup near Fort Simpson can be classed as an overmature or thermal event. Unseasonably warm conditions during much of April produced extensive melt and thermal weakening of the ice sheet. Although flow on the Liard River was slightly above normal in the pre-breakup period, early melt of the snowpack precluded the development of a large spring flood wave. Discharge, therefore, remained below normal during the period of ice clearance.

Despite the weakened state of the ice sheet, an ice jam did develop near the Liard River mouth. Breakup water levels at the Liard River gauge reached a maximum of 122.2 m, 3.9 m of which was backwater produced by the downstream ice jam. These figures translate into a mean flow depth which is 2.3 times greater than that which would occur with equivalent discharge (1680 m^3/s) under open water conditions. In the seven year period for which there are reliable records of maximum breakup stage at this site (Prowse 1984), only the 1980 event, which was also a thermal breakup, resulted in lower water levels (maximum = 121.4 m). The average maximum for the other five years of mechanical breakups is 126.6 (range of 125.2 to 128.2).

Clearance of the Liard River ice jam was almost concomitant with breakup of the Mackenzie River upstream of the confluence. The resulting ice run temporarily jammed at a bend approximately 20 km downstream of Fort Simpson island. Ice jams which lodge at this location can create a significant flood hazard for the town of Fort Simpson. During the 1984 event, however, water levels at Fort Simpson reached a maximum of only 118.9 m. Notably, the magnitude of backwater from this jam (3.9 m) is identical to that which resulted from the Liard ice jam. Furthermore, as in the case of the Liard River, only the 1980 breakup produced a lower maximum water level on the Mackenzie River at Fort Simpson (118.4 m). A water level of approximatley 123.0 m is required before even the lower terrace of Fort Simpson island becomes flooded.

6. REFERENCES

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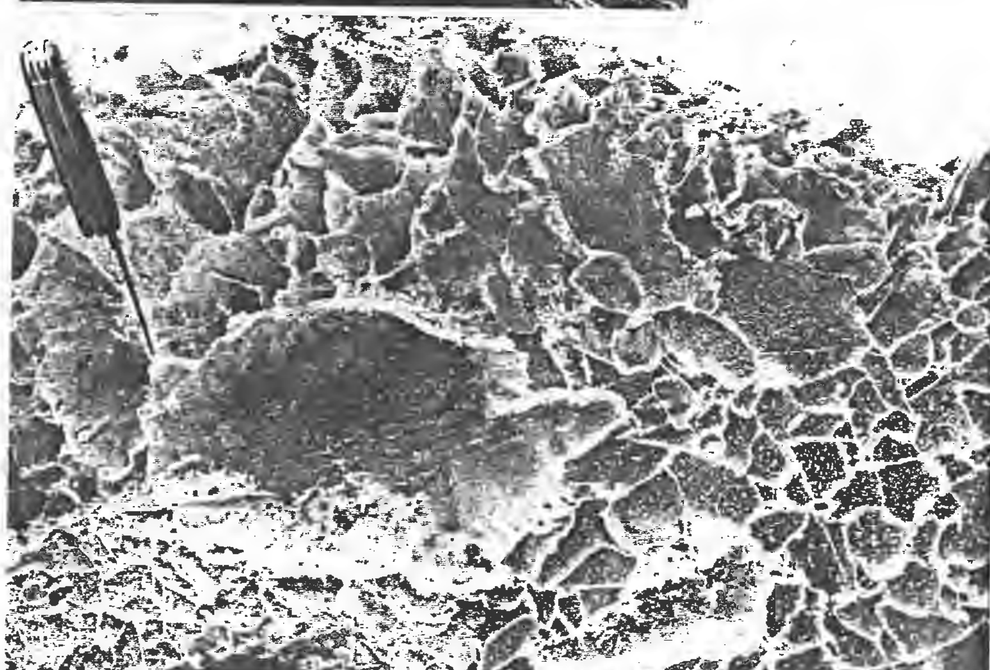
Photograph 1: DECAYED LIARD RIVER ICE COVER, APRIL 26. View downstream the Liard River from Sawmill Island (bottom right) towards the ferry crossing. Note the large areas of exposed shoal and the zones of open water in the central portions of the ice sheet.

Photograph 2. THERMAL MELT OF THE ICE BOTTOM. The bottom surface of recently upturned ice was pockmarked by holes approximately 2-4 cm wide and 5-8 cm deep. Note the pencil inserted into one of the holes for scale.

Photograph 3: ICE COVER RELEASE, APRIL 29. View upstream the Liard River from Sawmill Island. Large sections of the ice sheet began to separate and pull away from the remaining intact ice. Note the large expanse of open water in the background.



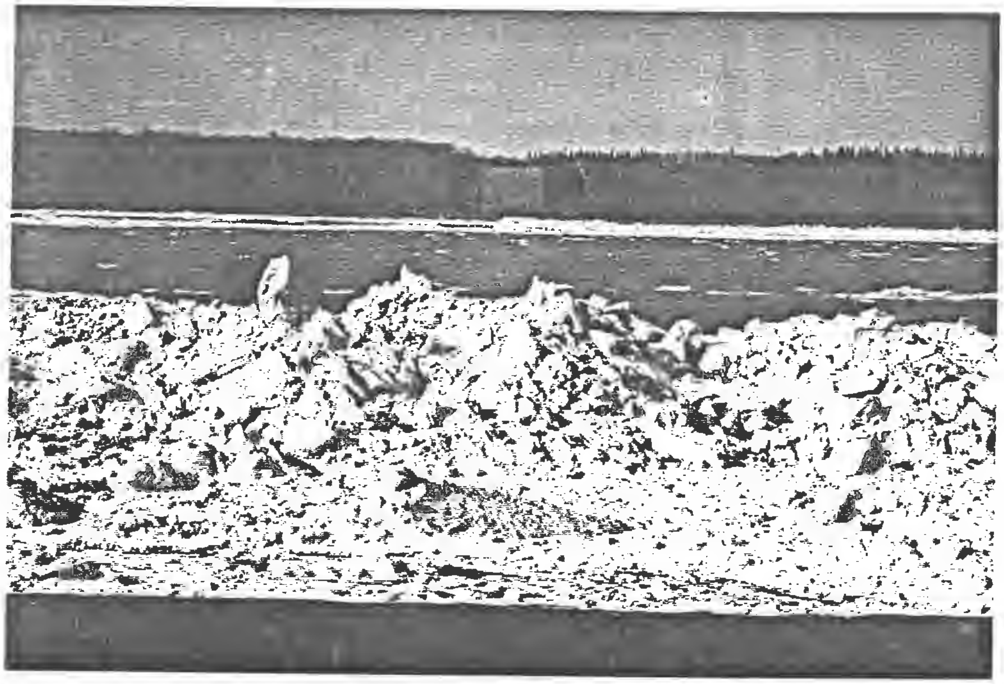
Photograph 4: SURFACE OF DECAYING BLACK ICE. Melt at crystalline boundaries exposed the crystal mosaic of the 'thermal' ice cover. In some locations, complete candling had occurred.

Photograph 5: TOE OF THE LIARD RIVER ICE JAM, MAY 1. View upstream the Liard from Franklin-Clarke Island shown on the left. The toe of the jam (foreground) was comprised of large floes, some 200 m or more in diameter, while the upstream portion (background) was filled in with small diameter brash ice.

Photograph 6: LIARD RIVER MOUTH, MAY 3, 07:00. View upstream the Liard River from the confluence with the Mackenzie River. Large areas of open water have developed in the river mouth around the Truesdell Island group (foreground) but considerable ice is still jammed further upstream (background).

Photograph 7: ICE RUN, MACKENZIE RIVER AT FORT SIMPSON, MAY 3, 17:25. Note the large diameter ice floes in the ice run and the water within the snye behind Fort Simpson island. Although the Liard River ice moved downstream with this ice run, the major run which ultimately cleared the Mackenzie River at Fort Simpson began approximately four hours later.

Photograph 8: UPSTREAM MACKENZIE RIVER, MAY 3, 17:26. View upstream the Mackenzie River from the Liard confluence to Green Island. The upstream portions of the Mackenzie River began to clear at approximately the same time that the Liard River ice began to spill into the Mackenzie River at Fort Simpson. Note the large ice island in the centre of the open water reach (background).



Photograph 9: ICE ISLAND, MACKENZIE RIVER, MAY 3. View across the Mackenzie River to the pipeline crossing road. This ice island (shown in photograph 8) remained after the upstream portions of the Mackenzie River cleared of ice. The island rises approximately 8 m above the water surface and is probably grounded on the Kellett Shoal.

Photograph 10: MACKENZIE RIVER BELOW FORT SIMPSON, MAY 4, 06:41. Ice temporarily jammed at the large bend (background) downstream of Fort Simpson. Note the difference in ice colour between the moving ice (dark) and the relatively stationary ice (white) along the margins.