The purpose of this investigation was to develop an economically viable means of obtaining automated river water level measurements in remote areas under ice conditions, with the objective of obtaining field data on ice jam formation and release. In addition to having the capability of obtaining continuous data during ice jam events, it was desirable to have a system which could alert a field team of ice events occurring at the remote site, in order to facilitate complementary observations during ice jamming events.

In this paper, details of the measures taken to develop and implement such a system on the Athabasca River near Fort McMurray, Alberta, are described and an assessment of the initial performance under freeze-up and winter conditions is provided. Each remote water level monitoring station employs a conventional (vented) pressure transducer linked to a communications system on the river bank, primarily for notification purposes. A back up system consisting of a submersible water level/data logger (with no communication system) ensures continuous data collection, even if the vented system is torn out by ice action.

The system was installed in the fall of 2000 and successfully survived the rigors of a relatively dynamic freeze-up. The major logistical problem seems to be freezing of the sensors into the ice cover due to extremely shallow flow conditions in winter. Details of the data collected to date are presented and recommendations for refining the design are presented. It is hoped that the information presented here will prove useful to others wanting to obtain similar data.
1. Introduction

When ice jams form and release, the physical interaction between streamflow and river ice is significant, and each has the potential to exacerbate the effects of the other. This inter-relationship is complex and, as yet, poorly understood. Consequently, current analysis techniques are still quite dependent upon site specific, empirical and statistical techniques. Unfortunately, such approaches do not provide for the transfer of methodology and knowledge between sites, or any means of assessing the potential impacts of climate change. Only a deterministic modelling approach, can facilitate such objectives; however, this requires a much better understanding of the physical processes involved.

Limitations in current knowledge can be directly attributed to a scarcity of documented field cases. Although numerous in-situ ice jams have been measured, to date only a very few field studies provide any information describing dynamic ice jam processes, such as ice jam formation and release. This is because these events often take place in remote areas and tend occur with very little warning. Not only have extremely few dynamic events been observed, in the best cases, the quantitative data obtained were limited to water levels at gauging stations and the documentation of the surface concentration and propagation velocity of ice floes (e.g. Jasek, 1999). Although such information is extremely valuable, it is not sufficient for developing a quantitative understanding of the impacts of meteorological and hydrological events on river ice jam formation and release.

The purpose of this investigation is to employ state-of-the-art remote measurement technology to obtain critically needed quantitative data describing the formation and release of river ice jams. In this investigation, we have taken advantage of recent innovations in remote data acquisition and communications technology to design a network capable of obtaining quantitative documentation of ice jam formation and release events including: automated water level monitoring before, during, and after ice jam formation and release. We have selected as our study site a 35 km reach of the Athabasca River upstream of Ft. McMurray, Alberta, within which the occurrence of ice jams is relatively common.

2. Study Reach

The Athabasca River stretches from its headwaters in the mountains of Jasper National Park northeast across the province of Alberta to its delta at Lake Athabasca. The reach of interest for this study extends approximately 35 km from Crooked Rapids to Fort McMurray, which is situated at the confluence of the Athabasca and Clearwater Rivers (Figure 1). Figure 2 presents a 1:250,000 NTS map showing this reach of the Athabasca River. Within the study reach, WSC operates an annual gauge (Station 07DA001) on the Athabasca River just downstream of the confluence with the Clearwater River.

Spring ice jam events are a frequent occurrence in this reach. For example, events were documented by the Alberta Research Council (ARC) and Alberta Environment in 1977, 1978, 1979, 1983, 1984, 1985, 1986, and 1987. More recently, in 1997, several million dollars in flood
damage occurred in Fort McMurray during a particularly severe ice jam event (comparable in magnitude to the 1977 event). Photos from the 1997 flood event are presented in Figure 3.

Because of the frequency and severity of river ice jams at Fort McMurray in the past, Alberta Environment and the Regional Municipality of Wood Buffalo (RMWB) operate a collaborative monitoring program on the Athabasca River each spring for flood forecasting purposes. For Alberta Environment, this primarily involves a 24-hour monitoring team stationed approximately 35 km upstream of the town of Ft. McMurray (near Crooked Rapids), reporting to an ice specialist stationed in Fort McMurray. Alberta Environment also conducts periodic aerial reconnaissance flights out of Edmonton to document ice and snowmelt conditions in the upper basin and the progression of breakup from the Pembina River downstream to Fort McMurray. Occasional short flights between Fort McMurray and the Crooked Rapids station are also conducted when conditions warrant. Staff from the RMWB measure ice thickness and monitor water level changes at key sites along the Athabasca and Clearwater Rivers in Fort McMurray, and maintain a 24-hour watch in the municipality once breakup is imminent.

As a part of breakup and ice jam monitoring studies conducted in the past by ARC and Alberta Environment, benchmarks had been established along the Athabasca River to facilitate water level measurements during ice jam events. This included the placement of staff gauges along the river at each of these benchmark sites (denoted as sites G5 to G150 in Figure 2) which can be photographed during ice jam events to facilitate water level determination. Almost all of the staff gauges are still in place in the remote reaches (upstream and downstream of Fort McMurray) and most are tied into the Geodetic Survey of Canada monument system. Typical staff gauge sites are shown in Figure 4.

3. Study Objectives

It is the objective of this investigation to take advantage of the latest innovations in remote data acquisition and communications technology to design a system capable of obtaining quantitative documentation of ice jam formation and release events including: automated water level monitoring before, during, and after ice jam formation and release; and, associated documentation of surface concentration and propagation velocity of ice floes. The core of the program, and the most challenging problem, is obtaining continuous, automated water level measurements during and after ice jam formation and release. To be effective, there must be a sufficient number of observational stations to establish ice jam profiles and to capture the peak attenuation of propagating surges, and the system used must be capable of withstanding significant ice events. In addition, because water levels are of limited value without documentation of associated ice conditions, the system must be capable of detecting the onset of a dynamic ice event and of notifying the field team so that they can get to the site immediately.
4. Field Installations

4.1. Measurement Strategy

Traditional water level monitoring methods, in which the pressure transducer is vented and routed to a data logger and/or communications device on the river bank, are inadequate for this purpose since they typically fail during even minor ice movements. An alternative approach is to use a submersible water level logger (typically of well applications) at each monitoring station. There are two limitations of the submersible system. First, since the pressure sensor is unvented, its precision will be limited to about 8 cm of head; this can be corrected with atmospheric pressure data. More limiting is the fact that the data collected by the submersible water level logger is not available until device retrieval (after breakup), therefore this device is of no use for field team mobilization purposes. To achieve the project objectives, a system of dual pressure transducers was employed (Figure 5). This consisted of a submersible water level logger encased in a segment of perforated pipe which was bolted to a concrete pad. A second, conventional, vented pressure transducer (linked to a datalogger on the river bank) was also anchored with the same concrete pad.

Funding was obtained for 6 water level monitoring stations. Three were installed during the fall of 2000, at station G120, 130 and 135 (Figure 2).

4.2. Protective Measures for the Water Level Monitoring Devices

Although the conventional pressure sensor was not expected to survive breakup, it was highly desirable to install the system before freeze-up and therefore, extensive measures were undertaken to enhance it durability during the ice formation period. Figures 5 through 7 illustrate the approach used. First, the 30 m long venting and communications cables from the conventional pressure transducer were wrapped in flexible aluminum electrical conduit (Figure 5 a). This was further protected within a 10 m segment of steel pipe in the vicinity of the edge of water. Where possible, this pipe segment was buried in a trench (Figure 6). To facilitate placement of the pressure sensors as far out into the channel as possible (desirable because of the shallow depths occurring here in winter), while insuring the cell phone data logger and communications tower were well away from the threat of ice jams, the venting tube and communication cables had to be interfaced to a transmission line which carried the data signal approximately 100 m further up the bank. The interface between these two systems is a delicate junction box coupling which also had to be protected from potential ice action. This was done using a short segment of a hollow steel structural member. The steel pipe carrying the venting tube and communication cables was welded securely to the protective steel box and re-bars were driven through drilled holes in the protective box to secure it in place (Figure 7).

Figure 8a show the transmission cable used to carry the signal up the bank to the communications tower. This cable is normally used in well drilling applications but is particularly useful for our application. It consists of 7 communication wires heavily encased in a wrapped wire conduit rated for 20,000 pounds tension. This same cable was used simply as a
mooring line, as an economic means of retrieving the concrete pad (Figure 8b). Figure 9a shows
the concrete pad being dragged into position on the river bed.

4.3. **Communications System**

The conventional, vented pressure transducer not only provides calibration data for the unvented
pressure transducer, its datalogger is programmed to phone out whenever there is a sudden
increase in water level (or a total failure of the signal). Dial in capability is facilitated as well,
allowing for real-time monitoring of the data being collected at each station. To facilitate this,
each of the remote water level monitoring stations incorporates a cell phone data logger, tower,
antenna, solar panel and battery (Figure 9b).

5. **Data Obtained with the Remote Water Level Monitoring System**

Figure 11 illustrates the data obtained through the freeze-up and winter period of 2000/2001.
Each of the stations records water levels on 5 minute increments. As the figure indicates, two of
the three water level monitoring stations successfully survived the freeze-up period, providing
continuous data throughout. In addition, the alarm system worked effectively, providing
notification of the water level increase which occurred as the freeze-up front passed through. At
Station G120, the flow depth at the time of installation was quite shallow (0.37 m) and it is
believed that the pressure transducer became frozen into the ice cover as the freeze-up front
passed through the section on Nov. 11, 2000, resulting in anomalous readings (red line of the
graph in Figure 11). As the figure illustrates, the gauge resumed normal operations by mid-
December, and continued working effectively until late February.

In late February, the cell phone data logger at Station G120 ceased responding to calls. A
service visit on March 21st revealed that one of the support wires for the communications tower
had been severed (Figure 12a) and evidence at the site suggests that a moose likely caused the
damage. The tower was reset and operations continued. In late March of 2001, the station at
G135 experienced a malfunction (similar to the unusual values measured at G120 in early
December), therefore it was speculated that the pressure sensor might be frozen into the ice
cover. A field inspection revealed that a large aufeis deposit was present at the site (Figure 12b),
supporting this theory.

6. **Assessment of the Remote Water Level Monitoring System**

Based on operations to date, the major problems with the system center around two issues. First,
the system is prone to freezing into the ice cover, because of the shallow depths at the probe
locations during the low flow winter period. The primary issue here was the length of the
venting and communications cable on the conventional sensor, since this limited how far out the
probe could be placed. The second, outstanding issue is the vulnerability of the venting and
communications cable on the conventional sensor as well as the junction box assembly. Neither
of these are expected to survive a dynamic breakup, making the system highly expensive.
7. Summary

This investigation explores methods for obtaining critically needed quantitative data on river ice jam formation and release. At this preliminary stage, it appears that the current system for remote measurement of river water levels under ice conditions is somewhat vulnerable to ice action, even during winter, because of the limited distance it can be placed out into the stream. As a solution to this problem, we will be taking advantage of more advanced technology in 2002 to implement a simpler, more robust system. Specifically, we will be employing a new type of a submersible data logger which will be encased in a watertight canister anchored right on the concrete pad with an unvented pressure probe. Communications will be facilitated directly with the data logger using the 20,000 lb. rated transmission cable running from the communications tower on the bank out to the submerged data logger, eliminating the need for the delicate venting tube and junction box required by the existing system. In addition, this new design will facilitate placement of the pressure sensor much further out into the stream. The pressure data from the unvented pressure transducer will be corrected with meteorological data on barometric pressure.

8. Acknowledgements

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9. Reference

Figure 1. Location of the study reach, Fort McMurray, Alberta, Canada.
Figure 2. Study reach, Athabasca River near Fort McMurray (Scale 1:250,000).
(a) Looking downstream along the ice jam, adjacent to the water intake in Fort McMurray, April, 1997 *(photo courtesy of Alberta Environment).*

(b) Looking upstream along the Clearwater River (backwater flooding).

Figure 3. Ice jam flooding at Fort McMurray, April, 1997 *(photos courtesy of Alberta Environment).*
(a) Staff gauge located at station G120 (March, 2001).

(b) Staff gauge located at station G50 (March, 1999).

Figure 4. Ice jam staff gauges along the Athabasca River at Fort McMurray.
(a) Both pressure transducers mounted on the concrete weight pad.

(b) Submersible water level logger and its protective pipe casing.

Figure 5. Dual pressure transducer system used at remote water level stations.
(a) Pressure venting tube and comm. cable encased in steel pipe for burial in trench.

(b) Backfilling the trench and placing rock weights.

Figure 6. Protective measures for the conventional pressure transducer’s venting tube and communication cable.
(a) Junction box between venting tube/comm. cable and transmission cable.

(b) Junction box installed in the protective steel box; these were anchored with re-bars driven vertically through holes at two corners.

Figure 7. Protective measures for the conventional pressure transducer’s junction box.
(a) Transmission cable used between the junction box and the communications tower.

(b) The transmission cable was also used as a mooring line to facilitate retrieval.

Figure 8. Transmission cable used in the system.
(a) Placing the concrete pad on the river bed.

(b) Comm. tower with solar powered cell phone data logger and directional antenna.

Figure 9. Completing the installation.
(a) Tower position at Station G120 after the support cable was severed.

(b) Aufeis accumulation at Station G135.

Figure 10  Logistical problems with the remote water level stations.
Figure 11. Water level data recorded by the remote stations during the winter of 2000/2001.