PEACE-ATHABASCA DELTA
Technical Studies

ARTIFICIAL ICE JAM
1993-94 FIELD REPORT

TASK F.3 - ARTIFICIAL ICE STRATEGIES

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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, 1993-94 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 1993-94 Artificial Ice Jam experiment.

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1.0 INTRODUCTION

The Peace-Athabasca Delta (PAD) is experiencing significant environmental change associated with changes in the flood regime over the past 25 years. An understanding of the dynamics of the flood regime is required to direct any efforts toward restoring the role of water in the PAD. Ice jams are recognized as significant factors in the natural flood regime as they generate the major overland floods that maintain water levels in the biologically productive perched basins of the Delta. Task F.3 of the PAD Technical Studies is a four year program investigating the feasibility of creating artificial ice jams in the PAD to, in part, replicate the natural regime. The promotion of ice jamming will occur in each year of the project by artificially increasing the ice thickness on small tributaries within the Delta. Monitoring the breakup of these artificial jams will increase our understanding of ice jam dynamics and improve the ability to create future jams and predict natural ones.

In the first year of the project an attempt was made to cause an ice jam by using traditional ice bridge construction practices to flood the ice surface (Peterson 1993). Surface flooding proved unsatisfactory for several reasons, including difficulty in directing water flow, delays to allow for freezing, frequent equipment breakdown, and slow ice growth. In addition, a high run-off from the Peace River is required to create an ice-run at breakup on the Quatre Fourches River because of the low slope of the smaller river. The winter of 1992/93 had significantly lower precipitation rates and a warmer break-up period, thus run-off was minimal and the rivers experienced a thermal break-up.

This report describes the results of the second year of the project. The objectives of the project in the second year are to:

1.1 build a partial width grounded longitudinal ice berm on the Quatre Fourches River to cause an obstruction at break-up in an attempt to cause an ice jam;
1.2 use spray ice technology to build the ice berm;
1.3 implement a monitoring program to record site specific meterological conditions, ice growth and decay, channel bed material and depth, break-up stage, ice and water temperatures, etc.; and
1.4 use data from the monitoring program to assess the success of the ice jam.

2.0 METHODOLOGY

As in the first year of the project, a site on the Quatre Fourches River was selected for the ice jam feasibility study, approximately 9 km south of the ice bridge river crossing on the Fort Smith winter road (58° 42'15"W and latitude 111° 24'30"N) (figure 1). The ice berm was constructed at the upstream bend with the expectation of the Peace River backing up into the Quatre Fourches River and causing ice to flow upstream.

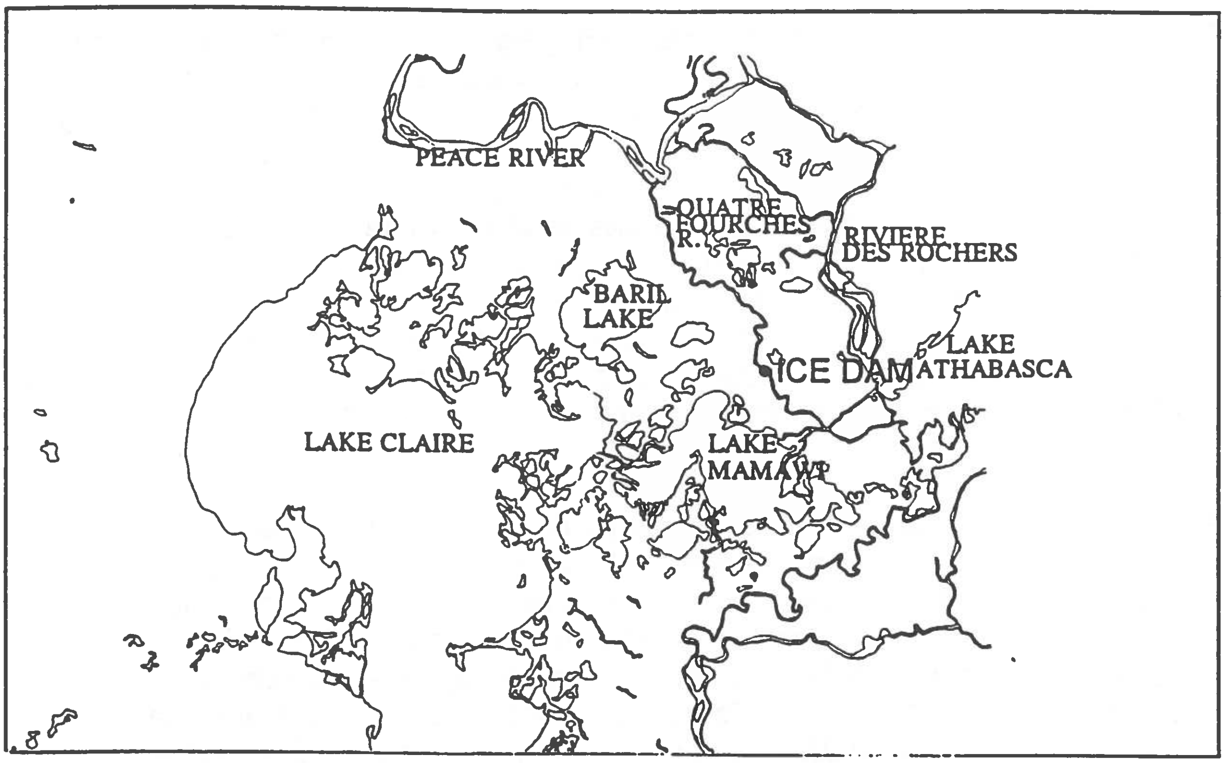

Figure 1. Site of the ice dam project on the Quatre Fourches River, Wood Buffalo National Park.

Spray ice technology was chosen instead of surface flooding to improve the potential for ice growth. Spraying water into the air in an arc breaks up the water stream into droplets varying in size from 1-10 mm in diameter. This provides a larger surface area for heat transfer from the water to air, and thus a shorter freezing time. The water spray freezes into layers of strong, highly-reflective polycrystalline ice.

The project required the purchase of a high pressure and volume pump (4000 litres/minute at 175 psi) with a rotating monitor (nozzle). The pump is powered by a 175 hp. diesel engine and the assembly is mounted in a building on skids. This equipment was built by Sandwell Inc. of Calgary.

The ice berm design and monitoring program was developed by Michael Demuth of the National Hydrology Research Institute (NHRI). The berm was designed to focus the drifting ice at break-up into the thalweg, while having sufficient ice along the shoreline to anchor the mass. With sufficient upstream forces, the drifting ice would be forced under the floating berm and thus constrict the thalweg. The berm was constructed through a contract with Mistee Seepee Development Corporation of Fort Chipewyan.

A monitoring program was set up to measure ice growth over the berm at 44 sampling sites (20m intervals) (figure 2). Stakes were set into the ice and the total ice thickness and exposed stake length recorded. Daily measurements were made of the length of exposed stake to determine depth of surface ice laid down. The ice growth on the bottom of the berm was expected to be negligible.

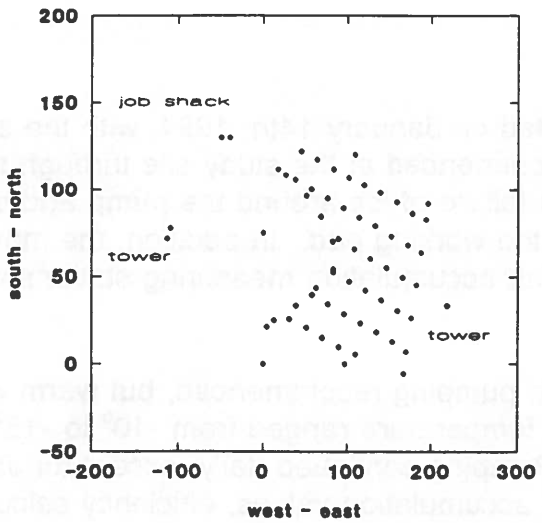

Figure 2. Ice measuring stations set at 10 m intervals over ice berm. The toe is the east line of stakes with stake T1 at the north end. Successive lines are "A" to" I".

The pump location was recorded using horizontal "X,Y" measurements from a single ice measurement stake. In addition, pumping hours, pump RPM, nozzle size and vertical angle from horizontal were recorded for each pumping period.

Micro-meteorological data was recorded at two sites, at each end of the study reach, outside of the ice berm. A tower at each site held instruments at three levels above the ice surface to record humidity, wind direction wind speed and temperature. A net radiometer measured net long wave and short wave radiation, and a thermistor string measured ice temperatures along the berm. A third thermistor string was placed within the berm. The instruments were in place on January 21 and were removed on April 20, 1994. Measurements were recorded at various intervals continuously during this time. All data is located at the National Hydrology Research Institute (NHRI), Saskatoon, Saskatchewan.

Break-up monitoring consisted of measuring water stage upstream of the ice berm and using aerial flights to visually record ice conditions on the Peace River. The water stage was measured using a survey level and temporary benchmark at a location approximately two kilometres upstream of the ice berm. Monitoring began April 24 and ended on April 30, 1994. Aerial flights were conducted from Fort Smith by

Dr. Terry Prowse and Michael Demuth (NHRI), and from Fort Chipewyan by the author and Willie Courtorielle.

3.0 RESULTS

The project started on January 14th, 1994, with the arrival of the Sandwell pumping unit. Training commenced at the study site through to January 16th. On January 17th there was creep failure of ice around the pump and operations were stopped for two days to thicken the working pad. In addition, the monitor swivel failed and needed replacement. The accumulation measuring stations were laid out during the down time.

On January 25th pumping recommenced, but warm weather limited the pumping time. The mean daily temperature ranged from -10^0 to -15^0 Celsius for the period January 22nd to 29th. Pumping continued daily, except for January 30th and 31st, for a total of 23 days. Ice accumulation values, efficiency calculations, etc. are computed from January 25th.

From January 25th to project completion the pump operated for 103.08 hours, at an average volume output of 4500 l/hr. This provided 463,860 litres of water or approximately 371,000 litres of water for ice production, based on a generally accepted efficiency rate of 0.8 and accounting for losses due to sublimation and over-spray (Prowse et al., 1994).

The ice berm covered an area of 15,000 m^2 to an mean depth of 184 cm (maximum 255 cm, minimum 105 cm). Total volume of ice produced was approximately 27,600 m^3. Ice was not applied uniformly, with some locations receiving half the volume of others, particularly along the south shoreline (figure 3). The shoreline areas were critical for anchoring the berm by freezing to the bottom.

Ice accumulation was measured daily at each sample site. Accumulation varied markedly from site to site. This was partially due to difficulties with the monitor swivel and lack of direction to the work crews regarding the desired shape of the berm. Accumulation measurements were inaccurate in some cases, and at times procedures were not followed by the crews which led to questionable data. Where possible, interpretations were made and data records updated. Ice accumulation increased daily although maximum and minimum daily records showed a high degree of fluctuation (figure 4).

Daily pumping hours were highly variable, from a minimum of 1.25 hours to a maximum of 7.0 hours (figure 5). Mean pumping time for each crew was 4.54 and 4.83 respectively. For the same period the contract paid an average of 10.7 hours/day. There is an obvious room for improvement in the number of pumping hours/day. Prowse et al. (1994) estimated that an increase of pumping time to 6.0 hours/day will increase overall accumulation by 33%. Starting the project earlier in the season would ensure more consistently cold temperatures. The pumping unit operated flawlessly in -40^0 Celsius temperatures if the engine was allowed to run continuously and the pump heated before being engaged. The contract ended on February 18th, 1994 when the pump casing was cracked, probably by incomplete draining of the lower casing and subsequent freezing.

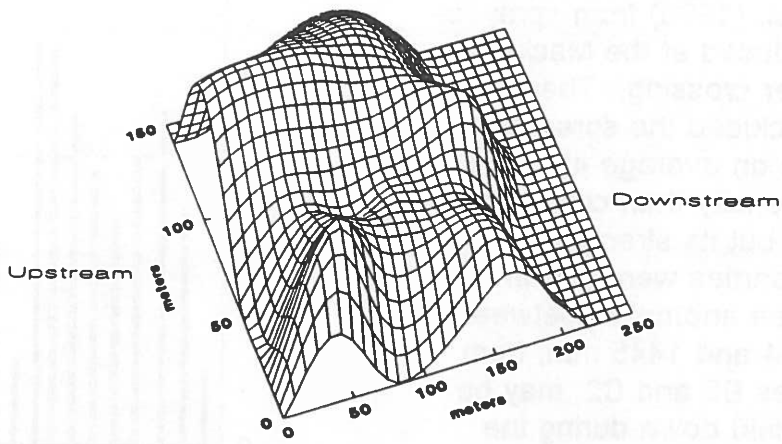

Figure 3. Variations in ice thickness over the surface of the ice berm, Quatre Fourches River.

In addition to the weather data records, ice density measurements were taken at three sites by taking a nine centimetre diameter core the full depth of the ice. Two cores were 2 m in length and the third was 2.25 m in length.

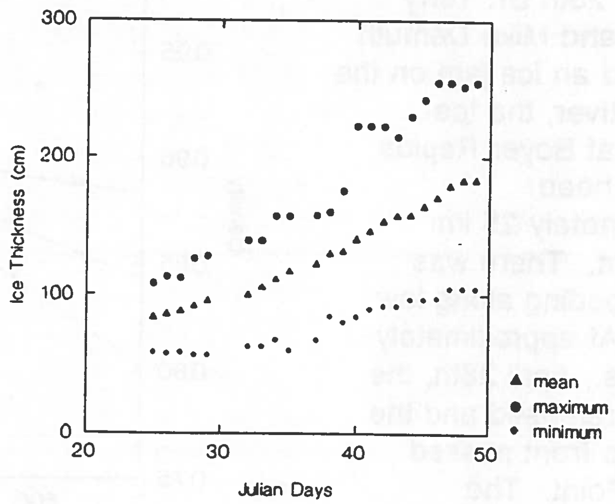

Figure 4. Ice accumulation at 44 sample sites on the ice berm from Jan. 25 - Feb. 18, 1994.

There was a high degree of variability in ice densities but overall ice density increased with depth ($r=0.789$, $P<0.005$) (figure 6). The addition of air bubbles in the spray ice and consistency of spray-ice at application time may account for some variability.

The values are similar to those reported by Gerard et. al. (1990) from spray ice produced at the Mackenzie River crossing. They concluded the spray ice was on average 4% lower in density than clear natural ice, but its strength properties were similar. Three anomalies between 1174 and 1445 mm, from cores B5 and C2, may be ice laid down during the warm period in late January.

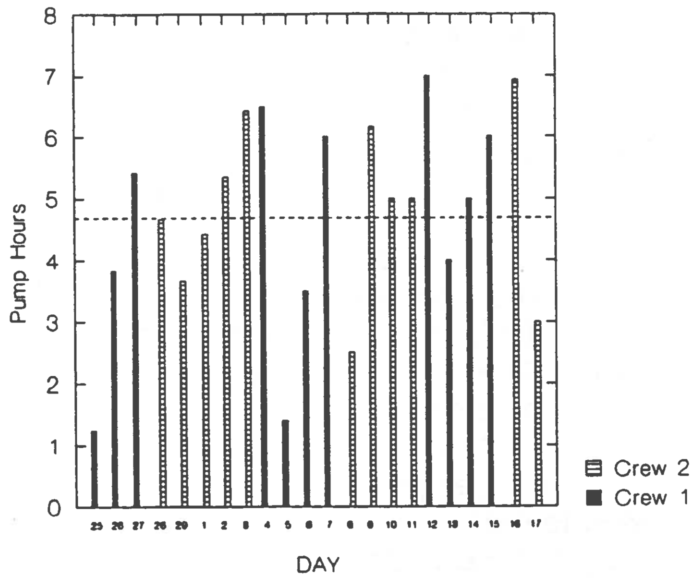

Figure 5. Daily hours of pump operation from Jan. 25 - Feb. 17, 1994. Mean operation time is 4.68 hrs./day.

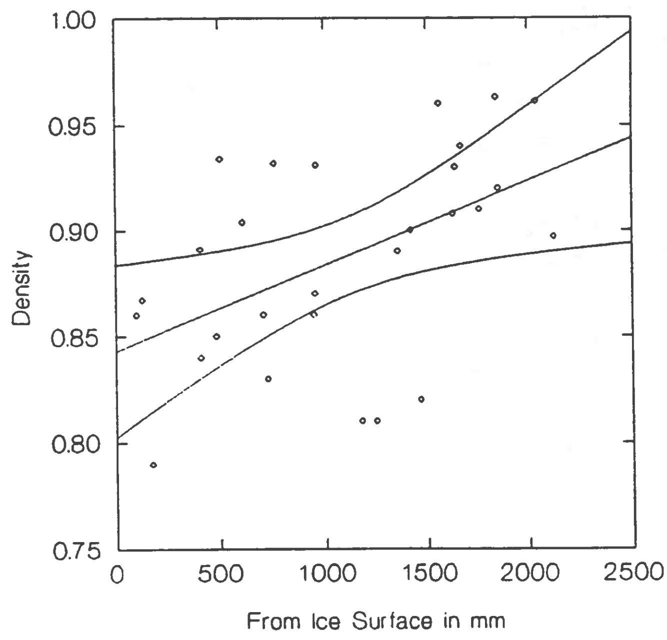

Figure 6. Ice density at various depths from three cores, F2, C2, and B5. Regression slope r=.789 with P<0.005.

Break-up monitoring upstream of the ice berm started on April 24th, 1994. On April 25th Dr. Terry Prowse and Mike Demuth observed an ice jam on the Peace River, the toe forming at Boyer Rapids and the head approximately 25 km upstream. There was minor flooding along low areas. At approximately 0400 hrs., April 28th, the ice jam released and the break-up front passed Peace Point. The maximum stage at Peace Point (station 07KC001) was recorded as 220.654 masl, within 0.5 meters of breaching the river bank (D. Robertson, pers. com.). The highest recorded open water level at Peace Point was 218.421 masl in 1990.

By 1500 hours on April 28th the ice jam had re-formed near Rocky Point. The toe was 1 km upstream of Rocky Point and the head was forming at Carlson's Landing. There was flooding on Moose Island, low areas above the river bank between Sweetgrass Landing and Moose Island Crossing, and water was flowing up the Claire and Baril Rivers. The maximum stage did not rise above the bank at Sweetgrass Landing (215.594 masl).

The water recording gage at Rocky Point (station 07KC005) recorded two peak water levels during break-up, on April 28th and 30th (figure 7). The maximum stage recorded was 211.385 masl on April 30th. In the last ice jam on the Peace River, April 1974, the maximum stage reached was approximately 215.46 masl. The maximum recorded open water stage was 211.578 meters in 1990.

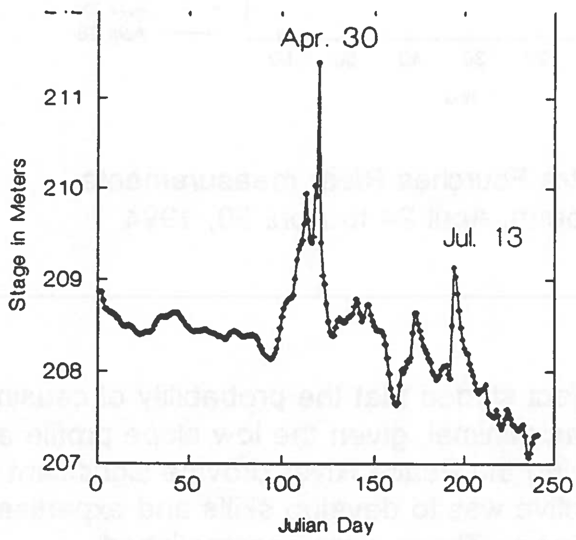

Figure 7. Daily mean water stage at Rocky Point, Peace River. Maximum recorded stage for April 30, 1994 (Uncorrected data from WSC).

Water stage on the Quatre Fourches River varied in response to the two ice jam occurrences. Peak levels were well below the bank elevation. On April 28th at 1600 hours the maximum reached 209.61 masl, but dropped rapidly as an ice jam formed upstream of Rocky Point (figure 8). This was 14 hours after the Boyer Rapids jam released. The second jam released between 1800 and 2100 hours on April 29th and the maximum stage reached at the monitoring site was 209.72 masl at 0800, the first measurement for that day. Apparently there were no signs of higher water earlier in the morning.

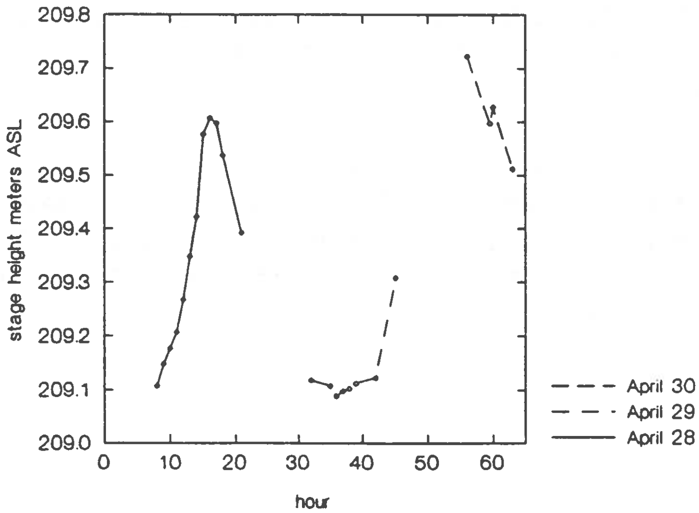

Figure 8. Quatre Fourches River measurements above the ice berm, April 24 to April 30, 1994.

4.0 DISCUSSION

It was recognized before the project started that the probability of causing an ice jam on the Quatre Fourches River was minimal, given the low slope profile and wide deep channel and the necessity of having the Peace River provide significant flow into the river at break-up. The main objective was to develop skills and expertise in building spray-ice and monitoring its efficiency. These were accomplished.

Prowse et al. (1994) reviewed the spray-ice program and determined it is entirely feasible to build a six meter thick ice berm, the original design proposal for this project. Increasing the daily production schedule and utilizing the coldest period of the winter are critical steps. In addition they concluded using a flood-freeze process could not provide the same volume of ice as the spray ice process.

Equipment performance was nearly flawless. Two problems were 1) a factory defect in the monitor swivel assembly, and 2) a vibration which caused short circuiting in the electrical panel for the engine. Both problems were corrected. The pump housing crack which ended the program was not a factory defect. This is repairable and must be repaired before the unit can be used.

The ice berm was built by Mistee Seepee Development Corporation as a service contract with WBNP. There was insufficient information available on ice growth potential to develop a product oriented contract. This approach caused several problems. The contractor had no milestones or interim completion schedules which could be measured, and there was little economic incentive to complete the project earlier. Modifying work hours to take advantage of cold weather or limit work in warm weather was not the responsibility of the contractor. Efficiency was compromised as a result..

Access was the responsibility of WBNP which required, on some days, daily trips over the road to clear snow. As the park does not have blade-mounted equipment, frequent dragging of the road surface with heavy tires was necessitated. There were several mechanical problems on the track-truck caused by this approach.

The project experienced several delays at the outset which caused increased expense. There was an initial training period of three days for both two-person crews, considered necessary for safe and efficient operation of the pumping unit. The creep failure problem and monitor swivel failure created unexpected delays. The ice growth monitoring program was not implemented until the delays noted above were experienced. Had the site been prepared and monitoring stakes erected prior to the contract starting, the delays would have been minimal.

Some difficulties were also encountered in implementing the monitoring program. More consistent measurement of pumping time, pressure and nozzle angle, more frequent measurement of spray ice density and consistency, and more accurate recording of ice accumulation and pump location are required to allow a complete evaluation of the project in the next field season.

The natural ice jam formation on the Peace River provided a unique opportunity to observe and record the phenomenon. Measurements were restricted to recording water levels at the two existing gages and on the Quatre Fourches River. Photographs and video-tape supplemented the observations.

The ice jam at Boyer Rapids may have been an unusual case. Fred Vermillion, a local trapper, has lived most of his life upstream from Boyer Rapids near Jackfish River. He stated to his knowledge a jam has never formed at the rapids. In this case, his cabin experienced minor flood damage.

When the jam released it re-formed upstream of Rocky Point, effectively cutting off water to the Quatre Fourches River and the artificial ice jam. Downstream of the ice jam the Peace River was free of ice so when it released there were no barriers holding water back to allow the Quatre Fourches River to rise. It is apparent that several factors must operate simultaneously to cause sufficient upstream force on the Quatre Fourches River to cause an ice jam.

In 1994/95 the project should be moved to a site on the west arm of the Quatre Fourches River near Dog Camp that is the outlet for Mamawi Lake. In this scenario, an ice dam will be constructed to block all flow out of Mamawi Lake for a short period of time, negating the need for sufficient upstream force to cause an ice jam. Basins which are connected hydraulically to the lake will be flooded as the lake level rises during breakup. Sufficient in-flow into the lake is required, however, if critical over-spill elevations are to be attained before the ice dam melts and releases. Modelling such a scenario using the 1-D Hydrodynamic model should provide the minimal temporal and stage requirements for designing an ice dam.

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