PEACE-ATHABASCA DELTA
Technical Studies

ARTIFICIAL ICE DAM
1994-95 FIELD REPORT

TASK F.3 - ARTIFICIAL ICE STRATEGIES

Towards an ecosystem management plan

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1994-95 FIELD REPORT

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PEACE-ATHABASCA DELTA
TECHNICAL STUDIES

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PREFACE

This publication reports the method and findings of one component of the Peace-Athabasca Delta Technical Studies. The Technical Studies comprised a three year program of research initiated to "understand available options and select the most suitable remediation strategy for restoring the role of water in the delta". The program was established in April 1993 through a Memorandum of Understanding signed by representatives from the Governments of Canada and Alberta, British Columbia Hydro and Power Authority, the Mikisew Cree First Nation, the Athabasca Chipewyan First Nation, and the Fort Chipewyan Metis Association.

The Peace-Athabasca Delta Technical Studies were initiated through a recognized need for further research regarding the effects of Peace River flow regulation and climatic variability on the hydrological processes of the delta, particularly with regard to the spring ice-jam induced flooding of the high elevation perched basin environments. The results of such research, and further assessments of remediation options, support the development of a strategy for restoring the role of water. Future implementation of this strategy will occur through an Ecosystem Management Plan for the Peace-Athabasca Delta as a next step following completion of the Peace-Athabasca Delta Technical Studies. This plan will require rigorous development of specific ecological objectives prior to the selection or implementation of any remedial measures directed toward the general objective of restoring the role of water in the delta.

Study Perspective:
Artificial Ice Dam, 1994-95 Field Report

Strategies employing man-made ice structures to promote breakup water levels capable of inundating the elevated perched basins of the delta were evaluated in recognition of the historical role of ice in generating such floods. As ice structures, such interventions are attractive because they are temporary in nature. Two contrasting strategies - artificial ice jams (AIJ) and artificial ice dams (AID) - that operate on different scales and under different hydraulic conditions were investigated during the life of the Peace-Athabasca Delta Technical Studies. This report describes the results of the 1994-95 Artificial Ice Dam experiment.

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1.0 INTRODUCTION

The goal of the Peace Athabasca Delta (PAD) Technical Studies is "to understand available options and select the most suitable remediation strategy for restoring the role of water in the delta" (Peace Athabasca Delta Technical Study Committee, 1993). This goal is being carried out by a Technical Studies Steering Committee. As the past hydrological regime in the delta was influenced by natural ice jams, one of the task assignments of the Steering Committee was to investigate the feasibility of creating artificial ice jams in the delta to, in part, replicate the natural regime. The original objectives of the ice jam studies were to:

1. promote ice jamming by artificially increasing ice thickness on small tributaries within the delta. Ice jams will be attempted each year over the course of the project;

2. monitor the breakup of artificial jams to increase our understanding of ice jam dynamics and improve ability to create future jams and predict natural ones; and

3. obtain assistance from the National Hydrology Research Institute.

This report describes the results of the third artificial ice jam field season. The results of the 1992/93 and 1993/94 artificial ice jam field seasons are described by Peterson (1993,1995). The Steering Committee recommended revisions to the objectives of the study following review of the previous field seasons' results, including:

1. moving the ice jam site to a location on the Quatre Fourches River near Dog Camp, where spring runoff from the Birch River/Embarras cutoff could be backed up. An actual ice dam, blocking off the entire river channel, would be constructed rather than attempting to artificially cause an ice jam;

2. determining the required dimensions of the ice dam using:
   - ground penetrating radar to discern the nature of the river bed at the dam site, and
   - a one-dimensional (1-D) hydrologic model to predict the amount of flooding that would occur with varying degrees of flow blockage.

3. using microclimate data and rate of ice deposition data collected from previous ice jam attempts to maximize the efficiency of this year's activities;

4. implementing a monitoring program to record site specific meteorological conditions, ice growth and decay, channel bed material and depth, break up-stage, ice and water temperatures, etc.; and

5. using spray ice technology to build the ice dam.

2.0 METHODS

A terms of reference directed ice dam construction and monitoring activities (Wilson 1994a). As well, an environmental assessment of potential impacts of the dam was prepared (Wilson 1994b).

Ice dam construction was moved from its previous site to a new location on the Quatre Forches River near Dog Camp (58^0 39.50 N, 111^0 17.50 W) (Figure 1). A rock weir had been constructed at this site in 1971 to assist in raising water levels within the Lake Claire/Mamawi Lake complex, and had washed out during the 1974 flood event. The dam was constructed over the remains of the weir so that the remaining rocks might assist in anchoring the dam in place. The dam was envisioned to be a block of ice extending entirely across the river channel (150 meters), grounded to the bottom (varying water depths of 3 to 5 meters), and built to a height sufficient enough to cause flooding. This ice block was expected to back up the spring runoff from the Birch River, Mamawi Creek and other smaller tributaries within the Lake Claire/Mamawi Lake complex.

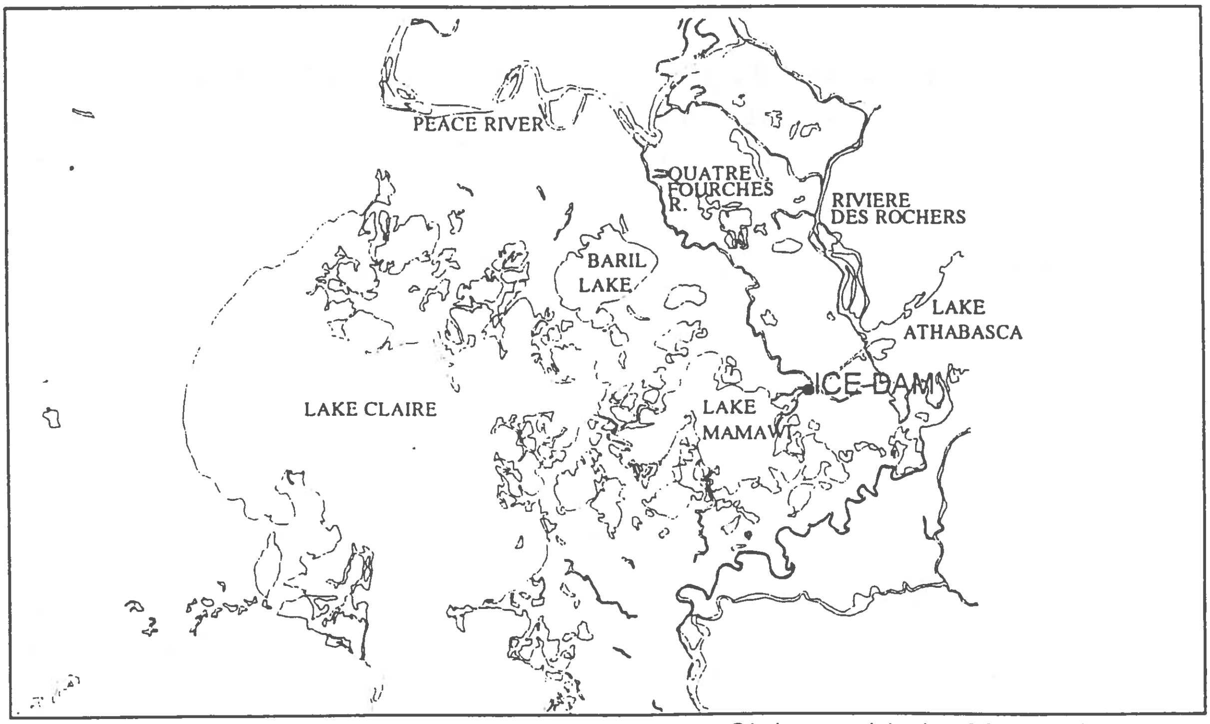

Figure 1: Location of ice dam in relation to Lake Claire and Lake Mamawi.

A high pressure (175 psi), high volume (4000 litres/min.) pump powered by a 175 horsepower diesel engine was used to construct the dam using spray ice technology. This procedure involves spraying water into the air in an arc, breaking up the water stream into droplets varying from 1-10 mm in diameter. This provides a larger surface area for heat transfer from the water to air, and thus shortens freezing time. The water spray freezes into layers of strong, highly-reflective polycrystalline ice. Figure 1 indicates the methodological guidelines prepared by Mike Demuth (NHRI) for optimal spray ice application.

Table 1: Methodological guidelines for optimal spray ice application.

T_{AIR} (^{0}C)	Methodological Guidelines
>-15 Daytime	5 cm. max., spray at night if cooler (-13 to -15 max.)
-15	5-8 cm. max, cure 8 to 10 hours
<-15 to -25	10-15 cm. max., cure 4 -8 hours
<-25	Accumulate with little or no cure time

A monitoring program was set up to measure ice growth over the dam. This involved daily measurements of the amount of ice buildup around 67 stakes placed in three lines at 10 m intervals across the width of the dam.

Micro-meteorological data was recorded on site. Instruments mounted on a meteorological tower recorded humidity, air temperature, net longwave and shortwave radiation, and wind speed and direction at two levels above the ice surface. A thermistor string within the dam recorded ice and water temperatures. The instruments were in place on December 18, 1995 and were removed on April 22, 1995. Measurements were recorded at various intervals continuously during this time. All data is stored at the National Hydrology Research Institute (NHRI), Saskatoon, Saskatchewan.

A plan for break-up monitoring was prepared (Appendix 1). The monitoring plan details the activities which would have occured in the event of a flood.

3.0 RESULTS

3.1 ICE DAM CONSTRUCTION

The application of the 1-D hydrologic model did not occur in time to contribute to ice dam design. This was due to difficulty incorporating a number of variables into the model, such as the expected rate of leakage through the dam, predicted climatic conditions through the winter and the nature of the breakup period. The dam size was ultimately determined through consultation between NHRI and WBNP staff . It was felt that the maximum height of the dam should not exceed 209.8 meters, the surrounding bank height and, therefore, the level to which water would have to rise to create an overland flood. The width of the dam would be determined by limitations imposed by time and weather.

Ice dam construction began on December 3, 1994 and continued to March 9, 1995 (Appendix 2). During this time there were 53 twelve hour shifts where mechanical problems and adverse weather conditions did not slow production down. During these shifts, actual pumping time averaged 6.52 hours/shift. There were also 21 shifts were either mechanical problems or weather conditions slowed production down to an average of 3.2 hours of pumping per shift. The total amount of pumping time during the season was 412.85 hours creating app. 60,000 m^3 of ice. The dam was built approximately 100 meters wide, and extended across two channels, 50 m. and 100 m. wide, on either side of an island. The middle 50% of the dam attained an average height of greater than 209.6 m (Figure 2).

Problems encountered during ice dam construction were numerous and were generally related to either climatic or hydrologic conditions. Climatic problems included mild winter conditions (Table 2), due probably to the El Nino effect. These conditions would have largely precluded the use of spray ice technology had the methodological guidelines been complied with. In addition, it was found that building spray ice on an incline (after the dam had grounded out and rose above the natural river ice elevation) generally resulted in water draining out of the ice over a number of hours, leaving behind a hard packed snow layer. This water drainage was unpredictable as so many variables were at play. In one observation, the angle of the ice was measured at two locations 5 meters apart. At the first location, the ice angle was 20^0 while at the second it was 25^0. The air temperature was -24^0 C and a 12 km./hr. wind was blowing. Three centimeters of apparently good spray ice was applied to the whole area. After 24 hours, the ice was examined and good spray ice remained at the first location while the second location consisted of hard packed snow. An increase in slope of only 5^0 was, in this case, the factor determining whether good ice was created or not. After similar observations of this nature it was determined that snow and ice berms along the outside boundaries of the dam would have to be constructed to keep the water in and to level the dam off.

On Feb. 3, 1995, the first snow berms were constructed. A small tracked vehicle was utilised to push snow from the surrounding river into berms along the edges of the dam were it was angling upwards. A light application of spray ice was administered to the berms to create an outside layer of ice. This process did not work adequately as water which would drain from the ice would pool along the berms and seep through. A layer of plastic was then applied to the berms, followed by an application of spray ice. This system worked very well if the plastic was sealed with ice at the bottom of the berm. After the berms were constructed, the pump was used to spray up to 15 cm. of

FIGURE 2

CHENAL DES QUATRE FOURCHES
AT DOG CAMP
ICE DAM 1994/5
T. Carter NHRI

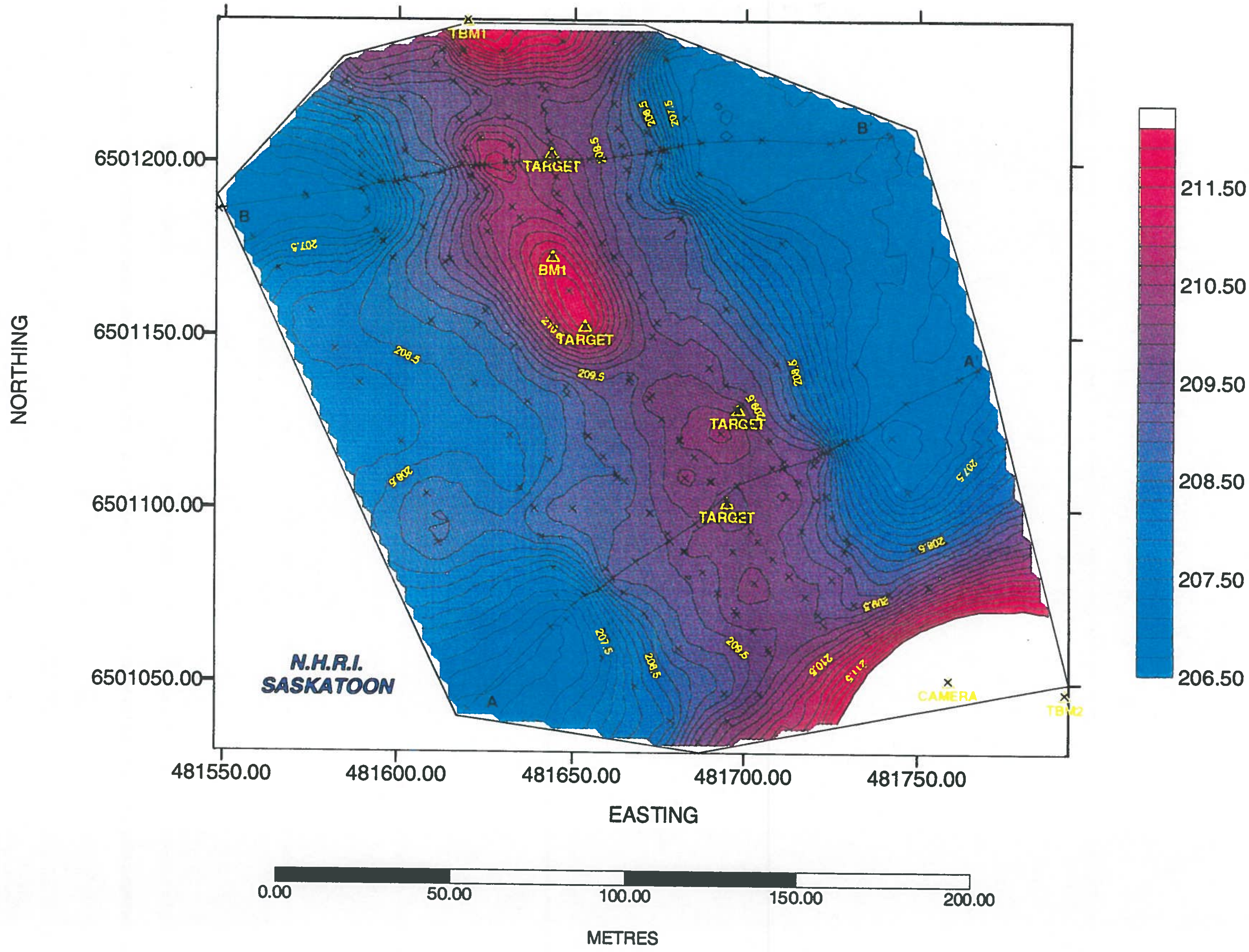

Table 2: Comparison of the daily mean temperatures from a thirteen year average (1967 - 1990) and the 1994/95 winter.

TEMPERATURE	DECEMBER	JANUARY	FEBRUARY	MARCH
13 YR. AVE. DAILY MEAN	-20.2	-24.2	-19.7	-12.1
1994/95 DAILY MEAN	-11.6[a]	-14.6	-18 5	-12.8

[a] Mean from Dec. 20 -31, 1994

slush/water onto the ice even if it was too warm to produce spray ice. This slush/water would freeze between applications, which were generally about 24 hours apart. On some occasions, however, the slush hadn't entirely frozen prior to another application. Regardless, all of these layers did eventually freeze as the temperature of the surrounding ice was well below freezing. No production time was lost due to the formation of slush layers. The application of cold water to the dam also re-saturated the few snow layers which had formed when the water had drained following an application of spray ice on an incline. These re-saturated layers set up as ice.

Once the dam was built to the level of the original berms, there was an inadequate supply of snow in the area to build a second set of berms. Ice blocks were then cut and placed by hand to form a 1.5 meter wall. The wall was then sprayed with ice to hold it together and a layer of plastic was hung over it, followed by another application of spray ice. This procedure was time intensive but did work quite well. All of the plastic used in construction of the berms was recovered by hand as it melted out of the snow and ice during breakup.

When construction of the ice dam ended it consisted of more than 99% spray, flood or natural ice. Constant auguring of test holes was done throughout the winter to ensure good quality ice was being produced.

Another problem encountered was the dramatic mid winter draw down of water in the Quatre Fourches River. The river elevation dropped 1.791 meters from January 1 (208.463 ASL) to April 8, 1995 (206.672 ASL). Conversely, the lowest the water fell in 1993/94 was to 208.464 ASL and in 1992/93 it dropped to only 208.598 (ASL). The low water this year resulted in the dam being constructed an extra 1.7 meters above the river elevation with the resulting problems of water drainage of ice as discussed above. The low water level also required that the dam would have to stay in place for an extended length of time at breakup to bring the waters in the channels to a height where they would flood over the banks. The final problem associated with the low water was that large hinge cracks formed between the banks and the dam as the dam settled. The spray pump was used to flood and seal the cracks, but they still presented problems at breakup.

3.2. BREAKUP MONITORING

Ice dam construction was completed on March 9, 1995. During the middle of March, a back-end loader was used to cover the middle half of the dam with a 0.7 meter layer of snow. This snow was applied because solar ablation of the dam could result in the loss of as much as .75 meters of ice before breakup. This technique was successful in that no loss of ice occurred where the snow had been placed before the dam was melted by flowing water. In areas not covered by snow there was a loss of up to .4 meters of ice through solar ablation.

It was expected that for the dam to be successful in causing a flood, a fast warm breakup period would have to occur with a strong pulse of water coming through the Mamawi Creek cut off and the Birch River. The breakup conditions this year were, however, very delayed due to a lengthy cold period and low water flows. The Athabasca River was at a near record low level with only 30% to 40% of the mean normal flow for the end of April. Prairie River, which connects Lakes Mamawi and Claire, and through which the Birch River waters flow, actually flowed backwards until the first week of May. The Birch River watershed did not contribute any water to the Quatre Fourches River while the dam was in place.

The dam was visited on a near daily basis beginning in April. On April 9 the river elevation began a slow rise on both sides of the dam. On April 18, staff gauges were installed above and below the dam to provide an accurate measure of river elevation (Table 3). The gauges were surveyed using a permanent elevation benchmark which had been installed on the island at the dam site. On April 21, the river ice lifted up but the thickened areas of ice adjacent to the dam remained under .48 meters of water. These "wings" were about 2.5 meters thick adjacent to the dam berms and gradually decreased in thickness as they extended up and downstream approximately 50 meters. These wings had been formed by water draining out of the ice before the berms were constructed and by blow over. On April 22, a difference in water elevations above and below the dam was recorded. From April 22 to April 28 there was no apparent leakage through the dam and water elevation slowly increased in height behind it. On April 28 however, the wings of the dam cracked down the middle and lifted partially to the natural ice elevation. Apparently the lifting of these wings also caused the dam to lift off the bottom. Whirlpools were seen at the centre of both the north and south dam on the upstream side. These whirlpools appeared to pull material straight down to the rivers bottom. Within 3 days this flow under the dam eroded channels upwards to the dams surface. Water also started to flow through hinge cracks on the north dam on April 30. These cracks were quickly widened by this flow. On May 1 the north dam was found floating downstream from the dam site. By May 2, there was only 25% of the south dam left. There was no expectation of a dam induced flood after this date.

Table 3: Water elevations upstream and downstream of the dam during breakup.

DATE	DOWNSTREAM (METERS ASL)	UPSTREAM (METERS ASL)	DIFFERENCE (METERS)
APRIL 18	206.663	206.663	0
APRIL 22	207.973	207.984	0.011
APRIL 23	207.973	207.984	0.011
APRIL 24	208.033	208.134	0.101
APRIL 27	208.255	208.645	0.390
APRIL 28	208.325	208.625	0.300
APRIL 29	208.345	208.785	0.440
APRIL 30	208.565	208.830	0.265
MAY 1	208.704	208.899	0.195
MAY 2	208.900	208.900	0

3.3. BUDGET

There was $40,000 allocated for this years ice dam project. That money was expended in the following ways.

WAGES	$24880.57
FUEL	$1750.00
OIL, GREASE, ANTIFREEZE, PROPANE, ETC.	$811.51
PUMP REPLACEMENT PARTS (GASKETS, GAUGES, ETC.)	$664.88
TRAVEL (NHRI STAFF - 3 TRIPS)	$3889.79
CAMP RENT	$1635.60
PUMP AND CAMP TRANSPORTATION (BOTH WAYS)	$2082.40
SNOW CLEARING	$1773.90
MISTEE SEEPEE (RENTALS, SUPPLIES, SERVICES)	$1908.55
TRACK TRUCK (REPAIRS AND PARTS)	$695.00
MISC. SUPPLIES AND TOOLS RENTAL AND PURCHASE	$1110.13
FORT CHIPEWYAN LODGE (SANDWELL WELDER)	$190.40
TOTAL	$41,367.73

There was a difference of $1,367.73 between projected and actual expenses. The remaining funds came from an in-Park PAD contingency fund.

Of the funds expended for ice dam construction ($41,367.00), $38, 200.00 was expended locally on wages, supplies and services. Only money for specialized replacement parts and the cost for NHRI staff travel to Fort Chipewyan was spent elsewhere.

4.0 DISCUSSION

The winter and spring of 1994/95 was less then optimal for ice dam construction. A very mild winter, near record low water elevations and minimal spring runoff all contributed to the failure of the dam to produce a flood.

However, the low water elevations appear to have been the most problematic during this year's ice dam construction. Had the water elevations been at a normal stage a flood may have occurred. Figure 3 displays this years water elevations above and below the dam as well as the app. bank height of 209.8. It is evident that a great deal more water was required to cause a flood. Figure 4 uses the river elevation for 1994, measured at the Old Dog Camp gauge just upstream of the dam site, as the estimated downstream river elevation if the mid-winter draw down had not occurred. The upstream plot was derived by taking the difference between this years upstream and downstream measurements and adding them to the 1994 elevations. In this scenario, given similar runoff and dam performance as in 1995, water elevation does exceed bank height. Given a winter with normal temperatures for greater ease in ice dam construction and average spring runoff conditions, this over bank flooding could have been dramatic.

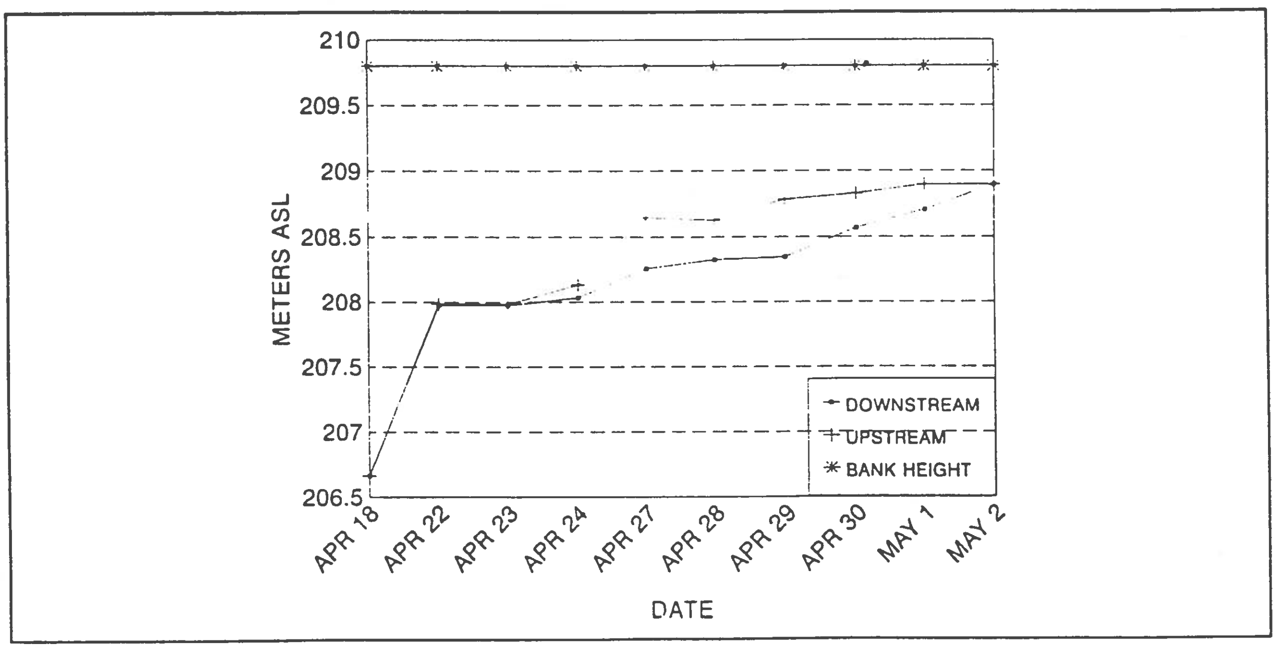

FIGURE 3: 1995 water elevations upstream and downstream of the ice dam compared to bank height.

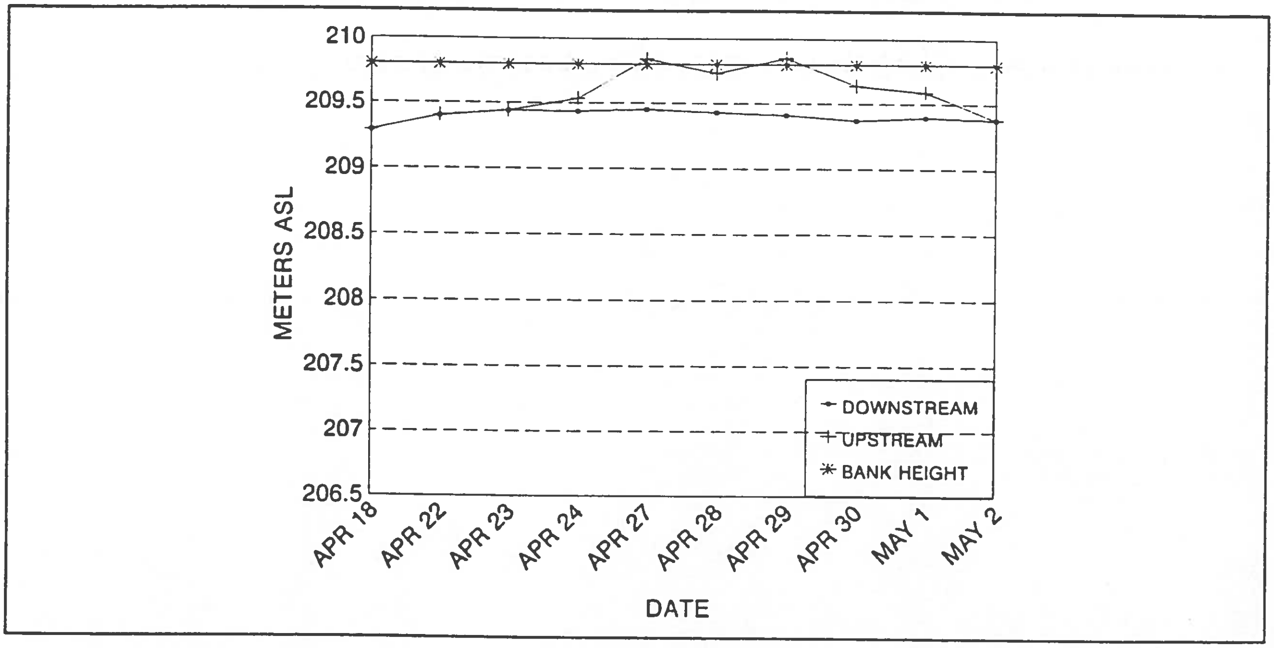

FIGURE 4: Estimated 1995 upstream water elevations using 1994 water elevations at Old Dog Camp for the downstream plot. The upstream plot was produced by applying the difference in 1995 elevations above and below the dam to 1994 elevations.

5.0. RECOMMENDATIONS

These recommendations are largely focused on what things should be done or done differently if another attempt is made at building a dam at Dog Camp. Most of the recommendations would also apply to an artificial ice jam project at Rocky Point.

1. Provide adequate resources for the project. This would include the purchase of new motorized tools such ice augers, heaters and generators. The purchase or lease of a moderate size tracked vehicle with a blade would greatly speed up the time it takes to move the pump around. The vehicle would also be available to build snow berms.

2. Attempt to procure a long term forecast for the winter season. Should it appear that there will be a strong El Nino influence then consider postponing ice dam construction.

3. Construct snow and ice berms upon the onset of dam construction. These berms allow for ice dam construction under relatively warm conditions.

4. Prevent the build up of artificial ice (wings) on the outside of the berms. The "wings" constructed this year appear to have acted as a life preserver for the dam and may have caused the dam to prematurely lift from the bottom. If "wings" do develop,

remove them by using chain saws upon the completion of ice dam construction.

5. Flood and seal off whatever hinge cracks become apparent.

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APPENDIX 1
MONITORING PLAN FOR ICE DAM EFFECTS

This is a rough outline of what we propose to monitor. M. Demuth is coming up next week and at that time we will have in place the final plan. This draft attempts to predict costs.

The 1-D flood model that was being worked on has failed to predict what, if any, flooding may occur as there are too many confounding variables (snow depth, runoff rates) and a lack of adequate data (elevation benchmarks). The rate of solar and thermal ablation of the dam cannot be accurately predicted either. It is therefore largely unknown how long the dam will remain in part or in whole. The monitoring plan focuses on measuring the dam itself and then measuring the effects that will be produced from it. These effects may range from virtually nothing occurring to flooding of some of the perched basins surrounding Lake Mamawi and possibly Lake Claire.

The following tasks will be accomplished whether nothing occurs or full scale flooding takes place. Further monitoring, which will be discussed later, will occur with a flooding event.

Monitoring Preparations (tasks which will be conducted in any event).

1. Surveying and placement of staff and crest gauges. (Staff gauges are one meter long metal measuring sticks which can be read from the air or some distance off. Crest gauges are plastic tubes with a measuring tape and cork dust inside. The cork dust rises with the water and sticks to the measuring tape at the highest water level obtained.)

Staff and crest gauges will be located at Old Dog Camp (Mamawi South Tributary), Mamawi Creek, Otter lake, Jemis Lake, Prairie River and Claire River. These sites are either surveyed in by Environmental Protection or will be surveyed in association with the Hydrologic Modelling work. Staff gauges will also be placed immediately up and down stream of the ice dam. These gauges will be surveyed in by using the permanent benchmark placed on the island at the ice dam.

Costs incurred for this work include NHRI staff (Mike Demuth, Tom Carter) living and travel expenses. The total cost is approximately $2750.00, of which $1425.00 has already come out of the ice dam construction fund. Another **$1325.00**, then, is required.

2. Activation of Environmental Protection water monitoring stations at Old Dog Camp, Prairie River and Quatre Fourches River at Dog Camp. These stations monitor river elevation through the use of a nitrogen tube on the river bottom. This task is being

discussed with Scott Flett, Environmental Protection. No costs should be associated with this work.

3. Automatic camera installation. A camera with a timer and a 250 picture capacity will be mounted at the ice dam site. The camera will take photographs of the dam at whatever interval is deemed necessary at the time. The photos will be a history of how the dam reacted to the stream flow. There should be considerable movement at times when it lifts off the bottom, etc. NHRI is supplying the camera and it will be installed by Mike Demuth on his March 23 visit. Costs for film and processing are estimated **$300.00.**

4. Surveying in and measurements of the ice dam. The dam has been thoroughly surveyed with 149 shots taken at various locations on it's surface. The survey is digitized and will give us total ice production when coupled with the ground penetrating radar which was conducted last December. The present measuring stakes will be used to record the rate of melt. The rate of melt will be correlated to net incoming long and short wave radiation through the use of a net radiometer and to water temperature. The amount of overflow above and below the dam is presently being measured when it occurs. There should be no extra costs incurred for these tasks.

Flood Monitoring (the costs for this will vary depending on the extent of flooding, costs for no flood (or limited localized flooding) and for a large scale flood (ie: water gets into Jemis Lake) have been estimated).

1. Mike Demuth will travel to Fort Chipewyan and remain on site for approximately two weeks during breakup. He will be here to assist in measurement taking and documenting the ice dam effects. The Peace River will also be monitored at this time.

Costs incurred will be about the same in any event and will be about **$1500.00**.

2. Aircraft time to monitor flood, check staff and crest gauges and to obtain flow rates on the Embarras Cutoff and Birch River. I will have to discuss with Mike Demuth whether the flow rates should be monitored in any situation to determine how much water is coming into the system. If a flood occurs, oblique aerial photography will be conducted. The photos will be correlated back to the water depths at the staff gauges. The flood waters should form elevation contour lines with the water elevation known from the staff gauges at any given time. We had originally considered formal aerial photography flights for this but they are very costly. Terry Prowse has said that by using oblique photography (taking pictures out of a window) that the virtually the same data could be gathered at a fraction of the price.

Costs incurred with no or localized flooding:

Helicopter time required is presently unknown.
Airplane time would be approximately 10 hours at $350.00/hr. = **$3500.00**

Costs incurred with large scale flooding:

Helicopter time to measure flow rates in the Birch and Embarras cutoff. Three trips of two hours each plus six hours ferry time from Fort McMurray equals 12 hours. 12 hours at approximately $700.00/hr. = **$8400.00.** (This could be reduced as it may be possible to use the airboat to measure the Embarras cutoff).

Airplane time is required to monitor the extent of the flood, take staff gauge readings and for oblique photography. I would not expect the dam to last for more then 7 days with water flowing over it. Water would have to flow over it if a flood occurred. Therefore approximately. 4 hours/day for seven days would be required for flood monitoring. This would total **$9800.00**.

3. Monitoring personnel are needed at the ice dam site to record water elevations and the process of ice dam breakup. This work could be conducted by wardens and NHRI. The site should be accessible by orbit and a camp may not be required. The costs incurred would be for groceries, gas, etc. and would amount in any event to about **$500.00**.

There may be changes to this plan after Mike Demuth's visit, but as it stands now the monitoring program would require the following funds.

In the event of no or localized flooding:

Travel (two trips for NHRI)	$2825.00
Photography	$300.00
Airplane	$3500.00
Groceries, gas etc.	$500.00
Total	**$7125.00**

In the event of large scale flooding:

Travel (two trips for NHRI)	$2825.00
Photography	$300.00
Airplane	$9800.00
Helicopter	$8400.00
Groceries, gas etc.	$500.00
Total	**$21,825.00**

Aircraft time could be cut back in either scenario to reduce costs

APPENDIX 2
ICE DAM CHRONOLOGY

NOV. 28 Flooding of area around island begins so as to allow for enough ice for spray ice pump to be used.

DEC. 5 Spray ice pumping begins.

DEC. 18 - 29 Pumping operations shut down due to warm weather and holidays.

JAN 30 Problems are developing with water draining out of spray ice before it can solidly freeze. The problem has now developed as the natural river ice elevation has fallen over two meters from freeze up levels and the crews have to build the dam into a hill.

FEB. 3, 1995 Ice berms were constructed using a small tracked vehicle (Bombardier) to stop water leakage from the ice dam. The construction of the berms also allows for the dam to become level on top and therefore allows for spray ice formation once again.

FEB. 4 Ice berms continue to be constructed. Removed a layer of snow from the north dam by moving the pump up to the berms and spraying down onto the layer and therefore peeling it off.

FEB. 25 Pump radiator developed leak in lower valve connection. Crew pumped for only .5 hour before shutting down.

FEB. 26 Radiator valve repaired by soldering. A 12 hour shift was completed by crew. Snow berms were again constructed using the Bombardier.

MAR 6 Last day of dam construction.

APRIL 15 The river on the west side of the dam has noticeably more overflow on it then does the east side.

APRIL 21 The natural river ice on both sides of the dam have lifted. The "wings" (areas of thickened ice outside of the dam proper) on the dam are still underwater

APRIL 22 Staff gauges are installed on the east (0 at 207.973 ASL) and west (0 at 207.984 ASL) side of the dam. A difference in elevation of .011 m. is measured. Maximum water depth over the wings on the west side of dam is .485 m.. Natural river ice is largely free of overflow.

APRIL 23 No increase in water levels from April 22.

APRIL 24 Water levels on the west side of the dam have increased to 208.134 ASL and 208.033 on the east side. A difference in water elevation of .101 m..

APRIL 27 Water levels on west side of dam have increased to 208.645 ASL and 208.255 m. on the east side. A difference in water elevation of .390 m..

APRIL 28 Water levels on west side of dam have decreased to 208.625 ASL but have increased to 208.325 m. on the east side. A difference in water elevation of .30 m.. The "wings" of the dam have popped up and cracked in the centre.It appears that the dam has also lifted from the bottom and that water is flowing underneath it.

APRIL 29 Water levels on west side of dam have increased to 208.785 ASL and 208.345 m. on the east side. A difference in water elevation of .440 m.. This being the greatest difference measured between the two sides. Increased flow appears to be occurring underneath the dam at the location were the wings have popped up and cracked in the middle.

Prairie River was visited and no noticeable flow was occurring. Mamawi Creek has minimal flow.

APRIL 30 Water levels on west side of dam have increased to 208.830 ASL and 208.565 m. on the east side. A difference in water elevation of .265 m..

Water is bubbling out of the north side of the north dam and flowing through hinge cracks on both sides. The south dam is leaking through underneath.

May 1 Almost the entire north dam is afloat at the four forks. It appears the water flowing under the dam erode away enough ice so that the dam was no longer anchored to the bottom. It then popped up and floated free. There is a strong flow of water through the north channel. There is still a difference in water elevation of .195 m. between the west (208.899 ASL) and east (208.704 ASL) sides.

Water has eroded up from the bottom of the south dam, exposing a stream of water app. 10 meters wide through the middle of the dam.

MAY 1 The stream of water through the south dam has widened to 20 m. The flow through the old dam location appears to have slowed and is at the same rate as the rest of the river.

MAY 2 The stream through the south dam is app.3/4 the width of the channel. There does not appear to be any chance of a flood occurring here after.

APPENDIX 3
PHOTOGRAPHS OF ICE DAM

Photo 1: The dam stretched 110 meters across the width of the Quatre Fourches River. The "wings", or submerged areas of ice next to the dam, are evident in this photo taken on April 25, 1995. River flow is from the left to the right and the north dam is at the top.

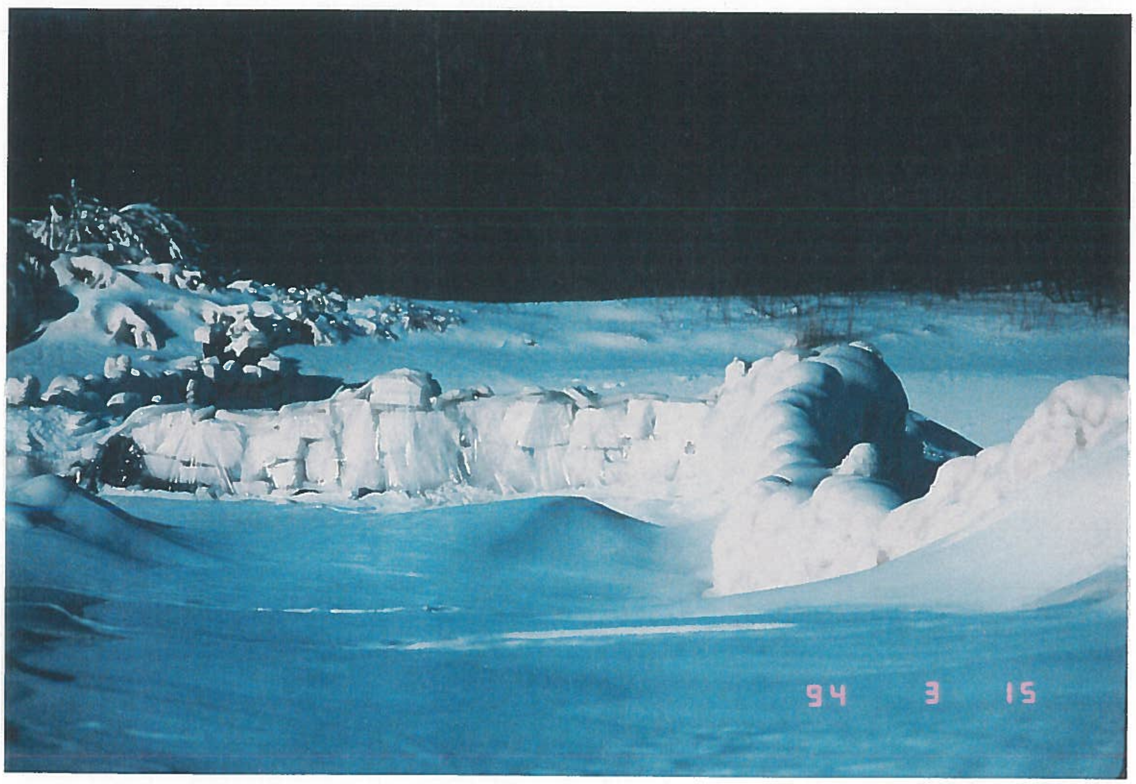

Photo 2: Snow and ice berms were built at times by hand to contain the water. Virtually all of the plastic used for berm construction was recovered as it melted out of the dam.

Photo 3: The southwest berm was a nearly perpendicular wall of ice over 2 meters in height. The track truck is parked atop the dam.

Photo 4: On April 28, 1995 the "wings" on the dam lifted up, apparently also lifting and creating cracks along the dams bottom. In this photo, a vortex in the cave like opening was sucking material underneath the dam.

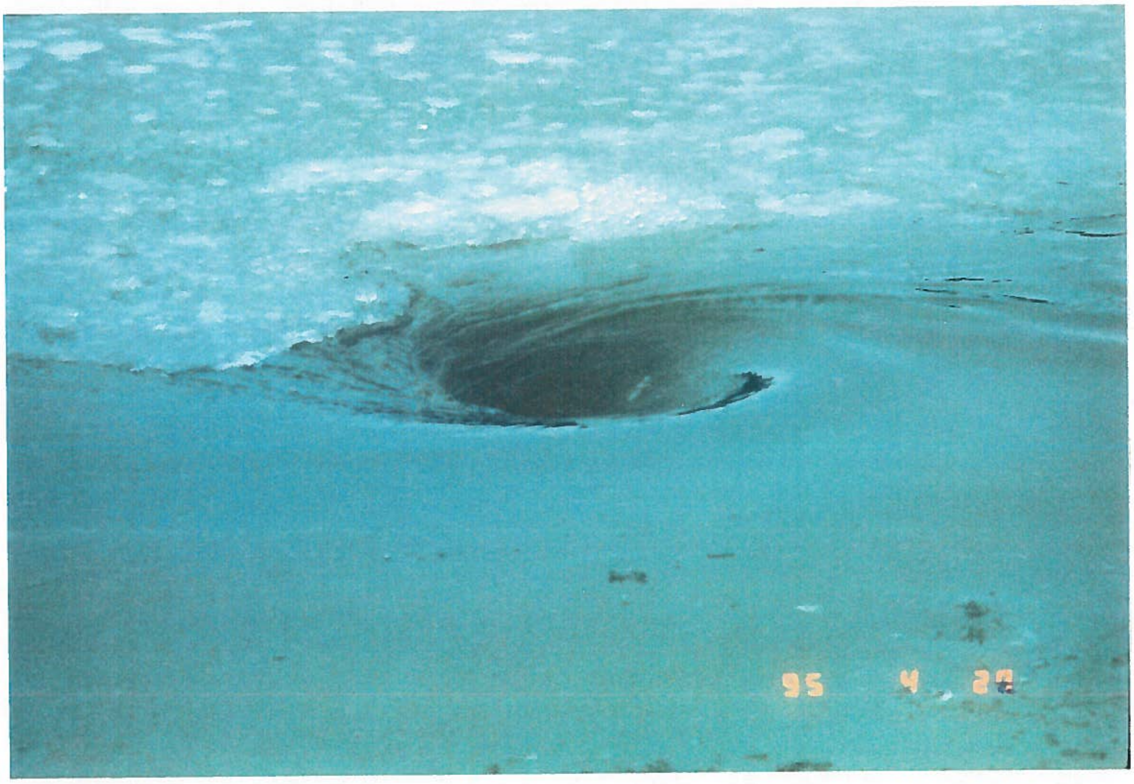

Photo 5: One of the three vortices which formed along the upstream side of the dam.

Photo 6: Water flowed through and enlarged the hinge cracks on the north dam.

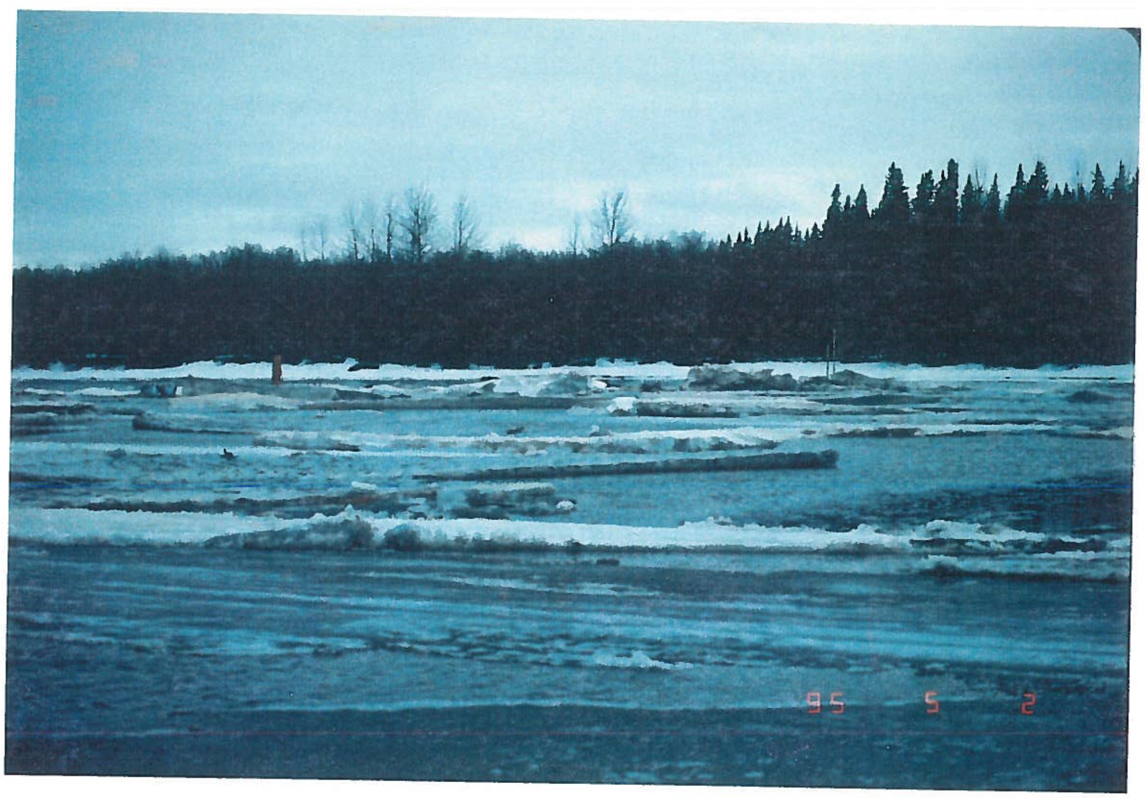

Photo 7: Water flowing though the hinge cracks on the north dam cut the dam free and it floated in it's near entirety down the river.

Photo 8: The south dam eroded away from the bottom up, with a channel finally developing through it's centre.