Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 14	No. 3	pp. 557-562	2015

Original Research Paper

Analysis of an Anomalous Flooding Event in the Peace River in Canada

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com
Received: 13-11-2014
Accepted: 19-1-2015

Key Words:
Anomalous flooding
Peace river
Flood mitigation
Ice jam flooding

ABSTRACT

This paper provides an analysis of a major river ice breakup on the Peace River in Canada, which led to the flooding of the Town of Peace River on February 28, 1992. The event is unique, as it occurred in the mid-winter under regulated river conditions with no clear explanation of its cause, and despite the implementation of extensive mitigation measures. Investigative analysis of weather and river flow conditions in the Peace River region, prior to and during this flooding event, provides clues to the possible causes of the breakup. These clues could be used to predict similar events in the future with sufficient lead time to avert the occurrence of the ice jam flooding.

INTRODUCTION

The 360 km stretch of the Peace River from Hudson Hope in British Columbia (B.C.), Canada to the Town of Peace River (TPR) in Alberta, Canada (Fig. 1) is characterized by severely cold and extended winters, which result in the formation of an ice cover layer over long reaches of the river. Warmer temperatures in the spring result in the gradual disintegration of ice cover, a phenomenon known as a thermal break-up. Occasionally, however, early spring runoffs could be large enough to rapidly break the ice cover, known as mechanical break-up. This could lead to the piling up of broken ice sheets, increasing the potential of ice jam flooding that can have significant economic and ecological consequences (Prowse & Beltaos 2002, Beltaos et al. 2006, Morse & Hicks 2005 & Michel 1971).

Ice jam flooding was always a concern for the TPR, since its establishment in early 1900. The impoundment of the Peace River by British Columbia Hydro Corporation (BC Hydro) in 1968, as it exits the Rockies near Hudson Hope (Fig. 1) has brought about major changes to the river flow conditions and consequently the mechanisms of ice cover formation and break-up. To manage these changes and reduce the risk of ice jam flooding, a joint task force was formed in 1974 by the BC Hydro, B.C. Government and Alberta Environmental Protection (AEP). The task force was successful in containing the risk of flooding from 1982 and until 1992.

However, on February 27, 1992, in the middle of winter, a 70-km long river ice cover extending upstream from the TPR, broke up prematurely. The broken ice jammed a few kilometres downstream of the town, causing river stage to rise above an already high freeze-up level, leading to the overtopping of the town's dikes and flooding of certain areas in the town. A state of emergency was declared and 4,000 residents were evacuated. A report by AEP, summarized the freeze-up and break-up events that led to the flooding (Fonstad 1992). Although the report identified some of the factors that led to the ice cover break-up, it did not provide enough evidence to explain the main causes of the break-up. The current study provides an analysis of available hydrometeorological data and recorded events that illustrates the most likely cause of this premature break-up.

Physical Setting

The Omineca Mountains and the western slopes of the Rocky Mountains in B.C. drain into the Rocky Mountain Trench to form the start of the Peace River at the confluence of Parsnip and Finlay Rivers. Since 1968, the Bennett Dam impounds the Peace River a few kilometres upstream of Hudson Hope to form Williston Reservoir. Outflows from the dam are used to generate electricity through the GM Shrum Generating Station. From Hudson Hope, the Peace River flows easterly for approximately 360 kilometres to the TPR. From there it follows northerly and then a north-easterly direction for approximately 850 kilometres where it joins the River des Rochers to form the start of the Slave River. In addition to the releases from BC Hydro Hydro-electric Plants, the discharge at the TPR also consists of runoff from main tributaries such as the Pine, Halfway, and Beatton Rivers in B.C. and the Smoky River in Alberta.

Impact of River Regulation on River Ice Breakup

Prior to the regulation by BC Hydro, marginal groundwater

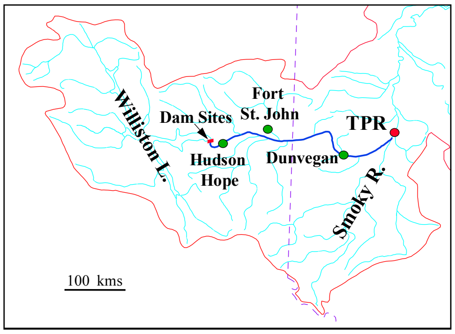

Fig. 1: Peace river region above the town of Peace River (TPR).

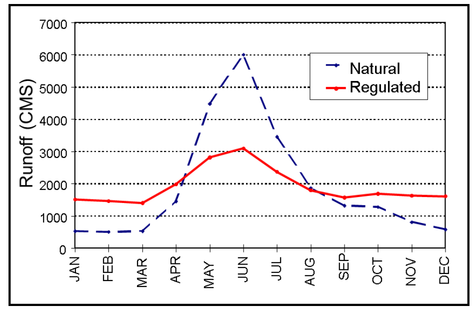

Fig. 2: Monthly runoff normals (1972-1993) at the Town of Peace River.

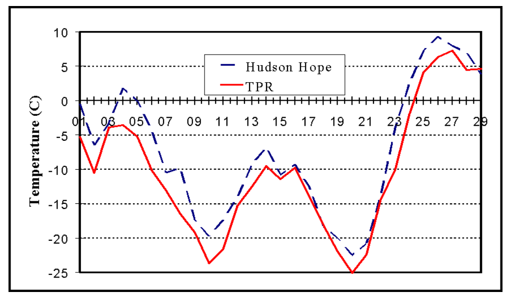

Fig. 3: Daily mean temperatures at Hudson Hope and the TPR (February 1992).

contributions from tributaries made up the main source of winter discharges in the Peace River. The combination of low and steady winter discharges and long periods of cold weather resulted in a rapid formation of a thin layer of river ice cover by juxtaposition of ice floes and downward cooling process. Near the TPR, ice cover was usually formed in early November with freeze-up river stage increase in the range of 1 meter (InterGroup Consultants Ltd. 1993). Ice cover break-up in the Peace River was usually initiated in early April by relatively warmer runoffs from its southern tributaries, particularly the Smoky River. In general, the river stage rise at the TPR due to break-up was in the order of 2 meters, although stage increase above 4 meters were also recorded (InterGroup Consultants Ltd. 1993).

Regulation by BC Hydro altered dramatically the yearly distribution of runoff in the Peace River, as more water released from the dams in winter to accommodate higher demand for power. As a result, winter discharges at the TPR tripled from a monthly average of 500 m^3/s to 1500 m^3/s, while high summer runoff were trimmed from a 6000 m^3/s to 3000 m^3/s in June (Fig. 2) based on the records from 1972 to 1993, with recreated natural flows (Peters & Prowse 2001).

Winter flow releases from Williston Reservoir are generally larger and warmer than would-be natural flows impeding, as a result, the development of thermally-induced ice cover. Ice covers advances upstream by a combination of juxtaposition of ice floes and shoving of incoming ice mass against a stable ice cover front (Andres 1994). Under regulation, the river ice cover has become thicker and freeze-up stage has increased to the order of 3 to 4 meters. During the break-up season, the warmer flow releases from the dams speed up the process of ice cover thermal break-up and consequently reduce the risk of dynamic breakup. Nevertheless, the Smoky River broke up into the Peace River causing ice jamming in two consecutive years 1973 and 1974 (Fonstad 1992).

The Peace River Ice Task Force was formed to study and plan strategies to mitigate ice jams caused by the mechanical break-up. Its mandate was later amended to include freeze-up ice jams. The mitigation strategy of the Peace River Ice Task Force is based on three main guidelines. First, during freeze-up, the dam flow releases are maintained at levels sufficient to facilitate forming a solid cover at river stages high enough to accommodate subsequent increase in dam flow releases; second, after formation of ice cover, fluctuations in flow releases are kept to a minimum to avoid premature break-up; and third, during the break-up stage, flow releases are maintained at high levels to ensure in-place melt out of ice cover before the break-up of the Smoky River (Parmley 1994). The Task Force was successful in preventing serious ice jam events for a decade following the 1982 event. However, it did not foresee the flooding of February 28, 1992.

February 28, 1992 Ice Jam Event

The winter of 1991/92 in the Peace River Region was very mild with temperatures above normal throughout December and January. Progress of ice cover front was very slow and occasionally reversing. Following a major dip in temperatures in the first third of February (Fig. 3), the ice cover front advanced to the TPR on the night of February 11/12, making it the latest date of freeze-up on record (Fonstad 1992). River stage levels rose to a record high of 4.7 meters, leaving only unprecedented 3.11 meters of freeboard to the crest of the dikes.

The ice cover had advanced 70 kilometres upstream of the TPR when it was broken up between February 26 and 27, following a week of an abnormal warming trend (Fig. 3). The mass of broken ice consolidated a few kilometres upstream of the town causing a temporary ice jam, and later gave way, releasing the water stored behind it and creating a surge that lifted and fractured the ice cover as it advanced downstream towards the town. The break-up front finally came to rest some 23 kilometres downstream of the town. As the mass of broken ice from 93 kilometres of ice cover stacked against the downstream solid ice cover, it formed a backwater that extended upstream to the town and caused overtopping of dikes in several locations (Fonstad 1992).

The break-up event of 1992 differs from previous ones, as it was not caused by a break-up on the Smoky River. The event of 1982 is the only other exception, where large increases in flow releases from BC Hydro dams created a surge that broke up the ice cover prematurely in early January. Fonstad (1992) suggested that the 1992 event was primarily caused by the warming trend that weakened an already weak young ice cover. Although the weakened state of the ice cover made it more vulnerable to break-up, a break-up of this scale had to be initiated by large hydrodynamic forces acting on the ice cover. Since flow releases from BC Hydro dams were kept essentially steady prior to the onset of break-up, they can be ruled out as the cause of the break-up. As will be demonstrated in the following section, the warming trend prior to break-up is much more intense and widespread than what is depicted in Fig. 3. It will also be shown that as a result, extensive melting of the snowcap had taken place causing rapid increases in contributions from tributaries and forcing the break-up of ice cover in the Peace River.

Warming Trend in the Peace River Region (February 22-28, 1992)

Climatic records indicate that, temperatures exceeded record highs in several locations in B.C. and Alberta during the period from February 24 to March 1, 1992 (Climatic Perspectives 1992). To investigate the intensity and extension of this warming trend, daily temperatures from 27 Atmospheric Environment Services (AES) and BC Hydro Data Collection Platform (DCP) stations located in the region, upstream of the TPR were compiled and plotted on maps of the region. Fig. 4 shows the sequence of daily mean temperatures for the period February 22 to 27, 1992 inclusive. The names and elevations of these stations are shown in Fig. 5.

Fig. 4 shows that the daily mean temperatures steadily rose from sub-freezing levels on February 22 to much warmer levels that lasted over the period from February 25 to 27. Daily mean temperatures as high as 13°C was recorded on February 27 at the Simonette AES station, located in Alberta at elev. 880 meters. Warming was so persistent that even night temperatures, represented by minimum temperatures, for most of the basin stayed above the freezing level for the three-day period from February 25 to 27. The warming trend was also earlier and more intense in the southwestern and southern parts of the basin. For example, daily mean temperatures at Grande Cache in the southern part of the Smoky Basin were 8, 10 and 12°C for the days February 25, 26 and 27, respectively, while the corresponding temperatures for the station at Eureka, northwest of Dunvegan were 0, 2 and 5°C, respectively.

Comparing maps of daily mean temperatures with that of elevations show that a state of thermal inversion existed, where the upper parts of the basin were warmer than the lower ones. For example, the station at Grande Cache (Elev. 1250 meters) always recorded higher temperatures than Grande Prairie (Elev. 670 meters). Thermal inversion can have a great impact on snowmelt contribution from tributaries. Since upper areas of the basin tend to receive more snowfall than lower regions during the winter, snowmelt from these areas can be very significant under conditions of warm weather.

Analysis of precipitation and temperature data and news coverage by Climatic Perspective (1992) indicate that the Peace River region received above normal snowfalls in the winter months preceding the warming trend. Climatic Perspectives also reported that the warming trend was accompanied with clear and cloudless skies. The above-normal snowpacks, relatively long period of very warm temperatures and high solar radiation, which can initiate snowmelt even in subfreezing temperatures (Michel 1971), were ideal conditions for generating significant snowmelt in the basins feeding the Peace River. To investigate the existence of this snowmelt, records of discharges in the Peace River and some of its tributaries obtained from Water Survey of Canada (WSC) were compiled and analysed.

Analysis of WSC Records and Extent of Snowmelt

Examination of WSC records shows contradictions between discharges published for stations located on the mainstem of the Peace River and those for tributaries. While mainstem stations show that runoffs from tributaries in B.C. started rising on February 22 and reached peak values on February 26, discharges for stations located on these tributaries started rising two days later with much less volume. However, personal communications with WSC staff revealed that almost all of these discharges, with the exception of Hudson Hope,

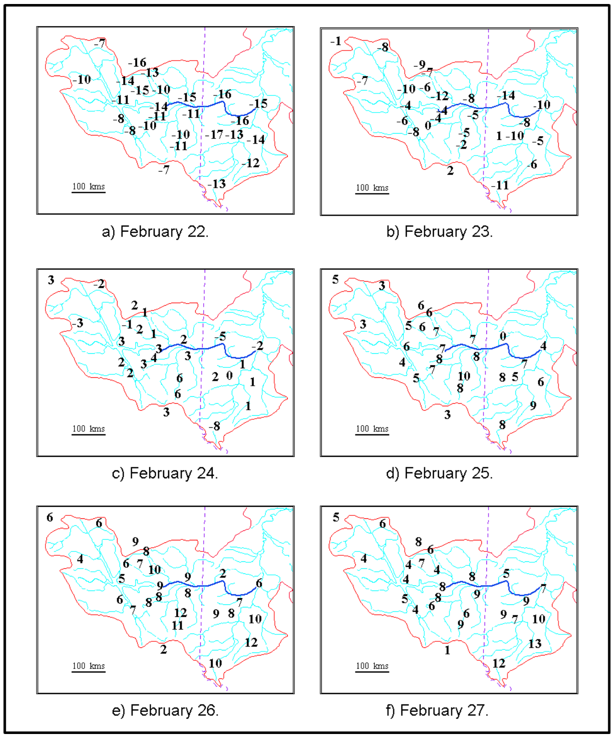

Fig. 4: Daily mean temperatures (February 22-27, 1992) at selected AES and DCP stations in the Peace River region above the TPR.

were estimated. Discharges for all tributaries in B.C. and most of the ones in Alberta were estimated using late January measurements, based on extending groundwater recession curves and subjective adjustment to account for weather elements.

Fortunately, personnel of the WSC office in the TPR measured discharge of the Saddle River near Woking on February 26 and 28. The Saddle River, with a drainage area of 538 km^2 above Woking, joins the Peace River approximately 70 kilometres upstream of the TPR, just over one kilometre downstream of the location where ice cover had advanced to shortly prior to break-up (Fig. 6). On both of these days, WSC staff measured the flow velocities at more than twenty points across the river within 30 minutes. The total discharge was then calculated by summing products of mean velocities and their corresponding cross-sectional areas. The procedure applied is considered very reliable for measuring runoff.

Runoff measurements, published daily WSC discharges, and hourly runoffs, estimated from hourly stage measurements, for the period February 25 to March 5 are plotted in Fig. 7. Runoff started rising on February 26, two days after temperatures went above freezing level in the vicinity of Woking (see daily mean temperatures at Wanham in Fig. 4). After a short decline, runoff rose sharply in the last hours of February 26, most likely responding to diurnal changes in temperatures. After going through a plateau during the first three quarters of February 27, runoff jumped to more than double its value to reach a peak of over 15 m^3/s on the early hours of February 28. The runoff was high enough to break and overtop the ice cover (WSC staff notes). Considering that the travel time within the small basin of the Saddle River is in the order of hours, this sharp increase in runoff is a clear indication of intensive melting of the snowpack taking place during the day hours of February 27. From February 23 onwards, rising temperatures and large doses of solar radiation reduced the cold content of the snowpack making it ripe and ready for large-scale melting during the exceptionally warm days of February 26 and 27.

The intensity of snowmelt is best described by the observation of a WSC staff (Dave Liston, personal communication) that about two feet of snow on his home yard in TPR melted completely by February 28. Considering that, temperatures at TPR were consistently lower and started rising above freezing level later than in most other parts of the region (Fig. 4), it can be concluded that snowmelt was more significant in the rest of the Peace River Region.

Estimation of Snowmelt Contribution From Tributaries

The availability of both measured temperatures and discharges for the Saddle River basin above Woking offered an important opportunity to model snowmelt from the Saddle basin and apply the results to other basins of the Peace River Region. Runoffs from the Saddle River were simulated using the UBC Watershed Model (Quick 1995), which is well suited to modelling snowmelt (Assaf 2007). The calibrated model was then applied to estimate runoff from two major sub-basins of the Peace River, the Halfway River basin above WSC station near Farrell Creek (9,350 km^2) and the Pine River basin above WSC station at East Pine (12,100 km^2) (Fig. 8a). The two sub-basins make up one third of the total non-regulated drainage area of the Peace River upstream of the February 27 ice cover front. Due to the steep-slope and heavily forested nature of these basins, their snowmelt runoffs tend to be large and rapid.

The estimated daily runoff for the Halfway and Pine basins, flow releases from BC Hydro dams and the Saddle River runoffs are plotted on a sequence of maps representing February 22 and 25 to 28 (Fig. 8). On February 22, prior to the onset of the warming trend, runoff from tributaries was insignificant in comparison with BC Hydro flow releases (Fig. 8b). Runoff picked up on February 25 (Fig. 8c) as a result of daily mean temperatures rising above freezing level (Fig. 4). Runoff continued to increase to much higher levels on

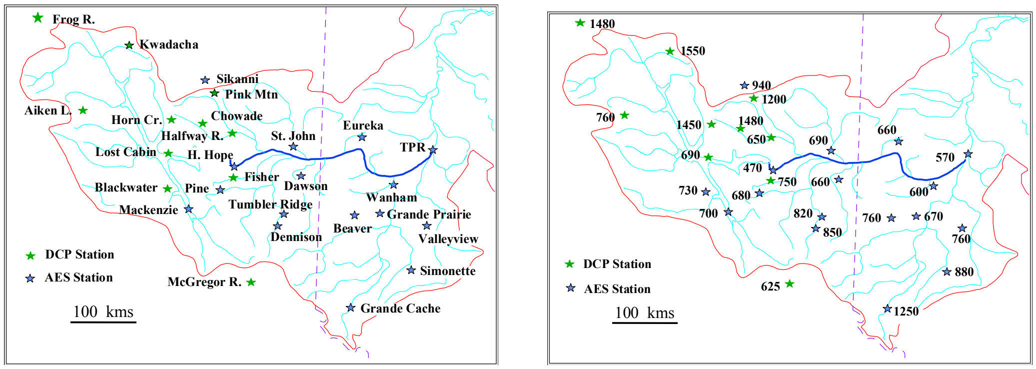

Fig. 5: Selected AES and DCP stations in the Peace River region, with corresponding elevations (meters) shown in the lower plate.

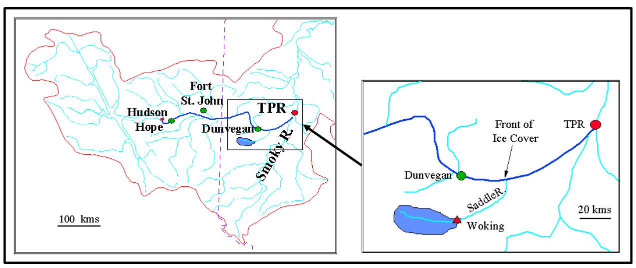

Fig. 6: Location of the Gauged basin near Woking.

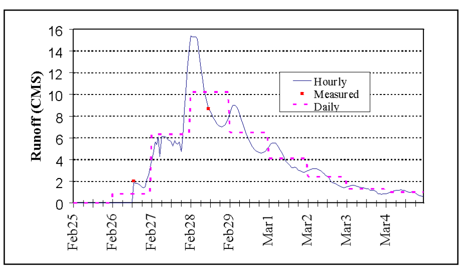

Fig. 7: Runoffs in the Saddle River near Woking (1992).

February 26 and 27 (Fig. 8d and 8f) as the warming trend spread over the region and intensified. At runoff peaks of 380m^3/s for the Pine basin and 260m^3/s for the Halfway basin, contributions from these tributaries had become a much more significant portion of the total Peace River discharge. Throughout the period of the warming trend, runoff from the Pine basin was much higher in terms of runoff per unit of drainage area than that from the Halfway basin, which indicates that warming was more intense and earlier in the southern parts of the Peace River Basin.

Suggested Scenarios of the 1992 Ice Jam Event

The above analysis shows that the warming trend resulted in a major increase in contributions from tributaries that started on February 25 and peaked on February 26 and 27. Considering that it takes one to 1.5 days for changes in runoffs from the main tributaries to impact Peace River discharges just upstream of the ice cover front, it can be concluded that the discharge upstream of the ice cover front started rising on February 26 and attained peak values on February 27 and 28. It is therefore likely that the initial break-up of the ice cover, described in an earlier section, was partly caused by the early rapid rise of discharge between February 26 and 27, in much the same way large flow releases from BC Hydro dams contributed to the premature break-up of ice cover in early January of 1982. The persistently high discharges rapidly built up the head behind the initial ice jam, and led eventually to its release and the creation of a surge that further broke up the ice cover downstream. As stated earlier, the accumulation of broken ice caused a major ice jam downstream of the TPR and resulted in the overtopping of the dikes.

CONCLUSIONS AND RECOMMENDATIONS

The mitigation strategy adopted by the Ice Task Force was successful in preventing serious ice jamming on the Peace River for almost a decade. However, it did not foresee the dramatic breakup of river ice on the night of February 26/27, 1992 which subsequently led to extensive flooding of the TPR. The February 1992 event is unique in its characteristics and the circumstances that led to its initiation. The winter of 1991/92 was very mild with temperatures occasionally rising above freezing level. As a result freeze-up occurred very late in the season on the night of February 11/12. The rise in river stage level that usually accompanies freeze-up was a record high 4.7 meters, leaving only 3.11 meters of freeboard safety to the top of the dikes. Break-up was initiated very early in the season following an abnormal warming trend and well before break-up of the Smoky River. The period between freeze-up and break-up was too short for the ice cover to gain strength through consolidation and for the smoothing of the underside of the ice cover that usually leads to a decline in the freeze-up stage level. The combination of sustained very high freeze-up stage and

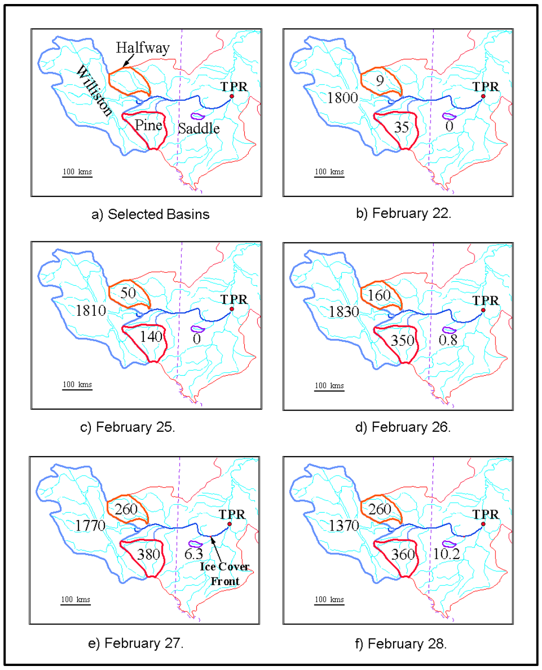

Fig. 8: Estimated runoffs (CMS) from selected basins in the Peace River region.

stage increase due to the ice jam led to the overtopping of the dikes.

Analysis of the data from 27 meteorological stations showed that the Peace River region experienced a widespread warm spell that started about five days before the initiation of breakup and persisted throughout the course of the ice jam event. Higher temperatures were recorded in the upper parts of the region as a mass of warm air was moving across the Rocky Mountain Ridge. Southern parts of the basin experienced earlier and more intense warming. Watershed simulation results show that contributions from tributaries started to increase on February 25 and appreciated considerably on February 26 and 27. Allowing for travel times in the mainstem of the Peace River, it is suggested that the initial increase in discharges broke up the ice cover on the night of February 26/27. The continuing rise in discharge accelerated the buildup of head behind the initial ice jam forcing its release and the resumption of break-up leading eventually to a second major ice jam as discussed earlier.

The suggested scenario for the February 1992 flooding event clearly illustrates the potential of tributaries other than the Smoky River to initiate a break-up of the ice cover in the Peace River. To help detect changes in discharge conditions of Peace River, BC Hydro is monitoring river stage levels in the mainstem near the border with Alberta. Although it is still a question whether the onset and the impact of the warming trend could have been predicted, the seriousness of the problem warrants investigating the feasibility of a weather and runoff monitoring/forecasting system, that can be used as a tool to mitigate similar future events.

ACKNOWLEDGEMENT

This paper is based on an analysis conducted by the author during his employment at BC Hydro, Canada. The author would like to acknowledge the contribution of Les Parmely, Alan Chan-McLeod and PieroGalvagno who provided valuable feedback.

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