PEACE-ATHABASCA DELTA
Technical Studies

ARTIFICIAL ICE JAM
1992-93 FIELD REPORT

TASK F.3 - ARTIFICIAL ICE STRATEGIES

Towards an ecosystem management plan

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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 of 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 Jam, 1992-93 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 1992-93 Artificial Ice Jam experiment.

ABSTRACT

Ice cover augmentation to produce an ice dam on the Chenal des Quatre Fourches in the Peace-Athabasca Delta was used in an attempt to produce a spring break-up ice jam. Surface flooding was successful in doubling the normal ice thickness and providing a fine grained ice surface which gave some protection to the natural ice against deterioration by solar radiation. Break-up on the Athabasca River occurred on April 19th, and on the Peace River in the area of Rocky Point on April 27. The break-up is characterized as a thermal break-up, with the ice melting in place with very little runoff surge. Significantly lower precipitation in the Peace River drainage basin, combined with higher than average temperatures in March and April contributed to the weak break-up. Recommendations are made modifying the methodology to produce a narrow width channel at the study reach by building a partial-width longitudinal grounded berm. This is possible using spray-ice technology. Success in producing an ice jam and flood is dependent upon having a dynamic break-up on the Peace River. Using the ice berm should increase the probability of causing an ice jam in a dynamic break-up.

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

An ecosystem based management planning workshop on the Peace/Athabasca Delta (PAD) was held in Edmonton on May 11-15, 1992, and January 14-15, 1993, to bring together stakeholders and agencies responsible for water and ecosystem management in the regional drainage system. The primary objective of the workshops was to develop the framework for an ecosystem based management plan for the PAD. Secondary objectives were to identify the existing knowledge base and determine information deficiencies.

In January 1993 the Peace Athabasca Delta Ecosystem Management Plan was produced to direct a three year program of technical studies. Within the plan Task F.3, Artificial Ice Dams, investigates the feasibility of flooding perch basins through creating ice dams on delta river systems, and investigating its applicability on major river systems. The project will attempt to increase the probability of causing an ice jam by ice-cover augmentation to thicken the existing ice, and monitoring the breakup to assess the success and recommend modifications.

The objectives of the ice jam project are:

1. Using local knowledge and expertise in ice building; construct an obstruction to ice flow at spring breakup in one of the PAD channels to cause an ice jam, and thereby attempt to cause local flooding.

2. Develop a monitoring plan to monitor the various factors which affect the cause and destruction of an ice jam, which include but are not limited to ice thickness, strength, geographic location, timing of breakup, regional weather parameters, run-off characteristics, water levels and discharge above and below study site, water temperature, etc..

3. Using the data from the monitoring program, describe what factors led to the success or failure of the ice jam and the applicability of the project to a larger river system such as the Peace River.

2.0 METHODOLOGY

The Chenal des Quatre Fourche River was chosen as the test river for several reasons. It is part of the Peace River drainage system, traditional oral history indicate it had flooded frequently due to ice jams, water stage recording stations are located at the outlet on the Peace River and the Mamawi Lake outlet, and it is easily accessible from Fort Chipewyan. The study area is located at 58^0 42' 15" north latitude and 111^0 24' 30" west longitude and includes two bends in the river and the intervening straight reach, approximately 1.5 km in total length **(Figure 1)**. The Quatre Fourche River flows in reverse at breakup and therefore the normal downstream bend is then upstream of the ice dam.

Data is available on daily stage and discharge of the Peace River at Peace Point from 1959, and at the community of Peace River from 1915. Within the delta, stage and daily discharge is only available for the Embarrass and Birch rivers starting in 1987 and 1967 respectively. Daily stage data is available for the Athabasca River at Old Fort Point, Lake Athabasca, Rocky Point on the Peace River, Chenal Des Quatre Fourche at Dog Camp, Mamawi Lake channel at Old Dog Camp, Prairie River, and several sites on the Riviere Des Rochers. The station on the Mamawi Lake channel is year round and has good data for ice breakup. Most of the other stations have missing data for the April-May breakup periods. Except for the Lake Athabasca station which started in 1930, the delta located stations started in 1960 or 1971.

Ice-cover augmentation started on January 26, 1993 using a crew of three and ended on March 1, 1993. The construction of the ice dam was contracted out to Misti Seepee of Fort Chipewyan, Alberta. The ice surface was flooded daily using Typhoon Wajax pumps to achieve approximately 5cm of water covering daily. On February 17 a hydraulic driven 18 inch auger was obtained from NWT Highways of Hay River. This allowed more rapid flooding and was less prone to breakdowns than the Typhoon pump. Flooding was concentrated at the normal downstream bend until the total thickness was double the natural ice thickness outside the study area. The whole study area was then flooded daily until the end of the project. During that

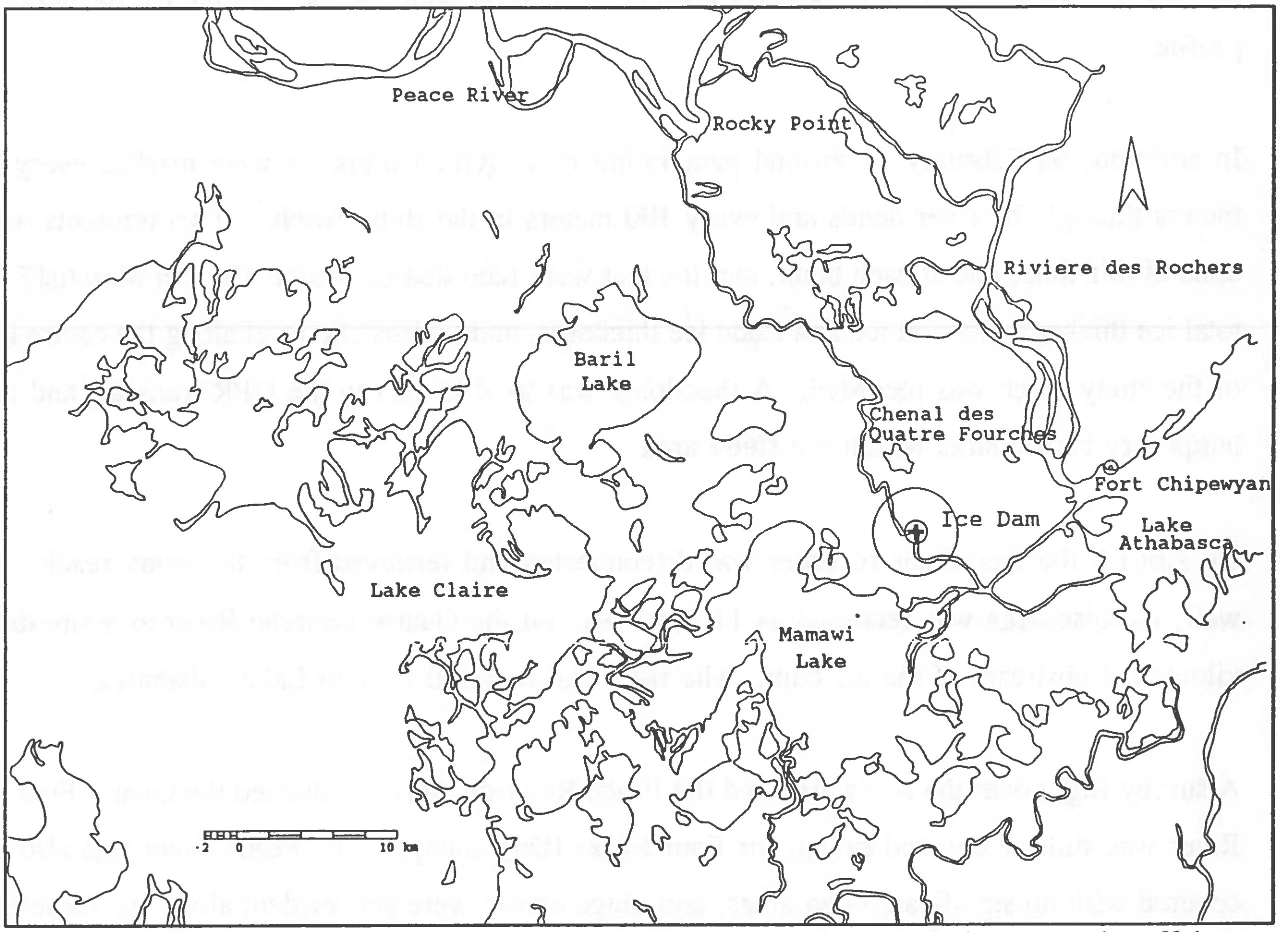

Figure 1: Site of the Ice Dam Project on the Chenal des Quatres Fourches, Wood Buffalo National Park

time the ice thickness was increased to approximately 120-170 cm, with the most significant ice increase occurring at the normal flow downstream bend and the least occurring at the normal flow upstream bend.

On February 17 a thermistor series and data storage platform was set up at the normal downstream end of the study area. Six temperature sensors recorded air, ice and water temperature. For each thermistor the average temperature for each 30 minute period was recorded. The data is used to identify local air and water temperature, and the ice temperature profile.

In addition, on February 17 ground penetrating radar (GPR) transects were marked every 50 meters through the river bends and every 100 meters in the study reach. Two transects were done at this time, one at each bend, and the rest were recorded on March 16. On March 17 the total ice thickness, natural ice and flood ice thickness, and hydrostatic level along the centre line of the study reach was recorded. A theodolite was used to survey the GPR transects and two temporary benchmarks within the study area.

On April 8 the thermistor recorder was disconnected and retrieved from the study reach. As well, the discharge was recorded as 11.3 m^3 sec^{-1} on the Quatre Fourche River at a site three kilometres upstream of the ice dam. The river had reversed flow to Lake Athabasca.

A survey flight over the study area and the Peace River on April 18 showed the Quatre Fourche River was still ice covered except for Four Forks (Dog Camp). The Peace River was also ice covered with no significant open areas, and hinge cracks were still evident along the shoreline.

During a second survey flight, on April 21, silt laden water was observed flowing out of the Quatre Fourche River to Lake Athabasca. On April 20 the water initially flowed into Lake Athabasca and then reversed in the afternoon (pilot observations). This reversal was due to the break-up of the Athabasca River on April 19. The river was free of ice upstream of the ice dam site, and ice covered between the study reach and the Peace River.

Two field crews were flown to observation points above and below the ice dam site on April 23. Daily and hourly water stage was recorded using a theodolite from a temporary benchmark. Current speed was estimated daily using a pre-measured distance marked out on the bank. The Peace River broke up on April 27 below Peace Point and on April 29 the observation stations were shut down.

3.0 RESULTS

The ice on the Peace River did not move within the Peace Point to Rocky Point reach until April 27. At this time there was very little ice upstream of Peace Point or downstream of Rocky Point, and within the reach several large leads had opened up. In the Chenal des Quatre Fourche the ice had melted out over several kilometres south (normal upstream) of the ice dam. North of the ice dam the ice surface was intact but colour and surface ponded water indicated it was candled and had very little strength. At the ice dam the normal downstream end had sufficient surface strength to hold a person up on April 29 when the rest of the river was nearly free of ice. By May 6 all ice had melted out on the river.

Lack of winter precipitation and meltwater runoff appears to be the limiting factor in the 1993 breakup. Total monthly precipitation for the Fort Chipewyan area was significantly lower ($P < 0.05$) than the 19 year mean for October, December, January, February and March (**Figure 2**). In addition, the mean temperature for November, January, March and April was significantly higher ($P < 0.05$) than the 19 year mean values (**Figure 3**). The mean temperature in degrees celcius for March and April was -4.1 and 2.9 respectively, and the 19 year mean is -12.59 and -0.58 respectively. This melted the winter accumulated precipitation gradually and did not develop the spring melt surge needed to move the river ice.

This is reflected in the community of Peace River which is near the upstream end of the Peace River drainage basin. Precipitation was significantly lower ($P < 0.05$) for October through March, except for December when total precipitation was significantly higher than the 19 year mean (**Figure 4**). The mean monthly temperature was significantly higher ($P < 0.05$) in March and April, which allowed the lower winter precipitation to melt over a longer period of time.

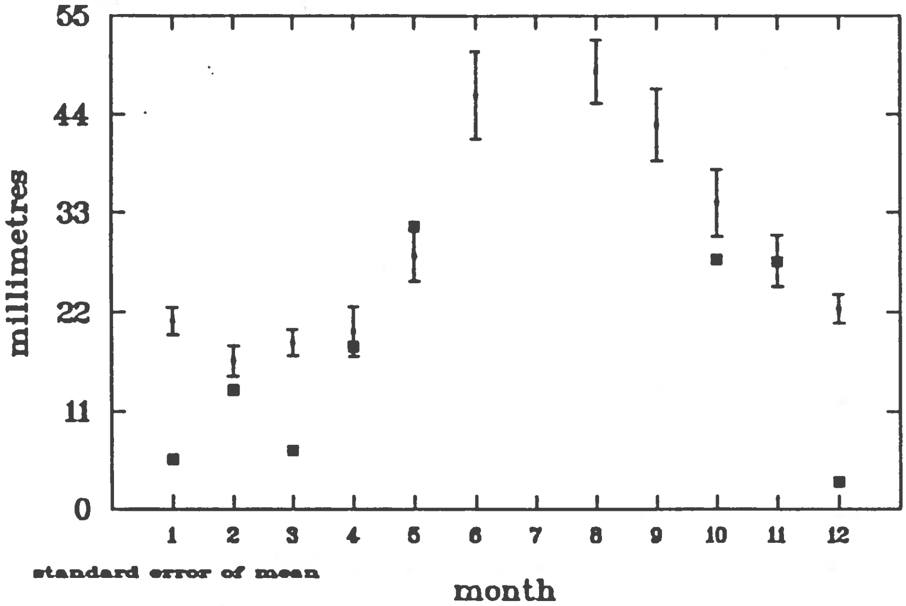

Figure 2. Precipitation at Ft. Chipewyan, AB, 1963-92. Bars represent mean and 95% confidence limits, boxes represent monthly percipitation for Oct/92 - May/93. Data from AES.

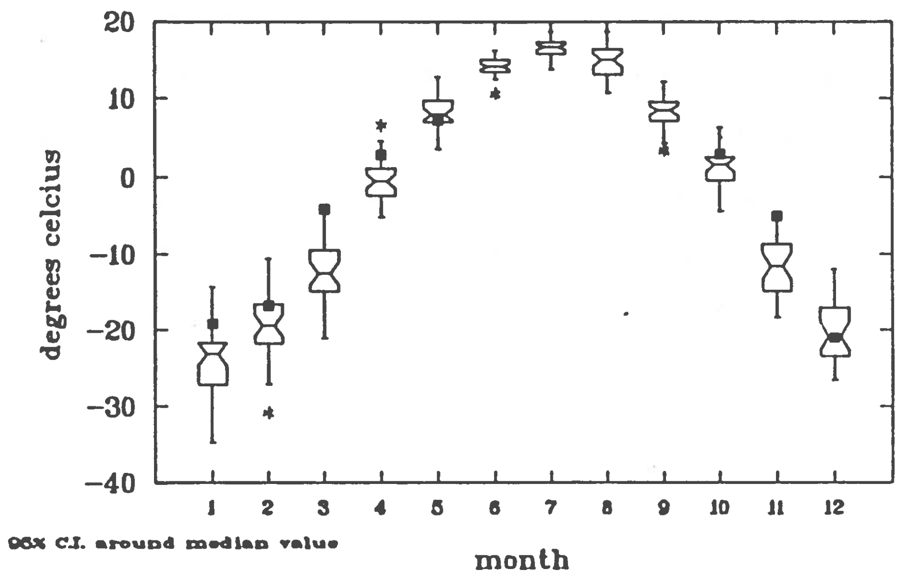

Figure 3. Temperature at Ft. Chipewyan, AB, 1963-92. Polygons represent median with 95% confidence limits around the mean, boxes represent mean temperature for Oct/92 - May/93. Data from AES.

The mean temperature for March was -0.5 degrees celsius, while the 19 year mean is -9.0 degrees **(Figure 5)**.

Ice construction was marred by frequent breakdown of pumps and warm periods. Ice growth averaged approximately five centimetres per day. Over a fifty day periodice depth measurements recorded an increase from fifty centimetres to 100 centimetres **(Figure 6)**. This would include natural ice growth at the bottom of the ice sheet as well as flood induced growth at the top.

A thermistor pole was located at the normal downstream end of the study reach and recorded air, ice and water temperature. The maximum and minimum air temperature at the study reach was 13.88 and -39.39 degrees celsius respectively, with a mean temperature of -5.59 degrees (SD=10.10) **(Figure 7)**. There was two periods of above zero daytime temperatures; from February 27 to March 7, and March 20 to April 5. Ice growth at the bottom of the ice sheet apparently absorbed the bottom thermistor, at 110 cm, temporarily for two periods; February 26 to March 2 and March 14 to March 23, when the maximum temperature was below -1 degrees. The mean temperature recorded at the bottom thermistor was -0.56 (SD=0.25). Natural ice growth ended on March 23 when maximum temperature within the ice sheet reached zero degrees celsius.

The lack of precipitation and above average temperatures during March and April translated into low meltwater run-off at breakup for the PAD rivers. On the Peace River discharge had been higher than the 30 year mean for October, November, December and January, with levels significantly higher ($P < 0.05$) for February and March **(Figure 8)**. This may be a result of B.C. Hydro increasing electrical production at the Bennett Dam for the winter months, apparently to offset lower production at other generating stations. When the lower than average run-off occurred, its effect of increasing river water levels was diminished.

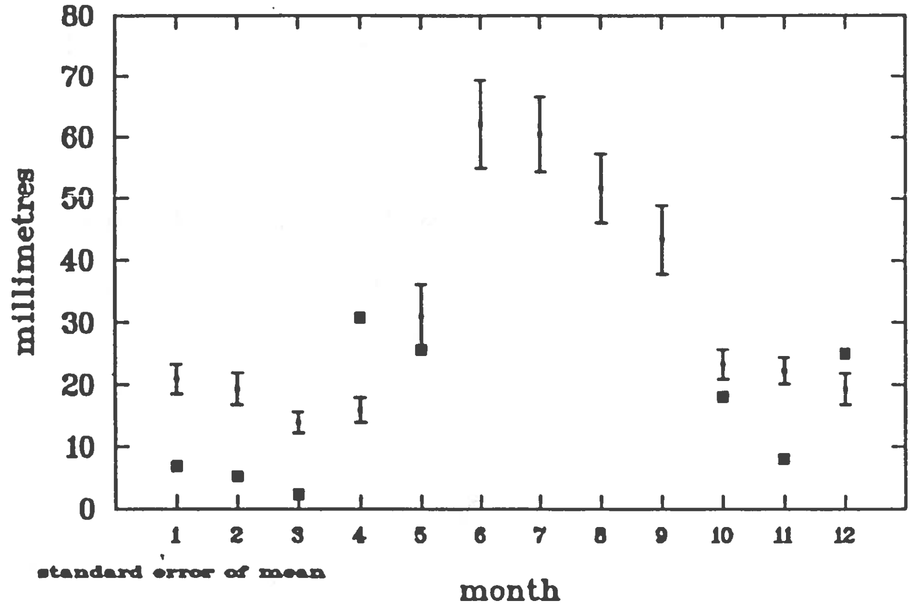

Figure 4. Precipitation at community of Peace River, AB, 1963-92. Bars represent mean and 95% confidence limits, boxes represent monthly precipitation for Oct/92 - May/93. Data from AES.

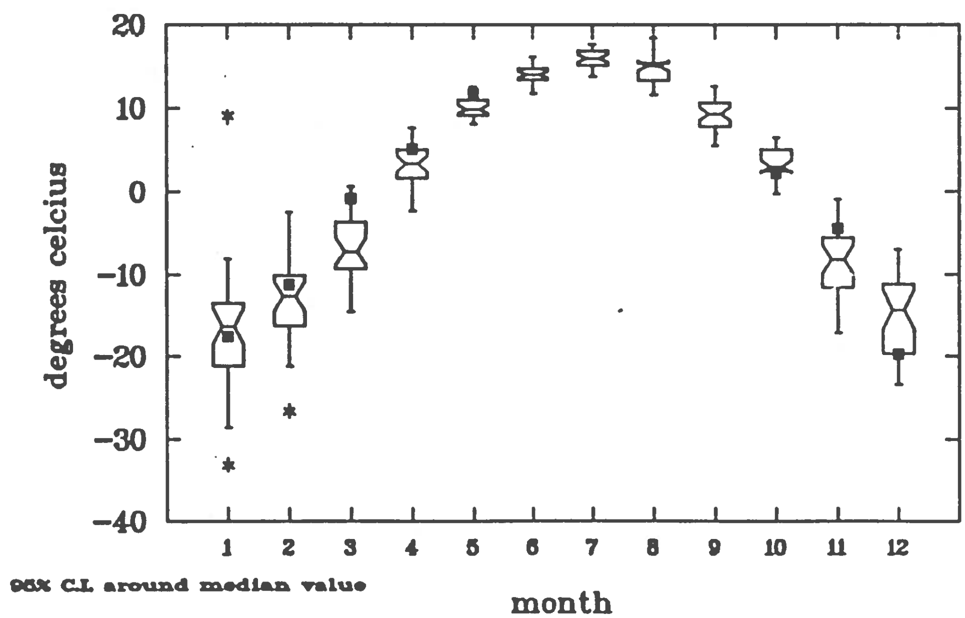

Figure 5. Temperature at community of Peace River, AB, 1963-92. Polygons represent median with 95% confidence limits around the mean, boxes represent mean temperature for Oct/92 - May/93. Data from AES.

GPR transects through the study reach indicated a poorly defined thalweg (main channel), except at the normal upstream end where the thalweg is a narrow steep trench along the east bank. Depth is estimated at 11 meters. Downstream the thalweg varies between 4.5 - 8 meters.

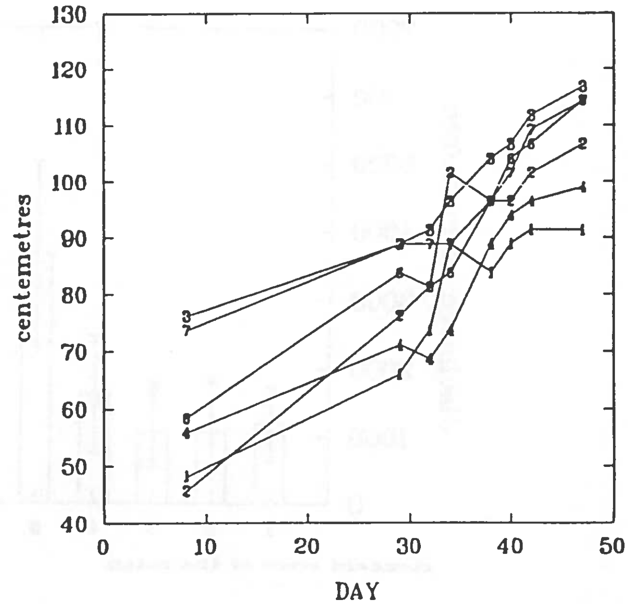

Figure 6. Measurements of total ice thickness at six locations over the study reach.

The slope of the Chenal des Quatre Fourche has been measured by Alberta Environment in the 1970s when several water level measuring stations were installed. The slope profile has not been obtained to date but field observations indicate an even slope with little variation in current speed from Dog Camp to the Peace River.

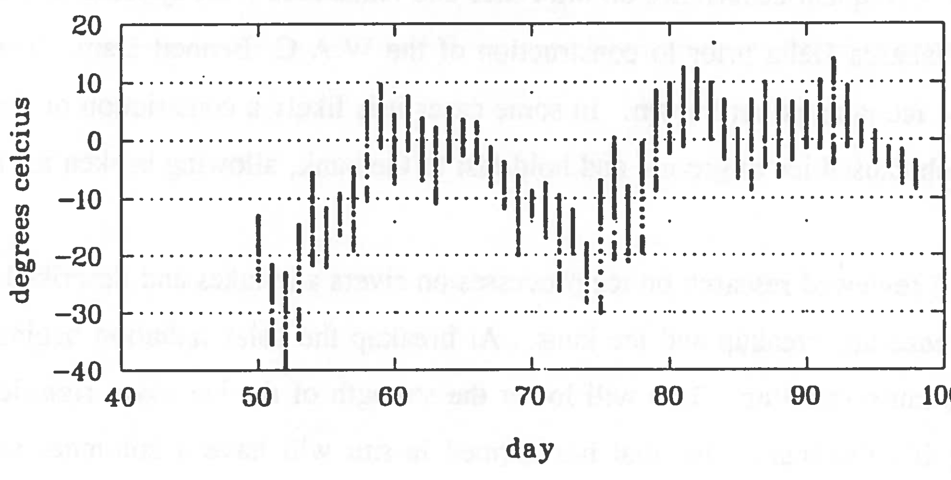

Figure 7. Air temperature at study reach recorded every 30 minutes daily.

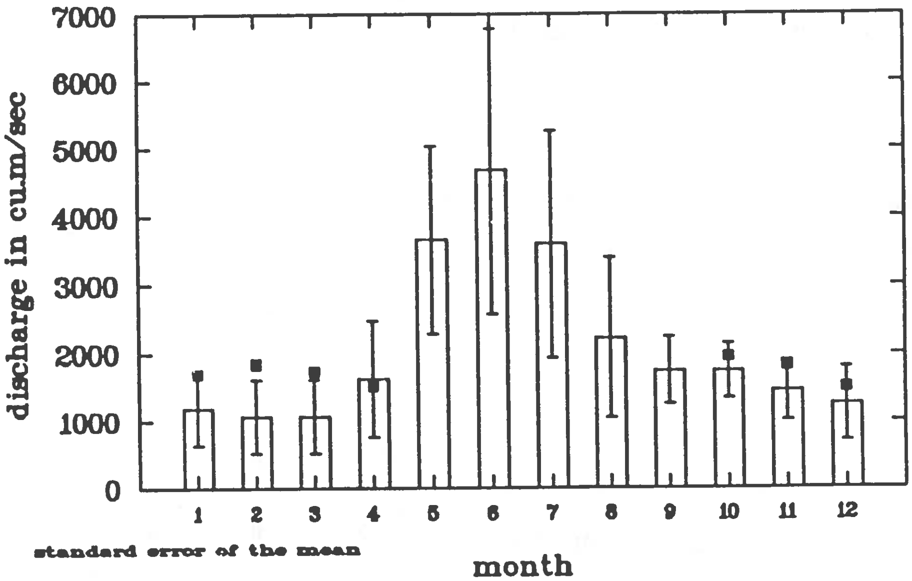

Figure 8. Peace River discharge estimates at Peace Point, AB, 1959-92. Bars represent mean with 95% confidence limits, boxes represent mean discharge for Oct/92 - April/93. Data from Water Surveys Canada.

4.0 DISCUSSION

Ice jams were a frequent occurrence on the Peace and Athabasca river systems as well as within the Peace/Athabasca Delta prior to construction of the W.A.C. Bennett Dam. The particular cause of these ice jams is not known. In some cases it is likely a constriction or sharp bend in the river which caused ice to ground and hold fast to the bank, allowing broken ice to build up.

Gerard (1990) reviewed research on ice processes on rivers and lakes and described the general process of freeze-up, breakup and ice jams. At breakup the solar radiation begins to weaken clear ice and cause candling. This will lower the strength of the ice cover significantly while not affecting it's thickness. Ice that has formed in-situ will have a columnar structure and melting occurs at the boundaries of these columns. White ice, overflow ice, will be fine-grained, opaque and resistant to candling and will retain it's strength longer than clear ice.

At the same time snow melt causes an increase in the river water level. If the river discharge remains steady through the melting process the river ice will decay and fragment until the river is free of ice, resulting in a thermal break-up. If the discharge increases substantially and the ice cover fails to hold fast a run is initiated, a dynamic break-up. When the ice moves the water depth falls and the water storage from freeze-up is released. This, combined with runoff causes a surge. This ice run will stall and cause an ice jam if the run has been attenuated to the point that it cannot break the in-place ice cover, or if it encounters a sudden increase in waterway depth or width thus reducing current speed, or if the run encounters a sudden reduction in channel slope and the water current decreases. When the ice jam fails another surge can be initiated and a second ice jam could occur downstream.

The 1993 breakup on the Peace River was characterized as a thermal breakup. The ice deteriorated through melting, both on the surface and along grain boundaries, and fragmentation until the ice cover broke into ice crystals and weak ice pans. The downstream forces from meltwater run-off discharge was not large enough to break the ice cover until very little strength remained in the ice.

Use of ice-cover augmentation in the study reach had the effect of increasing total ice thickness and slowing the process of candling in the natural ice. This provided more surface strength at breakup than was found in the natural ice. Ice strength measurements were not taken, so it is difficult to determine if the surface strength would have been sufficient to cause an ice run to stop. Ice measurements taken from holes indicate only the surface flood ice maintained some strength, but probably not enough to stop an ice run.

There were numerous pump breakdowns which severely limited the amount of flooding possible in the first three weeks of the project. By February 17 a hydraulic driven 45.7 cm (18 inch) ice auger was obtained from NWT Highways to replace the Wajax pumps. The volume of water pumped increased but obtaining an even flood of water became a problem. With minor depressions in the ice surface where flood water pooled, some areas were not able to be flooded without pumping too much water into the depressions. Greater control of the flood water is necessary to provide a uniform layer of new ice.

With the uniform slope profile and known ice jam history, the current site selected will probably give the best chance for success, if the channel geometry can be changed to mitigate the loss of a break-up surge on the Peace River. The forces needed for a dynamic breakup on a wide stream-bed, as on the Quatre Fourche River, may not be feasible given the controlled flow regime on the Peace River. Modification of the ice channel geometry, to a narrow width channel, may give the necessary strength to withstand the downstream forces caused during a dynamic breakup and provide less room for ice to pass (Demuth, in draft). High break-up stage on the Peace River will still be required to force sufficient water upstream on the Quatre Fourche River to first provide the energy to cause an ice dam, and second stage height sufficient to breach the river levees.

The creation of a narrow river ice jam using a partial-width longitudinal grounded ice berm at the normal upstream bend in the study reach is possible using spray ice technology. A longitudinal grounded ice berm will halve the width-to-stage ratio, a critical criteria for a narrow ice jam (Demuth, in draft). The ice berm will be located centrally in the river bend, and will be grounded with sufficient hydrostatic level to resist movement at breakup. M. Demuth is completing the design concept and methodology for spray-ice production.

Spray-ice is recommended because using surface flooding cannot produce the quantity of ice needed, given the season length, channel geometry and atmospheric conditions. Spray-ice involves a high volume pumping unit, 2000 l min^{-1}, and a nozzle capable of variable spray pattern. Spraying water versus flooding results in a 75:1 increase in water surface area exposed to freezing temperatures allowing for rapid cooling (Demuth, in draft). The trajectory, droplet size and velocity of the spray can be changed to allow continuous ice growth, without stopping for necessary heat transfer on the ice surface. It is suggested that with continuous 24 hour ice augmentation, the necessary size and volume of ice required for the ice berm can be achieved in approximately four weeks.

5.0 RECOMMENDATIONS

1.0 Set up a micro-meterological station and data collection unit at the study area to improve local weather data and collect solar radiation measurements, both unavailable at the present time.

- Local weather data for the study reach is necessary for monitoring spray-ice heat transfer, ice deterioration through solar radiation, etc.

2.0 Move the Rocky Point water gauge station to a location downstream of the existing site where less erosion will provide a more complete database at break-up, and increase recording speed to record the maximum stage and rate of change.

2.1 Convert the Rocky Point water gauge station to a data collection platform to obtain real time data on the Peace River breakup.

3.0 Use spray ice technology to build a spray-ice berm in the study reach as per recommended methodology and geometry proposed by M.N.Demuth, NHRI.

-Complete guidelines for spray-ice technology to augment ice-cover geometry on the Quatre Fourches River, as drafted by M. Demuth.

- Include a research design for monitoring the spray-ice augmentation.

5.0 Purchase a 2000 L min^{-1} high pressure pump and variable nozzle with an insulated platform designed to be dragged or slung under a helicopter. The pumping unit should be powered by a diesel engine, enclosed in an insulated platform, include suction hose, and have a 4000 Watt generating capacity.

6.0 Contract the construction of the spray-ice berm to a local Fort Chipewyan contractor with the design criteria as outlined by M. Demuth, NHRI.

6.0 LITERATURE CITED

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