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Proposed Artificial River Ice Damming to Induce Flooding of a Delta Ecosystem

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ABSTRACT

Over the last twenty-five years, significant ecological changes have occurred in the Peace-Athabasca Delta largely because of changes to the hydrological regime of the Peace River, including flow regulation. Spring floods historically inundated the delta and supplied the major input to the water balance of many of the perched basins. No flooding of these basins, however, has occurred since 1974 despite historically high flows on the Peace River. As a result of long-term drying, there has been a significant reduction in wetlands and meadows and an invasion of more persistent shrub communities. Recent recognition that ice jams on the Peace River were the only way in which flooding of the perched basins could have occurred, a project has been initiated to flood these basins through the creation of artificial ice dams. An initial trial using surface-flooding was attempted in late-winter of 1993. Although the cover thickness was augmented no flooding occurred. Future plans are to employ spray-ice technology which should permit more rapid ice growth and a greater obstruction of the total flow depth.

INTRODUCTION

Delta ecosystems are frequently comprised of a myriad of channels and lakes, the latter of which can be subdivided according to the degree to which they are connected to the main flow system. The overall biological structure and productivity of such lakes depend on their flooding and flushing during high-stage events. In warm temperate climates, such flooding can only be produced by high flow conditions. In cold regions environments, however, flooding of high-elevation or "perched" lakes can be produced by high flow events and/or ice-jam backwater. Often the flood levels produced by ice-jams, even at relatively low discharge, far exceed those possible under open-water conditions and for much greater discharge. Such ice-induced flood levels have been found to be critical to the flooding of perched lake environments in, for example, the Mackenzie River (e.g., see Marsh and Ommanney, 1989) and Peace-Athabasca Deltas (e.g., see Peace-Athabasca Delta Implementation Committee, 1987). Unfortunately, in the latter case, the magnitude and frequency of high-elevation flooding has been reduced over the last two decades and significant impacts have occurred to the perched lake environments. The reduction in flooding has been attributed to the reduction of spring ice jamming, which in turn is related to changes in the flow regime and most probably the regulation effects of a dam on the upper Peace River. In an attempt to restore, at least localised, flooding of some of the perched basins, a project has been initiated to create artificial ice dams on Delta tributaries. It forms part of a multi-agency three year management plan for the Peace-Athabasca Delta. This paper reviews the hydrologic sensitivity of the perched lake system, the environmental changes that have occurred over the last two decades due to the lack of flooding, and the current and potential other approaches to creating artificial ice dam flooding.

PHYSICAL SETTING

The Peace-Athabasca Delta is one of the world's largest freshwater deltas, formed by the Peace, Athabasca and Birch Rivers at the western end of Lake Athabasca in the province of Alberta (Figure 1). Approximately 80% of the 3900 km^2 delta lies within the Wood Buffalo National Park and includes almost 1200 km^2 of sedge and grass meadows, one of the largest undisturbed grassland areas in North America. A multitude of shallow perched basins are scattered across the grasslands providing ideal habitat for nesting waterfowl and muskrat. Three large shallow lakes (Claire, Mamawi and Baril; <1 to 3 m deep) occupy the delta and are connected to Lake Athabasca and the upper grassland zones by a myriad of active and inactive channels. Figure 2 shows the major flow connections. Levees of the channels are vegetated mainly by poplar and white and black spruce.

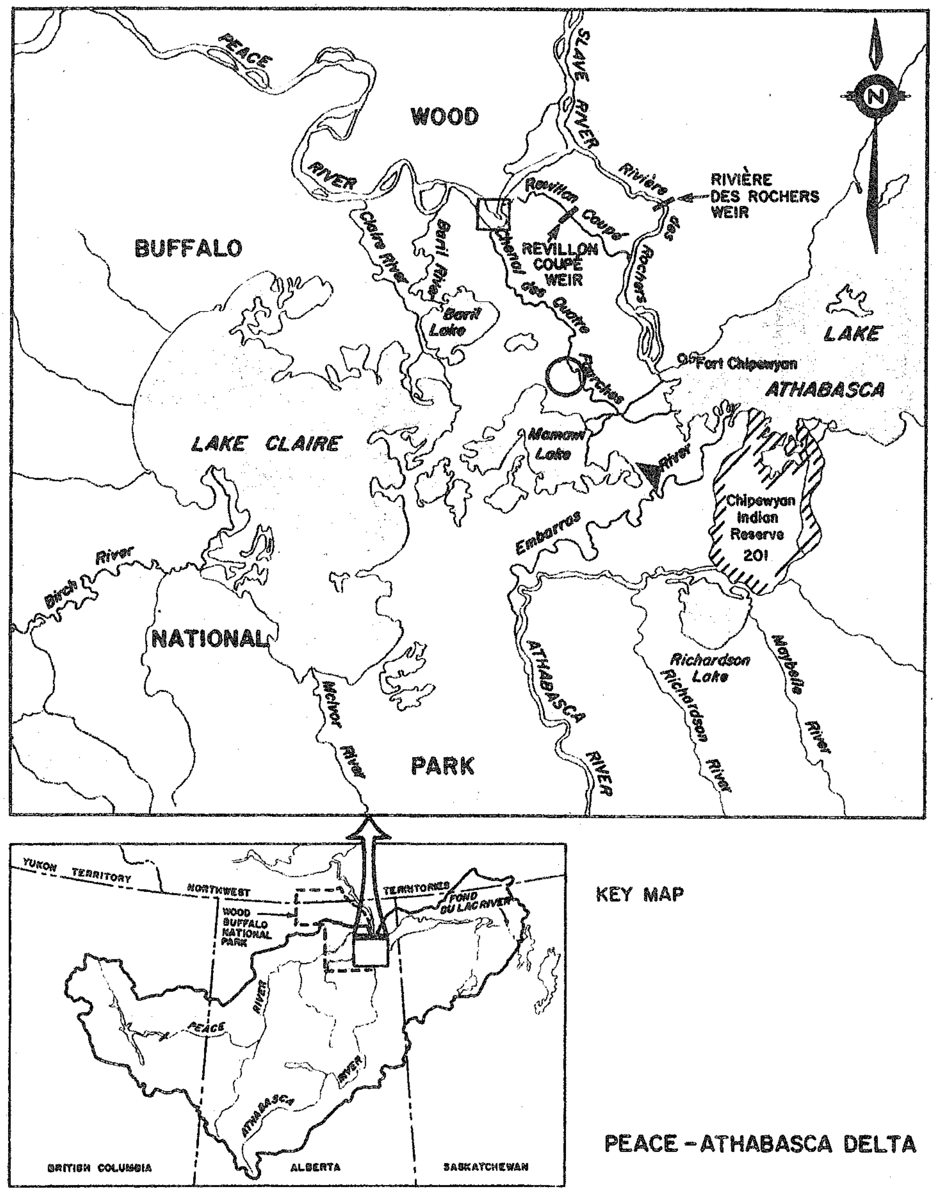

Figure 1. Peace-Athabasca Delta and locations of artificial ice-jam test site (circle), Rocky Point-Peace River ice-jam site (square) and the vantage point for Figure 3 (triangle) (modified from: Peace-Athabasca Delta Implementation Committee, 1987)

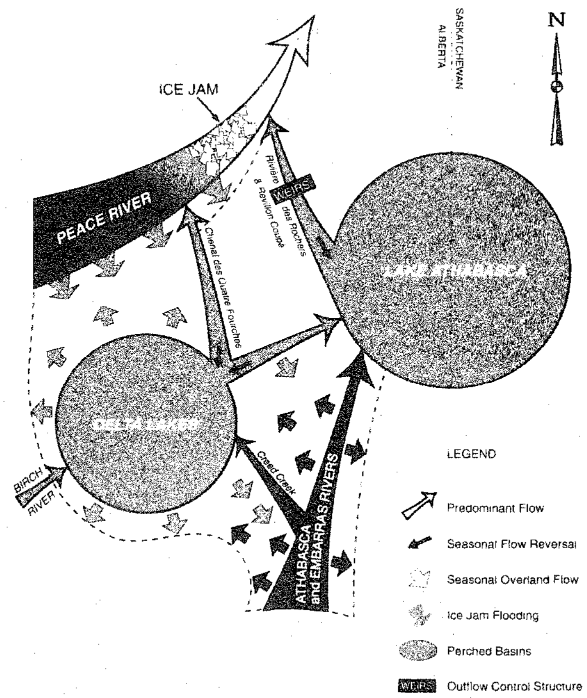

Figure 2. Schematic of surface-water flows in the Peace-Athabasca Delta under the influence of ice jamming and artificial remedial controls such as weirs (modified from: Peace-Athabasca Delta Implementation Committee, 1987)

The Delta and Lake Athabasca are connected to the northward flowing Peace and Slave Rivers by the major channels, Riviere des Rochers and Chenal des Quatre Fourches (Figures 1, 2). Discharge in these channels is proportional to the difference in water levels of the lake systems and the Peace River, both of which can vary significantly between winter and summer. Although flow is normally northward, it reverses during most spring floods when the Peace River is typically higher than the level of Lake Athabasca. The formation of ice jams on the Peace River serve to enhance the flood levels and, as described below, are responsible for the high-elevation flooding of many of the "perched" marsh and lake environments.

Water levels are typically highest in the Delta and on Lake Athabasca during the spring and summer but then recede during fall and winter. Such fluctuations have been found to be essential to maintaining the ecological balance of the delta environment (e.g., Peace Athabasca Delta Implementation Committee, 1987)

HYDROLOGIC AND ECOLOGICAL CHANGES

Beginning in 1968, filling of Williston Lake behind the W.A.C. Bennett Dam marked the beginning of lower than average flows on the Peace River. Spring floods were reduced by as much as 5500 $m^3 s^{-1}$ thereby reducing water levels on the connected system of lakes and eliminating the potential for flooding of the higher perched lake environments (Peace-Athabasca Delta Project Group, 1973). Since the vertical range of most delta plant communities are quite small, only minor changes in water levels can lead to the advance or retreat of plant succession over large areas.

Between 1968 and the fall of 1970 receding water levels exposed 500 km^2 of lake and marsh bottom of which 280 km^2 of mud flats became vegetated by seedling growth of annuals, grasses, sedges willows and other plants (The Peace-Athabasca Delta Project Group, 1973). Similar impacts, for example, occurred to the muskrat population which was estimated as high as 1.4 million during the mid-60's but only near 17,000 by 1972. Both the reduced water levels and associated winter freezing to the bed of perched marshes and lakes were believed responsible (The Peace-Athabasca Delta Project Group, 1973).

Recognizing the ecological impacts to the Delta, the governments of Canada, Alberta and Saskatchewan established the Peace-Athabasca Delta Project Group in 1971 to identify methods for raising water levels (Peace-Athabasca Delta Project Group, 1973). The recommended solution involved the construction of fixed crest weirs on the Riviere des Rochers and Revillon Coupe. Detailed hydrologic and biologic evaluations of the success of these structures are contained in a series of reports by the Peace Athabasca Delta Implementation Committee (1987). Although the control structure served to restore water levels in the lower elevations portions of the Delta, perched basins along the Peace River and at higher elevations in the Delta were not recharged. To date, these basins have not been flooded since 1974, a year of significant spring run off and ice jamming on the Peace River. Figures 3a to 3c show the difference in water coverage from 1974 to 1985 and Figures 4a and 4b, some of the drying and vegetative changes that have occurred from 1927 to 1993.

The lack of annual flooding has killed sedge meadows and allowed the invasion of more persistent shrub communities, such as willow and

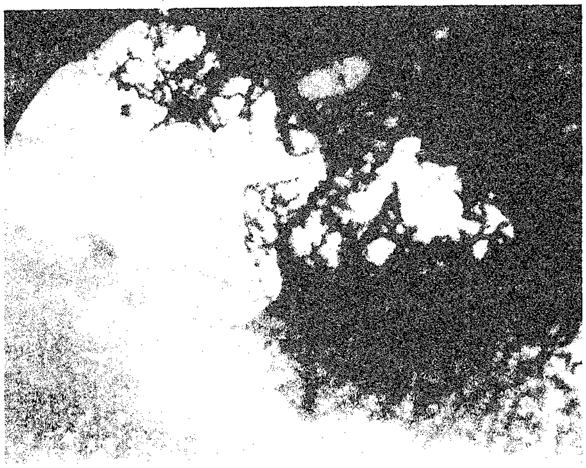

Figure 3a.

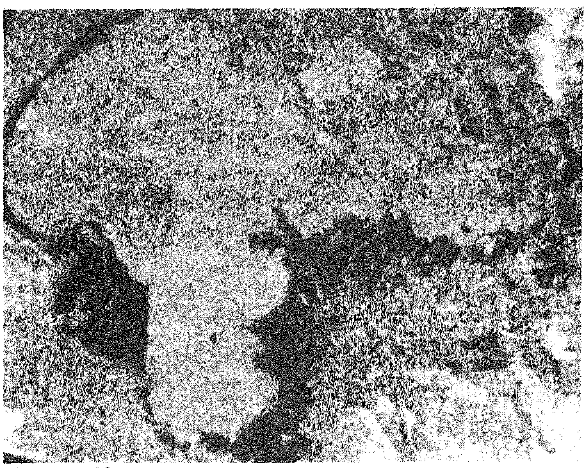

Figure 3b.

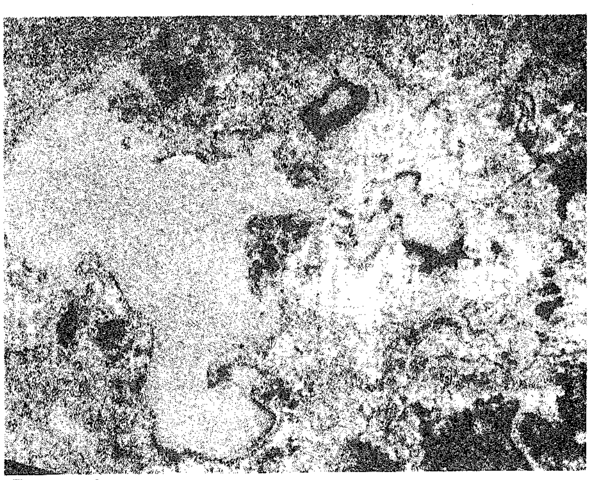

Figure 3c.

Figures 3a,b,c. LANDSAT Multi-Spectral-Scanner images of the Peace Athabasca Delta contrasting the extent of flooding in a) May 1974 under ice conditions, b) subsequent extent of flooding in June 1974, and c) dry conditions of August 1985 (after: Jaques, 1989).

poplar (Figure 5). From an analysis of Landsat images of delta water levels and vegetation, Jaques (1989) estimates that there has been a 47% reduction in the aquatically- productive vegetative community from 1976 to 1989. Notably, over 78% of the wetlands and meadows occur above the elevation of the mean-peak, summer water level in the post-regulation period (Jaques 1989) and influenced by the existing weirs.

HYDROLOGIC ROLE OF ICE JAM FLOODING

With the long-term lack of flooding of the perched-lake environments, it became increasingly obvious that the role of spring break-up and associated ice-jam flooding was more important than previously considered. Although ice jamming typically occurs at discharges lower than those produced during the later spring and summer periods, it is the elevated backwater due to flow obstruction by the ice which is responsible for the flooding (Figure 6). This point was further strengthened following the 1990 historically-high open-water flow on the Peace River which failed to flood the perched-basins. Although there is a lack of water-level data (standard hydrometric records) in the Delta prior to regulation, historical accounts from local inhabitants gathered by Thorpe (1986) and Peterson (1992) have confirmed the hydrologic and biological significance of backwater flooding created by spring ice jamming in the Delta. One site of major ice jamming is believed to be at a sharp bend in the Peace River at Rocky Point, located just downstream of the Quatre Fourches channel (Figure 1). Numerous other minor sites have also been identified on the secondary channel network.

ARTIFICIAL ICE JAMMING

Recognizing the historical role of ice jamming in the Delta, it was decided by a multi-agency body (comprised of Alberta Environment, British Columbia Hydro, Fort Chipewyan, and Environment Canada's Park Service and Ecosystem Sciences and Evaluation Directorate) to evaluate potential remediation techniques such as artificial ice jams for restoring water levels in the perched basins (Peace-Athabasca Delta Ecosystem Management Plan 1993). Although the historic ice jam sites on the Peace River are likely to be the most effective locations for inducing flooding of

Figure 4a.

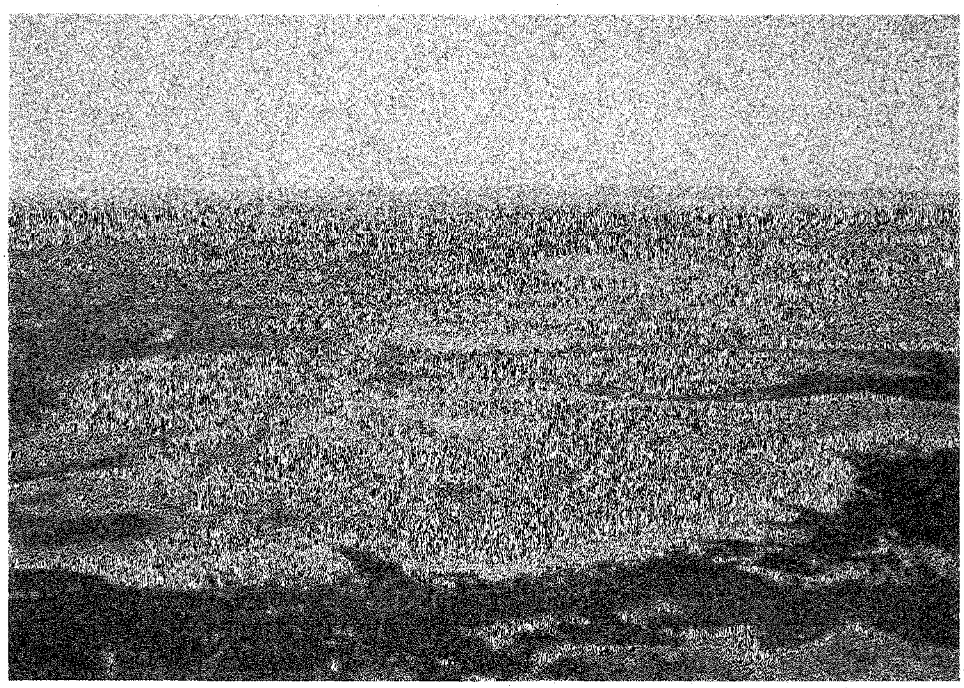

Figure 4b.

Figure 4a,b. Views along the Embarras River looking south-west (see Figure 1) in a)1927 and b)1993, illustrating the drying of perched lakes and associated vegetative encroachment.

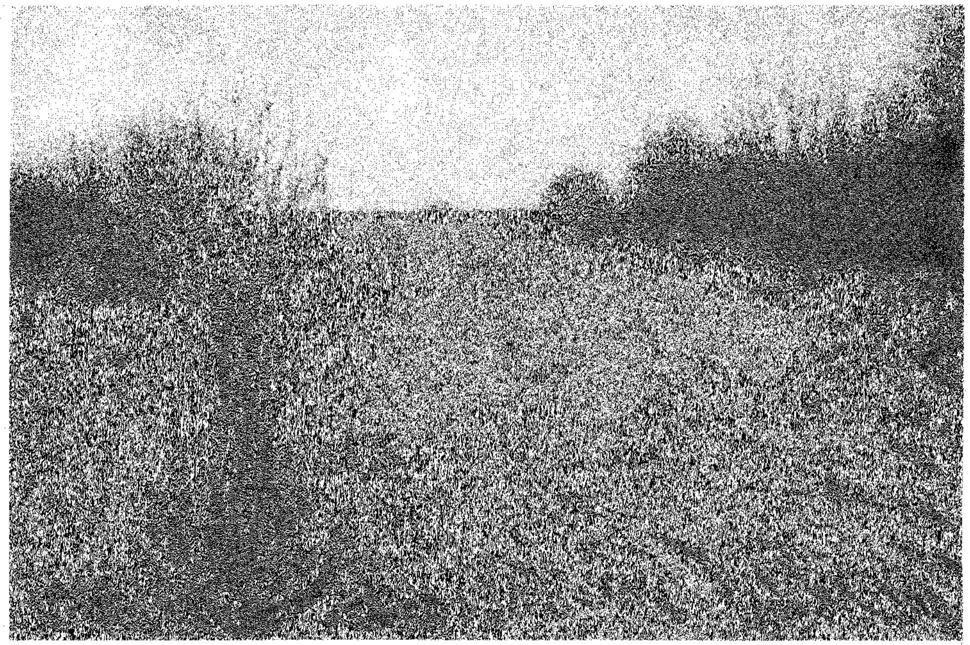

Figure 5. Sedge grasslands showing typical vegetative succession of low shrub ie. willow and poplar.

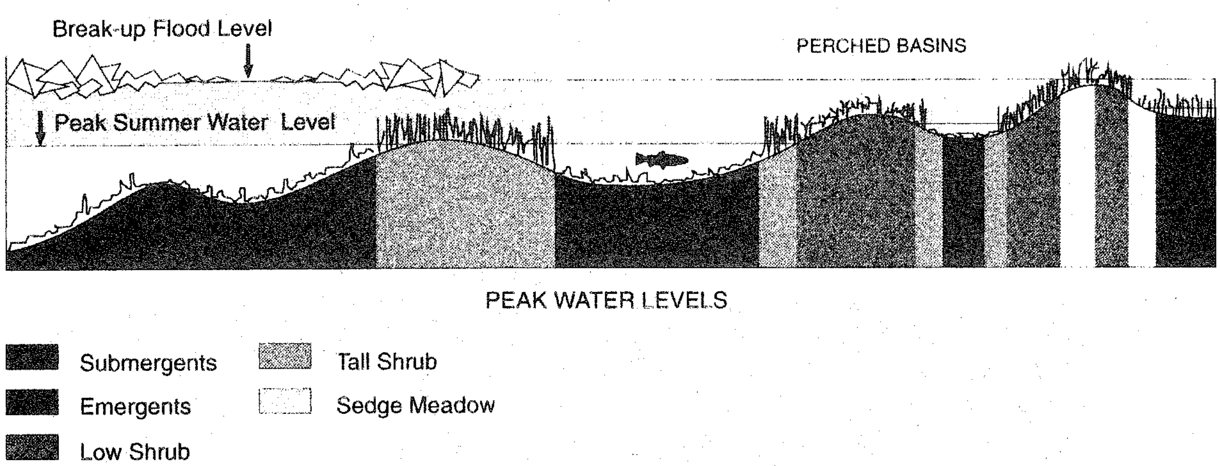

Figure 6. Schematic of perched basin flooding for a northern deltaic ecosystem, contrasting the annual maximum water stages produced by ice-jam and open-water conditions. (modified from: Peace-Athabasca Delta Implementation Committee, 1987)

the Delta, it was considered prudent to first develop and evaluate construction-methodologies at smaller and more controllable sites, such as on the Chenal des Quatres Fourches (Figure 7).

Immediately following project approval, the first trial construction phase was begun in February 1993. Unfortunately, however, this late start-date meant that only surface ice-flooding technology could be used. Moreover, it also meant that a full dam-obstruction could not be constructed at such a late time of the winter season. Despite these restrictions, using a combination of typhoon pumps and auger pumps, it was possible to augment the ice-cover by approximately 35 cm above the natural thickness (70 to 110 cm). Spatial variability of ice-cover thickness and the flood ice/natural ice proportion was determined by drilling and conducting impulse radar surveys along and across the study reach. The selected reach was approximately 1 km long, 100 m wide, and 5 to 10 m deep along the thalweg (the greatest depths being in channel bends). Hydrometeorlogical conditions prevailing during early spring of 1993 resulted in thermal break-ups of most rivers near the study site. Flow did not significantly rise on the Peace River and, with warm air temperature and high solar-radiation conditions, much of the river-ice cover tended to melt in place and ultimately only produced a very minor ice run without significant ice jamming. Although similar conditions prevailed at the artificial ice jam site, it is noteworthy that a portion of the augmented cover lodged in the study reach as shown in Figure 7, while the remainder of the reach became ice free. Longer duration of the artificial ice cover was due not only to a greater ice thickness but also due to a reduction in solar radiation melt because of an enhanced surface albedo. The latter was due to a thick layer of highly-reflective polycrystalline ice produced by the surface flooding process. Unfortunately, the low flow contributions from the Peace River, however, precluded an assessment of the artificial cover to induce significant backwater, and preferably over-bank flooding.

SUMMARY- Performance Assessment and Future Studies

It was recognized at the beginning of the study that the hydraulic conditions of a low-slope and wide-deep channel would not favour the formation of a significant ice jam without an appreciable discharge from the Peace River. In general, the severity of break-up and ice jamming is determined by the magnitude of a) the hydraulic forces on the ice cover, and b) the resistance of the ice cover to motion. No matter how large an artificial ice dam (enhanced resistance) is constructed, jam formation depends on the presence of a significant downstream flow to resist. The probability of such flows occurring have been diminished through the effects of regulation on the Peace River.

Without a large spring flow, the Quatre Fourches test site can only be used for testing methodologies for increasing the ice cover resistance to motion, i.e., artificial ice dams. To this end, future work is focussing on the use of spray-ice technology to construct an ice berm of suitable geometry and size which would promote the rubbling and thickening of incoming ice (Demuth and Prowse, 1993). The advantage of a spray-ice over a flood-ice strategy is simply the greater growth potential (although it may not

Figure 7. Artificial ice jam test reach in the Chenal des Quatre Fourches. Remnant ice from the artificially enhanced cover remains lodged in the section.

produce as strong an ice cover). For example, under the same meteorologic conditions, spraying water into the air as opposed to flooding results in a 75:1 increase in the water-surface area exposed to sub-freezing temperatures (e.g., see Zarling 1980). As an additional comparison, the rate at which ice can be augmented for comparable water pumping power increases by similar orders of magnitude as evidenced by experience to date in the construction of spray-ice islands in the Arctic offshore (Arctic Exploration, 1984).

Efforts are also underway to more closely define flood plain topography and identifying other potential ice jam sites in the Peace-Athabasca Delta. This is being conducted in concert with other groups working on, for example, hydrologic-vegetation interactions and flow modelling of the system. If artificial flooding of perched basins within the Delta can be shown to be an effective ecosystem management tool at the small scale, major ice-jam flooding involving the Peace River directly would be a logical extension to this work.

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