ICE RELATED FLOODING ON HARRY'S RIVER

by J. E. Anderson[1], L. D. Bungay[2], S. Beltaos[3], and I. K.Hill[4]

ABSTRACT

A hydrotechnical study of Harry's River, on the west coast of Newfoundland, was recently completed by Acres International Limited for the Provincial Department of Environment, under the Canada-Newfoundland Flood Damage Reduction Program. The purpose of the study was to determine the 1:20 and 1:100-yr recurrence interval flood levels.

Historically, severe flooding on Harry's River has resulted from ice processes during both the ice formation period and the midwinter/spring break-up period. Some flooding has also been reported from large open water flows caused by heavy rains. As part of this study, a review of the mechanisms and processes of the ice related flooding was undertaken, including computer simulation of ice jams and cover progression.

Acres river ice simulation model, ICESIM, was calibrated for both freeze-up and break-up periods using data from documented ice events. The calibrated ice parameters were tested for sensitivity and verified independently. Historical freeze-up and break-up situations were identified based on hydrological and meteorological criteria. ICESIM, was used to calculate flood water levels along Harry's River for each historical event.

The 1:20 and 1:100-yr flood profiles were determined by combining the probabilities of water levels resulting from each of freeze-up, break-up, and open water floods.

---

[1] Water Resources Engineer, [4] Project Manager of Acres International Limited, Niagara Falls, Ontario

[2] Water Resources Engineer of Acres International Limited, St. John's, Newfoundland.

[3] Research Scientist, National Water Research Institute, Environment Canada, Burlington, Ontario

1 - INTRODUCTION

In 1981, the Government of Newfoundland and Labrador and the Government of Canada entered into a "General Agreement Respecting Flood Damage Reduction". The objective of this agreement is the reduction of flood damages on floodplains along the shores of lakes, rivers and the sea. The agreement recognizes that the potential for flood damage can be reduced by control of the areas prone to flooding. This is accomplished by the identification and delineation of flood prone areas and ultimately the designation of these areas by flood risk mapping.

Black Duck Siding is a small community located approximately 15 km east of the town of Stephenville on the west coast of Newfoundland (Figure 1) which has experienced historical ice related and open water flooding. The community is built on low lying land along the banks of Harry's River, which flows from George's Lake to St. George's River in Stephenville Crossing. Many areas on the right bank have been cleared for farming. Harry's River itself has an average width of approximately 60 m and an average flow of 27 m^3/s. The river slope averages about 0.3%, but varies widely along its length.

This paper describes the hydrologic and hydraulic analyses carried out to identify flood-prone lands in the community of Black Duck Siding, more specifically to

- identify the mechanics, physical processes and factors (physical, hydrometeorologic, hydraulic) responsible for flooding
- provide reliable estimates of the 1:20 and 1:100-yr recurrence interval flood levels and the extent of flooding associated with each.

Acres was retained to carry out this study. Detailed technical information and data are contained in the final study report entitled "Hydrotechnical Study, Stephenville Crossing and Black Duck Areas" which was approved by the Technical Project Committee.

History of Ice Processes

Historically, severe flooding in the Black Duck Siding area has resulted from ice jams which have occurred both at freeze-up and during break-up. Residents report that substantial flooding has occurred four or five times since 1936.

The most recent severe flood event was in February 1984 with flooding caused by an ice-jam. An ice jam flood also occurred during the spring of 1979. In addition, the Department of Transportation documented an ice related flood in February 1971 where ice jammed at the piers of the Trans Canada Highway (TCH) bridge causing scour at the footing and subsequent collapse of the bridge. Since the 1984 flood, there have been two more less severe ice formation floods, in January 1985 and January 1986.

The maximum recorded instantaneous open water flow for Harry's River is 688 m^3/s which resulted in only limited flooding.

In general there was limited water level, ice thickness and ice process data from which to base analyses of historical ice related flooding. Most quantitative data were provided by the Newfoundland Department of Environment (1984, 1985, 1986) and Goebel (1986).

Flow data were obtained from the Water Survey of Canada gauge 02YJ001 on Harry's River at the TCH Bridge while temperature and precipitation data were available from the Atmospheric Environment Service (AES) Station at Stephenville Airport.

Field Program

A field program required to calibrate the river ice simulation model was designed to meet the following specific objectives subject to weather, budget and time constraints:

- to establish the river geometry
- to observe phenomena such as rate of ice production, ice thickness, and border ice
- to observe ice processes and the impact of flow conditions on the ice processes
- to observe water levels resulting from ice effects.
- to establish parameters such as ice strength and hydraulic roughness required for mathematical simulation.

A fall field survey of Harry's River was carried out to obtain river cross sections and water profiles. A total of 52 carefully located cross sections were surveyed along the 5.8 km study reach. Water surface profiles were measured under moderately low-flow conditions.

During the winter of 1986-1987, several field trips of Harry's River were made. The manner and type of data collected in the field programs were consistent with guidelines provided by Acres (1986) and Prowse (1985). Unfortunately, the 1986-1987 winter was very mild, making it difficult to collect a great deal of useful data. The field program consisted of

- a walkover reconnaissance during freeze-up in December. Observations were made of ice front location, approximate ice thicknesses and formation processes.

- a helicopter reconnaissance in mid-January to monitor the progress of the ice cover. Quantitative ice thickness and water level data were not collected since the ice cover had not progressed through the reach.

- a mid-winter survey in late February to measure ice thicknesses, snow cover thicknesses and water elevations at selected locations along the reach.

Ice Mechanics Analyses

The general methodology used to estimate historical ice-induced flood levels is summarized.

- Acres river ice simulation model, ICESIM, was calibrated separately for freeze-up and break-up using documented events and river cross sections.
- Criteria to identify historical freeze-up and break-up events were determined from flood documentation as well as available meteorological and streamflow records.
- Historical records were then searched to identify likely historical freeze-up and break-up events.
- The ICESIM model was used to estimate the flood water levels along Harry's River for each identified freeze-up and break-up event.
- Frequency analyses of the generated water levels was then used to determine the 1:20 and 1:00 year water levels.

Numerical River Ice Simulation Model (ICESIM)

ICESIM is a time-step steady-state gradually varied flow backwater model which simulates the major ice processes of a thermal or fragmented river ice cover during the freeze-up or break-up periods. The model is based on a number of empirical and physically based formulae to characterize different ice processes which affect the water profile along a river, namely

- rate of ice generation
- ice cover advancement by juxtaposition
- ice submergence in high velocity areas and transport downstream to areas of low velocity
- erosion of an unconsolidated ice cover
- thickening of an ice cover to achieve mechanical stability.

The hydraulic backwater profile is recomputed to update the velocity and water level conditions in the river as the ice regime changes. The reader is referred to Petryk (1986) for a more detailed description of the ICESIM model.

ICESIM requires basic river geometry, hydraulic, ice, and meteorological data as input. The estimated values of the various ice parameters depend on the type of event being modeled (break-up or freeze-up). The parameters are adjusted within the range of experience during model calibration.

Significant ice related ICESIM parameters are described below:

Critical Froude Number - The critical (limiting) Froude number defines the conditions for which the ice pieces will queue in an orderly manner and progress upstream. The ice cover may be either an accumulation of frazil slush and/or small ice pans as found at freeze-up or solid ice floes found at break-up. If the limiting Froude number is exceeded, the ice floes are drawn under the ice cover and transported downstream. Theoretical limiting Froude numbers range from 0.08 to 0.154 depending on porosity [Kivisild (1959), Pariset et al (1961), Michel (1984)]. Critical Froude numbers ranging from 0.054 to 0.13 have been used for freeze-up conditions on a number of Canadian rivers [Kivisild and Pennel (1974), Michel (1984), Michel and Drouin (1981), Andres and Doyle (1984)].

Cohesion (τ) - Prowse (1986) suggested that cohesion in winter ice jams is realized by refreezing from high compressive forces. Cohesion estimates are generally derived from back calculations of relevant equations using more easily measured field parameters. Typical cohesion values at formation are 1000 Pa (Calkins, 1984) and 1200 Pa (Shen and Yapa, 1984). Cohesion has been found by many investigators to much smaller at break-up than during freeze-up and is often considered negligible when modeling break-up jams [Calkins (1983), Pariset et al (1966)].

Ice Friction (μ) - This quantity represents friction between ice and the banks as well as the internal resistance of the cover as described by Pariset et al (1966). There is reasonable agreement in the literature as to the limits of this parameter. Generally, values ranging from 1.2 to 1.6 have been reported for a number of Canadian rivers [Pariset et al (1966), Beltaos (1983), Andres and Doyle (1984), Calkins (1984) and Shen and Yapa (1984)], with 1.3 often considered a reasonable average.

Deposition Velocity - The deposition of ice is a function of temperature, section shape, channel hydraulics and density of ice. Normally, field data are limited. Deposition velocities at freeze-up have been found between 0.7 m/s to 1.7 m/s [Michel and Drouin (1975, 1981), Shen and Yapa (1984), Michel (1971)].

Erosion Velocity - Although field data are seldom available to determine this parameter, it must be greater than the deposition velocity. Petryk et al (1980) used an erosion velocity of 1.2 m/s in modeling the Peace River.

Under-Ice Roughness - Michel (1971) summarizes ice cover roughnesses during freeze-up. Manning's "n" roughness values are shown to vary from 0.03 to 0.10 depending on both the type of accumulation and the ice thickness. The under-ice roughness may change along a reach to reflect different ice processes. It is difficult to accurately estimate a-priori the under-ice roughness of a jam, therefore this parameter is often adjusted within reasonable bounds as a primary means of calibration.

Of all the ice parameters, under-ice roughness and the critical froude number have the largest impact on the simulated ice processes, ice thicknesses and water levels.

Freeze-up Analysis

Harry's River is, for the most part, categorized hydraulically as a wide river. This means that the ultimate thickness of the ice cover is generally governed by the accumulated forces in the cover. At any section, the net downstream force in the cover results from the hydrodynamic thrust on the ice cover front, the hydrodynamic drag force on the underside of the ice cover, and the weight of the ice along the slope of the ice/water interface.

At freeze-up, the ice cover on Harry's River forms from a combination of thermal ice in low velocity areas and frazil slush ice in reaches with a fragmented cover. The quantity of ice depends on the severity of the winter with the ice cover gradually proceeding upstream.

A known lodgement position was observed during the January 1987 field trip at lower White's farm, approximately 1.5 km downstream of the study area. The lodgement results from a decrease in the net downstream driving force due to a wide, long reach with islands and a mild slope. This lodgement position was used as a starting point to model the upstream progression of the ice cover during freeze-up.

The ice cover requires a minimum heat loss over time to progress upstream to the study reach and in warm years the ice cover does not progress through the study reach.

The model freeze-up calibration was based on the observed January 4-9, 1985 event. Data used as a basis for the calibration included

- Harry's River ice monitoring notes for the 1985 winter.
- photographs
- plan view of historical flood levels (Department of the Environment)
- Harry's River WSC discharge data.

This calibration event was based on a discharge of 15.8 m^3/s. The calibrated model parameters are shown in Table 1. These parameter values are consistent with values cites in the literature.

The calculated water levels provided very good agreement with those observed as shown in Figure 2. Calculated thicknesses were somewhat large compared with field observations, but reasonable considering the limited extent of these data. Comparisons between the estimated and actual water levels and ice thicknesses are given in Table 2.

The areas of spatial flooding compared well with field observations, i.e. the lower field of Tanglewood including the lodge and the lower field of Hickey's. The model predicted a rough fragmented cover primarily in four reaches where photographs and reports confirmed the presence of a very rough cover. The ice cover progressed through the remainder of the study area by deposition, followed by juxtaposition. This also agreed well with documented evidence.

The January 18 - 20,1986 period was chosen to verify the calibrated ICESIM freeze-up parameters.Boundary conditions for this event were a discharge of 31 m^3/s and a downstream water level of 16.5 m. As with the calibration event, the predicted river profile compared favorably with the observed water levels.

Criteria for the Selection of Historical Freeze-up Events

In order to predict water levels resulting from ice formation in Harry's River, flow and air temperature data are required to calculate the rate of ice cover advancement. In some years, the ice cover does not progress upstream into the study area. A cumulative degree day-discharge criteria (Figure 3) was derived from observed data to predict the date each year when the ice cover would advance to the downstream boundary of the study reach. The criteria for determining the freeze-up dates and flows for each of the historical years are described.

- The beginning of winter was identified as the earliest time when freezing temperatures accumulated without a significant warm period in the record.
- The cumulative mean daily air temperatures were plotted versus a moving discharge average until the ice cover formation region of Figure 3 was encountered.
- The steady state discharge was taken as the average flow over the next 7 days (corresponds approximately to the progression time of the ice front through the 5.8 km study reach).

For the period 1968/69 to 1985/86, it was predicted that the ice would arrive in the study reach in all but two winters. It would take, on average, 21 days from the start of winter for the ice to progress to the downstream boundary of the reach with a maximum travel time of 30 days and a minimum time of 12 days.

Freeze-up Flood Levels

The calibrated ICESIM model was used in conjunction with the estimated freeze-up flows (based on freeze-up event criteria) to determine water levels along the river for applicable winters.

Break-up Analysis

Several major floods have been observed in Harry's River resulting from break-up ice jams. The break-up event is typically characterized by a rapid increase in discharge and a weakened ice cover due to rain and/or snowmelt. As the discharge increases, the ice cover lifts breaking contact with the banks. This results in the sudden release of a large quantity of broken pieces of solid ice which may jam at a number of locations. Ice jam locations are typically characterized by sections having a sudden reduction in flow conveyance and/or large resistance in comparison to the net downstream forces (strong ice cover in a deep reach, islands, shallow grounded sections, etc).

Important elements in determining the flooding associated with a break-up event are therefore

- identifying ice jam location(s)
- determining the criteria which cause a break-up event.

Potential jam locations were identified by reviewing the conveyance at each section through the study reach. Five locations showed a significant change in conveyance reduction from upstream to downstream. Stations 2+802 and 4+667 (TCH Bridge) were at the same general locations as documented in the February, 1984 event. The other three locations were at Stations 4+227, 3+904 and 1+347. The first two Stations, 4+227 and 3+904, occur in steep reaches where jams are not likely to form, and where no jams have been reported. Station 1+347 is located at a bend in the river where the river is very shallow. A deep reach exists immediately downstream which provides a stable cover for resistance. Water levels have been observed in some years to flood properties immediately upstream.

The break-up calibration was based on the observed February, 1984 event. Calibrated ice parameters were identical to the freeze-up parameters except that the ice cover cohesion was reduced to 200 Pa.

The calibrated river profile is shown in Figure 4, along with the observed water levels. Calibrated ice thicknesses from 2 m to 2.3 m were estimated in the ice jam extending from Section 2+177 to 2+702 where the ice thickness was observed at 2.5 m. The calibration resulted in good agreement between calculated and observed ice thicknesses and water levels.

Although break-up events have been observed in other years, such as 1979, sufficient data were not available to enable a rigorous verification of the break-up model parameters. Available information for potential break-up model verification events was primarily anecdotal evidence from local residents. Observations suggest that in 1979 flooding was similar to the February 1984 break-up event. ICESIM predicted flooding on Hobb's farm as in the 1984 event, but with slightly higher water levels (sufficient to flood Campbell's road).

Criteria for the Selection of Historical Break-up Events

Ice cover break-up is generally caused by a combination of increased discharge, thermal ice weakening and melting. Break-up can also occur from any one of these factors individually. The most severe flooding in Harry's River occurs in mid-winter when there is a sudden increase of discharge with a strong cover in place.

Harry's River commonly experiences changeable winter temperatures. During some years a cover does not progress upstream to the study area, while in many other years the temperatures are not sufficient to adequately strengthen the ice cover to withstand larger forces associated with greater discharges. When subject to higher temperatures in the spring, the cover often weakens and melts quickly causing the ice to move out of the reach without an ice jam forming. Residents report that major historical break-up jams have occurred in only four years; 1936, 1951, 1979 and 1984.

Potential break-up events were screened in a preliminary manner using the following approach:

- Meteorological and flow records were examined to identify potential break-up events. Snowpack, rainfall, temperature and flow records were reviewed concurrently for the winter period (usually December to March) of each year.
- If any of the following criteria were exceeded the occurrence was considered a potential break-up event.
  - a rapid decrease in snowpack (e.g. 30 - 40 cm in over 2 days)
  - a rapid increase in air temperature (e.g. 10 - 12 cumulative melting degree days in a 2 day period)
  - a sudden increase in discharge (e.g. 30 - 50 m^3/s in a day)
  - a significant rainfall in the basin (e.g. 30 - 40 mm over 2 days).

Twelve potential events were identified. By reviewing conditions from freeze-up through mid-winter for these events in more detail as well as the chart records at break-up, only three situations (1970, 1979 and 1984) were considered break-up events.

Break-Up Flood Levels

Break-up flood profiles were determined by simulating ice jams at each of the potential jam locations (Section 1+347, 2+802 and 4+677) for the 1970, 1979 and 1984 break-up events.

As with freeze-up events, key stations were selected for the frequency analysis of water levels. The maximum break-up levels at the key stations (caused by ice jams at any of the likely jam sites) were simulated for the 1970, 1979 and 1984 events.

Open Water Flood Profiles

Flow records were available for Harry's River from the WSC gauge (02YJ001), located just downstream of the TCH Bridge. The annual series of maximum flows were taken directly from this record, with a suitable adjustment for the contribution of the local tributary flows. The open water season is generally from May to November.

Frequency analyses were based on maximum instantaneous flows which were derived from maximum mean daily flows (proration factor of 1.7). The HEC-2 open water backwater model was used to estimate the water levels at key stations along Harry's River for each of the annual instantaneous flood flows.

Determination of 1:20 and 1:100 Year Flood Profiles

The 1:20 and 1:100 year flood levels were predicted at key stations along Harry's River using the following relationship from probability theory.

$$P_t = P_o + P_f + P_b - (P_o * P_f) - (P_o * P_b) - (P_b * P_f) + (P_o * P_b * P_f)$$

where

P_t = annual total probability of exceedence of a given water level
P_o = annual probability of exceedence of a given water level from an open water event
P_f = annual probability of exceedence of a given water level from a freeze-up event
P_b = annual probability of exceedence of a given water level from a break-up event.

The analysis proceeded as follows:

- A frequency curve was plotted for each type of event (freeze-up, break-up, open water) at each key station using the annual series of water levels.

- Several water levels were selected at each key station for which probabilities of exceedance were calculated. The probabilities obtained from the frequency analyses were multiplied by the probability of that type of event occurring in any year. (It was necessary to assume that the small sample of 3 break-up events was representative of the population of break-up events. The break-up frequency analyses plotted the 3 points at return periods calculated using the Cummane plotting position formula).

- The total probability of exceedance of each of the chosen water levels was calculated at each key station by summing the probabilities of occurrence from each type of event. (The very small contributions of the joint probability terms were neglected).

- For each key station, the total probability of exceedance of each of the selected water levels was plotted to obtain the water levels corresponding to return periods of 1:20 and 1:100 years.

Table 3 and Figure 5 show the application of this technique for Station 2+552. Figure 6 shows the extent of flooding resulting from the 1:20 and 1:100 year flood events. The combined probability is strongly influenced by break-up data which is based only on three events. The curve is therefore reliable at higher return periods, however it may not be as reliable at lower return periods.

Effects of Channel Modifications

As a result of recent flooding events, the Newfoundland Department of Environment modified the channel in December 1986 to reduce the risk and extent of ice related flooding.

The modifications consisted of

- removal of the island near Hickey's Farm
- excavation of the shallow section of the river near Tanglewood Ranch
- construction of a berm at Tanglewood Ranch
- construction of a berm at Hickey's farm, upstream of the excavated island.

The new channel modifications were incorporated to derive annual series of flood water levels necessary to compute the 1:20 and 1:100 year flood levels for the current river geometry.

These analyses showed that there are two main benefits to be realized from the recent channel modifications undertaken by the Newfoundland Department of Environment.

The first is that slightly lower water levels will result just upstream of the Tanglewood Ranch if the downstream jam locations remain the same.

The second benefit is that the jam located just upstream of Tanglewood (Station 1+950) will not likely occur in the future due to removal of the island by Hickey's Farm. The large downstream external forces resisted by the island and also by shallow shoal areas (now excavated) will increase, making the jam more likely to collapse giving relief to Hickey's farm.

Summary

The occurrence of flooding along Harry's River from ice freeze-up, ice break-up and open water events is typical of may northern Canadian rivers and streams.

As with Harry's River where the most severe flooding results from ice events, it is necessary to consider the combined probabilities from each of the events in determining the 1:20 year and 1:100 year flood levels.

Often, flooding data from ice events is sparse. Therefore, simulation of flooding from the formation or break-up of an ice cover using a numerical backwater model (such as ICESIM) is an important component of such flood studies.

Acknowledgements

Technical comments, suggestions and advice provided by the Technical Project Committee throughout the course of this study are greatly appreciated.

<u>REFERENCES</u>

Acres International Limited, "Field Measurements and Instrumentation", draft contribution to Primer on Hydraulics of Ice Covered Rivers, Subcommittee on Hydraulics of Ice Covered Rivers, National Research Council of Canada, December, 1986.

Andres, D. D. and P. F. Doyle, "Analysis of Breakup and Ice Jams on the Athabasca River at Fort McMurray, Alberta", Canadian Journal of Civil Engineers, Volume 11, pp 444 - 458, 1984.

Beltaos, S., "River Ice Jams: Theory, Case Studies and Applications", ASCE Journal of Hydraulic Engineering, Volume 109, No. 10, 1983.

Calkins, D. J., "Ice Jams in Shallow Rivers with Floodplain Flow", Canadian Journal of Civil Engineering, Volume 10, pp 538 - 548, 1983.

Calkins, D. J., "Numerical Simulation of Freezeup on the Ottaquechee River", Workshop on the Hydraulics of River Ice, Fredericton, New Brunswick, June 20 and 21, 1984.

Goebel, M. Newfoundland Department of Environment. <u>Case Study of Ice Related Flooding of Harry's River at Black Duck Siding, Newfoundland.</u> Paper presented at the 6th CSA/CWRA Atlantic Region Hydrotechnical Conference June, 1986.

Government of Newfoundland - Department of Environment, <u>Ice Monitoring Notes - January 1985 to April 1986</u>; 1985, 1986.

Government of Newfoundland - Department of Environment. <u>Report on the Flooding in Black Duck February 5 - February 12, 1984.</u>

Kivisild, H. R., "Hanging Ice Dams", IAHR 8th Congress, Vol. III, Paper 1-SI, 1959.

Kivisild, P. H., J. Penel, "Ice Jams Related to Climatological and Hydraulic Parameters - Yukon River at Dawson City", Seminar Thermal Regime of River Ice, Quebec City, N.R.C. Tech. Mem. No. 114, pp 170-177, 1974.

Michel, B., "Winter Regime of Rivers and Lakes", 1971.

Michel, B. and M. Drouin, "Courbes de remous sous les couverts de glace de la Grande Riviere", Canadian Journal of Civil Engineering, Volume 8, pp 351 - 363, 1981.

Michel, B. and M. Drouin, "Equilibrium of an Underhanging Dam at the La Grande Riviere", Report CGS-75-03-01, Department de Genie Civil, Universite Laval, Quebec, Quebec, 1975.

Michel, B., "Comparison of Field Data with Theories on Ice Cover Progression in Large Rivers", Canadian Journal of Civil Engineering, Volume 11, pp 798 - 814, 1984.

References (cont'd.)

Pariset, E. and R. Haussar, "Formation and Evaluation of Ice Covers on Rivers", Transactions of the Engineering Institute of Canada, Volume 5, No. 1, p 41, 1961.

Pariset, E., R. Hausser and A. Gagnon, "Formation of Ice Covers and Ice Jams in Rivers", ASCE Journal of the Hydraulics Division, Volume 92, HY6, pp 1 - 24, November 1966.

Petryk, S., "Numerical Modeling of Ice in Rivers - Annex C - ICESIM Model by Acres", Notes for Short Course on River Ice Engineering, Ecole Polytechnique, Montreal, June 17 - 18, 1986.

Petryk, S., U. Panu and F. Clement, "Recent Improvements in Numerical Modeling of River Ice", presented at the Workshop on Hydraulic Resistance of River Ice, Burlington, Ontario, September, 1980.

Prowse, T.D., "Guidelines for River Ice Data Collection Programs", Working Group on River Ice Jams, Subcommittee on Hydraulics of Ice Covered Rivers, National Research Council of Canada, June 1985.

Prowse, T. D., "Ice Jam Characteristics, Liard-MacKenzie Rivers Confluence", Canadian Journal of Civil Engineers, Volume 13, pp 653 - 665, 1986.

Shen, H. T., and P. D. Yapa, "Computer Simulation of Ice Cover Formation in the Upper St. Lawrence River", Workshop on the Hydraulics of River Ice, Fredericton, New Brunswick, June 20 and 21, 1984.

TABLE 1

CALIBRATED ICESIM PARAMETERS: FREEZE-UP

Open Water Area Upstream:	100 000 m^2
Critical Froude Number:	0.10
Deposition Velocity:	1.0 m/s
Erosion Velocity:	1.5 m/s
μ = (friction property)	1.3
Fragmented Under Ice Roughness:	0.045
Fragmented Ice Cohesion:	1 kPa

TABLE 2

COMPARISONS OF WATER LEVELS AND ICE THICKNESSES: JAN/85 FREEZEUP EVENT

Observed Ice Front Location	ICESIM Section	Water Levels @ ICESIM Section (m)		Ice Thickness @ ICESIM Section (m)	
		Observed	Calibrated	Observed	Calibrated
1+756 - 2+332	1+591	20-20.5	20.4	-	1.2
2+332 - 3+907	2+063	-	21.9	0.8	1.1
2+332 - 2+802	2+332	22-22.5	22.7	-	0.9
2+802 - 3+232	2+802	23.5-24	24.3	0.8	1.4
2+063	4+627	29.4	29.3	-	-
3+232		29.8	29.3	-	-
>4+712		29.7	30.1	0.3	1.26

TABLE 3

SAMPLE CALCULATIONS - SECTION 2552

P (WL = 26.0)

Open Water (1 - 0.9995) = 0.0005
Break-Up (1 - 0.985) = 0.0150
Freeze-Up (1 - 0.9988) = 0.0012
P (26.0) = 0.0167*
T_r = 60 yrs

Notes:

(*) These points are plotted on Figure 5, and used to draw the curve to obtain 1:20 and 1:100 year flood levels.

T_r = Return period in years.
P(x) = Probability of water level reaching or exceeding x m above sea level in any one year.

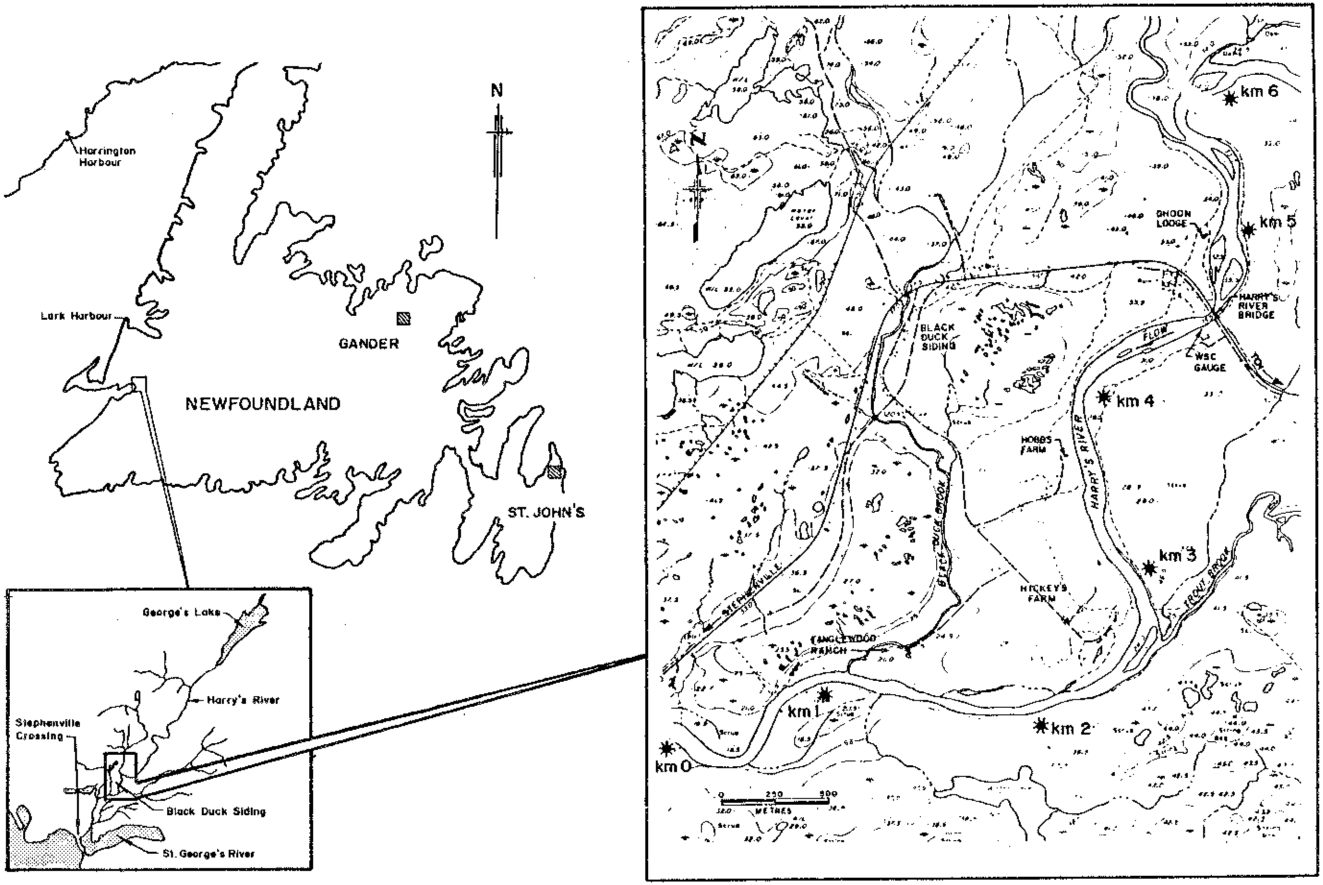

FIGURE I
STUDY AREA LOCATION AND PLAN

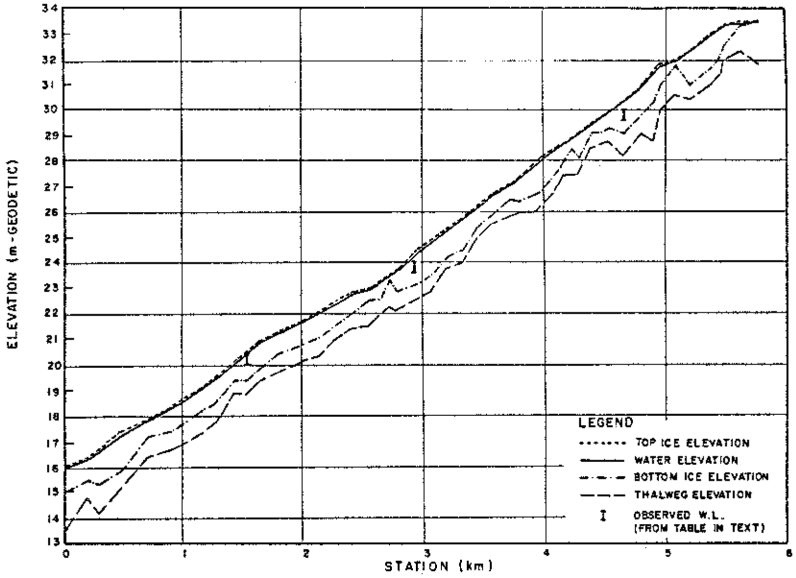

FIGURE 2 — JANUARY 1985 FREEZE-UP CALIBRATION

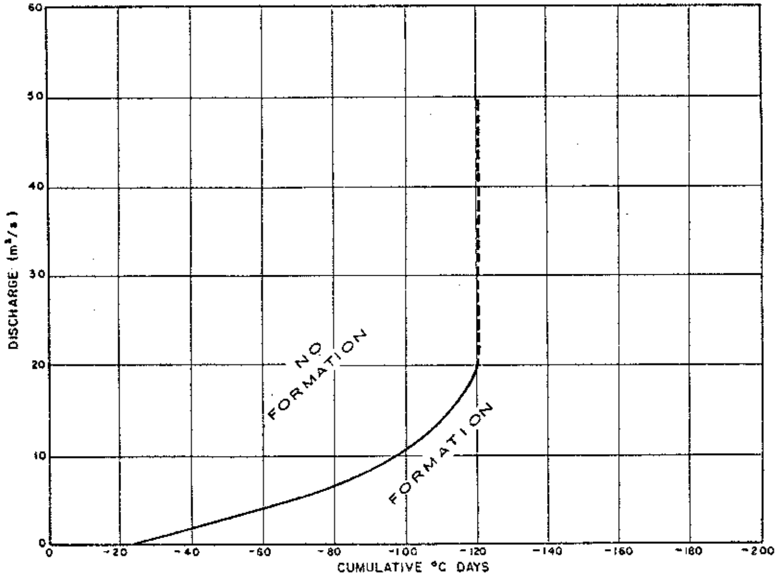

FIGURE 3 — FREEZE-UP EVENT IDENTIFICATION FUNCTION

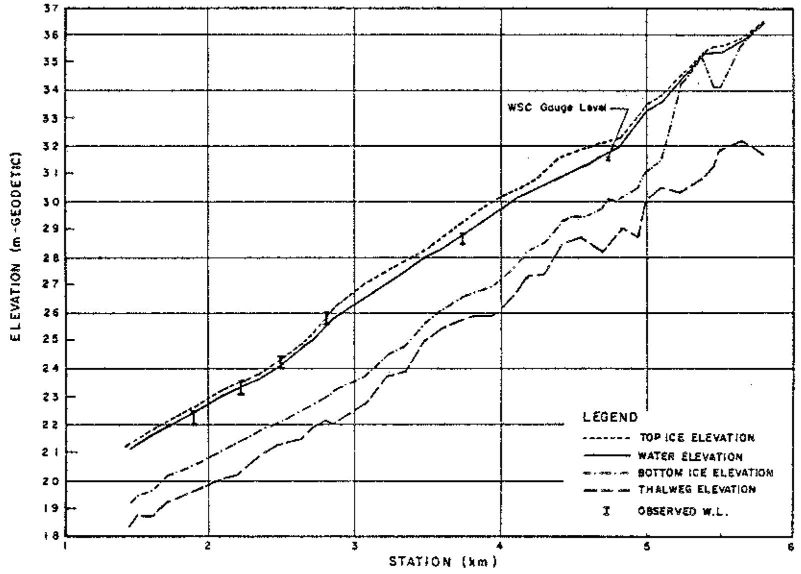

FIGURE 4 — FEBRUARY 1984 BREAK-UP CALIBRATION

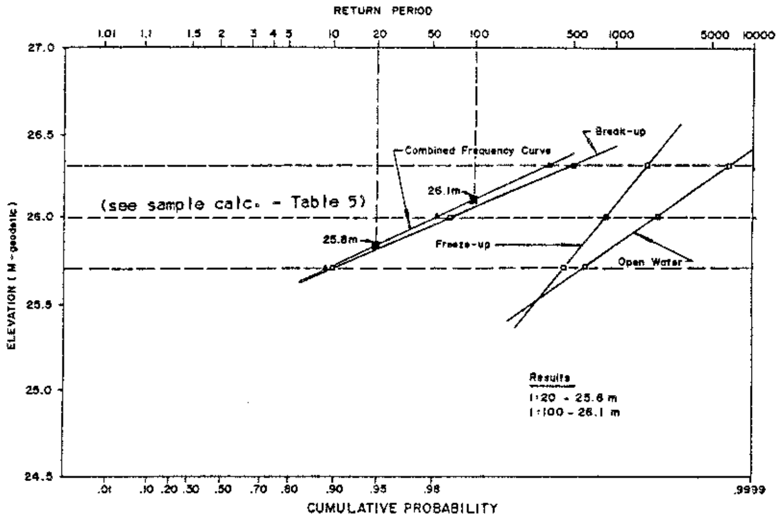

FIGURE 5 — FREQUENCY CURVES SECTION 2552

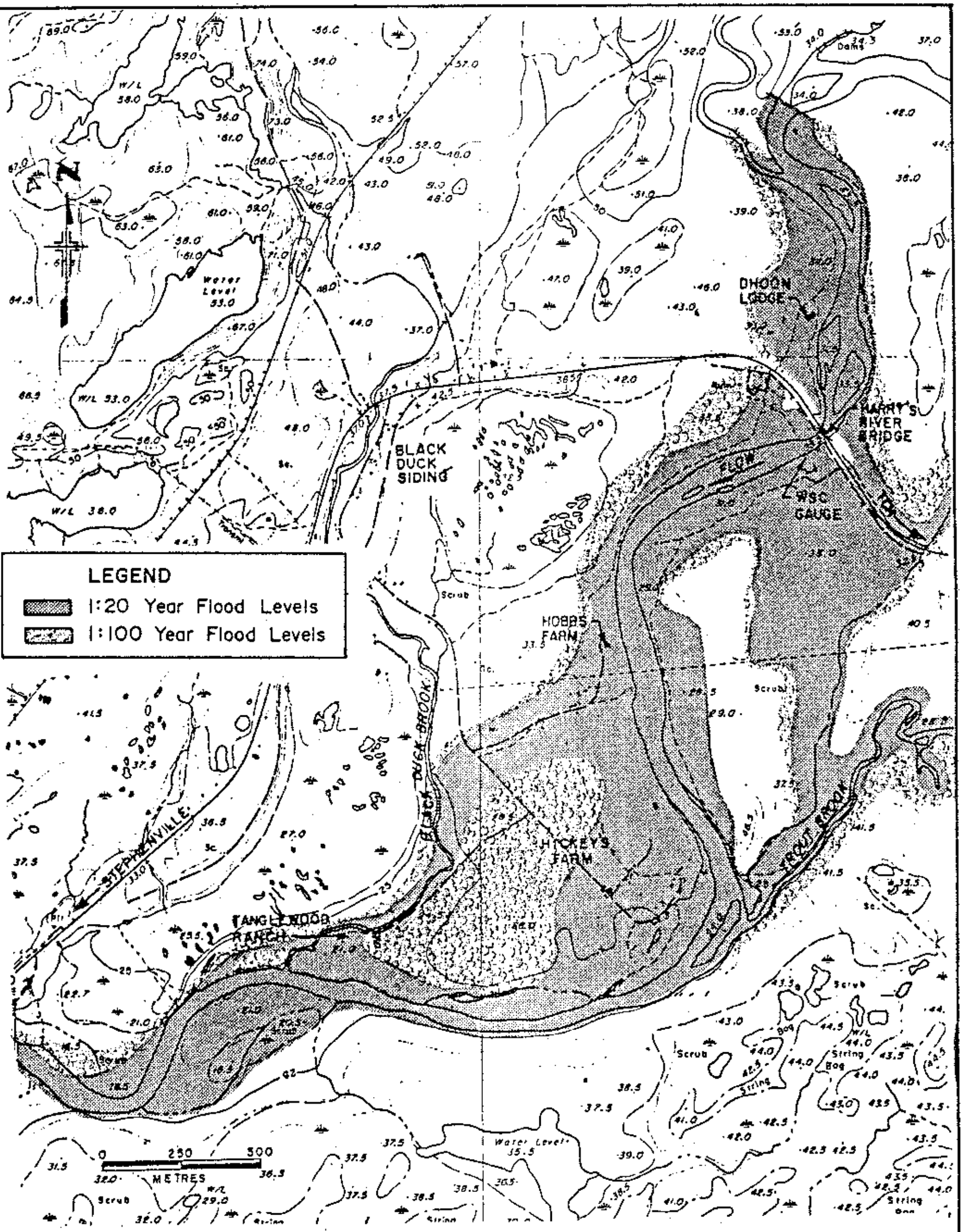

FIGURE 6 — 1:20 AND 1:100 YEAR FLOOD LEVELS

QUESTIONS BY: P. M. Pelletier, WRB, IWD, Environment Canada

How do you explain the large differences between the observed and simulated ice cover thickness during January 1985 freeze-up event (Table 2)?

RESPONSE: It is difficult to discern whether the error is numerical or measurement based. Only a single ice thickness measurement was taken across the section and it was not clear whether this was solid ice and slush ice or just solid ice. The numerical thickness estimate is a sectional average of a composite ice cover.

QUESTIONS BY: Jan Wong

How did you identify the locations of ice jams in your study reach?

RESPONSE: Some historical ice jam locations were identified from photographs and discussions with residents. Other potential ice jam locations (arising from remedial work) were identified on the basis of hydraulic (conveyance, width, slope, etc.) considerations.

QUESTIONS BY: Greg Snyder, WMS Associates Ltd.

1. Concerning your field program, you used 55 field cross-sections and say they were surveyed in 3 to 4 days - that's 13 per day or nearly 2 per hour. The crew must have operated at a dead run. Was it possible to wade across the river to reduce the difficulty of getting the sections; how wide were they and were they tied to geodetic?

2. One further point: Newfoundland typically will have a number of freeze-up and break-ups in one winter. How did you account for the period between a mid-season break and the re-freeze; was this also based on an accumulation of degree days? If so, was the equation re-set to zero for the cummulation or modified to account for presence of border ice etc.? This was the procedure used at Rushoon, in which we assumed 2 or 3 days of subzero would be sufficient for a re-freeze of cover.

RESPONSE: 1. Surveyed cross-sections were completed in 4 working days. All but one section were done with waders during low flow. An additional two days were required to establish TBM.

2. Similar criteria were applied to identify freeze-up and break-up of events, a detailed description of which can be found in the technical report. If more than one freeze-up or break-up event was identified in a given winter, only the most severe was considered in the frequency analysis.

QUESTIONS BY: Steve Smith, Ontario Hydro

1. From a regulatory aspect, can joint probabilities with a statistically limited data set be confidently applied in defining flood profiles?

2. It would appear that a sample size of 3 data points predominates the design level probability function.

3. While the technique may be valid, the practicality versus event simulation/documentation must also be considered. Where the ice and/or open water sample size is limited, so is the validity of the frequency distribution.

4. In this instance, perhaps a sensitivity concept or confidence degree approach warrants consideration.

RESPONSE: 1. Yes, this approach provides probabilistic information regarding the exceedance of water levels, where distinct and well defined different populations exist.

2. The point here is that the ice break-up mechanism dominates flood levels; it just happens that there are only 3 points describing this process.

3. and 4. Some work was done testing the sensitivity of the results to various assumed distributions. The results were not sensitive to the assumed distribution.

QUESTIONS BY: R. Gerard

1. I don't believe there is any <u>doubt</u> the combined probability approach is required when there is such obvious mixed populations (other examples include tides, storm surges and floods in estuaries) and, particularly, where the historical recurrent is very limited and extrapolation on the basis of deterministic modelling is required. Nevertheless it would be of interest to know how the annual peak stage probability distribution, based on just the direct historical stage record, compares with your derived combined distribution.

2. This case study is an excellent example of the circumstance and approach envisaged in the preparation of the paper by Gerard and Calkins (1984), CSCE Cold Regions Conference, Edmonton (see Winnipeg Short Course Notes).

3. Was any thought given to combining the 'best' of the historical and deterministic records and deriving the probability distribution from that?

4. What was the length of the available meteorological records - from 1968?

5. It seems that for some of the higher break-up jam situations there was significant overbank flow. How was this allowed for in the jam simulation?

RESPONSE: 3. No, this was not considered.

4. Meteorological data available from early 1948, however there was no flow data or historical observation prior to 1968.

5. Full cross-sections were used describing flood plains where they existed and where there was clear overland flow. In areas where there was not a clear flow path (i.e. only storage) full cross-sections were not used.