

RECOMMENDATIONS FOR SITE-SPECIFIC OBSERVATIONS OF RIVER ICE

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ABSTRACT

In response to a need for fundamental field data about river ice, the NRCC Working Group on River Ice Jams has developed a set of guidelines to be used in river ice data collection programs. The observations have been designed for a user who has limited access to a river and who must perform all monitoring from a single bank location. Recommendations for supplementary observations of ice composition and river discharge are also included for cases where additional personnel and equipment are available. Observations are broken into the following periods: freeze-up, main winter, pre-break-up, break-up, ice jams, and post break-up. A set of illustrations and photographs has been included to assist the observer.

INTRODUCTION

For a large part of the winter season, ice covers most of Canada's rivers creating numerous and wide-ranging hydrotechnical problems. Detrimental effects caused by the formation, growth and break-up of river ice can be extremely diverse, including for example the forced shut-down of power plants due to frazil accumulation, damage to engineering structures from large ice runs, disruption of normal open water and surface ice transportation, and the flooding of communities by ice jam-induced backwater. Gerard (1979, 1984) and Acres Consultants Ltd. (1971) provide reviews of the myriad of problems and present research associated with river ice. Serious and costly ice problems have occurred on most Canadian rivers where an ice cover develops, ranging from such major rivers as the Mackenzie (MacKay and Mackay 1973) and Athabasca (Andres and Doyle 1984) to smaller rivers like the Moira (Lathem 1975) and Rideau (Frietag 1980). Halliday (in prep.) is currently preparing an up-dated review of ice jam related damages in Canada for the National Research Council of Canada, Working Group on River Ice Jams. Evidence suggests that the incidence of problems and adverse economic effects associated with river ice will increase as development continues to encroach on southern rivers and extends further into the north.

Over the last two decades, significant advances have been made in river ice research, particularly with the development of theoretical models of ice jams (Pariset et al. 1966; Michel 1971; Uzuner and Kennedy 1976; Beltaos 1983a). Unfortunately, further advances and even the testing and calibration of existing models have been thwarted by the dearth of quantitative field information. Good field data are fundamental to this type of research and a comprehensive data base is needed if significant new advances are to be made in the understanding of river ice processes. In response to this need, the Working Group on River Ice Jams (affiliated with the NRCC Subcommittee on Hydraulics of Ice Covered Rivers and the Associate Committee on Hydrology) defined a task: to develop guidelines for needed data collection programs (Beltaos 1984). The recommendations outlined in this report and in Prowse (1985) are the results of this task.

Within Canada there are a number of private and public agencies involved with the collection of river ice field data. On a national scale, two agencies of Environment Canada, Water Survey of Canada and the Atmospheric Environment Service, collect ice data

from numerous stations across the country. Unfortunately, only elementary information, such as ice thickness and dates of freeze-up and break-up, is systematically collected, having only limited utility for river ice studies. More detailed quantitative field data have been collected by private consulting firms, hydro-electric companies and other government agencies, such as the Alberta Research Council, the National Hydrology Research Institute, the National Water Research Institute and provincial conservation authorities. In many cases, however, these agencies have conducted site specific studies focused on a single research interest. As a result, disparate data are often collected which are difficult to compare and sometimes to access. In view of this problem, Petryk (1984, 1985) compiled a casebook on ice jams which should improve the accessibility to at least this type of river ice information.

Despite all the data collected in the various case studies and by the national agencies, there still remains a definite scarcity of river ice information about many Canadian rivers and about some important river ice processes. Since it is unlikely in the immediate future that a single agency will be given the mandate to collect the necessary data, the next best step for improving the current data base is to define a set of guidelines for data collection which a) can be readily used by any individual or agency interested in river ice processes and b) most effectively addresses the needs of current river ice research. In order that the guidelines be usable by as many groups as possible, the observations outlined in this report have been designed for a user who has limited access to a river and who must perform all monitoring from a single bank location. These design criteria ensure that the observations can be undertaken equally well in all parts of Canada, including remote areas where access by road and bridge crossings is rarely found. It should be stressed that this report is directed towards 'site specific' observations whereby the information will be used by future researchers and practitioners to study ice conditions at a given site. These types of observations are simpler than and quite different from 'reconnaissance level' observations where sufficient observations are made along the river to understand the ice regime in a given reach. A future objective of the NRCC Working Group on River Ice Jams is to formulate a second set of guidelines for situations in which monitoring of an entire river reach is possible, preferably by aerial reconnaissance, and where additional personnel could be made available during periods of high activity such as during the formation and release of ice jams. These 'reconnaissance level' guidelines will be designed to supplement the routine or 'site specific' guidelines outlined in this report.

GUIDELINE DESIGN

Each temporal phase of the guidelines is introduced by a brief description of the objectives in collecting the data and some indication of their ultimate utility. Figures 1 to 4 illustrate the types of observations to be conducted at each phase. Although the guidelines have been principally designed for use by individual observers who are restricted to making visual observations from a single shore location, it was also recognized that some observers may have access to additional equipment or personnel which would permit the recording of other site specific information. In particular, two types of supplementary observations - ice thickness and river discharge - would be extremely valuable to the understanding of the river ice regime. In the case of ice thickness and stratigraphy, holes would have to be drilled in the ice sheet to permit the measurement of individual snow and ice strata. For most regions, this additional observation could be carried out by a single observer with relatively simple drilling equipment. In contrast, discharge is a much more complicated measurement and usually requires additional personnel and specialized measurement equipment. Individual observers would, in most cases, not be capable of undertaking field measurements of discharge. Where the personnel and equipment are available, however, it is strongly recommended that efforts be made to obtain direct measurements of discharge. In view of the importance of these two types of supplementary observations and the number of existing observational programs which could record this type of information, appropriate data collection guidelines have been included. For individual observers who lack the necessary additional equipment or personnel, these supplementary observations will have to be forgone and the remainder of the shore-based observations conducted as outlined.

A high proportion of the users of these guidelines are expected to be agencies or organizations which already operate some form of hydro-data collection program. In such cases, the river ice observations will probably be incorporated as part of an existing data collection program, and the location of observation sites will therefore be pre-determined. Notably, however, the combining of programs may affect the type of ice observation data which are collected. For example, the Water Survey of Canada normally selects straight river sections, devoid of any major obstacles to flow such as islands or shoals, at which to establish gauging sites. The probability of collecting observations of ice jams at such sites may therefore be low. In cases where new study sites are being selected, or existing data collection programs are being expanded, a number of selection criteria should be considered which will assist both in the monitoring of river ice conditions and in future research analyses. Firstly, the site should have some history of significant ice problems. A river gauging site and meteorological station, both with reliable records, should be in close proximity. Sites with more than one good vantage point from which to conduct upstream and downstream observations are preferred. Access to a bridge is ideal and creates the added opportunity of obtaining discharge measurements immediately following, and possibly during, break-up.

In situations where ice observations are incorporated as part of an existing data collection program, the timing of observations may be largely controlled by the established frequency of site visitation. It should be remembered, however, that one of the major reasons for the scarcity of good field data from some water data collection programs is the relatively low frequency and untimeliness of site visits in comparison to the degree of river ice activity. The scheduling of some existing field programs could possibly be modified to allow for more frequent site visits during the river ice period - particularly during freeze-up and break-up. The frequency of site visits should ideally correspond with the degree of river ice activity. During freeze-up, daily visits should be made. Once an intact ice cover has been established, visits can be reduced to one every two or four weeks, the frequency increasing as the break-up season approaches. After appreciable melt has occurred, observations should again be conducted on a daily basis with as many observations per day as possible during the main break-up period. To assist in the recording of river ice information, users are referred to the recording forms developed by Anderson and Prowse (1983), Beltaos (1984), Prowse and Anderson (1984) and Prowse (1985).

GUIDELINES - ICE OBSERVATION PHASE

1) Freeze-up

During freeze-up, accumulation of ice within a river changes the open water relationship between stage and discharge. The degree of distortion is primarily dependent on the form, thickness, and roughness of the accumulating ice cover. Knowledge of the freeze-up processes is critical to the interpretation of stage records, the assessment of discharge, and ultimately to predictive modelling of freeze-up. Freeze-up characteristics have also been shown by Shulyakovskii (1966) and more recently Beltaos (1983b) to have important ramifications for break-up. In particular, the stage required to initiate break-up and the maximum stage reached during break-up has been found to be closely linked to the stage at freeze-up. Even the structure of the freeze-up ice cover can be important to the decay and fracturing of the ice cover at break-up.

The main types of observations to be taken during freeze-up include: stage, discharge, ice types, concentration, method of freeze-up, nature of the ice cover formed, and rate of upstream progression (Fig. 1).

a) Stage and discharge: Monitor the stage leading to freeze-up, particularly at the time of formation of the first permanent ice cover. Notably, under some conditions, the annual peak river stage occurs during freeze-up. Measure or estimate discharge before and after freeze-up.

b) Ice types and concentration (Photograph 1)

Border ice: Border ice is composed of ice which has gradually grown outwards from the shore or from exposed objects in the channel, and/or from drifting ice (primarily frazil ice) which has accumulated along the ice-water margin. Where

border ice is subject to water level fluctuations, repeated flooding and freezing of river water can produce a layering of abnormally thick ice along the banks. Note the type, thickness and lateral extent of border ice.

Floating ice: Estimate the dimensions, distribution, and concentration of frazil (or other) ice passing through the river reach. Where close inspection of the ice can be made, provide a qualitative estimate of ice strength and porosity. In the case of frazil pans, note the thickness of the overall pan and the surface crust.

c) Method of freeze-up: Describe whether the formation of the final complete ice cover results from the lodgement or bridging of ice floes across the section (Photograph 2) or from the accumulation of ice particles against a downstream intact ice cover (Photograph 3). Note the rate of upstream progression of the freeze-up front through the observable river reach.

d) Nature of freeze-up ice cover: Describe the surface of the final ice cover with particular reference to surface roughness and ice types. Estimate overall thickness.

2) Main winter period

Ice growth during the winter season determines the quantity and strength of ice which must be removed at break-up. Since break-up does not necessarily occur at the same time each year, and ice thickness may vary depending on the severity of winter conditions, regular monitoring of ice thickness is necessary. Because of spatial variations in ice thickness, a number of measurements should be taken across the river cross-section, if possible. In cases where such measurements are taken as part of a winter discharge measurement, the total ice thickness (ie. top to bottom of ice cover) should be measured rather than the common measurement of the thickness of ice beneath the water surface which is used in deriving the depth of flow beneath an ice cover.

Attempts should also be made to record the general stratigraphic composition of the ice cover when thickness is measured. In the simplest case (Photograph 4) the top of the ice cover will be comprised of an upper strata (often multiple layers) of relatively opaque, white ice formed from frazil accumulations at freeze-up and the slushing and refreezing of surface snow. Beneath this ice will be a more transparent 'blue' or 'black' ice formed by the downward freezing of river water. The interface between these two strata can best be observed by drilling a hole part way into the ice cover, so as not to allow water to fill the hole, and then inspecting the side of the drill hole. In addition to differences in visual appearance, these two layers are distinguishable by differences in texture along the side of the drill hole. The surface layers of white ice will be characterized by a rough granular texture while the underlying layer of black ice will generally be much smoother. Once the location of the interface between these two layers is determined, drilling of the hole can be completed and total ice thickness measured. The presence of frazil ice accumulations beneath the main ice cover should also be noted (Photograph 5). Thickness of the frazil can usually only be determined from vertical profiles of water velocity beneath the ice cover.

It should be stressed that the above describes only the simplest case of river ice stratigraphy. The composition of river ice is often so complex that observers will only be able to accurately measure total snow and ice thickness. Where an ice cover has evolved from a complex assortment of freeze-up and growth processes, identification of major strata can only be accomplished by extracting an ice block or ice core, a procedure which requires resources beyond those described for this set of guidelines. Further discussions of river ice types can be found in, for example, Adams (1976), Ashton (1979) and Michel (1971).

The major types of observation to be taken during the main winter period include: stage, discharge, snow and ice thickness, ice cover composition, and surface ice appearance and shape (Fig. 2).

a) Stage and discharge: Monitor the stage during the winter period paying particular attention to periods when the ice cover drops and forms hinge cracks. Discharge measurements should be made frequently enough to produce a reliable discharge recession curve.

b) Snow and ice thickness: Measure the thickness of the surface snow cover and thickness of the underlying ice cover at a number of points across the river cross-section.

c) Cover composition: When measuring ice thickness, note the thickness of different ice layers and the presence of frazil accumulations beneath the main ice cover.

d) Surface ice appearance: Note the surface roughness of the ice cover, including the location of pressure ridges and other areas where the ice appears to be grounded, and the presence of shear lines along the shore.

3) Break-up

Systematic documentation of break-up conditions over a number of years will lead to a refinement of existing classifications of break-up processes and to a better understanding of the physical mechanisms which control break-up. One of the more immediate benefits of the data will be the opportunity to develop site-specific forecasting capability of ice conditions. Over the longer term, the probability of specific break-up events will hopefully be linked to measureable morphologic and hydrometeorologic characteristics which can then be used to extrapolate forecasting capabilities to other areas.

Of all the break-up observations, special efforts should be made to obtain accurate records of maximum stage. For most rivers, break-up is typically the period with the poorest stage record because of the damage to stream-implanted recording devices by moving ice. Manual surveys of stage should be conducted during each visit and notes made of any recent high water marks or strand lines. Where resources permitted, crest-stage gauges and even time-lapse cameras have been used in attempts to improve the stage record during break-up.

Because ice jams are responsible for the highest water levels on many rivers, information should be collected regarding their mode of initiation and failure, their effect on stage, and even their size in terms of elementary parameters such as length, depth, and width. This type of information will provide direction to further field, laboratory, and theoretical studies.

Due to the complexity of the break-up process, observations have been broken into four periods: pre-break-up, break-up, ice jams, and post break-up. The possibility of obtaining many of the listed observations depends on the position of the observer relative to specific break-up forms and processes, particularly ice jamming.

4) Pre-break-up (Fig. 2)

a) Stage and discharge: Stage should be measured daily until the water level approaches that recorded at freeze-up. The frequency should then be increased (every eight to twelve hours) especially if mild weather has set in and significant attendant runoff is anticipated. Special efforts should be made to obtain a flow measurement as close to the time of break-up as possible.

b) Snow and ice thickness: Once the main snowmelt period has begun, a final survey of snow and ice thickness across the reach should be made before the surface becomes unsafe for travel.

c) Cover composition: In conjunction with the final thickness survey, note the thickness of the different ice layers including surficial ice forms and frazil accumulations beneath the main ice cover. As water begins to saturate the snow and ice, individual strata will become increasingly difficult to distinguish.

d) Surface conditions: Once surface travel is unsafe, note the percentage cover of snow and exposed ice, the presence of ponded meltwater, and when the water drains from the surface. The ice surface often has a dark appearance when covered with meltwater but quickly brightens after draining.

e) Shore conditions: Note the depth and width of any water accumulating near the shore and if any flow is apparent. Also describe the formation, size, and position of any major cracks, and note when the main ice cover 'lifts' and detaches from the shore. Lifting of the ice sheet is usually concomitant with the draining of surface meltwater. Note whether bottom fast ice is present beneath the shore lead.

5) Break-up (Fig. 3)

a) Stage: Water levels should be monitored as frequently as possible. Points of specific interest include: the rate of rise in water level immediately prior to the initial fracturing and movement of the ice sheet, water levels at the time of first ice movement, the maximum break-up water level, and changes in water level as fractured ice clears the study reach.

b) Break-up front: The character of a break-up front can vary considerably but there are usually two distinct styles. The first involves a rapid transition from intact ice cover to highly fractured ice (Photograph 6). In such cases estimate the rate at which this fractured break-up front moves downstream. The second style is characterized by a large scale fracturing of the ice sheet followed by a downstream movement of large pans which often rotate and fracture within the flow (Photograph 7). In this second case, estimate the speed at which the initial pans move downstream. In extreme cases (thermal break-ups) the ice cover will almost melt in situ (Photograph 8).

6) Ice jams (Figs. 4, 5)

In cases where the clearance of fractured ice from the study reach suddenly stops, formation of a jam downstream can be assumed. The type of observations to be taken then depend on the position of the observer relative to the various parts of the jam. If the observer has good vantage of other parts of the river, or access to other sites, every effort should be made to observe as much of the ice jam as possible. Even where observations are limited to one site, if final clearance of the jam can be monitored, the observer may be able to estimate what other characteristics of the jam may have been, such as location of the head (upstream end of ice jam, see Fig. 5) and jam length.

a) Stage and discharge: Water levels should be monitored as frequently as possible. Points of specific interest include: the rise in water level when the moving ice stops, the maximum water level while the jam is in place, and the water level when the jam breaks and ice again begins to clear from the reach.

If other points are accessible along the ice jam, make notes of the water level at each site relative to local objects which can be later surveyed to obtain true elevations.

Estimate the velocity of the break-up front which leads to formation of the ice jam and the velocity of surface ice when the ice jam releases.

b) Areal extent of ice jam: Note whether the ice completely or only partially blocks the river cross-section. If visible, also record the location of the downstream (toe) and upstream (head) portions of the jam (Figs. 4, 5).

c) Conditions at toe of ice jam: If the ice jam toe is visible, describe whether the jam has been either i) forcibly halted by some downstream obstruction, such as an intact ice cover (see Fig. 5), man-made structure, geomorphic feature (shoal, sharp bend), etc. or ii) stopped by the lodging or bridging of ice floes across the river channel (similar to freeze-up situation in Photograph 2). If possible make a discharge measurement downstream of the toe where no backwater effects are apparent.

d) Conditions at head of ice jam: If the head of the ice jam is visible, estimate the size (dimensions of floes) and concentration (percentage of river surface covered) of incoming ice. Also note whether the ice is adding to an upstream

extension of the jam or is being entrained underneath the jam. If possible make a discharge measurement upstream of the ice jam (see notes under post break-up).

e) Surface conditions: Note the roughness and texture of the ice jam surface. Estimate the distance from shore of any shear lines which have formed from differential movement within the ice jam. Attempt to identify whether the jam is comprised of a single layer of floes or if there has been noticeable compaction and thickening of the jam. Note also if the surface is 'buckled' or has localized ice mounds. This may indicate that ice is grounded on the river bed. Record the presence of any major ice shoves (Photograph 9).

7) Post break-up (Fig. 4)

a) Stage and discharge: Continue regular monitoring of water levels until the majority of floating ice has completely cleared from the study reach. Discharge measurements during the active break-up period are normally not available for hydrometric sites in Canada, largely because of the lack of safe access and the relatively short duration of the break-up period. Where access is available, such as from a bridge spanning the river reach, discharge should be measured as soon as the river becomes sufficiently clear of floating ice to allow the lowering of current meters. Details should be provided regarding the stability of the flow at the time of the measurement and the relative location of any ice accumulations in the river both upstream and downstream of the measurement site. Observations of stage and discharge should continue until backwater effects due to ice disappear.

b) Ice thickness: Measure the thickness of ice floes which have been stranded along the shore. Where possible use ice floes which show a complete stratigraphy and disregard those which have been sheared in cross-section or badly deformed by ice jam forces. Provide a brief description of the quality or structural integrity of the ice floes, such as whether the ice is heavily canded or remains relatively competent.

c) Shear wall dimensions: Following the clearance of an ice jam, there often remain large masses of strongly deformed ice which have been 'plastered' along the shore. The outer edge of these masses is normally marked by a very precipitous edge termed the shear wall (Photograph 10). Once the water level has receded, to the point where the base of the shear walls becomes exposed, measure or estimate the overall height of the wall and its distance from the channel bank. This gives a good indication of ice jam thickness, a parameter of crucial importance in ice jam research.

SUMMARY

This set of data collection guidelines was developed in response to an expressed need for a coherent and extensive data base concerning river ice processes. The existing data base is unsatisfactory because of the brevity of most site records, the lack of uniformity in the types of collected data, and the scarcity of detailed information for many parts of the country. The structured format of these data collection guidelines will hopefully lead to the assembly of a uniform data base beneficial for operational as well as research purposes.

The observations have been selected based on the needs of current and future river ice research, while also considering the difficulties and practicalities of field monitoring programmes. In general, the observations can be made by a single individual who has only limited access to a river. This criterion ensures widespread usability of the guidelines.

The next step in developing a comprehensive data base will be the design of a further set of 'reconnaissance level' guidelines which can be used by agencies and researchers for more intensive studies of a smaller number of sites. At this level, entire river reaches will be monitored and much more elaborate observations will be possible with additional personnel and equipment. The more sophisticated set of observations will serve to augment, rather than replace, those outlined in this report.

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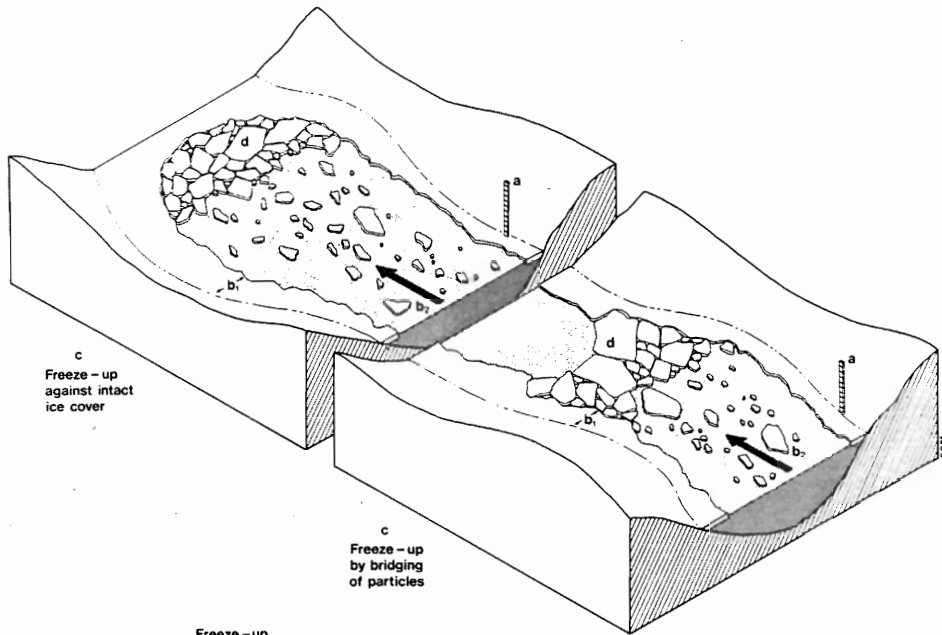
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Freeze-up

- (a) Stage and discharge
- (b.) Border ice: type and extent from shore
- (b.) Floating ice: dimensions, distribution and concentration
- (c) Method of freeze-up: against an intact ice cover or by bridging of particles
- (d) Nature of freeze-up cover: roughness and form

Figure 1 : Freeze-up Observations

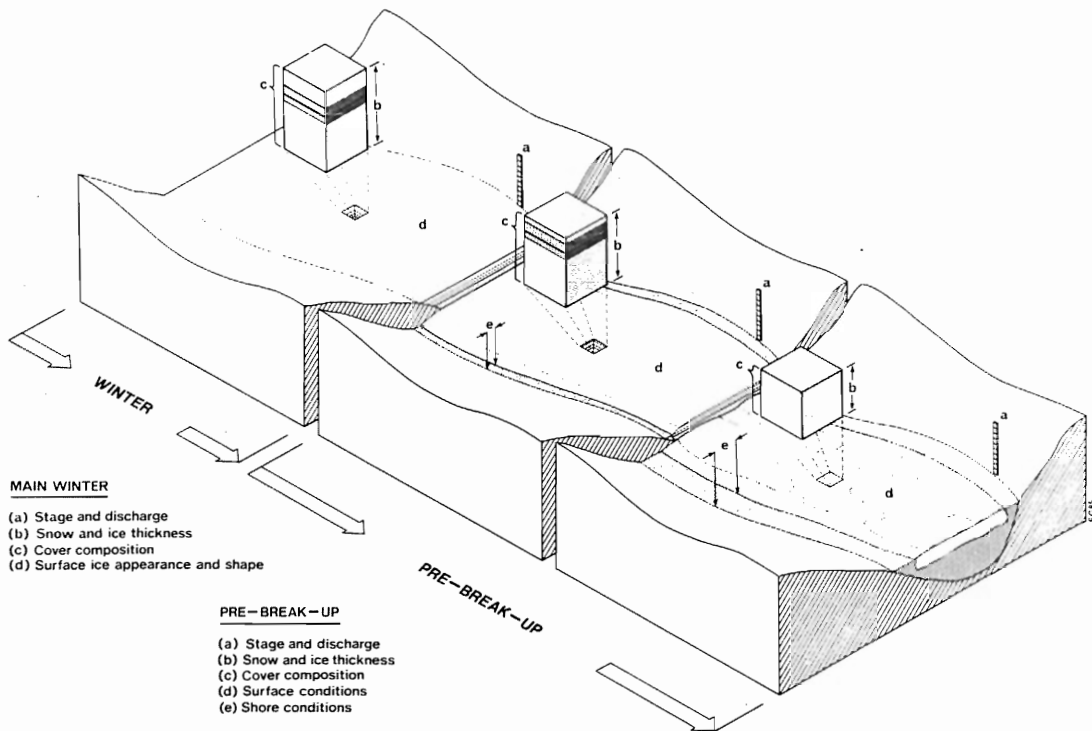
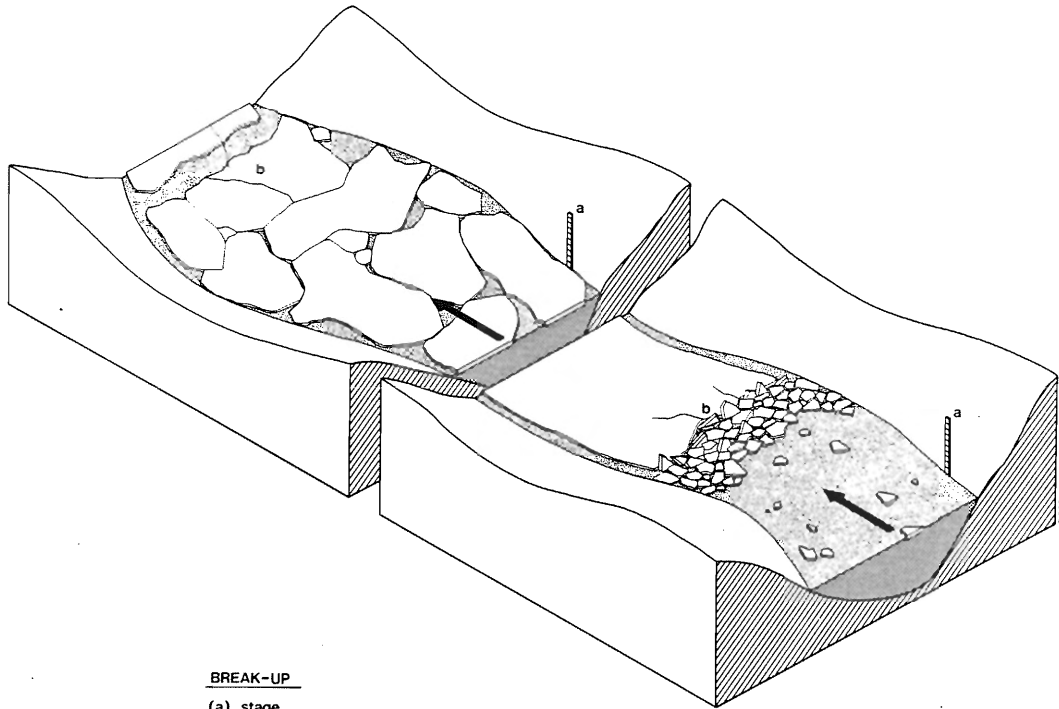


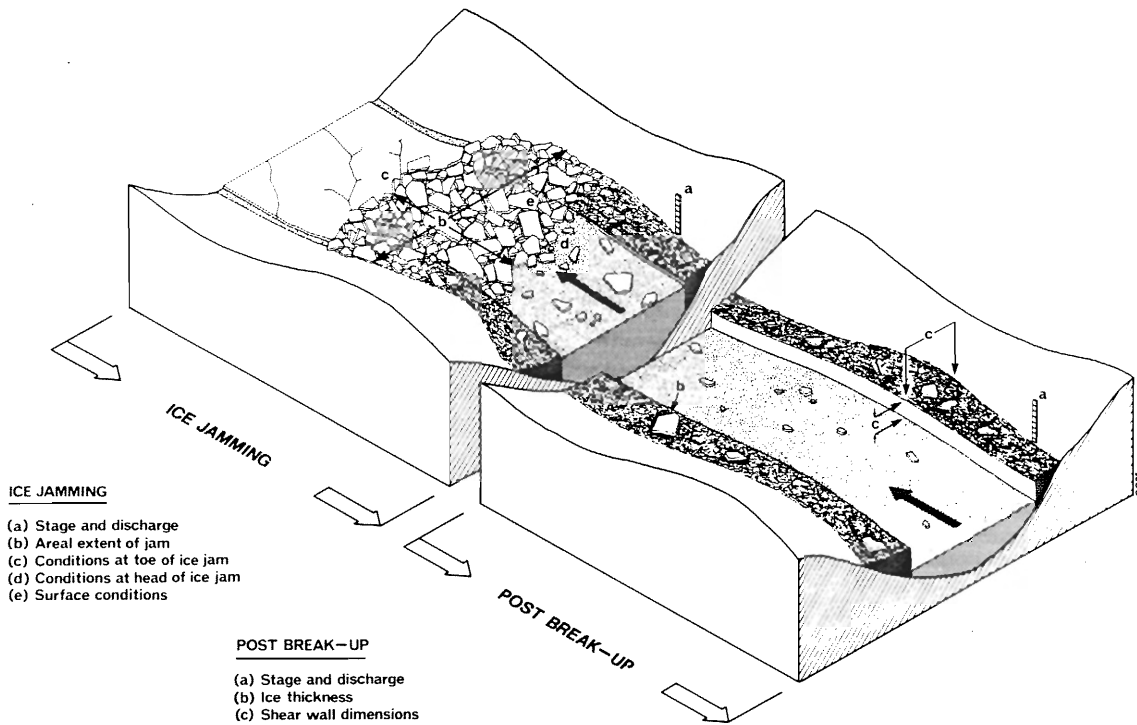
Figure 2 : Main Winter and Pre-break-up Observations



BREAK-UP

- (a) stage
- (b) break-up front ; large scale fracturing or rapid transition in floe size, speed of front

Figure 3 : Break-up Observations



ICE JAMMING

- (a) Stage and discharge
- (b) Areal extent of jam
- (c) Conditions at toe of ice jam
- (d) Conditions at head of ice jam
- (e) Surface conditions

POST BREAK-UP

- (a) Stage and discharge
- (b) Ice thickness
- (c) Shear wall dimensions

Figure 4 : Ice Jam and Post Break-up Observations

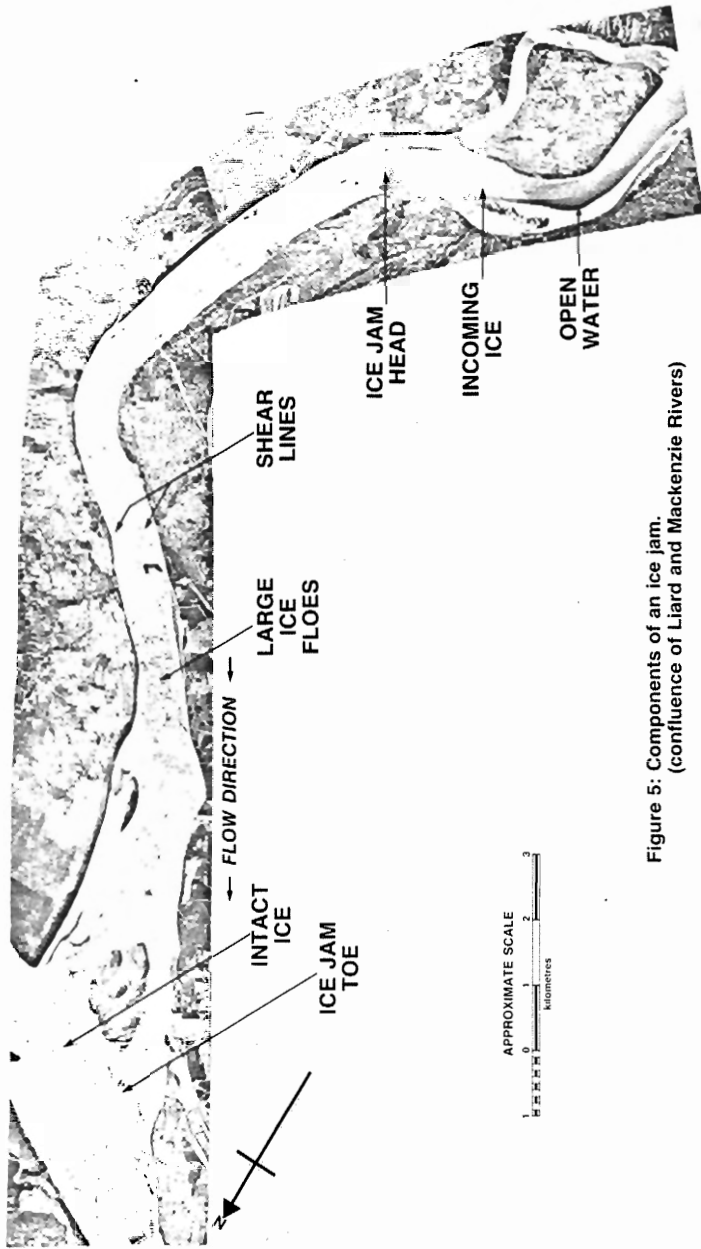


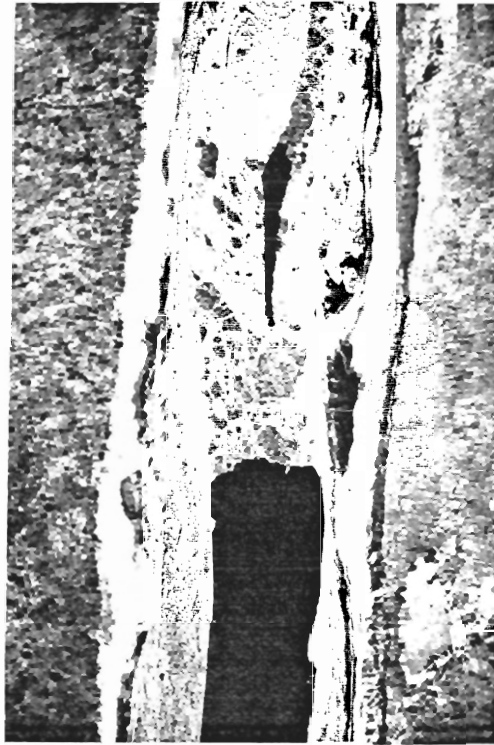
Figure 5: Components of an ice jam.
(confluence of Liard and Mackenzie Rivers)



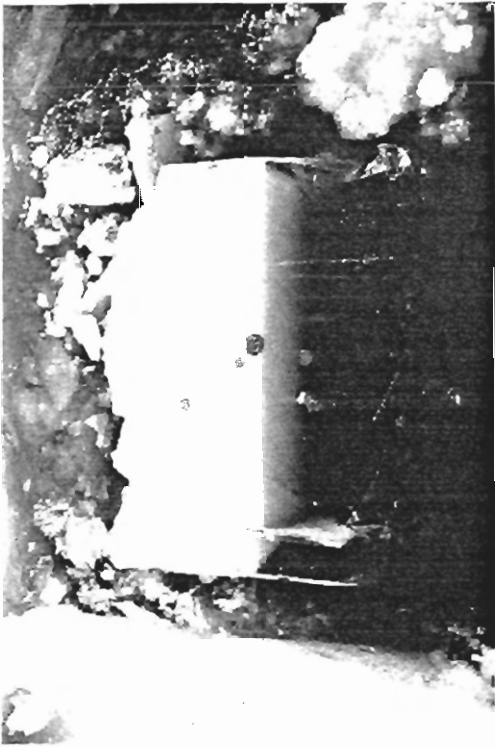
Photograph 1. Growth of border ice along the bank with frazil pans flowing in open channel. North Saskatchewan River. Photo: D. Andres, Alberta Council.



Photograph 2. Large ice pans pinching main channel which has a heavy discharge of slush. Liard River. Photo: F. Parkinson, Lasalle Hydraulic Laboratory Ltd.



Photograph 3. Floe arrangement in freeze-up ice cover. Note extent of border ice and range of floes in accumulation. North Saskatchewan River. Photo: D. Andres, Alberta Research Council.



Photograph 4. Block of ice showing upper layers of white ice overlying transparent black ice. Bottom of white ice can be seen through top layer of black ice.



Photograph 5. Accumulation of frazil deposits beneath main ice cover. Note high bubble content in black ice (centre) in comparison to that in previous photograph.



Photograph 6. Break-up front showing a rapid transition from intact ice to heavily fractured ice. Front was advancing in excess of 5 m s^{-1} , Liard River.



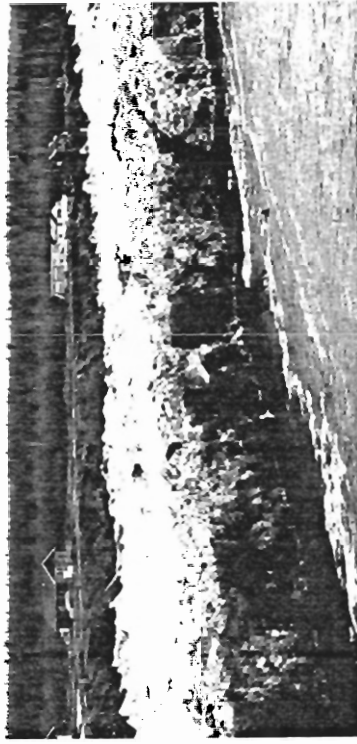
Photograph 7. Break-up front characterized by large scale fracturing of the intact ice sheet and downstream movement of large ice floes. Liard River.



Photograph 8. Break-up occurring from in situ thermal decay of the ice cover. A situation similar to that which occurs on lakes. Liard River.



Photograph 9. Ice shove into trees along river banks at break-up. Upper point of ice is 10 m above the main break-up level. Mackenzie River.



Photograph 10. Shear walls remaining after release of ice jam. Walls are approximately 8 m high and give good indication of ice jam thickness. Liard River.