AN ANALYSIS OF EVENTS LEADING TO THE FEBRUARY 1992 FLOODING OF THE TOWN OF PEACE RIVER, ALBERTA

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ABSTRACT

In cold regions, like that of the Peace River, the winter season is characterized by the formation of river ice cover that progresses upstream as temperatures continue to fall. In the spring, warmer temperatures reverse the process and eventually lead to the total meltout of the ice cover. Sudden changes in flow conditions such as those associated with early snowmelt contributions from tributaries or regulated releases from reservoirs or a combination of both may initiate an early breakup of the ice cover. The breakup progresses downstream until it is stalled by a solid ice cover resulting in a jam. This leads to increases in river stages and possibly overbank flooding.

An early river ice breakup and subsequent flooding due to ice jamming, as described above, occurred on late February, 1992 at the Town of Peace River located on the banks of the Peace River, about 240 km downstream of B.C./Alberta borderline. The present study provides an analysis of weather and river flow conditions in the Peace River Region prior to and during this flooding event. The analysis may provide some clues to the possible causes of breakup. These clues could be used to predict similar events in the future with sufficient lead time to avert the occurrence of ice jam flooding.

INTRODUCTION

The long and cold winters that characterize many regions of Canada, such as that of the Peace River, are usually accompanied by the formation of an ice cover layer over long reaches of the river. With the onset of spring, warm temperatures induce snowmelt runoff and weaken ice cover leading to the disintegration of ice cover and eventual clear-up of water surface. If the freshet runoffs from tributaries are fast and large enough, the ice cover can be destroyed in a short period of time (dynamic break-up) leading to jamming of broken ice sheets and possible flooding of sites located upstream in the vicinity of river banks.

The potential of ice jam flooding has always been one of the main concerns for the residents of the Town of Peace River since its establishment in early 1900 on the banks of the Peace River eight kilometers downstream from the Peace-Smoky confluence (see Figure 1.) Since 1968, British Columbia Hydro Corporation (B.C. Hydro) has been regulating the Peace River for the purpose of power generation. The regulation brought about major changes to the flow conditions and ice cover formation and break-up processes. In 1974 B.C. Hydro, B.C. Government and Alberta Environmental Protection (AEP) formed a joint task force to coordinate efforts to reduce the potential of dynamic ice cover break-up near populated sites along the Peace River. Beyond 1982 and until 1992 the task force was successful in containing the risk of ice jamming.

In spite of efforts by the joint task force, the ice cover 70 kilometers upstream of the Town of Peace River broke up prematurely on February 27, 1992. The mass of broken ice jammed few kilometers downstream of the town. The river stage increase from back water effect on top of an already very high freeze-up level led to the overtopping of the town's dikes and flooding of certain areas in the town. A state of emergency was declared and 4000 residents were evacuated. AEP published a report (Fonstad, 1992) summarizing the freeze-up and break-up events that led to the flooding. Although the report identified some of the factors that led to the ice

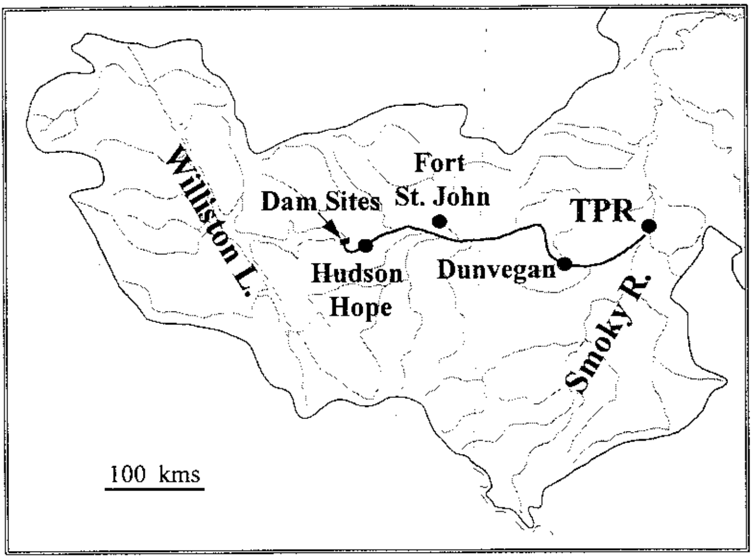


Figure 1: Peace River Region above the Town of Peace River (TPR).

cover break-up, it fell short of explaining the main cause of the break-up. The current study provides an analysis of available hydrometeorological data and recorded events that illustrates a possible cause of this premature break-up.

PHYSICAL SETTING

The Omnica 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. The end of 1967 was marked by the completion of Bennett Dam, located few kilometers upstream of Hudson Hope, which impounds the Rocky Mountains Trench to form Williston Lake. In 1970 filling of Williston Lake was completed and since then outflows from the lake have been regulated to generate electricity through the GM Shrum Generating Station. In 1979 the Peace-Canyon Hydroelectric Facility was constructed downstream from GM Shrum. From Hudson Hope the Peace River flows easterly for approximately 360 kilometers to the Town of Peace River. From there it follows a northerly and then a north-easterly direction for approximately 850 kilometers where it joins the Rivere des Rochers to form the start of the Slave River.

In addition to releases from B.C. Hydro Hydroelectric Plants, the discharge at the Town of Peace River also consists of runoff from main tributaries such as the Pine, Halfway, and Beatton Rivers in B.C. and the Smoky River in Alberta. As will be discussed in a later section, the Smoky River plays a crucial role in the break-up of ice cover at the Town of Peace River.

FORMATION AND BREAK-UP OF ICE COVER AT THE PEACE RIVER AND IMPACT OF REGULATION

Prior to regulation by B.C. Hydro, marginal groundwater 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 relatively thin layer of river ice cover through a combination of juxtaposition of ice floes and downward cooling process. Near the Town of Peace River, 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 earlier break-up in its southern tributaries, particularly the Smoky River, which tend to receive warmer weather earlier in the season. Although break-up river stage increases at the town were 2 meters on average, stage increases above 4 meters were also recorded (InterGroup Consultants Ltd., 1993).

Regulation by B.C. Hydro altered, dramatically, the yearly water distribution in the Peace River. Larger flows are released from the dams in the winter to accommodate higher winter demand for power. As a result, winter discharges at the Town of Peace River 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 for the month of

June (based on the period from 1972 to 1993, with recreated natural flows) (see

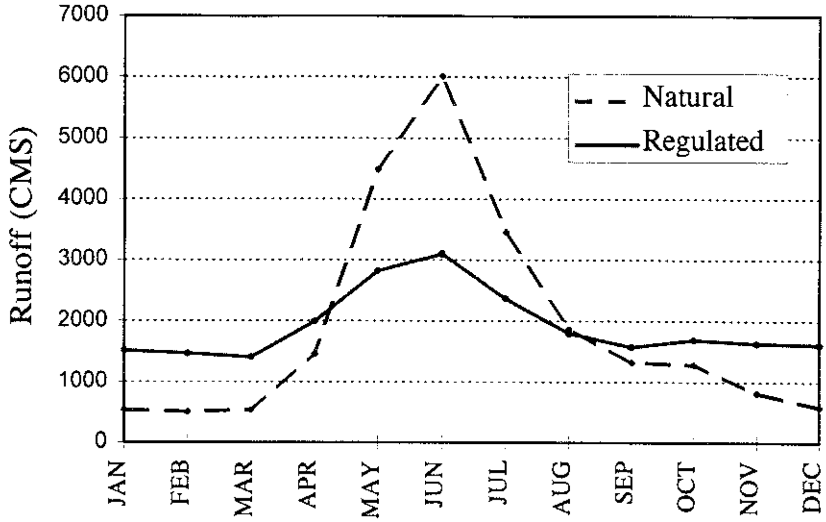


Figure 2: Monthly Runoff Normals (1972-1993) at the Town of Peace River.

Figure 2.) Since flow releases are drawn from the vast Williston Lake, they tend to be warmer than would-be natural flows. The higher- and warmer- than natural winter runoffs hinder the development of thermally-induced ice cover, prevalent during the pre-regulation period. Instead, ice cover 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 ice cover is thicker and freeze-up is accompanied by a much higher increase in river stage (3 to 4 meters).

The warmer flow releases from B.C. Hydro dams speed up the process of ice cover melt-out (thermal break-up) in the spring, thus reducing the likelihood of the Smoky River breaking up into an intact Peace River. Nevertheless, the Smoky River broke up into the Peace River causing ice jamming in two consecutive years 1973 and 1974 (Fonstad, 1992). Although these events did not cause very critical increases in river stage levels, they led to the formation of the Peace River Ice Task Force.

PEACE RIVER ICE TASK FORCE: FORMATION AND STRATEGY

Formed in 1974, the initial mandate of the Peace River Ice Task Force was to study and plan strategies to mitigate ice jams caused by dynamic break-up. The mandate was later amended to include freeze-up ice jams following a premature break-up and subsequent ice jam in early January 1982 as a result of significant increases in dam flow releases.

The main strategy of the Peace River Ice Task Forces (Parmley, 1994) can be summarized as follows:

1) Freeze-up: Maintain sufficient dam flow releases to form solid ice cover at a stage level high enough to accommodate subsequent dam flow releases.

2) Ice cover conditions: Avoid major fluctuations in dam flow releases that may result in premature break-up.

2) Break-up: Maintain high dam flow releases to ensure in-place melt out of ice cover before the break-up of the Smoky River.

Although the Task Force was successful in preventing serious ice jam events for the next ten years following 1982 event, it could not avert the flooding of February. 28, 1992.

FEBRUARY 28, 1992 ICE JAM EVENT

The winter of 1991/92 in the Peace River Region can be described as 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 (see Figure 3) the ice cover front advanced to the Town of Peace River on the night of February 11/12, making it the latest date of freeze-up on record (average freeze-up date is Dec. 26) (Fonstad, 1992). River stage levels jumped up by an exceptionally high 4.7 meters, which is highest on record (second highest is 3.9 meters), leaving only 3.11 meters of freeboard to the crest of the dikes, smallest on record. Although flow releases from B.C. Hydro Dams

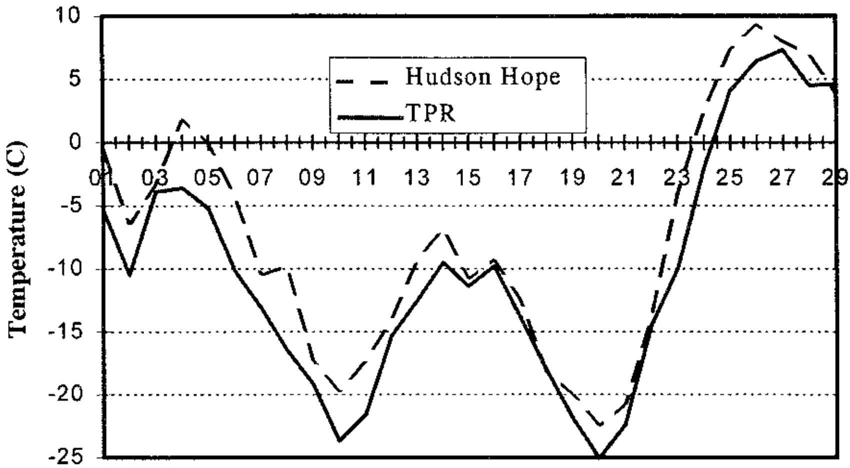


Figure 3: Daily Mean Temperatures at Hudson Hope and the Town of Peace River (February 1992).

were kept at a relatively high 1800 m^3/s, record shows that no clear relationship exits between freeze-up stage increase and flow releases from B.C. Hydro Dams (see Figure 4). It should be noted however that the contributions from tributaries have not been considered in Figure 4, and further investigation is required to determine their role in the freeze-up process.

The ice cover had advanced 70 kilometers upstream of the Town of Peace River when it was broken up sometime between February 26 and 27 following a week of an abnormal warming trend (see Figure 3.) The mass of broken ice consolidated a few kilometers upstream of the town causing a temporary ice jam. Subsequently, this initial ice jam gave way, released the water stored behind it and created 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 kilometers downstream of the town. Accumulating in front of a solid ice cover, the mass of broken ice from 93 kilometers

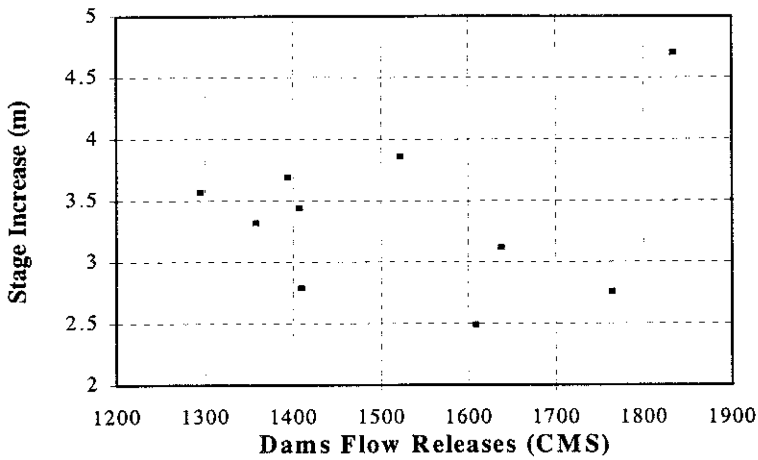


Figure 4: Freeze-up Stage Increase vs. BC Hydro Dams Flow Releases (1982-1992)

of ice cover formed a typical ice jam. Back water extended upstream to the town, raised stage levels and caused an overtopping of dikes in several locations (Fonstad, 1992).

The break-up event of 1992 differs from previous ones in that it was not caused by a break-up on the Smoky. The event of 1982 is the only other exception, where large increases in flow releases from B.C. Hydro dams created a surge that broke up the ice cover prematurely in early January.

Fonstad (1992) suggested that the weakening by the warming trend of an already weak young ice cover that did not have enough time to consolidate is the main cause of the break-up. Although the authors agree that the weakened state of the ice cover made it more vulnerable to break-up, they believe that a break-up of this scale had to be initiated by large hydrodynamic forces acting on the ice cover. Since flow releases from B.C. 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 wide-spread than what is depicted in Figure 3, which shows daily mean temperatures for only two stations. 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 (FEB. 22-28, 1992)

"Has spring arrived in the West?". This was the headlines of the February 24 - March 1, 1992 issue of Climatic Perspectives published by Environment Canada, indicating the early arrival of warming trend. Quoting again from the same issue: " A ridge of high pressure over British Columbia allowed very warm air to spread over the western half of Canada. In Alberta, temperatures over the province ranged from 14°C to 20°C above the long-term normals. Numerous record highs were set."

To further investigate the intensity and range of this warming trend, daily temperatures from 27 Atmospheric Environment Services (AES) and B.C. Hydro Data Collection Platform (DCP) stations located in the region upstream of the Town of Peace River were compiled and plotted on maps of the region. Figures 5 (a) to (e) shows the daily mean temperatures, calculated as the average of maximum and minimum temperatures recorded at these stations, for the period February 22 to 27, 1992 inclusive. For reference purposes, names and elevations of these stations are shown in Figures 5 (a) and (b), respectively.

Figure 6 (a) shows that daily mean temperatures were well-below the freezing point on February 22. However, Figures 6 (b) to (e) show that for the following few days temperatures rose steadily reaching peak values on February 26 and 27. Daily mean temperature as high as 13 °C were 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 south-western and southern parts of the basin. For example, daily mean temperatures recorded at the AES station

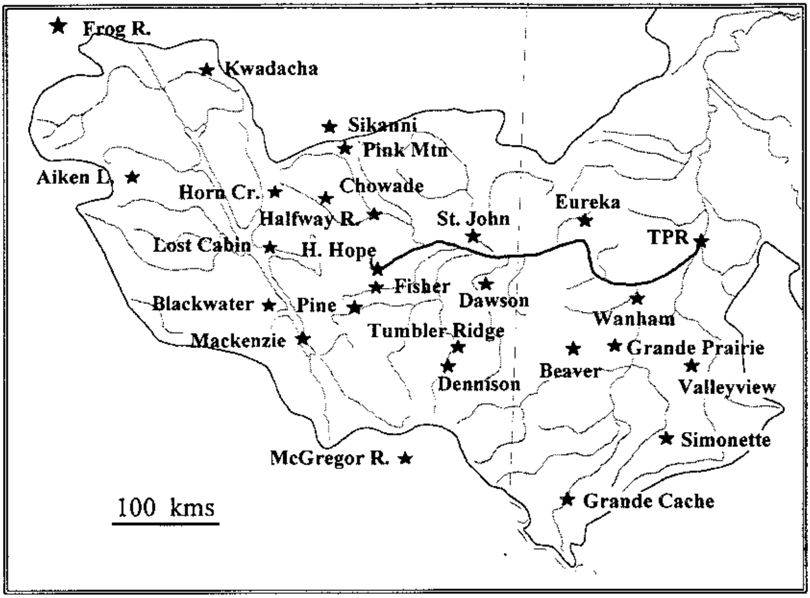


Figure 5-a: Selected AES and DCP stations in the Peace River Region.

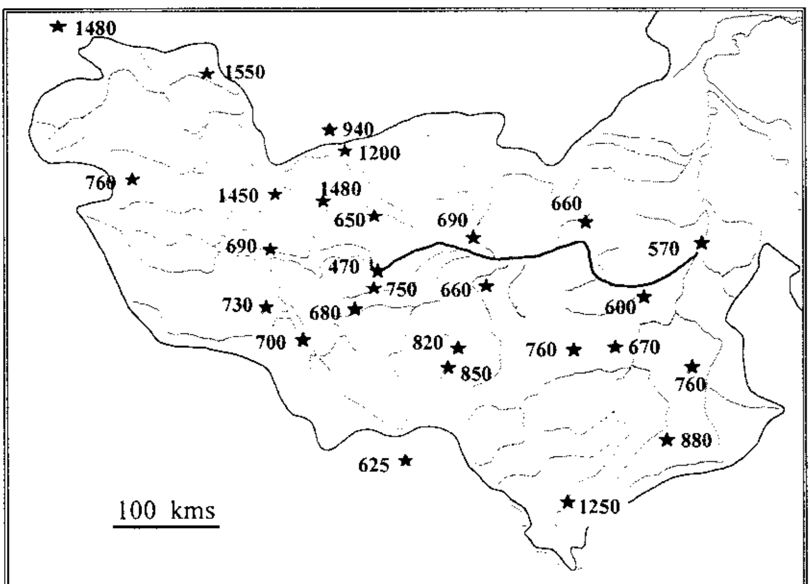
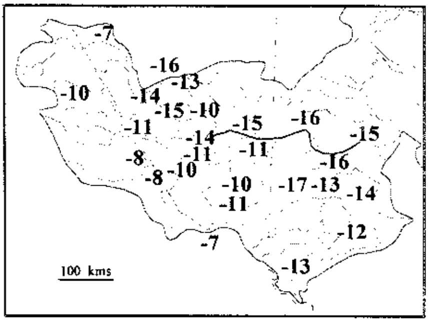
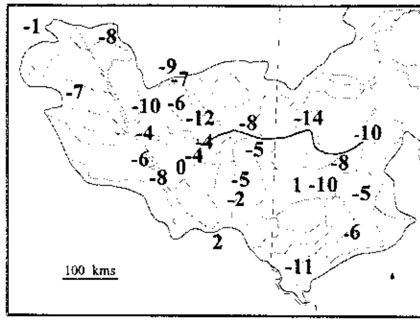


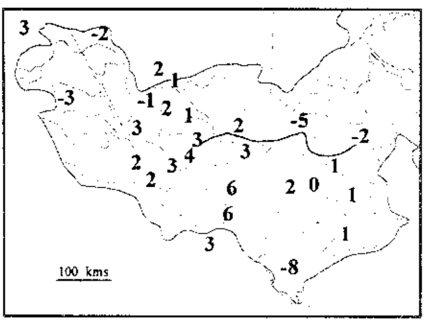
Figure 5-b: Elevations (meters) of Selected AES and DCP stations.



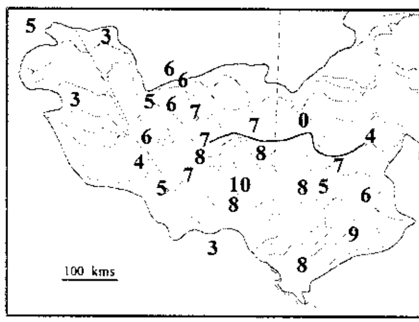
a) February 22.



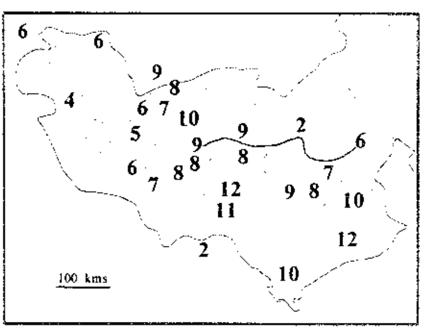
b) February 23.



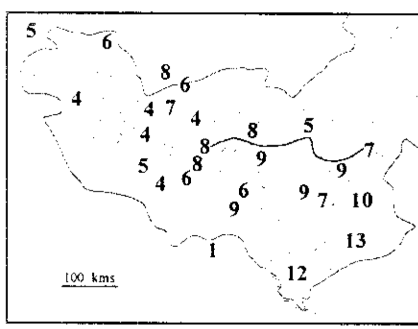
c) February 24.



d) February 25.



e) February 26.



f) February 27.

Figure 6: Daily Mean Temperatures (February 22-27, 1992) at Selected AES and DCP Stations in the Peace River Region above the Town of Peace River.

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.

Comparing maps of daily mean temperatures with that of elevations shows that a state of thermal inversion existed, where upper parts of the basin were warmer than the ones located at lower elevations. 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 temperatures 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 analyzed.

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

Fortunately, personnel of the WSC office in the Town of Peace River 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 kilometers upstream of the Town of Peace River, just over one kilometer downstream of the location where ice cover had advanced to shortly prior to break-up (see Figure 7.) On both of these days, WSC staff measured flow velocities at more than twenty points across the river within 30 minutes. The total discharge was then calculated by summing multiples 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 Figure 8. 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 Figure 6). 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). Taking into consideration 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 onward, rising temperatures and large doses of solar radiation reduced the cold content of the snowpack making it ripe and ready for large

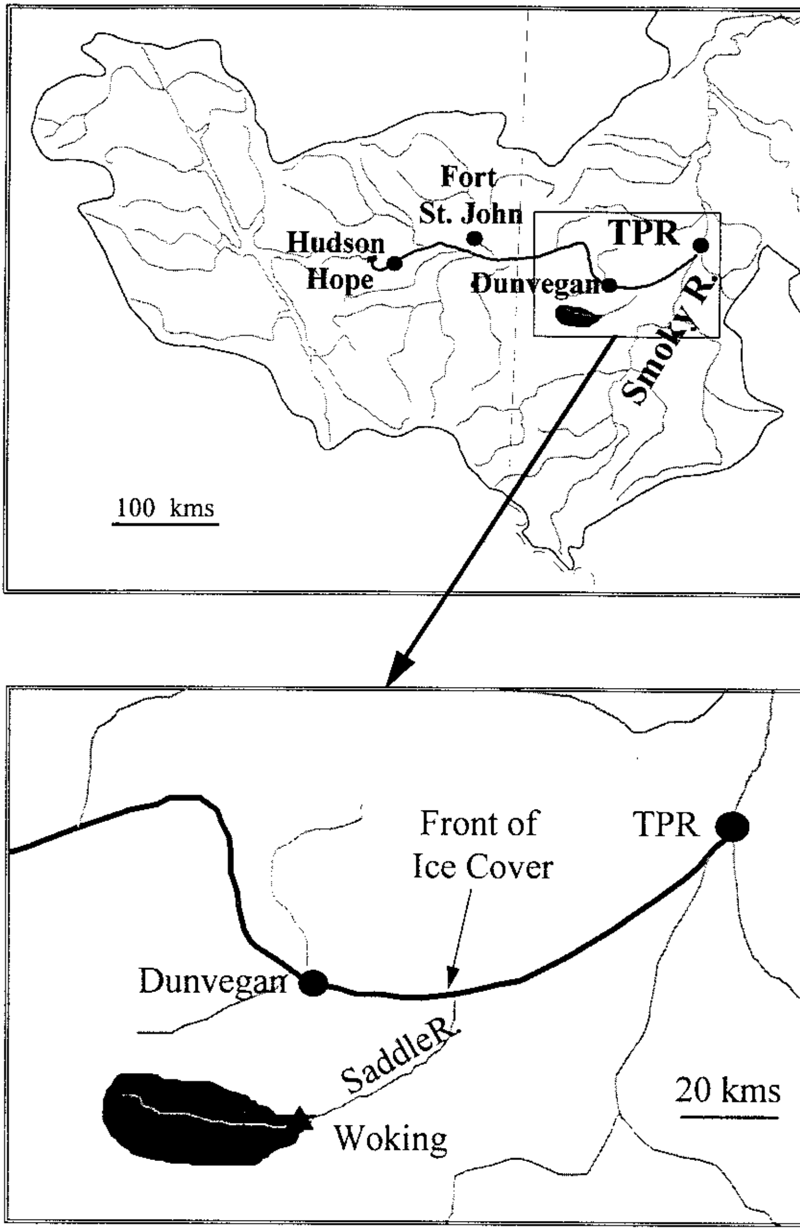


Figure 7: Location of the Gauged Basin near Woking.

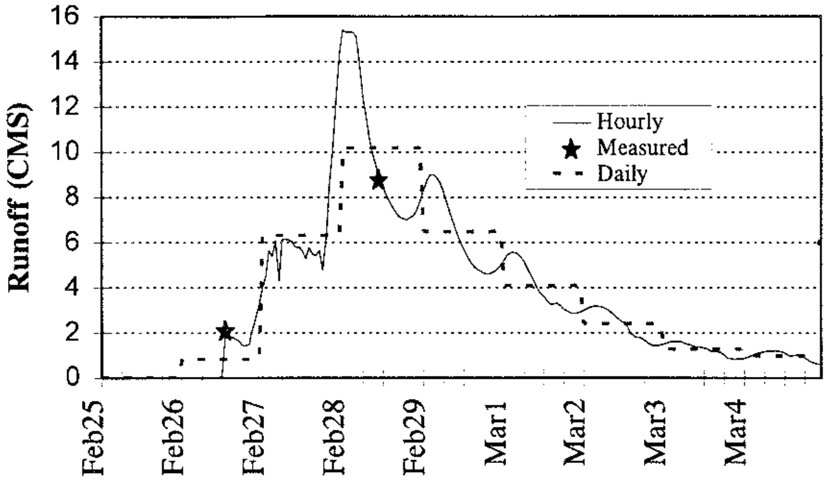


Figure 8: Runoffs in the Saddle River near Woking (1992).

scale melting during the exceptionally warm days of February 26 and 27.

The intensity of snowmelt is probably best described by the observation of a WSC staff (Dave Liston, personal communication) of two feet of snowpack on his home yard, Town of the Peace River, disappearing by February 28. Considering that the temperatures at the town were consistently lower and started rising above freezing level later than the most other part of the region (see Figure 6), it can be concluded snowmelting was more significant in the rest of the Peace River Region.

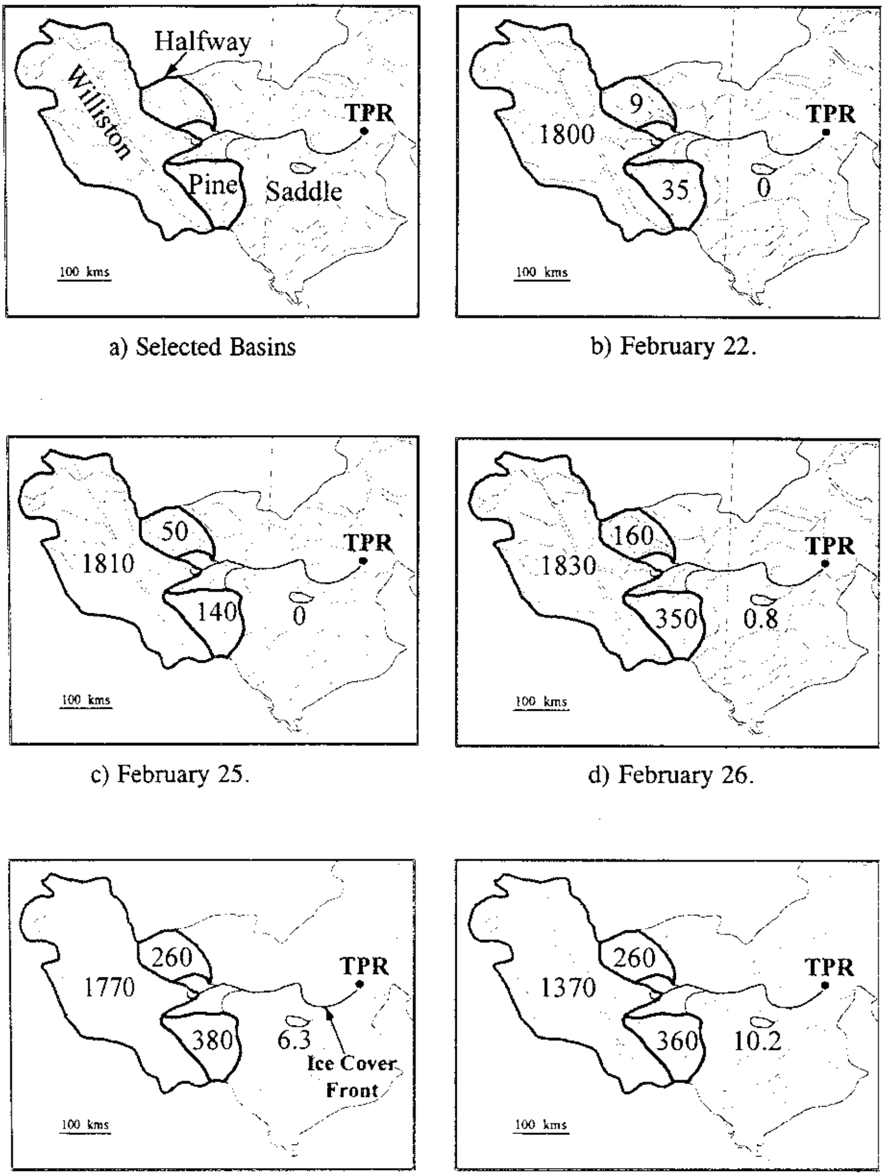
ESTIMATION OF SNOWMELT CONTRIBUTION FROM TRIBUTARIES

Although the drainage area of Saddle River above Woking constitutes only a small fraction of the total drainage area upstream of the ice cover front, the availability of both measured temperatures and discharges for this area provided 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 snowmelt-based UBC Watershed Model (Quick and Pipes, 1989). 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), both located in B.C. (Figure 9-a). These 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. They, however, represent the more rugged, steep-sloped and heavily forested western parts of the region. As a result, increases in runoffs from these sub-basins tend to occur shortly and at high rates following a significant snowmelt event.

The estimated daily runoff for the Halfway and Pine basins, flow releases from B.C. Hydro dams and runoffs in the Saddle River are plotted on a sequence of maps representing February 22 and 25 to 28 (Figure 9). On February 22, prior to the onset of warming trend, runoff from tributaries was insignificant in comparison with flow releases from B.C. Hydro Dams (See Figure 9-b.) Runoff increases starting on February 25 (Figure 9-c) as a result of daily mean temperatures rising above freezing level (See Figure 6). Runoff continued to increase to much higher levels on February 26 and 27 (Figure 9 -d and -f) as the warming trend spread over the region and became more intense. At runoff peaks of 380 m^3/s for the Pine basin and 260 m^3/s for the Halfway basin, contributions from these tributaries had become a much more significant portion of the total the 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. This difference is a direct reflection of the earlier and more intense warming in the more southern parts of the Peace River Basin as discussed in earlier section.

SUGGESTED SCENARIO OF 1992 ICE JAM EVENT

The above analysis shows that the warming trend resulted in major increases in contributions from tributaries that started on February 25 and peaked on February 26 and 27. Considering that it takes from one day to 1.5 days for changes in runoffs from



a) Selected Basins

b) February 22.

c) February 25.

d) February 26.

e) February 27.

f) February 28.

Figure 9: Estimated Runoffs (CMS) from Selected Basins in the Peace River Region.

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 B.C. 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 Town of Peace River and resulted in the overtopping of the dikes.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Being situated on the banks of the Peace River only 8 kilometers downstream from the confluence with the Smoky River, the Town of Peace River has always been at a risk from ice jam flooding as a result of the Smoky River breaking up into intact Peace River. This risk has been alleviated by the adoption of operating guidelines for B.C. Hydro Dams set by the Joint B.C. Hydro - Alberta Peace River Ice Task Force. These guidelines were designed to encourage the formation of a solid ice cover that can accommodate subsequent flow releases from the dams, prevent freeze-up ice jam events by avoiding large increases in flow releases once the ice cover is formed and consolidated, and control flow release such that ice cover at the town melts out before break-up of the Smoky River.

Although the strategy adopted by the Ice Task Force proved to be successful for almost a decade, the ice cover 70 kilometers upstream of the Town of Peace River broke up very early in the season on the night of February 26/27, 1992. Following the release of a short-lived ice jam upstream of the town, a surge was formed and the ice break-up front resumed its journey only to be stopped by a solid ice cover 23 kilometers downstream of the town. The mass of broken ice from a 93 kilometer-long ice covered reach formed a major ice jam. Rising river stage levels extended upstream to the town and caused an overtopping of the town's dikes. State of emergency was declared and 4000 residents were evacuated.

The February 1992 event is considered 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 (latest in record). Increase in river stage level that usually accompanies freeze-up was an exceptionally high 4.7 meters (a record high), 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 (record low) 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 stage increase due to the ice jam led to the overtopping of the dikes.

A report by Alberta Environmental Protection Agency (AEP) on the 1992 event cited the thermally-weakened state of ice cover as the main reason for the initiation of break-up. Although the authors agree that the deteriorating conditions of the ice cover made it more vulnerable to break-up, they suggest that break-up was initiated by large increases in contributions from tributaries as a result of intense and extensive snowmelt in the region.

Analysis of meteorological data from 27 AES and BC Hydro DCP stations showed that the Peace River Region experienced a wide-spread 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 the mass of warm air was moving across the Rocky Mountain Ridge. Southern parts of the basin experienced earlier and more intense warming.

Published WSC records for the Peace River Region showed contradictions between data for mainstem stations and those for tributaries. Upon further investigation, it was found that most of these values were estimated based mainly on the assumption of the prevalence of typical winter conditions. Fortunately, the study team was able to get access to reliable flow measurements on small basin feeding the Saddle River in Alberta. These flow measurements and observations of WSC staff support the evidence of a large scale snowmelt in the region.

The UBC Watershed Model was used to simulate the snowmelt at the Saddle River sub-basin and later estimate snowmelt runoff from two major sub-basins. 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 increases 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, which is usually ignored, of tributaries other than the Smoky 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 at present 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.

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