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BREAK-UP AND FREEZE-UP DATES: A CASE STUDY OF INCONSISTENCIES IN CLIMATOLOGICAL DATA

by

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CHAPTER I

Introduction

1.1 Importance of Break-up and Freeze-up Dates

The advent and disappearance of an ice cover is a dramatic harbinger of winter and spring, so popular interest is understandable. The actual recording of the times of occurrence of these natural phenomena is of tremendous importance for climatological, hydrological, ecological, recreational and economic purposes.

The examination of climatic fluctuations and trends in certain areas is hindered by a lack of long-term instrumental records. In areas where formal meteorological data are limited, recorded observations of natural events can be a valuable source of information about past climate (MacKay and Mackay).[1] For instance, ice formation and ice disintegration on rivers and lakes reflect the integrated effects of climatic elements. Thus dates of freeze-up and break-up can sometimes be taken as fairly reliable indicators of variations in climate.

For instance, Arakawa[2] was able to deduce secular climatic changes from over five centuries of freezing dates for Lake Suwa in

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1. MacKay D. K. and J. Ross Mackay, "Historical Records of Freeze-up and Break-up on the Churchill and Hayes Rivers," Geographical Bulletin, Vol. 7, No. 1, 1965, p. 7.

2. Arakawa, H., "Fujiwhara on Five Centuries of Freezing Dates of Lake Suwa in the Central Japan," Archiv fur Meteorologie, Geophysik und Bioklimatologie, Serie B, Vol. 6, 1954, pp. 152-166.

Japan. Similarly MacKay and Mackay[3] were somehow able to estimate air temperatures for semi-monthly periods in areas where previous instrumental temperature data were lacking.

When a water body freezes up in the fall, a significant portion of its discharge is temporarily locked up. On the other hand, when the ice cover breaks up, the melt water that is suddenly released supplies an enormous volume of discharge at a tremendous rate. This type of situation is extremely important to hydro-electric power planning, reservoir regulation, flood control, and protection to bridges, dams and other structures.

Biotic life is also affected by the freeze-up and break-up processes. One of the most severe biological effects is the winter kill of fish. The problem water bodies are those in which the fish die in years of unusually cold and snowy springs (Bunge and Bryson).[4] The reason the ice cover is deadly is that the snow on the ice prevents photosynthesis so that oxygen is consumed and not replaced.

Recreational activities are also either hindered or fostered by the freezing and clearing of water bodies. The establishment of an ice cover encourages such activities as ice fishing, ice boating, skating and snowmobiling. On the other hand some sports such as canoeing, water skiing, swimming and open water fishing are curtailed.

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3. MacKay D. K. and J. Ross Mackay, p. 16.

4. Bunge, William W. Jr. and Reid A. Bryson, "Ice on Wisconsin Lakes, Part 3, No. 14 Report to the University of Wisconsin Lake Investigations Committee," University of Wisconsin, Madison, 1956, Ch. 5, p. 2.

The greatest effect of break-up and freeze-up phenomena however is on water transportation. With the ever increasing importance of Arctic ports, in Canada and the Soviet Union expecially, added interest is to be expected. The river or lake water turns from a relatively warm fluid to a cold, flat plane. Water transport by ship and similar vessels is temporarily halted. Also, some aircrafts have to change from float equipped to ski-equipped landing apparatus. The crucial period however is the time intervening the initial and final stages of each process. During these transitional periods, that last for approximately six weeks, neither ski-nor float-equipped aircraft can operate (Brown).[5] Communication by these which are sometimes the only means in small isolated communities is therefore briefly terminated.

One can also mention the fact that the floating of logs for the lumber industry is also affected by break-up and freeze-up conditions.

It transpires from the above that the precise timing of the occurrence of freeze-up and break-up events is of utmost importance. Apart from being a significant form of climatological data, these records are of basic importance to numerous forms of applied research. Methods that can predict the times of occurence of break-up and freeze-up events can be empirically deduced using previous records. These in turn can be of invaluable assistance in the planning and management of the various hydrological, economic, recreational and other activities.

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5. Brown, R. J. E., "Observations of Break-up in the Mackenzie River and its Delta in 1954," Journal of Glaciology, Vol. 3, No. 21, 1957, p. 133.

1.2 Reasons for Undertaking Research

Break-up and freeze-up dates form an integral part of climatological data. Very often however, some forms of data, as is the case here, contain an element of inconsistency.

It is the belief of the author that the records of break-up and freeze-up dates as kept by the Canadian Meteorological Service (CL1-1-71),[6] and as found in some of the written literature, are to a degree irregular and inconsistent. This arises from a number of factors that include the nature of the processes (Ch. 11), observational problems (Ch. 111) and the lack of standardized definitions for each process (Ch. 1V).

A tremendous amount of applied research within a variety of disciplines, some of which have been listed earlier is likely to be based on these dates. In fact several empirical studies (e.g. Rodhe,[7] and Jacobs,[8] Mackay,[9] and Williams,[10]) have already been attempted. These were done with an aim of predicting the time of break-up or

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6. Allen, W. T. R., and B. S. V. Cudbird, "Freeze-up and Break-up Dates of Water Bodies in Canada," Canadian Meteorological Service, CL1-1-71, Toronto, 1971, 144 pp.

7. Rodhe, Bertil, "On the Relation Between Air Temperature and Ice Formation in the Baltic," Geografiska Annaler, Vol. 34, 1952, pp. 175-202.

8. Jacobs, W. C., in Lee, Owen S., and Lloyd S. Simpson, "A Practical Method of Predicting Sea Ice Formation and Growth," Technical Report, No. 4, U. S. Army Hydrographic Office, Washington, D. C., Sept. 1954, pp. 5-6.

9. Mackay, J. Ross, "Freeze-up and Break-up Prediction of the MacKenzie River, N.W.T., Canada," Unpublished Paper, 1960, pp. 25-66.

10. Williams, G. P., "Freeze-up and Break-up of Fresh Water Lakes, N.R.C., Div. of Bldg. Research, Tech. Paper, No. 286, pp. 203-215.

freeze-up events using previously recorded dates. Furthermore these data can be used to give a better understanding of the nature of the processes. Obviously the success of these studies will depend to a large extent on the accuracy and meaningfulness of these dates.

One can therefore understand the concern for accurately recorded dates of freeze-up and break-up. Statistical and analytical scrutiny (Ch. lV and Ch. V) of selected sets of records for break-up and freeze-up do however reveal a significant amount of incoherence. Is is the opinion of the author that a substantial amount of this irregularity is due to measurement problems and the neglect of standardized observational procedures.

1.3 Literature Review and Previous Work

Naturally enough, world interest in river and lake ice has centered in areas where cold long winters are prevalent. Sweden, Finland, Germany and Switzerland produced most of the initial research in the mid 1800's (Bunge and Bryson).[11] Japanese records go back to the fifteenth century (Fujiwhara).[12] In the United States lake ice observations began to fill the diaries and journals of the New Englanders in the early part of the nineteenth century (Bunge and Bryson).[13] The

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11. Bunge, William W. Jr., and Reid A. Bryson, "Ice on Wisconsin Lakes Pt. 1," No. 13, Report to the University of Wisconsin Lake Investigations Committee, U. of Wisconsin, Madison, Ch. 1.

12. Fujiwhara, S., "Notes on the Climatic Variations Concluded from the Dates of First Complete Freezing of Lake Suwa in Japan, Geografiska Annaler, Vol. 3, 1921, pp. 358-61.

13. Bunge, William W. Jr., and Reid A. Bryson, "Ice on Wisconsin Lakes Pt. 1," Ch. 1.

biggest growth of interest however has occurred in Russia. There, since the 1930's a tremendous amount of research has been done not only on river and lake ice but on other winter ground covers as well.

In Canada, freeze-up and break-up observations began as early as the eighteenth century. These were mainly recorded in the journals of the Hudson's Bay Company (MacKay and Mackay).[14] Government officers, missionaries, the Royal Canadian Mounted Police, traders and private individuals have also contributed to these records (Mackay).[15]

The bulk of the literature on break-up and freeze-up phenomena can be classified under three major headings, namely the nature of the physical processes, the derivation of prediction equations using previously recorded data, and studies of climatic change based on these dates.

Those studies relating to the nature of the processes are adequately dealt with elsewhere (Ch. 11). With regards to the formulation of prediction equations, a sampling of such studies are treated here.

Most of these have focused attention on freeze-up conditions. Rodhe[16] developed a relationship between weighted air tempertures and the rate of cooling in the Baltic. Bilello[17] adopted this technique to

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14. MacKay D.K. and J. Ross Mackay, 1965, pp. 7-16.

15. Mackay J. Ross, "The Mackenzie Delta, N. W. T.," Geogr. Br., Dept. of Mines and Tech. Surveys, Mem. 8.

16. Rodhe, Bertil, ibid.

17. Bilello, Michael A., "Method for Predicting River and Lake Ice Formation, Journal of Applied Meteorology, Vol. 3, 1964, pp. 38-44.

compute the date of ice formation at several locations in the Arctic. Similarly Jacobs[18] gave a method for computing heat losses during the fall. Spence[19] used multiple correlation and regression analysis to examine the relationship between a number of hydrologic variables and the time of freeze-up. Finally, MacKay and Mackay[20] derived a regression equation from which to deduce temperature conditions, using break-up and freeze-up dates.

Fewer studies of this nature have been done for the break-up process. Stankiewicz (1947)[21] used a degree-day technique (using 32^{o} as a reference temperature) for estimating from air temperature records, the date when a river would be open for driving logs. Another approach, suggested by Bendennikov[22] emphasized the hydrodynamic aspects of break-up. He derived a formula that took into account the dynamic interaction between water flow and the ice cover during the initial melt period (Ch. 2.3). Finally Williams[23] (1965) developed a simplified ice melting formula which combined a solar radiation term with a degree-day term. This formula also applied to the initial melting period and was designed

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18. Jacobs, W. E., ibid.

19. Spence, E. S., "Water Cooling and Ice Thickening on Dingman Creek, near London, Ontario," Ontario Geography, No. 2, 1968, pp. 49-66.

20. MacKay, D. K., and J. Ross Mackay, pp. 14-15.

21. Stankiewicz, M. J., "Break-up can be Forecasted," Pulp and Paper Magazine, Canada, Vol. 48, 1947, pp. 118-120.

22. Bendennikov, V.P., "Dynamic Conditions of Formation of Ice Jams on Rivers," Soviet Hydrology: Selected Papers, No. 1, 1964, pp. 101-108.

23. Williams, G. P., p. 210.

for lakes not fed by rivers.

There are a multitude of studies that use break-up and freeze-up dates to infer climatic change or deduce regional variations of climate. The more important ones are discussed here.

Eriksson,[24] using break-up and freeze-up data of Swedish lakes, was able to show regional variations of climate. In addition, he concluded that climatic periodicities of 2, 4-5, 8, 11 and 25 years were evident.

Mackay (1961)[25] found significant long-term variations in freeze-up and break-up dates for the lower Mackenzie River Basin. MacKay (1962)[26] did a similar type of study for the Nelson River Basin.

Arakawa[27] was able to deduce secular climatic changes from over five centuries of freezing dates and "omiwatari" (compression ridges) for Lake Suwa in Japan. Similarly Fujiwhara[28] used this data to relate freeze-up dates to the tertiary variation of solar harmonic activity.

Very little however has been done by way of examining the

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24. Eriksson, J. V., "Ice Cover and Break-up in Sweden's Inland Lakes," in <u>SIPRE Report 12</u>, Vol. 11, Annotated Bibliography on Snow, Ice and Permafrost, U. S. Army, Corps of Engineers, p. 228.

25. Mackay, J. Ross, "Freeze-up and Break-up of the Lower Mackenzie River, Northwest Territories," <u>Geology of the Arctic</u>, Vol. 11, ed. G. O. Raasch, U. of Toronto Press, 1961, pp. 1119-1134.

26. MacKay, D. K., "Trends and Factors Affecting Break-up and Freeze-up Dates in the Nelson River Drainage System," <u>Geographical Paper No. 35</u>, Dept. of Mines and Tech. Surveys, 23 pp.

27. Arakawa, H., ibid.

28. Fujiwhara, S., ibid.

validity of these dates. In fact this is the major concern of this study. Only a few attempts have been made to inquire into the problems of obtaining and recording reliable dates.

These attempts however have focussed mainly upon the data extracted from Canadian historical records. This study is directed mainly towards the more recent records as compiled by the Canadian Meteorological Service (CL1-1-71).

In a study of the historical records of freeze-up and break-up, MacKay and Mackay (1965)[29] commented that:

> Dates of freeze-up and break-up extracted from the Fort Churchill and York Factory journals present some difficulties in interpretation. The recording of ice observations is subjective, especially so no doubt, at the Hudson's Bay Company posts, where the criteria for ice conditions were not defined and the observers were frequently changed. Ice conditions were nevertheless important enough to be normally recorded with care. Another complicating factor is the use of place names that do not appear on the present maps. Most of these were located with the help of the research staff at Hudson's Bay House, Winnipeg. A further problem encountered while the records were being scanned, is that in some years only intermediary stages of freeze-up and break-up were reported.

Despite these inconsistencies, they were able to reconcile these differing ice-condition dates and perform a series of statistical analyses using them. Spatial and temporal comparabilities of break-up and freeze-up were deduced for the two stations.

Mackay (1961)[30] did a similar type of study relating to the Lower Mackenzie River. With reference to the break-up and freeze-up records used, he commented that:

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29. MacKay, D. K., and J. Ross Mackay, p. 9.

30. Mackay, Ross J., 1961, p. 1120.

The reliability of these dates varies considerably from place to place and year to year, depending on the criteria used to define freeze-up and break-up, the interest of the observer, transcription errors, and so forth. At some settlements the dates recorded by two or more observers have differed by as much as two weeks for both freeze-up and break-up.

However, statistical analyses of the dates show that the records kept by a single organization (eg. a mission) or an individual tend to be internally consistent, because of adherence to specified definitions for freeze-up and break-up, even though the definitions do not conform to standards applied elsewhere.

Also, MacKay (1962)[31] working with freeze-up and break-up data collected within the Nelson River drainage basin noted that the records varied considerably in length, covered different periods, and lacked uniformity to definitions.

Bilello (1961)[32] in a study of "freeze-up" (the date when ice first forms), and "freeze-over" (the date on which the water body becomes completely covered with ice), in the Arctic, noted that the observers at the stations concerned, often found it difficult to determine the correct dates of ice formation to fit these terms. It was observed that sudden squalls and small tidal currents in small bodies of water affected "freeze-over" considerably.

In a later study (1964)[33] Bilello admitted that inconsistent and/or inaccurate observations on ice formation lead to poor results in establishing N, a numerical constant for predicting the date of ice

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31. MacKay, D. K., "River-ice Conditions in the Nelson River Drainage System," Geographical Paper No. 34, Geogr. Br., Dept. of Mines and Tech. Surveys, Ottawa, 1962, 28 pp.

32. Bilello, Michael A., "Formation, Growth, and Decay of Sea-ice in the Canadian Arctic Archipelago," Arctic, Vol. 14, No. 1, 1961, p. 4.

33. ______________________, 1964, p. 43.

formation from air temperatures. This discrepancy was attributed to a lack of a firm understanding of the terms "freeze-up" and freeze-over" on the part of the observers.

Burbidge and Lauder,[34] in a preliminary investigation of break-up and freeze-up conditions, made the following comment on the data encountered:

> Of the records on file, only a very small percentage can be considered to be highly reliable, with the information covering periods of 10 to 40 years. The great majority of the data was rated fair, where 3 to 9 years of records were available. Approximately 10% of the data was rated as poor, because the coverage might be only for a single year, or the data could not be checked.

One would get the impression that their criteria for validity was based on the length of the records.

Similar comments were made by Williams (1971)[35] regarding break-up dates. In an attempt to predict the date of lake ice break-up from previous records, he admitted that observational error would affect the reliability of the regression equations formulated.

Catchpole[36] et al, in a study dealing with a method for the identification of dates of first freezing and first breaking from historical accounts commented that:

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34. Burbidge, F. E., and J. R. Lauder, "A Preliminary Investigation into Break-up and Freeze-up Conditions in Canada," Meteorological Branch, Dept. of Transport, Canada, Cir. - 2939, Tec.-252, July 1957, p. 2.

35. Williams, G. P., "Predicting the Date of Lake Ice Break-up," Water Resources Research, Vol. 7, No. 2, 1971, p. 330.

36. Catchpole, A. J. W., D. W. Moodie, and B. Kaye, "Content Analysis: A Method for the Identification of Dates of First Freezing and First Breaking from Descriptive Accounts," Reprinted from The Professional Geographer, Vol. XX11, No. 5, Sept. 1970, pp. 252-257.

> It was inevitable that individual diarists drawn from a miscellany of cultural and environmental backgrounds, observing similar events from widely separated vantages in time and space, would inject diverse forms of literary expression into their journals.

Obviously they were referring to the problem of differences in definitional criteria.

They further maintained that it was natural to have built-in inaccuracies within the actual data of this type. This was mainly attributable to the complex spatial and temporal variations in the incidence of freezing and breaking.

It transpires from the above, that a significant amount of observer variance that can arise from a number of causes are incorporated into the recorded dates of freeze-up and break-up. An examination of the validity of these dates, especially in terms of homogeneity, is therefore understandable.

1.4 Definition of Problem

Break-up and freeze-up events are naturally occuring physical phenomena. For each specific stage of either process, there is a natural date. An observer perceptually recording this date however very often gives an alternative date. Furthermore different observers can be expected to give varying dates for a specific event at a single site (Mackay).[37] Likewise variance among observers at different stations is to be expected.

Problems of numerical observation of this nature however char-

37. Mackay, Ross J., 1961, p. 1120.

acterize the environmental sciences (Catchpole et al).[38] In this particular instance, these are usually negotiated through prescribed observational procedures (Form No. 63-2360[39] and No. 63-2361[40]) designated to standardize errors that cannot be avoided.

Measurement through visual perception however is rather subjective. Different observers at either the same site or at different stations are therefore likely to record idiosyncratic dates. This problem becomes further complicated when the different observers record their comments in varying definitional terms.

It follows from the above that two sources of error are incorporated into the dates of break-up and freeze-up. One relates to the difference between the recorded date and the natural date. This can be conveniently referred to as random measurement error. The other is associated with the differences among observers at a particular site, or at differently located stations, and the varying definitional criteria. These can be collectively put under the general heading of systematic observational error. It is the belief of the author that the magnitude of the latter type of error is significantly large, thereby giving rise to inconsistent dates of freeze-up and break-up.

1.5 Aims of Research

It is the intention of this study to indicate the nature and

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38. Catchpole et al, 1970, p. 255.

39. "Report on the Break-up of Water Bodies," Meteorological Branch, Dept. of Transport, Canada.

40. "Report on the Freeze-up of Water Bodies," ibid.

character of the inconsistencies inherent in the dates of break-up and freeze-up. This will be effected mainly through a systematic scrutiny of the Canadian Meteorological Records (CL1-1-71) and the written literature. The sources and character of these irregularities are to be related to the nature of the physical processes, variations of definitional criteria and observational problems. Evidence of inhomogeneity are to be expressed in statistical terms (Ch. V).

One would expect that stations that are adjacently located and that experience very similar environmental conditions, ought to yield uniformly associated data. Break-up and freeze-up conditions are affected by two major factors, namely climatological and hydrological (Ch. 11). These physical conditions however have a tendency to apply homogeneously over extended geographical areas. As a result one would expect that the dates of specified break-up or freeze-up events, at neighbouring stations within appropriately defined regions ought to concur both in sense and magnitude (Murray Mitchell).[41]

As has been stated previously it is the belief of the author that there are inconsistencies in dates of break-up and freeze-up, as recorded by the Canadian Meteorological Service (C11-1-71). In order to test for these, selected stations within specified station networks are statistically compared. The lack of comparability between pairs of stations is interpreted as evidence of inhomogeneity.

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41. Mitchell, J. Murray, "Observed Secular Temperature Trends," Journal of Meteorology, Vol. 10, August 1953, pp. 244-61.

1.6 Methodology

The content of this research will lead through several phases, all of which are designed to furnish evidence of inhomogeneity within the records of break-up and freeze-up. Emphasis however is placed upon the modern records as kept by the Canadian Meteorological Service (CL1-1-71).

The physical processes are examined with the intent of demonstrating how their variable nature is a major cause of the inconsistencies encountered (Ch. 11). Because of the exceedingly complex nature of these processes, a multitude of freeze-up and break-up characteristics are evident. This not only complicates the observation of the processes, but also contributes to a variety of definitional criteria for each process (Ch. 1V).

Observational and recording problems are then examined. The measurement of break-up and freeze-up dates is done through perceptual observation. Although standardized procedures are adopted, in certain cases, it is extremely difficult to eliminate observer subjectivity with this type of data collection (Ch. 111). Very often too, these procedures are not strictly adhered to. In a large number of cases alternative conditions to the ones specified are recorded (Ch. 1V).

Finally, in order to furnish concrete evidence of this form of error, numerical analyses are performed on data selected from the Canadian Meteorological records (CL1-1-71). Coded dates of break-up and freeze-up within specified regional networks are statistically analysed (Ch. V). These are tested for the homogeneity that is to be expected if the dates are uniformly recorded. The results, as expected, do provide evidence of a significant amount of inconsistency.

CHAPTER II

The Nature of the Processes

2.1 Introductory Statements

Water bodies in areas that experience winter and summer regimes have a tendency to freeze-up in the fall and break-up in the spring. Water has certain basic and unique properties that allows its surface to freeze into solid ice when its temperature is cooled to $0^{o}c$ and lower. Because of its ability to increase in volume and decrease in density upon freezing, a buoyant ice cover usually evolves at the water surface (Shipman).[1] Its further growth during the winter is determined by the rate and amount of energy exchange with the atmosphere above and the water beneath. With rising air temperatures in the spring melting is initiated. This, together with the wind and the force of the melt water released, finally leads to the destruction of the ice cover.

In the sections that follow, each of the processes of freeze-up and break-up are considered in detail. Descriptive considerations outline the nature and character of each process. Then, a typology of freeze-up and break-up events, which further illustrates the nature of the processes is attempted. Finally a listing of the physical and environmental factors that control both processes is given.

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1. Shipman, T. G., "Ice - conditions on the Mississippi River at Davenport, Iowa," Trans. Amer. Geophys. Union, Vol. 19, 1938, pp. 590-594.

2.2 The Freeze-up Process

The process of freeze-up extends over a period of days or weeks, commencing when ice crystals first appear on the water surface, and terminating when a permanent and stable ice cover is formed over the water body (Burbidge and Lauder)[2]. Although there is a continuum of physical activity from the initial to the final stage of the process, certain distinct components are discernible.

The following can be considered as separate phases:

1. Cooling to the freezing point (0^{o}c),
2. Initial ice formation,
3. Establishment of an ice cover.

The first phase can be attributed mainly to falling air temperatures during the fall. At the air-water interface, there is a exchange of energy between the water surface and the atmosphere, amd the water beneath. During the fall, when air temperatures have already dropped below the freezing point, the direction of energy transfer is towards the atmosphere. The duration of this process which depends on the intensity of heat loss from the water body usually extends over a considerable time period. Because of the thermal capacity of water, freeze-up results from a protracted period of freezing air temperatures (Arakawa)[3]. Some locations normally have about two months with mean

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2. Burbidge, F. E., and Lauder, J. R., "A Preliminary Investigation into Break-up and Freeze-up Conditions in Canada," Met. Branch Department of Transport, cir - 2939, Tec. - 252, 2 July 1957, p. 8.

3. Arakawa, H., "Fujiwhara on Five Centuries of Freezing Dates of Lake Suwa in Central Japan," Archiv fur Meteorologie, Geophysik, und Bioklimatologie, Sierie B, Vol. 6, 1954, p. 153.

temperatures below $0^{o}c$ before freezing occurs (Mackay)[4].

Williams[5] subdivides this cooling period into two parts:

(i) Gradual cooling until the entire water body is at a temperature of $4^{o}C$.

(ii) Cooling of the surface water from the time the water is isothermal at $4^{o}C$ until sheet ice forms.

During the first period cooling produces instability which aids stirring (Dutton and Bryson)[6]. This is due to the fact that water is densest at $4^{o}C$. As a result, the cooling of the surface layer beyond $4^{o}C$ is delayed by overturning, which constantly brings warmer less dense water to the surface. During the second period cooling produces a weak stability which hinders overturning and hastens the cooling of the surface layer to the freezing point.

Initial ice formation actually commences when the temperature of the water body drops to 0^{o} C and lower. The degree and extent of supercooling required to form ice crystals is largely dependent upon the extent of nucleation, the turbidity of the water, and the intensity of heat loss from the water surface. The value of supercooling has

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4. Mackay, J. Ross, "Freeze-up and break-up of the Lower Mackenzie River, Northwest Territories," G.O.Raasch, Ed., Geology of the Arctic, Vol. 11, pp. 1119-1134.

5. Williams, G. P., "Freeze-up and Break-up of Fresh Water Lakes," N.R.C., Div. of Bldg. Research, Tech. Paper, No. 286, 1968, pp. 203-215.

6. Dutton, John A., and Bryson, Reid A., "Heat Flux in Lake Mendota," Limnology and Oceanography, Vol. 7, 1962-63, pp. 80-97.

been found to vary between $-0.01^{o}c$ (Schaefer)[7] and $-1.2^{o}c$ (Rymsha and Donchenko)[8]. As will be seen later, the extent of supercooling actually determines the type of ice crystals formed.

Basically however there are two types of ice initiation, namely static and dynamic. Static ice formation is characteristic of undisturbed water surfaces, such as brooks and rivers with slow current velocities, and lakes in calm weather. Laminar flow is typical, with an absence of intermixing. The intensity of heat loss is great, in that energy exchange between the water and the colder air is restricted to a thin surface layer. Conditions for supercooling are ideal, and a regime of rapid freezing is common (Rymsha and Donchenko).[9]

The ice crystals formed under these conditions are mainly of the needle-shaped type. Crystals which are formed in water supercooled more than $0.9^{o}c$ are needles and stars (Arakawa)[10]. The further growth of crystals is determined by the balance of heat lost to the atmosphere, and heat supplied by the latent heat of fusion, upon crystallization. The formation of a gram of ice requires the release of approximately 80 cal/g of heat (Dutton and Bryson)[11]. The heat released

7. Schaefer, V. J., "The Formation of Frazil and Anchor ice in Cold Water," Trans. Amer. Geophys. Union, Vol.31, No.6, Dec. 1950, pp 885-893.

8. Rymsha, V.A. and Donchenko, R.V., "Investigations and Calculations of Freezing of Rivers and Reservoirs," Soviet Hydrology: Selected Papers, No.1, 1965, pp 372-83.

9. Ibid.

10. Arakawa, H., in Michel, B. and Ramseier, R.O., "Classification of River and Lake Ice," Canadan Geotechnical Journal, Vol. 8, No.1, Feb.71, p 42.

11. Dutton, John A., and Bryson, Reid A., p81.

by the formation of ice must be absorbed either by the ice crystals or by the surrounding water, one of which must be slightly supercooled in order to absorb the heat without terminating the freezing process (Devik).[12]

When ice crystal growth is continuous, the accretion of these forms into a thin film of ice, commonly known as skim ice. This type of ice cover is very unstable. A light wind or a slight warming can lead to its disappearance. During the early part of the freeze-up period, skim ice usually forms during calm cold nights, and disappears the next morning when the temperature rises above the freezing point.

Dynamic ice formation is associated with turbulent water bodies. This includes rivers with a fast flow velocity and larger lakes where wind induced waves and currents are prevalent. In turbulent water during freezing, two factors are simultaneously acting; an intensive intermixing and exchange of heat through the depth of the stream, and mechanical influences obstructing the freezing together of the ice crystals (Rymsha and Donchenko).[13] The formation of needle-like crystals is hindered by restricted supercooling and mechanical influence. Under these conditions, there occurs the formation of crystals of frazil or anchor ice in the form of rounded lenses of lenticular, lamellar and globular form (Rymsha and Donchenko).[14]

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12. Devik, O., "Ice Formation in Lakes and Rivers", Int. Assoc. of Scientific Hydrol., Vol. II, 1948, pp. 359-366.

13. Rymsha, V.A. and Donchenko, R.V., pp 372-83.

14. Ibid.

In this instance, supercooling occurs not only in the surface layer, but throughout the entire depth of the water body. The degree of supercooling required is rarely more than 0 to -0.01^{o}c (Schaefer).[15] Again, the rate of frazil formation will be moderated by the latent heat of crystallization.

As soon as frazil flocks are formed, they have a tendency to concentrate at the surface of flow to form frazil slush (Michel).[16] Sometimes frazil particles stick and grow on certain materials of favourable crystalline structure, such as stones and weeds in the river or lake bottom, to form anchor ice. During the early part of the freeze-up period, it is also common for frazil ice, and even anchor ice, to form during cold nights and disappear the next morning, with warming.

The formation of an ice cover is a complex process (Gifilian et al).[17] In calm water bodies, skim ice growth is controlled mainly by its energy exchange with the air above and the water beneath. Frazil ice however requires some form of an anchor around which to grow, into an ice sheet. Floating frazil slush is carried downstream or blown about the lake until a natural or artifical ice bridge impedes it (Pariset and Hausser).[18] Formation of an ice cover is then initiated.

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15. Schaefer, Vincent J., p.885.

16. Michel, B., "Properties and Processes of River and Lake Ice", International Symposia on the Role of Snow and Ice in Hydrology; Symposium on Properties and Processes, Session: UNESCO-5, 1972, p.3.

17. Gifilian, R.E., Kline, W.L., Osterkamp, T.E., and Benson, C.S., "Ice Formation in a Small Alaskan Stream", International Symposia on the Role of Snow and Ice in Hydrology: Symposium on Properties and Processes, UNESCO-5, 1972.

18. Pariset, Ernest and Hausser, Rene, "Formation and Evolution of Ice Covers on Rivers," Trans. Eng. Inst. of Canada, Vol. 5, No.1, 1961, p.42.

It's growth extends counter to the water flow as far as velocity permits, through the juxtaposition of ice floes, or the dynamic accumulation of drifting ice.

In spite of the differences in the conditions, types and sites of ice initiation, the process of an ice cover formation in rivers and lakes is attained for the most part by the accumulation of ice crystals at the water surface, and their accretion into a continuous ice sheet. In fact it is common for both types of ice cover initiation to occur over a single water body.

Ice is usually nucleated starting in contact with the colder more conductive material of the banks. This sometimes happens to be areas of calm sheltered water. Shore ice is thus the first to be formed. This then propagates towards the middle. The edge of this ice sheet gradually comes in contact with more turbulent water, and its further progress is delayed. Michel [19] maintains that an ice cover growth depends only on the thermal atmospheric exchange, rather than on the temperature or turbulence of the water. An ice cover may grow at any water velocity, if the temperature of the water is close enough to the freezing point (Michel).[20] Supercooling of the water must therefore overcome the frictional heat produced by turbulence, to initiate freezing.

After a stable ice sheet is established, its further increase in thickness is controlled by the intensity of heat loss at the ice-air boundary. (Michel)[21] refers to the initial ice cover as primary ice.

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19. Michel, B., pp. 1-2

20. Ibid.

21. Ibid.

Its growth continues until equilibrium is attained between the heat flow from the water to the ice, and from the ice to the atmosphere. It must not be forgotten though that a warming trend, or a sudden increase in flow velocity or windiness can temporarily dislodge the ice cover. Several cycles of the freeze-up process, before a permanent ice cover is established, are therefore not uncommon.

The secondary ice which forms beneath the initial ice cover is of a different crystallographic structure, usually columnar (Michel).[22] Superimposed ice that accumulates through snowfall and icing also adds to its thickness. Snowfall however has the adverse effect of reducing heat loss to the atmosphere through its blanketing effect. The freezing of floating frazil to the underside of the ice cover is another growth mechanism.

The formation of an ice cover therefore, regardless of the type of water body, is a complex and prolonged process. Apart from the different rates and conditions of supercooling, unpredictable weather conditions introduce further complications. A warming trend or an increase in windiness can reverse the freezing process. One must also bear in mind that in water bodies with surface flow, formation of ice at any given point is dependent upon both local environmental conditions and the conditions upstream in a river or upwind in a lake (MacKay).[23]

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22. Ibid.

23. MacKay, D.K., "Trends and Factors Affecting Break-up and Freeze-up Dates in the Nelson River Drainage System", Geographical Paper No. 35, Geogr. Br. Dept. of Mines and Technical Surveys, Ottawa, p. 12.

Because of the complex nature of the freezing process, an ice-cover formation takes place under a variety of conditions. Different types of ice phenomena are therefore prevalent. As a result, an array of terminology, both genetic and descriptive, become associated with the different ice types. These terminologies are discussed more fully elsewhere (Chapter 4).

As a means of pictorially illustrating some of the ice conditions mentioned above, a series of photographs describing different stages of the freeze-up process are included hereunder. These were taken during field observations of the freeze-up process for the fall of 1971 along the Red and Assiniboine Rivers, Winnipeg. (See Appendix 1).

2.3 The Break-up Process

The break-up process also extends over a period of days or weeks. It starts with a gradual melting of the ice cover with increasing solar radiation, and terminates when the water is free of ice. The clearing of ice from water bodies at break-up is affected by heat gain from the atmosphere, snow and ice conditions, wind and currents, and inflow of runoff (Williams).[24] Like freeze-up, there are several distinct phases of the break-up process. The author chooses to recognize the following stages:

1) The initial melt period,
2) The disintegration of the ice cover,
3) The clearing of the ice.

During the initial melt period, deterioration of the ice cover is mainly due to the increasing intensity and duration of solar radiation. Under clear skies, it is common to have melting of the snow cover before the average air temperature has exceeded $0^{\circ}c$, through direct solar radiation.

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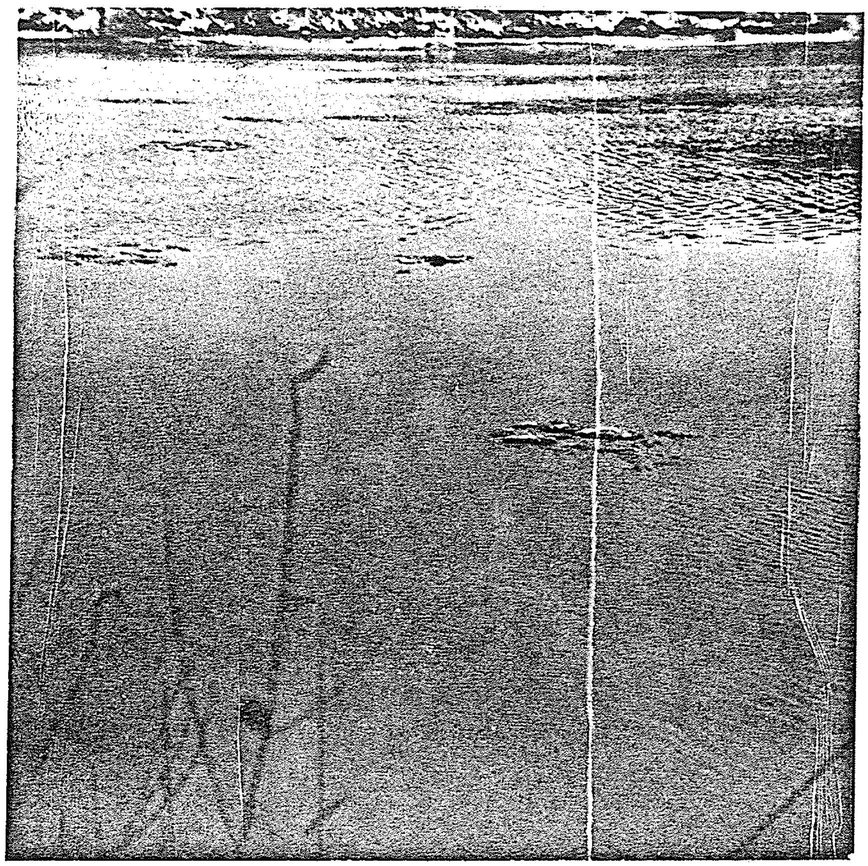
24. Williams, G.P., 1968, p. 208.

Fig. 2.1

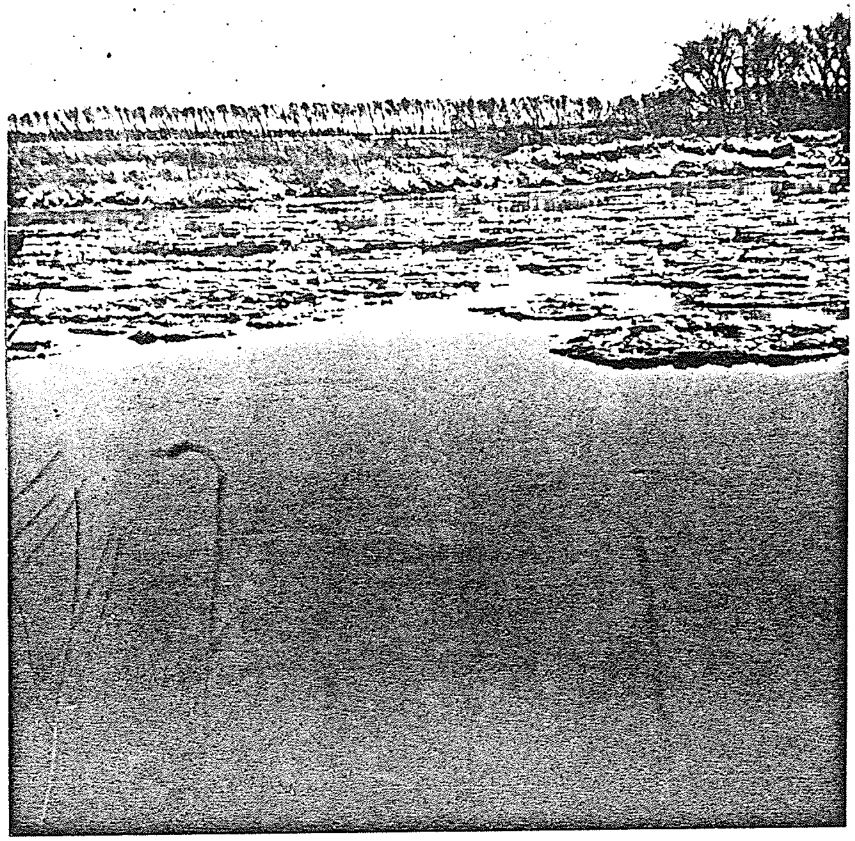


First formation of Ice; frazil slush

Fig. 2.2

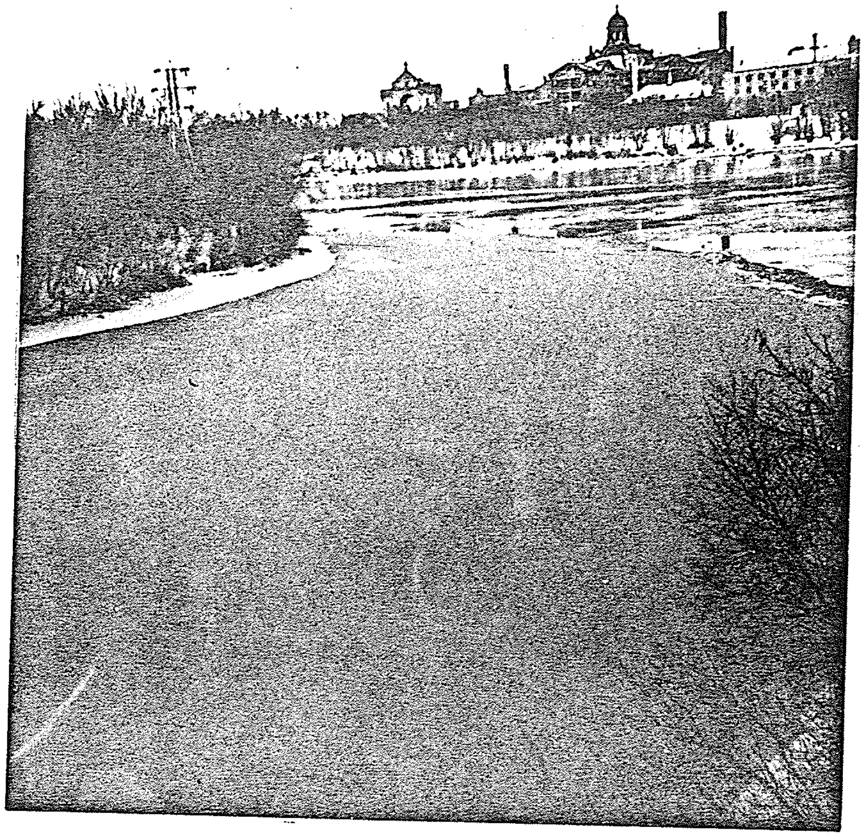
Ice cover first established at the sides

Fig. 2.3



Frazil Ice Floes

Fig. 2.4



Intersection of Red and Assiniboine Rivers;

Assiniboine completely frozen over, Red open in places.

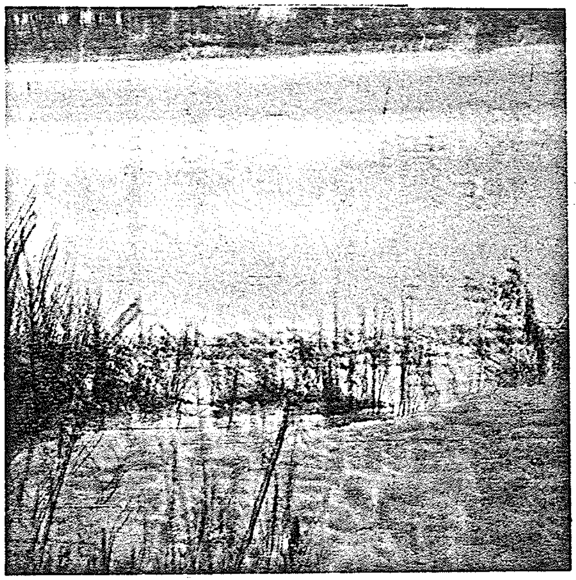
Fig. 2.5

Complete Freeze-over aided by snowfall

Fig. 2.6

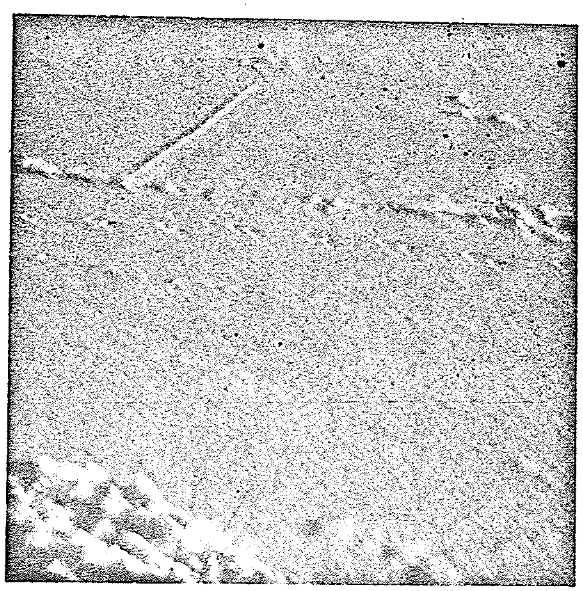
Reversal of Complete Freeze-over

Fig. 2.7



Final Complete Freeze-over

Fig. 2.8



Formation of compression ridges, following final complete freeze-over

This leads to a remarkable decrease of the surface albedo, brought about by the exposure of as yet undisturbed dark crystalline ice (Polyakova).[25] As a result of this type of melting, Polyakova observed a rapid decrease in albedo from 85 per cent to 34 per cent. Evidence of this on the ice cover is usually a mottled appearance.

The lower albedo causes more energy to be retained at the ice surface. This encourages further melting, and in a matter of days puddles of melt water appear. These usually develop first at the edges of the water body, and form what are commonly referred to as shore leads. Melting at the sides is believed to be initiated for a number of reasons. These include a darker and shallower location, bank runoff, the type of ice, and man induced leads caused by the pumping of hot industrial water (Bunge and Bryson).[26] In many cases, rivers and lakes first open up where major tributaries enter (Mackay).[27] A cold spell however can lead to the refreezing of the water, thus delaying the break-up process.

With further melting, the discharge of melt increases appreciably, and the ice cover may become flooded over. Most of this water forces its way beneath the ice cover through old thermal cracks or at

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25. Polyakova, K. N., "Characteristics of the Melting of the Ice Cover and the Opening of the Middle Lena River," Soviet Hydrology: Selected Papers, 1965, pp. 276-292.

26. Bunge Jr., William W., and Bryson, Reid A., "Ice on Wisconsin Lakes, Pt. 3," No. 14 Report to the University of Wisconsin Lake Investigations Committee, U. of Wisconsin, Dept. of Meteorology, Madison, June 1956, Ch. 4.

27. Mackay, J. R., "Progress of Break-up and Freeze-up along the Mackenzie River," Geographical Bulletin, No. 19, May, 1963, pp. 103-116.

the sides, where the ice is usually thinnest. The ice cover is then subjected to pressure lift that increases with increasing discharge.

Eventually, the ice cover disengages itself from its supports. In doing so it may even fracture at its weaker points, such as thermal cracks. At this stage the areal extent of the river or lake water increases, and the central part of the ice cover floats freely. From here onwards, the break-up process may be either of a dynamic or a static character.

Dynamic ice break-up is characteristic of rivers and lakes with through flow and high discharge. The ice cover is shoved and moved by wind and water currents, which further disintegrate the ice cover. (Michel)[28] refers to this stage as the drive.

The drive depends mainly on the river or lake discharge and the strength of the ice cover. With continued increasing discharge, the tangential friction forces of the water under the ice reach become high enough for it to become unstable (Michel)[29]. The frontal accumulation breaks through the ice sheet, and a complete reach is destroyed and moved downstream in a river and downwind or downcurrent in a lake to the following reach, which may not have moved at the same time. This usually occurs first where the ice is thinnest and weakest, as in the vicinity of pressure ridges (Bunge and Bryson).[30]

The final stage of ice clearing, which Michel[31] refers to as

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28. Michel, B., 1972, p. 10.

29. Ibid, p. 11.

30. Bunge Jr., William W., and Bryson, Reid A., Ch. 11.

31. Michel B., p. 10.

the wash is usually quite rapid, except when ice jams occur. By this time, the water level of the river or lake, fed by melt water, and sometimes rainfall, is at its highest. There is therefore sufficient flow velocity and volume to carry away the disintegrated ice cover. Large floes are broken down into smaller pieces through overturning and collision with one another. This also disturbs the thermal stratification of the water. Warmer water is brought to the surface, and this further aids melting. Ice floes, unless delayed by an ice jam, usually melts after a few days travel (Shipman)[32].

An ice jam formation in the spring is determined mainly by the break-up conditions, the morphometry of the channel, and apparently by the characteristics of freezing (Polyakova).[33] Ice jams usually start at restrictions to flow caused by bends in meandering rivers, islands, bridges or other structures and by stable immobile ice covers Williams).[34] In certain cases, jams are also common at the mouths of rivers entering into shallow tidal estuaries, or lakes that are still ice-covered. Ice jam formations are another way whereby an ice cover may reappear at a site after having previously cleared. The only difference is an agglomeration of broken-up ice floes instead of a continuous ice cover.

The destruction of an ice jam may be brought about by several factors. These include surface melt through solar radiation, internal

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32. Shipman, T. G., p. 590-594.

33. Polyakova, K. N., p. 290.

34. Williams, G. P., "Break-up and Control of River Ice," National Research Council of Canada, Division of Building Research, Ottawa, 1970, p. 4.

melting by the warm water, windiness, and the volume and rate of discharge. In general however, the jam is destroyed when the force from the head of water created by the ice is sufficient to overcome the forces resisting downstream or downlake movement of the accumulated ice (Williams 1970).[35]

In the case of smaller lakes that are not fed by streams, and with limited drainage slopes, break-up is mainly of a static nature. The ice cover first melts completely around the shoreline, leaving the main body of ice floating free. During this stage, melting of the ice cover takes place mainly through solar radiation from above, and the warmer water beneath. Melting from beneath is encouraged by the penetration of solar radiation through the darker ice surface.

Surface melt water usually creates drainage patterns on the ice cover. It can drain to the open water adjacent to the shoreline, or down the holes that appear to develop preferentially along old thermal cracks (Williams). [36] If the surface melt water can drain away, the surface of the ice becomes a porous, crumbly white structure which reflects solar radiation readily, thus retarding break-up. A cold spell can have a similiar effect. Melting however eventually takes place in situ, except when strong winds occur.

The currents created by strong winds break up the ice cover and induce circulation that brings the warmer subsurface water to the

35. Ibid.

36. Williams G.P., 1968, p.209.

surface (Williams).[37] Simojoki[38] states that break-up is most hydrographically dependent on lake area, which influences wind fetch. The effect of wind however depends not only on fetch, but also on wind speed, direction, and duration, and on the degree of ice deterioration when break-up occurs (Williams, 1971).[39] In the early spring there is a large amount of heat stored in the lake, more than enough to melt the ice cover (Bunge and Bryson).[40] It is prevented from doing so by the thermal stratification of the water. This is easily disturbed by wind action.

The break-up of ice in rivers and through-flow lakes is much earlier than in enclosed lakes (Burbidge and Lauder).[41] Only enough melting is required to initiate weakening and fracturing of the ice cover. The flood of melt water runoff is mainly responsible for its eventual clearing. Polyakova[42] claims that only 30 percent of the ice cover is destroyed by solar radiation, the remaining 70 percent being destroyed by the mechanical action of water pressure. These

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37. Ibid, p. 210.

38. Simojoki, Heikki, 1939, referred to in No. 14, Report to the University of Wisconsin Lake Investigations Committee, University of Wisconsin, Madison, 1956, Ch. lV, Bunge Jr. and Bryson, "Ice on Wisconsin Lakes," Part 111.

39. Williams G. P., "Predicting the Date of Lake Ice Break-up," Water Resources Research, Vol. 7, No. 2, 1971, p. 332.

40. Bunge Jr., William W., and Bryson, Reid A., Ch. 111.

41. Burbidge, F. E., and Lauder, J. R., p. 4.

42. Polyakova, K. N., p. 228.

values however can obviously be expected to vary with the stage of the process, and local site and environmental conditions.

Like freeze-up, the break-up process is also very complex. A variety of ice conditions occur, at the different stages. These are also described variously by the many observers.

As was done for the freeze-up process, the following series of photographs are included as a means of further illustrating some of the break-up characteristics referred to earlier (See Appendix 1).

2.4 Typology

It is readily conceivable that there is a wide variety of break-up and freeze-up conditions. Physical and environmental factors interact so as to produce different types of break-up and freeze-up. Several authors have in fact attempted to construct typologies for each process.

As for freeze-up, Rymsha and Donchenko[43] formulated the following classification based on the type of ice formed and the place of ice formation:

(a) Calm undisturbed stretches of water, where freezing occurs strictly on the surface, with the formation of shore ice consisting of needle shaped crystals.

(b) The freezing together of ice floes in agitated waters such as in the larger rivers of the U.S.S.R.. Ice formation occurs throughout the entire depth of the water body. Crystals of frazil ice coagulate

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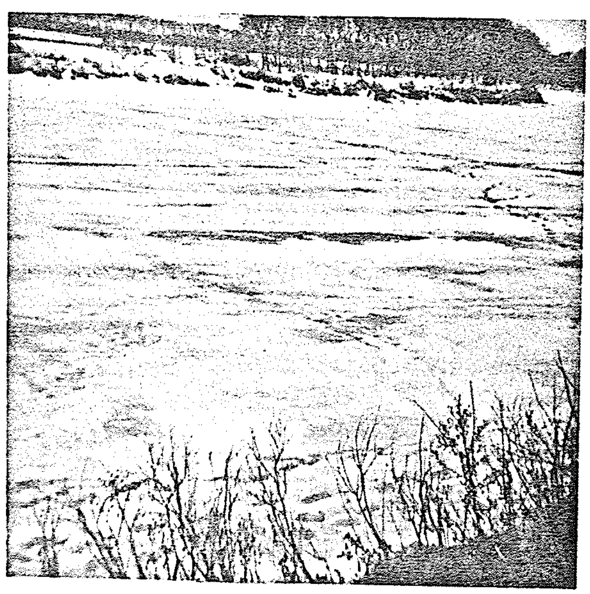
43. Rymsha, V.A., and Donchenko, R.V., pp. 372-383.

Fig. 2.9

River Condition Prior to Break-up

Fig. 2.10

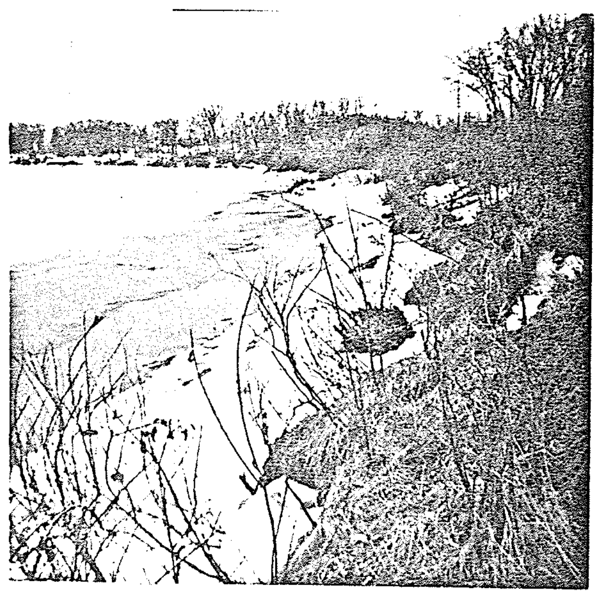


First signs of break-up; darkening of ice surface.

Fig. 2.11

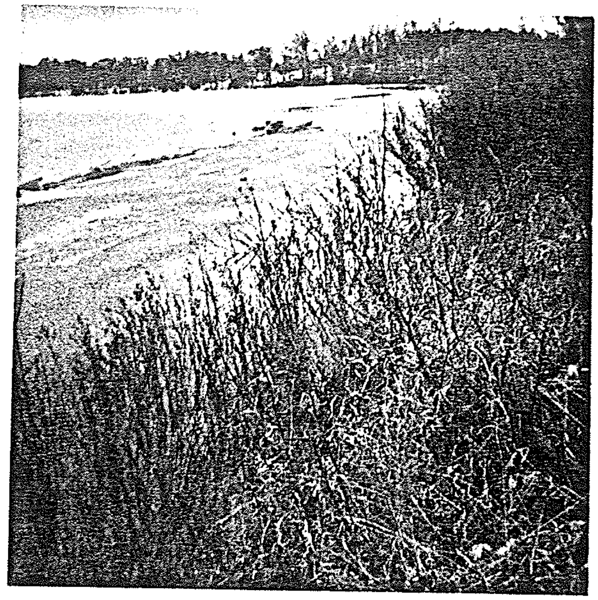
Melting commences at the sides; ice cover also begins to deteriorate, dappled appearance.

Fig. 2.12



Melt established at the sides.

Fig. 2.13



Refreezing of Melt Water

Fig. 2.14

River completely frozen again, and blanketed by a snow cover.

Fig. 2.15

Rising level of river from melt upstream; ice cover flooded at sides.

Fig. 2.16

Ice cover breaks from hydrostatic pressure of flood wave.

Fig. 2.17

River in flood; ice cover floating in the middle.

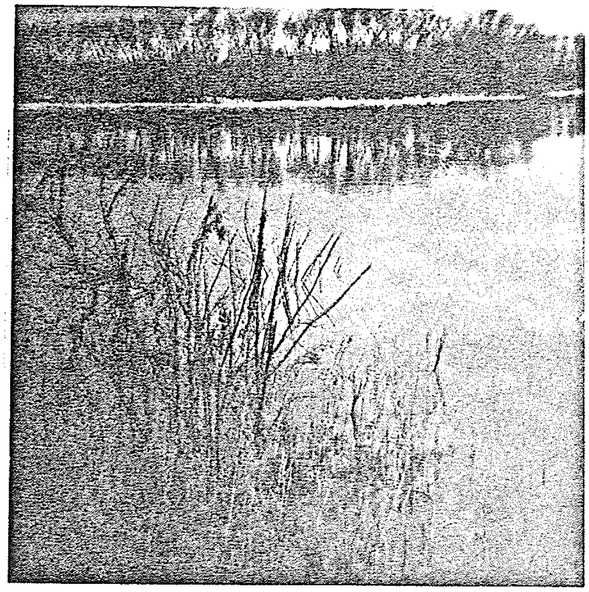
Fig. 2.18

Partial refreezing after breaking of the ice cover.

Fig. 2.19

The day the ice first moved.

Fig. 2.20



Water clear of ice at the observation site, although ice jams were found both upstream and downstream.

Fig. 2.21

Disintegrated ice cover, during the wash stage.

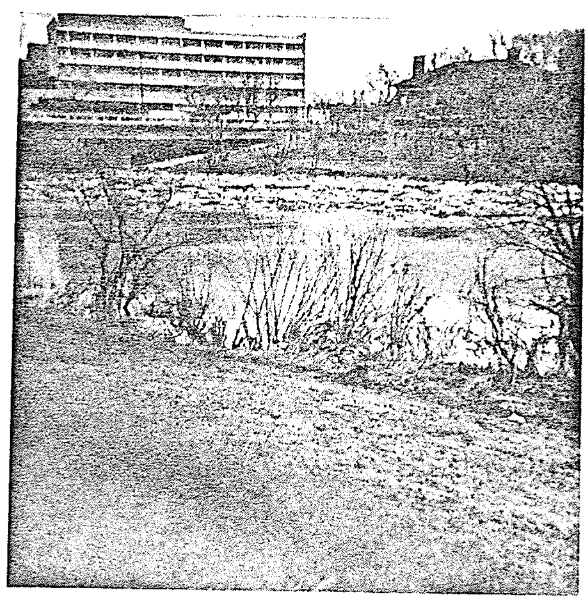
Fig. 2.22

Last bits of floating ice.

Fig. 2.23

First day the river is completely clear of ice.

Fig. 2.24



An ice jam on the Assiniboine, By this time the Red was already completely clear of ice at the observation site.

at the surface to form ice floes.

(c) Freezing that takes place chiefly during the formation of slush (frazil) ice. Ice formation is mainly in depth. The accumulation of this slush eventually forms an ice cover on the stream surface. This type of freezing occurs in rivers carrying slush ice.

Michel and Ramseier[44] constructed a classification of river and lake ice according to the mode of formation. They recognize the following three types:

(a) Primary: formation through supercooling.

(b) Secondary: growth of columnar ice beneath the initial ice cover.

(c) Superimposed: surficial ice growth through snowfall and icing.

In a further classification, they subdivide these major ice types according to genesis, structure and texture, in the following manner:

(a) Primary Ice

(i) Calm Surface, Small Temperature Gradient.

The ice crystal grains are large to extra large with irregularly shaped boundaries. The crystallographic orientation of the c-axis is preferred vertical. This type of ice is found in reservoirs, lakes, and very calm areas of rivers.

(ii) Calm Surface, Large Temperature Gradient.

The grain size is varied, ranging from medium to extra large. The crystallization progresses rapidly. The grain shape varies from tabular to needle-like and can be several cm in length. Dendrites are

44. Michel, B., and Ramseier, R.O., "Classification of River and Lake Ice," Canadian Geotechnical Journal, Vol. 8, No. 1, pp. 36-45.

also common. The crystallographic orientation is random or vertically preferred superimposed on a random orientation. This type of ice is also common to lakes, reservoirs and very calm areas of rivers.

(iii) Agitated Surface, Nucleated From Frazil

The grains are fine to medium, the grain shape being tabular. The crystallographic orientation is random. This type of ice can be found on lakes, reservoirs, and rivers.

(iv) Nucleation by Snow

The ice crystal grains are fine-to-medium sized and are equiaxed. These properties depend to a large extent on the snow type. The crystallographic orientation is random. This ice can form in lakes, rivers and reservoirs.

(b) Secondary Ice

(i) Columnar Ice, Preferred Vertical Orientation of c-Axis

The grains form parallel to the heat flow. The grain size increases with depth, since unfavourably oriented grains are consumed by those more favourably oriented. The crystallographic orientation of the c-axis is preferred vertical and remains so for the entire columnar ice depth. The grain size is usually large to extra large, with irregular shape. This type of ice forms as a result of the conditions given for primary ice types (i) or (ii); and very occasionally (iii) or (iv) if the ice cover is under pressure. It is found in lakes, reservoirs, and rivers with low flow velocities.

(ii) Columnar Ice, Preferred Horizontal Orientation of c-Axis

The conditions are the same for (i) above except for the primary ice having a random orientation. The crystallographic orientation changes continuosly with depth becoming preferred horizontal after 5 to 20 cm. of growth. This type of ice forms as a result of conditions given for primary ice types (ii), (iii), and (iv).

(iii) Columnar Ice, Preferred Aligned Horizontal Orientation of c-Axis

This type of ice forms at the bottom of thick ice sheets and covers. It is found in perennially frozen lakes, Arctic ice islands, and possibly in river ice at great depth. It develops from a preferred horizontal orientation to one with several of the c-axes nearly parallel.

(iv) Congealed Frazil Slush

The grains are equiaxed and tabular in shape. Their size is fine to medium and depends on the age of the originating frazil. The crystal boundaries are irregular and the crystallographic orientation is random. The frazil is formed in turbulent water and is swept under the secondary ice cover. An entire ice cover can consist of congealed frazil slush. It can also be found in different layers of the cover alternating with the columnar ice. It is found in rivers as well as reservoirs and lakes fed by turbulent waters.

(v) Drained Congealed Frazil Slush

The grains range from fine-to medium size and are angular in shape. The density is low: over 0.4 g/cm^{-3}. This ice is found where water has drained through ihe ice cover leaving the slush to be refrozen.

(c) Superimposed Ice

(i) Snow Ice

The grain size ranges from fine-to-medium, the shape is round to angular depending on the age of the snow, and the grains are equiaxed with a random orientation. The density may vary from 0.83 to 0.90 g/cm^{-3}. It is formed when water saturates the snow deposited on an ice cover which then refreezes.

(ii) Drained Snow Ice

The grains range from fine-to-medium size, and are well rounded. The layer is homogeneous and randomly oriented. It has a density of a approximately 0.6 g/cm^{-3}. This ice is found where water levels can vary rapidly. A previously saturated snow cover can therefore be easily drained, thereby facilitating refreezing.

(iii) Surface Ice

This refers to layers of columnar ice which have formed on top of the original primary ice.

(d) Agglomerate Ice

This final ice type is added on as an extra category. It is an agglomeration of various ice types and forms. At any point where the natural growth process is disturbed by mechanical or other types of interference the horizontal layering will become indistinguishable. The grain size can vary from fine to extra large and the shape can vary from equiaxed to tabular to columnar with the crystal boundaries regular to angular in shape. The orientation can vary from random to preferred. This type of ice which is essentially an agglomeration of individual ice pieces which have refrozen, is frequently found in areas of turbulent flow or rapids in rivers.

The above classification underlines the fact that the type of ice formed is essentially a function of environmental conditions. Meteorological and hydrodynamic conditions are the dominant factors here.

Donchenko (1972)[45] presented another classification of the freeze-up process. This was however restricted to reservoirs, and was based on the intensity of ice cover formation, and the duration of the freeze-up period. The following table summarizes the types of freezing:

Table 2.1

Types of Freeze-up based on the intensity of an ice cover formation (P_o) and the duration of the freezing period (τ).

Type of Freezing	Freeze-up Character	P_o (10^5) in cal/cm^3 sec	Duration (τ) (days)
I	(a) Formation of shore ice and ice cover with the initial thickness up to 1 cm.	>4	1 - 2
	(b) Formation of shore ice, ice slush, feeble ice drift and ice float, increase of shore ice up to complete freezing, complete ice cover formation. Initial ice cover thickness up to 3 cm.	>4	3
II	Shore ice formation, ice drift, complete ice cover. Initial ice cover thickness up to 15 cm.	4 - 2	5 - 10
III	(a) Shore ice formation, frazil ice drift, complete ice cover. Initial ice cover thickness exceeds 15 cm.	<2	10 - 15
	(b) Shore ice formation, prolonged drift of frazil ice, complete ice cover for a short period of time. Initial ice cover thickness exceeds 20 cm.		>20

45. Donchenko, R.V., p. 10.

From the above, one can readily conclude that there are basically two factors that determine the type of freeze -up: the intensity of heat loss from the water surface and the type of water body.

The greater the intensity of freezing, the shorter is the duration of the freeze-up (complete ice coverage) process, and the thinner is the ice sheet formed. Skim ice is therefore characteristic of regimes of rapid freezing. On the other hand, frazil ice commonly occurs with prolonged periods of freezing.

With respect to the break-up process, fewer classifications are encountered. Burbidge and Lauder[46] compares break-up between rivers and lakes, based on the time of break-up and the duration of the break-up period. Furthermore, Williams[47] distinguishes between lakes subjected to through-flow and runoff, and lakes with little basin discharge.

One of the more detailed classifications however is presented by Antonov, Ivanov and Nalimov.[48] It refers specifically to rivers in the Siberian arctic and sub-arctic zones.

Type (a) This type comprises of rivers or river reaches in which the processes of break-up are characterized by sufficient dynamic effect of the flood wave on the ice causing break-up and shearing in a river channel at a distance of 60 - 180 km. This zone is followed by a zone of drifting ice 25 - 90 Km., with subsequent complete ice clearance.

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46. Burbidge, F.E., and Lauder, J.R., p. 5.

47. Williams, G.P., 1968, p. 208.

48. Antonov, V.S., Ivonav, V.V., and Nalimov, Yu.V., "On the Types of Break-up of Rivers in the Siberian Arctic and Sub-Arctic Zones," Int. Symposia on the Role of Snow and Ice in Hydrology: Symposium on Properties and Processes, Session: UNESCO: 5, 1972.

This type of break-up is characteristic of large lowland rivers with vast drainage basins, and weakly developed flood plains, and medium size or small mountain rivers characterized by large river bed slopes and corresponding flow regime.

Type (b) In this second type, the dynamic effect of flood waves is reduced. This is due to the fact that the river flow is regulated by long distances and swamps. This category is typical of the large lowland rivers with well developed wide flood plains.

Type (c) The third type includes medium sized rivers flowing through the Siberian tundra and forest tundra regions. These streams usually freeze to the bottom, due to the severe climate, the low precipitation, and the lack of ground water because of permafrost. They are therefore characterized by a number of alternating reaches of deep pools covered with thick ice and completely frozen-up bar reaches. Drifting ice is rarely observed on these rivers, and melting of the ice *in situ* is common.

Type (d) This fourth and final type comprises of the mouth reaches of almost all the large and medium sized rivers flowing into the Arctic. Break-up is of a quiet nature. The dynamic effect of the flood water is excluded as the flood wave is considerably reduced by the journey over the large flood plains and numerous delta arms. The bulk of the transit ice melts in the lower reaches before it gets here. Ice here is therefore mainly of local origin.

This classification, together with the others, is essentially hydrodynamic in nature. They are based mainly upon the type of water body, and the intensity of the flood wave during break-up.

2.5 The Controlling Factors

It transpires from the above, that there are basically two major controls of both the break-up and the freeze-up process. These are as follows:

(1) Climatological

(2) Hydrological

Climatological Factors

(a) Air Temperature: Air temperature is basically the major factor determining break-up and freeze-up conditions, (Foward) [49]. It is the cooling of the atmosphere, which in turn cools the water, that produces freezing conditions in the fall. Similarly, with the warming of the atmosphere in the spring, the ice cover is melted. Air-water energy exchanges are mainly through conduction, convection, and latent heat transfer mechanisms.

(b) Windiness: Wind is definitely of fundamental importance in respect to ice conditions. It has the characteristic of acting together with or against air temperature to initiate or terminate freezing and breaking conditions.

During freeze-up a wind encourages freezing of the water surface through induced evaporative cooling. On the other hand a wind can discourage ice formation at a particular site, in that it increases water turbulence which disturbs crystal growth. However, windiness produces

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49. Foward, Charles, N., "Sea Ice Conditions along the Hudson Bay Route," Geographical Bulletin, No. 7, 1955, p. 47.

a compression of the ice field to the leeward side, thereby creating a thicker ice cover (Mackay).[50]

During break-up, a wind is primarily responsible for the removal of the ice cover. It does so either directly through its own frictional force or indirectly by creating strong water currents. Also, warm winds such as the Flohn variety, are very effective in evaporating snow (Woodsworth and Gordon).[51]

(c) Precipitation: During freeze-up, snowfall furnishes the water surface with added nucleation for ice crystal growth (Murakami).[52] On the other hand, if a snow cover were to blanket an initial ice cover (a few cm. thick) it would retard its further growth, in that it suppresses heat transfer from the water beneath to the air.

When break-up is active, a snow cover will have had the effect of producing a thinner than usual ice cover. In addition, freshly fallen snow would continue to create high albedo situations, when the sun's zenith angle is already quite high, thus retarding the break-up process. Rainfall during the spring is also very effective in destroying the ice cover.

(d) Sunshine: Sunshine during freeze-up has the basic effect of

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50. Mackay, G. A., "The Effect of Protracted Spring Thaws on Ice Conditions in Hudson Bay," Bull. of Amer. Met. Society, Vol. 33, No. 3, March 1952, p. 101.

51. Gordon, A. R., and Woodsworth, W.C., "Some Inter-Relationships of Snow and Ice Conditions and Weather in the Arctic," Bull. of Amer. Met. Soc., Vol. 31, No. 8, October 1950, p. 276.

52. Murakami, M., (1941), in Mackay, J. Ross, "Freeze-up and Break-up Prediction of the Mackenzie River, N.W.T., Canada," Preliminary Paper, No. 1, March 1960, p. 26.

warming the water at depth, thus maintaining a positive heat balance for the water body as a whole for a longer time period.

During break-up, direct solar radiation is effective in heating the water beneath the ice cover, which in turn induces melting (Williams).[53] It is responsible for the direct melting of the ice cover, which is usually dirtier and darker in the springtime.

(e) Cloudiness: The amount of cloud cover has a profound effect upon the rate at which an ice field disintegrates during break-up (Gordon and Woodsworth).[54] With a high solar angle prevailing at this time of the year, the lesser the amount of cloud cover, the greater is the effect of solar heating.

On the other hand, cloudy skies tend to retard freeze-up in the fall. This is due to the fact that the direction of energy transfer is towards the atmosphere at this time. Clouds therefore act so as to impede energy loss.

Other climatological factors what can be considered, but whose effect is negligible, are evaporative cooling during freeze-up, and latent heat of fusion release during break-up.

Hydrological Factors

Hydrological factors are influenced to a large extent by the subaerial and submarine morphology of the river or lake basin. These are discussed in the following sections.

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53. Williams, G. P., "Water Temperature During the Melting of Lake Ice," National Research Council of Canada, Div. of Bldg. Research, Research Paper, No. 421, pp. 1134-38.

54. Gordon, A. R., and Woodsworth, W. C., p. 276.

(a) Discharge: Discharge has several characteristics. Discharge rate or flow velocity is determined by the slope of the basin and the amount and intensity of precipitation. The volume of discharge on the other hand is mainly determined by precipitation conditions.

When flow velocity produces turbulent conditions, both freeze-up and break-up are affected. During freeze-up, turbulence causes a delay of the freezing process, and induces frazil ice formation. On the other hand turbidity aids the break-up process; it leads to mechanical disintegration of the ice cover, and is responsible for disturbing the water stratification, which further propogates melting (Williams).[55]

The volume of discharge is important during the break-up period. It creates a lifting force on the ice cover. This is one of the major mechanisms of ice break-up.

(b) Depth: Water depth mainly affects freeze-up conditions. Simojoki[56] claims that the depth of a water body is the most important factor in determining the date of lake ice freezing outside of meteorological conditions. This is due to the great heat storage capacity of water and thermal density characteristics.

(c) Size: The size of a water body is important only in its influence upon windiness. Larger rivers and lakes provide ample areal extent for a favorable fetch. River or lake orientation is also important in this respect.

(d) Basin Characteristics: Basin characteristics, such as shape, topography, vegetative cover and soil texture determine the intensity of runoff. This is a major hydrographic factor during break-up, in that it affects the magnitude of the flood wave.

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55. Williams, G. P., 1968, p. 210.

56. Simojoki, Heikki, 1939.

(e) Local Conditions: Local conditions essentially arise from anomalous physical conditions, which in turn introduce minor irregularities in both the break-up and freeze-up pattern. Shallow reaches in rivers or lakes encourage early freeze-up. These also cause ice jams during break-up. On the other hand rapids and waterfalls discourage freezing conditions.

In order to emphasize the importance of some of the controlling factors mentioned above, empirical approaches that give some idea as to the behavior and magnitude of these are discussed. These methods were derived with the aim of predicting the times of occurence of specified stages of each process. The following sections list some of the more important attempts.

With regard to the freeze-up process Rodhe[57] used the following relationships between weighted air temperatures and the rate of water cooling in the Baltic:

$$\frac{d\tau}{dt} = K(T - \tau) \qquad [2.1]$$

where

T = air temperature
τ = water surface temperature
t = time
K = a constant with inverse dimension of time

He maintains that freeze-up does not depend solely on below freezing temperatures during a limited period of time. However, over an extended time period, temperature is the major controlling factor.

57. Rodhe, Bertil, "On the Relation Between Air Temperature and Ice Formation in the Baltic," Geografiska Annaler, Vol. 34, 1952, pp. 175-202.

Bilello (1964)[58] adopted this technique to compute the date of ice formation at several locations in the Arctic. Similiarly Mackay (1960)[59] extended this method to include flow travel time when measuring surface water temperatures. He contended that freezing at a particular site was dependent not only on local environmental conditions, but on upstream conditions as well.

Spence (1971)[60] used a multiple correlation and regression analysis to examine the relationships of the various possible combinations of the independent variables, stream depth, flow velocity, distance from the nearest bank, and their log transformations, with the dependent variable, time of freeze-up in degree days, and its log transformation.

In the correlation analysis between the hydraulic variables and the time of freeze-up, results were encouraging for velocity and distance from the nearest bank, In the regression analysis, the following relationship was derived:

LCUMDT = 1.18 - 0.008 VELt1.41 (0.10) (0.20) LBANK - 0.37 DEPTH (0.10) [2.2]

where

LCUMDT = log transformation of the time of freeze-up in degree

58. Bilello, Michael A., "A Method for Predicting River and Lake Ice Formation," Journal of Applied Meteorology, Vol. 3, 1964, pp. 38-44.

59. MacKay, J.R., "Freeze-up and Break-up Prediction of the Mackenzie River, N.W.T., Canada," Upublished Paper, 1960, pp. 25 - 66.

60. Spence, E.S., "An Empirical Approach to Time of Freeze-up Analysis," The Albertan Geographer, No. 7, 1971, pp. 6-11.

days from the time the water temperature became equal to 32^{o}F (degree days).

VEL = velocity (feet per second).

LBANK = log transformation of distance from the nearest bank (feet).

DEPTH = Depth (feet).

This equation is actually the highest coefficient of determination available for the data and the variables used. It is significant at the 0.05 level for an analysis of variance "F" test. Again, it emphasizes the effect of water velocity and distance from the nearest bank on the time of freeze-up.

As for the break-up process, Williams (1968)[61] developed a simplified ice melting formula which combines a solar radiation term with a degree-day term. The formula, which applies to fresh water lakes, is as follows:

$$Qm = 0.05 \sum R_{sw} + 10 \sum \Delta T \text{ cal/sq. cm.} \qquad [2.3]$$

where

Qm = heat available for melting the ice cover over a given period of time.

R_{sw} = accumulated short wave radiation over the period cal./sq.cm.

ΔT = accumulated degree days over the period, ^{o}F.

The formula assumes that over the break-up period, 50 per cent of the available short-wave radiation (solar) is absorbed by the ice and is available for melting. Evaporation is assumed to be slight during the break-up period, and is neglected. Combined long-wave radiation and convective heat gains or losses are assumed proportional to the degree-day term.

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61. Williams, G. P., 1968, p. 210.

The above formula however applies to lakes not fed by rivers, and with little basin discharge. For lakes that show increased spring discharge, this formula can only be applied to the initial melting period mentioned previously.

Another approach, suggested by Bendennikov[62] emphasizes the hydrodynamic aspects of break-up. He states that during the period preceding the opening of a river or a lake and clearing of the ice, the dynamic interaction between water flow and the ice cover is characterized by an increase in the energy of water flow which is manifested by a rising stage and an increased discharge. A weakening of the strength of the ice cover, which is revealed by lesser adhesion to the banks, and a decrease of the ultimate strength with an increasing fluidity of the ice itself is also observed.

This interaction is defined by the following expression:

$$Pm + w + Pv + Qi + Fv - P\sigma - T = 0 \qquad [2.4]$$

where

Pm = the thrust against the edge of the ice cover by the mass of the ice floating down from the upper reaches which have already been opened up.

w = the friction force of the air masses (wind) against the ice.

Pv = the total hydrodynamic pressure against the leading edge of the ice cover.

Qi = the weight component of the ice masses (parallel to the water surface) proportional to the slope of the water surface.

Fv = the friction force of the water under the ice cover.

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62. Bendennikov, V.P., "Dynamic Conditions of Formation of Ice Jams on Rivers," Soviet Hydrology: Selected Papers, No. 1, 1964, pp. 101 - 108.

P_{σ} = the normal component to the cross-section of the ice stress.

T = the tangential stress component caused by the friction of the ice against the banks.

The above condition is obviously one of stability, when the ice cover at a particular point has not yet fractured or moved. It describes the hydraulic processes preceding the drive phase. With increasing melt, P_{σ} and T (the counter pressures) are eventually overcome, and the ice breaks and moves.

The empirical techniques discussed above would seem to indicate that air temperature and water turbidity are basically the major environmental factors affecting freeze-up and break-up conditions.

2.6 Conclusion

The behavior of ice in all phases of its formation and destruction is controlled by the physical factors of the environment. Some factors are non-variable, namely the hydrological factors. These are tied to the physical conditions of the environment: physiography and morphometry. Although these conditions are heterogeneous, in that they influence the spatial variability of break-up and freeze-up phenomena, they maintain an element of permanence and consistency. They would therefore be expected to exert the same type of influence on break-up and freeze-up conditions from year to year. In other words the nature of their heterogeneity is spatially predictable and regular through time.

Climatological factors on the other hand, are variable. They cause both spatial and temporal variations of break-up and freeze-up conditions. These however, are noted to exhibit homogeneous effects over broad geographical areas (Murray Mitchell).[63] Stations within appropriately defined regions, recording these phenomena should concur in both sense and magnitude. The pattern of break-up and freeze-up events should therefore be consistently uniform from year to year over extended climatological regions.

Although there exist complex spatial and temporal variations of the physical factors that control break-up and freeze-up conditions, one can expect them to exert uniform and predictable influences over delineated geographical areas, from year to year. Regional networks of stations recording specific break-up and freeze-up events should therefore yield homogeneous and comparable sets of data.

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63. Mitchell, J. Murray, "Observed Secular Temperature Trends," Journal of Meteorology, Vol. 10, August 1953, pp. 244 - 261.

CHAPTER III

Perception of the Environment

3.1 Introductory Remarks

Until recently, studies relating to the perception of the environment had been somewhat neglected by geographers. Emphasis was placed more on explaining the nature and behavior of the physical world and these explanations often neglected man's perception of these phenomena. The proliferation of perception studies in geography that has appeared over the last decade however, has a definite bias towards the behavioral environment: The environment man perceives, experiences and acts in. These studies have hinged largely on psychology; they have occasionally gone to the other extreme and have attempted to explain the physical environment in terms of its cognitive structuring by man.

In order to fully comprehend the everyday environment however, one must come to grips with both the stimulus field (the physical environment), and the response field (the psycho - social environment). Both fields are subject to immense variability, and neglect of one at the expense of the other can only result in biased and distorted views. The present study is an attempt to show how variability within the physical environment, and within the social environment, can affect one's perception of what can be appropriately termed the operational environment (the environment in which man operates).

3.2 Variability of the Stimulus Field

The natural environment is by no means a laboratory situation. Variations over different ranges of time and space are a common characteristic. The atmosphere, in particular is in a state of constant agitation, and measurement of certain parameters such as air temperature and vapor pressure, are rendered extremely difficult (Middleton).[1] The waters of the rivers, and lakes, and oceans, are also in constant motion, and similiar measurement problems are encountered.

The processes of both break-up and freeze-up of water bodies that are directly or indirectly affected by air temperature mainly, and windiness and water movement, and other hydroclimatic conditions (See Ch. II) are subject to similiar variations, though of a lesser magnitude. Rigorous and systematic measurement techniques are therefore desirable to assure accurate and meaningful records. Most break-up and freeze-up data however are obtained from several indirect sources, none of which have any completely standardized methods of observation.

The following are the break-up and freeze-up conditions and their definitions that are to be examined in this section:[2]

a. Freeze-up 1 . . . . First Permanent Ice

b. Freeze-up 11. . . . . Complete Freeze-over

c. Break-up 1. . . . . First Deterioration of Ice

d. Break-up 11 . . . . Water clear of ice.

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1. Middleton, Knowles, W.E., "The Present-Day Accuracy of Meteorological Instruments," Quarterly Journal of the Royal Meteorological Society, Vol. 70, 1944, pp. 32 - 49.

2. Allen, W.T.R., and Cudbird, B.S.V., "Freeze-up and Break-up Dates of Water Bodies in Canada", Canadian Meteorological Service, CL1-1-71, Toronto, 1971, pp. iii - viii.

It is extremely difficult to visually perceive initial freeze-up (Freeze-up I), which actually involves a phase change from liquid water to solid ice. This problem becomes even more complicated when movement is involved as along fast flowing stretches of rivers or lakes. The turbidity of water currents causes newly formed ice crystals to continually appear and disappear. It must not also be forgotten that these initial ice crystals (needle or frazil), like water, are transparent in color. Whether aney are noticed or not would therefore depend, to a large extent, on the observer's keenness of visual perception. Also, during initial freeze-up, ice crystals that form at night and disappear the next morning, are hardly ever noticed.

Another problem in perceiving Freeze-up I occurs when snow, falling prior to intial freezing is lodged on the banks or shores of water bodies. Quite often, especially where ripples or waves are prevalent, snow adjacent to the water body, is usually washed down and accumulates at the edges. As has been shown already (Ch. II), freeze-up of most water bodies progresses from the sides inwards. It is extremely difficult to differentiate visually between drifted snow and sheet or frazil ice; whether initial freeze-over has occurred or not, is doubtful.

One final problem concerning initial freeze-up at a particular site, involves water bodies that are characterized by through-flow. In this case, it is difficult to say whether frazil slush and frazil floes (Figs 2.1 and 2.3) that float by were formed at the observation site or upstream.

Final freeze-over (Freeze-up II) is a more tangible process. In this case, wide, thin films of ice have established themselves and a smoother, less mobile, and less transparent surface is thus being presented. Distance here becomes the most distorting factor, especially in large bodies of water. Since the middle innermost sections of rivers or lakes are usually the last to freeze over (Burbidge and Lauder),[3] it is exceedingly difficult to tell whether these areas are completely frozen over or not, merely because they lie outside the visual range of the observer. A similar oondition was observed in Hudson Bay. Contrary to previous belief, the centre of the bay was found to be frozen during winter, while shore leads persisted at the periphery (MacKay).[4]

This matter becomes even more complicated when snowfall has blanketed the frozen-over areas. In this case a tremendous amount of white light is reflected, the irradiance of which the observer's eye cannot readily adapt to, and which distorts his view.

Break-up presents similar perceptual problems as were encountered for freeze-up.

The precise determination of the date of initial deterioration of the ice (Break-up 1) is often more difficult than for other dates in the freeze-up/break-up cycle, as melting may be in progress for many

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3. Burbidge, F.E., and Lauder, J.R., "A Preliminary Investigation into Break-up and Freeze-up Conditions in Canada," Met. Branch, Dept. of Transport, cir. - 2939, Tec - 252, 2 July 57, p. 7.

4. MacKay, G. A., "The Effect of Protracted Spring Thaws on Ice Conditions in Hudson Bay," Bull. Amer. Met. Soc., Vol. 33, No. 3, 1952, pp. 101 - 106.

days before any visual evidence of the phenomenon is apparent (Allen and Cudbird).[5]

A general darkening of the snow overlying the ice cover, which creates a mottled appearance seems to be the first visual symptom of initial break-up (personal observation).[6] The precise moment when this process is initiated is, however, extremely difficult to isolate.

When Break-up I refers to the formation of cracks, leads or open water areas in the ice, further perceptual problems are encountered. Areas of open water at the sides, where melt water normally first appears, can be due to break-up of the water body itself or to melt runoff from the adjacent slopes. The problem here appears to be one of definition regarding melt water appearing at the sides.

As for final break-up (Break-up II) perception would seem to be the least difficult, because of its tangible nature (See Ch V). Here time and distance are about the only two factors affecting the perception of the last appearance of river or lake ice. Mainly because of ice jams, it is possible to have a water body completely clear of ice for a few days or weeks, and have floating ice reappearing thereafter. The observer therefore has to be motivated enough to maintain a continuous vigilance over the body of water, even after

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5. Allen, W. T. R. and Cudbird, B. S. V., p. vi.

6. Personal Observation on the Red River near the University of Manitoba, Winnipeg, (See Appendix 1).

the initial disappearance of river or lake ice, to obtain accurate records. Again, in the case of larger water bodies, accurate observations are hindered by the limited visual range of the observer.

One final problem is that during break-up, the river or lake level rises to unduly high proportions, resulting from spring melt run-off. As a result large ice floes are deposited or trapped by vegetation on the banks or shores. These are left stranded even after the final disappearance of the river or lake ice (Burbidge and Lauder).[7] One would therefore wonder whether the final disappearance of ice would depend on the complete melting of these perched ice slabs. The problem here would definitely involve defining and delimiting the river or lake at different periods.

So far, attention has been directed to the problems of observing specified break-up and freeze-up events. It must not be forgotten however that these processes are not finite entities. There is a continuum of physical activity between initial freeze-up and final freeze-up. Likewise for initial break-up and final break-up. And, what is more significant is that every point on this continuum is subject to being reversed for short periods, depending mainly on weather conditions. Perception of break-up and freeze-up of a water body could therefore become even more complicated than outlined above.

Freeze-up conditions are the ones most susceptible to being reversed (Williams).[8] A strong wind or a warming trend can lead to

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7. Burbidge, F. E., and Lauder, J. R., p. 4.

8. Williams, G.P., "Freeze-up and Break-up of Fresh Water Lakes," Division of Building Research, Tech. Paper No. 286, N.R.C. 10422, Ottawa.

complete clearing of the water body, even after complete freeze-over (Freeze-up 11). Several cycles of this process in one season are therefore quite common. Break-up conditions undergo similiar cycles, at a particular site, through cold spells and ice jams. Final break-up however is least likely to suffer reverses (Brown).[9] The observer therefore has to be extremely cautious when recording break-up and freeze-up events, in that the same process could occur more than once in a given season.

3.3 Variability of the Response Field

The perceptual response to either break-up or freeze-up centres around the observer, the social being. Here we have a mediating mechanism between the environmental stimulus and the ensuing response. Environmental stimuli, in the form of patterned photic radiation impinges upon the observer's sensory organs, in this case, his eyes. This energistic message is then assimilated into the visual sensory, and then the central nervous system of the individual, and a perception, or what can more appropriately be called a judgement, is arrived at (Bartley).[10] This judgement however can vary from individual to individual, depending upon his momentary state, his personality, and his cultural affiliation, just to mention a few variables.

The observation of break-up or freeze-up is a momentary affair.

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9. Brown, R. J. E., "Observations of Break-up in the Mackenzie River and its Delta in 1954," Journal of Glaciology, Vol. 3, No. 21, 1957, p. 133.

10. Bartley S., Howard, Principles of Perception, Harper and Row, New York, 1958, p. 89.

The observer's set or mood, at that instant, determines, to a certain extent, the type of image that appears on his retina. Since keenness of sight is desirable to ascertain break-up or freeze-up conditions in most situations, the observer's mental attentiveness becomes quite decisive (Bartley).[11]

Additional to the mood conditions of the observer, is his personality, his basic behavior characteristics around which his mood revolves. This characteristic determines the motivation of the observer and will therefore predispose him to apprehend objects and situations in ways relevant to his basic value judgements (Shafer and Murphy).[12] Under the heading of personality, a number of physiological and psychological factors can be considered. There is the physical build and health condition of the individual, which can affect his frame of mind (Bartley).[13] Then there is his mental disposition, whether he is extroverted or introverted, or energetic or apathetic (Postman et al).[14] These more stable mental stages vary considerably from person to person, within the same society, or even the same family. Perception therefore is quite subjective, depending to quite an extent on the personality of the observer. This in turn influences the manner in which each

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11. Ibid., p. 39.

12. Schafer, R., and Murphy, G., "The Role of Autism in a Visual Figure-Ground Relationship," Journal of Experimental Psychology, Vol. 32, 1943, pp. 335-343.

13. Bartley, S. Howard, p. 386.

14. Postman L., Burner J. S., and McGinnies, E., "Personal Values as Selective in Perception," J. Abnorm. Soc. Psychology, Vol. 42, 1948, pp. 142-154.

observer perceives break-up or freeze-up conditions.

When one considers the observer in a social context, there is even more variability from person to person. Each individual's past experiences, educational background, and personal inclinations, only to mention a few variables, will definitely condition him to perceive the environment, in a way that is unique only to himself (Beck).[15]

Culture can also significantly influence the observer's visual perception (Segall *et al*).[16] In fact this has been a very common field of research for human geographer's over the last decade. Most of the results seem to agree with the fact that culturally shaped influences predispose people to perceive differently. Different responses may be a function of different abilities to respond to the environment or to different perceptions of the environment. In a recent study of perception among northern Alaskan peoples, it was found that cultural differences could be attributed mainly to differences in adaption level (Sonnenfield).[17] Another study contends that the human organism becomes selectively sensitized to certain arrays of stimuli rather than others, and that this is a function of the individual's membership in one cultural group rather than another, whatever other factors are involved.

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15. Beck, Robert, "Spatial Meaning and the Properties of the Environment in Lowenthal, David," *Environment Perception and Behavior*, University of Chicago, Illinois, 1967, Ch. 11.

16. Segall, Marshal H., Cambell, Donald T., and Herskovits M.J.,"*The Influence of Culture on Visual Perception*," Bobbs-Merrill, Indianapolis, 1966, Ch. 1 and 11.

17. Sonnenfield, Joseph, "Environmental Perception and Adaptation Level in the Arctic," in D. Lowenthal, *Environmental Perception and Behavior*, Ch. 111.

(Segall _et al_).[18]

Function or utility may also be critical in helping us to understand the variable sensitivity of individuals and populations to their environment (Sonnenfield).[19] A farmer may see snow as a significant source of soil moisture, while his youngster may perceive it primarily in its value for sledding, or the hydrologist for its potential in flooding. Similiarly the Japanese monk looks at freeze-up in terms of "omiwatari,"* whereas a transportation company in northern Canada views it as a time to terminate shipping or to change the landing equipment of his aircraft. Purpose of perception therefore predisposes the observer with different forms of awareness, which determines what he eventually perceives.

One cannot therefore deny the autistic nature of perception. Perception of the environment depends on more than the stimulus present and the capabilities of the sense organs. It also varies with the individual's past history and present set or attitude acting through values, needs, memories, moods, social circumstances and expectations. The major problem in studying people's perception however is that of measurement, since people often have difficulty articulating the con-

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18. Segall _et al_, Ch. 111.

19. Sonnenfield, Joseph, "Equivalence and Distortion of the Perceptual Environment," _Environment and Behavior_, Vol. 1, No.1, June 1969, pp. 83-99.

* _Omiwatari_: Characteristic ruptures that occur over lakes, two or three days after final freeze-over. The dates of occurrence of these were recorded by the Japanese monks at Yatsurugi Temple near Lake Suwa for over five centuries.

scious and unconscious feelings, attitudes, or ideas associated with perception (Saarinen).[20]

3.4 Measurement of Environmental Phenomena

The measurement of certain elements of the physical environment, such as air temperature and precipitation has for long created a problem for geographers. In fact the techniques used even to this day are rather rudimentary, and accuracy and meaningfulness of measurements leave much to be desired (Middleton).[21] This arises mainly from the constant variability of the physical environment, and the difficulty of establishing standardized instrumentation. As a result environmental conditions are selectively measured.

One can therefore imagine the magnitude of the problem, when one attempts to measure even more intangible environmental phenomena, such as break-up and freeze-up events, using a form of instrumentation that is almost impossible to standardize, namely the human observer. Here subjectivity as outlined above (Sec. 111), rather than selectivity, as in the case of instruments, is brought to the fore.

The complex nature of break-up and freeze-up events arises mainly from their susceptibility to variable weather conditions. Reversibility of each process is a common characteristic (See Ch. 11). Only the cautious and persevering observer will therefore be able to accurately record the progress of each event.

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20. Saarinen, Thomas F.,"Perception of Environment," A.A.G. Resource Paper No. 5, Commission on College Geography, Washington, D.C., 1969.

21. Middleton, W. E. K., pp. 32-49.

As has been outlined above (Sec. III), it is almost impossible to obtain completely standardized observers. But the procedure of observation as exists at present, can be greatly improved upon. There is no fixed routine of observation times; neither hourly, daily nor weekly. Furthermore there are no designated observers as such, of break-up and freeze-up conditions. Most of the records are obtained from indirect sources, all serving different interests (Allen).[22] These include transportation companies, hydro stations and river or lake engineering personnel.

In addition observation sites are very vaguely defined (Allen).[23] In fact, a change in site from year to year is not uncommon (See Ch.111). Each site has a unique break-up or freeze-up regime, depending mainly on river or lake morphology. Furthermore, the occurence of each process is independent of site conditions (Williams).[24] Standardization of sites can therefore improve the meaningfulness of records, even if only for purposes of comparability.

3.5 Concluding Remarks

From the foregoing, one can conclude that the measurement of break-up and freeze-up events is rather problematical. This stems

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22. Allen, W.T.R., "Break-up and Freeze-up Dates in Canada", Met. Branch, Dept. of Transport, Canada, Cir. 4116, Ice 17, Oct. 1964.

23. Ibid.

24. Williams, G.P., "Break-up and Control of River Ice", National Research Council of Canada, Division of Building Research, Ottawa, Ice Symposium, June, 1970.

mainly from the complicated nature of both processes. It renders systematic observation extremely difficult. Part of the problem however can be attributed to rather inefficient methods of measurement.

There is little one can do to the physical processes to make them less complex, except probably by way of improving our understanding of them. Apart from arriving at more precise conclusions regarding the controlling factors, one can at least define the components of each process more clearly. Similiarly site conditions can be more precisely defined.

Regarding tangible and precise definitions for each process, MacKay[25] seems to have a viable suggestion. He defines freeze-up and break-up in the following manner:

Freeze-up: "First-ice" - the first ice affecting the normal stage-discharge relation curve in the fall season.

Break-up: "Last-ice" - the last ice affecting the normal stage-discharge relation curve in the spring season.

Stage - discharge is a relation between the elevation of the water surface at the gauging site, and the rate of flow in the river. Obviously, this is a mechanical system for defining each process. This type of definition should expectedly lend itself more readily to measurement.

One can also do a lot to improve upon the observational procedures. Apart from standardizing observational routines and sites, the

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25. MacKay, D. K., "Trends and Factors Affecting Break-up and Freeze-up Dates in the Nelson River Drainage System," Geographical Paper No. 35, Geographical Branch, Dept. of Mines and Technical Surveys, Ottawa, 1962, pp. 2-3.

subjective element, the mediating human response can be reduced. Some mechanical device, adopting some form of radiometry or photometry can be advantageously utilized in this respect. The degree or color of illuminance can be monitored in such a way as to yield quantitative indices of break-up or freeze-up conditions.

CHAPTER IV

Inhomogeneity Among Canadian Observations

4.1 Introductory Remarks

Measurement of environmental phonomena, whether it is temperature or break-up and freeze-up dates, becomes relevant and meaningful, only when standardized valid procedures are adopted. In other words, climatological data collection, at any point and any moment in time, assumes significance when the method used for such is consistent within itself, and comparable to those at other similar data collection points.

Too often however, one encounters inconsistencies within climatological data that arise mainly from the lack of standardization in observational methods. In the case of temperature, incomparable measurements can result from differences in the exposure, calibration, or sensitivity of thermometers.[1] Similiar measurement problems are encountered in recording precipitation, wind and other climatological data. In collecting break-up and freeze-up dates however, the main cause of inconsistencies seems to result from definitional problems, i.e., the dates that are recorded can refer to any one of a number of definitions that describe each process. Other factors contributing to this effect are observer subjectivity (see Ch. 111), and the variable nature of the break-up and freeze-up processes (see Ch. 11).

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1. Middleton, Knowles, W. E., and Spilhaus, Athelstan F., Meteorological Instruments, 3rd. Ed., Rev., University of Toronto Press, 1953, pp. 3 - 117.

The processes of break-up and freeze-up are subject to immense variability. Each process extends over a period of days or weeks. During the course of each event, several distinct, but connected, stages are discernible. Besides, every stage on this continuum is subject to being reversed, depending mainly on weather conditions. Because of this complex state of affairs different notations become associated with the different stages of each process. These various definitions in turn have become attached to the integral events "break-up" or "freeze-up".

This in fact has been the case with the records of break-up and freeze-up events as encountered in the written literature, and as kept by the Meteorological Branch of Canada. A close scrutiny of these records reveals a long list of definitions for each event. The general academic literature contains a proliferation of definitional terms. Changes of the standard definitions, as stipulated by the Meteorological Branch, over the years, are quite common. In addition, a series of alternative definitions, for each event, are encountered.

4.2 Definitions Encountered in Academic Literature

A review of the literature on break-up and freeze-up dates reveals a multitude of definitional terms describing each event. This was found to be the case not only in Canada, but in other countries as well. A sampling of these studies is treated hereunder.

In a discussion of historical records of freeze-up and break-up for the Churchill and Hayes Rivers, Mackay and MacKay (1965)[2] mentioned the following definitions:

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2. MacKay, D. K., and Mackay, J.R., "Historical Records of Freeze-up and Break-up on the Churchill and Hayes Rivers," Geographical Bulletin, Vol. 7, No. 1, 1965, p. 9.

Freeze-up

(a) "river frozen over in some places"
(b) "river breaks-up with gale"
(c) "river frozen over 9 miles upstream"
(d) " river frozen over this day"
(e) "completely frozen"
(f) "river fast"
(g) "river frozen this day"
(h) "river nearly frozen"

Break-up

(a) "river broke-up 9 to 10 miles upstream"
(b) "South Channel broken up"
(c) "break-up at Factory"

These varying definitions were however adjusted so as to yield uniform quantitative data for various forms of statistical analysis.

Similarly Mackay,[3] in a study of break-up and freeze-up in the Mackenzie Delta area, made the following observations regarding the definition of these processes:

Break-up

He commented that the definition of break-up varied according to the water body and the interests of the observer. With regard to rivers, break-up usually related to the first movement of ice in the spring, or else to the final passage of river ice, except for a few drifting cakes.

As for lakes, harbours and sea coasts, break-up definitions were less precise. But they often referred to the general clearing of the ice from the standing body of water.

In addition, the following definitions, as were used at different stations, were given.

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3. Mackay, J. R., "The Mackenzie Delta Area, N.W.T.," Geographical Branch, Dept. of Mines and Technical Surveys, Ottawa, Mem. 8, pp. 157 - 163.

(a) Fort Providence to Fort Good Hope
"The first ice movement, even though it may later jam and movement temporarily ceases."

(b) Arctic Red River
"When the main river ice moves past, even though it may jam downstream."

(c) Lang Trading Post
"The time when peel driftwood passes the Lang Trading Post."

(d) Aklavik
"The time when the river is clear of ice."

(e) Reindeer Station
"When the ice clears out of the river in front of the settlements; that is the main ice, not the scattered floes which drift past for a day or so after the main ice has gone."

These dates were however adjusted to give the first movement of ice, although the method of adjustment was not specified.

Freeze-up

The definitions of freeze-up, like those of break-up, were determined by local usage. For rivers and channels, freeze-up was usually defined as the date when the river froze over and the ice stopped moving or jammed, although open holes may have persisted for some time afterwards, and in a few stretches may never have frozen all winter. He also mentioned that some of the historical records included dates on the appearance of the first skim or drift ice which may have come from upstream.

In another study, MacKay (1960),[4] gave a further series of definitions for the break-up process. This was also related to stations along the Mackenzie River. The following definitions were given:

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4. MacKay, J. Ross, "Freeze-up and Break-up Prediction of the Mackenzie River, N.W.T., Canada," Preliminary Paper, No. 1, University of British Columbia, March, 1960, p. 28.

(a) Fort Providence to Norman Wells
"The first movement of ice, even though it may later jam and cease moving."

(b) The Ramparts
"When the ice breaks loose and drifts from the ice-jam in the narrows."

(c) Fort Good Hope
"First movement of the ice."

(d) Arctic Red River
"When the main river ice moves past, even though it may jam downstream, as at Point Seperation."

(e) Lang Trading Post
"The time when Peel River driftwood passes by, which may be a day after the channel is clear of ice, although Mackenzie ice may jam and run for a week afterward."

(f) Aklavik
"The ice-free condition of the channel."

(g) Reindeer Station
"The day the ice clears out of the river in front of the settlement (that is, the main ice, not scattered floes which come down for a day or so after the main ice goes)."

In this case however no explanation was given as to how these dates were standardized.

MacKay (1962),[5] in a study of break-up and freeze-up dates in the Nelson River drainage system, gave the following mechanical definitions for each process.

Freeze-up
"first ice" - The first ice affecting the normal stage-discharge relation curve in the fall season.

Break-up
"last-ice" - The last ice affecting the normal stage- discharge relation curve in the spring season.

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5. MacKay, D.K., " Trends and Factors Affecting Break-up and Freeze-up Dates in the Nelson River Drainage System," Geographical Paper No. 35, Geogr. Br., Dept. of Mines and Tech. Surveys, Ottawa, 1962, pp. 2-3.

Bilello (1961),[6] in a study of ice formation and growth in the Canadian Arctic gave the following definitions of freezing:

(a) "freeze-up" - the date when ice first forms.

(b) "freeze-over" - when the body of water becomes completely covered with ice.

In a later study however, Bilello (1964)[7] used the above-mentioned dates to develop curves that could predict:

(a) "first appearance of ice in the fall."

(b) "ice formation from shore to shore on the Mackenzie River"

Elsewhere in the general academic literature, similar variations of definitional criteria for each process, are to be encountered.

Bunge and Bryson,[8] in a study of Wisconsin lake - ice conditions, referred to freeze-up and break-up dates as "in - and - out dates." These were however tabled as "opening dates" and "closing dates."

Similarly, Ragotzkie,[9] referred to these dates as "freezing and thawing dates." In his tables however the following dates were listed:

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6. Bilello, Michael, A., "Formation, Growth, and Decay of Sea Ice in the Canadian Arctic Archipelago," Arctic, Vol. 14, No. 1, March, 1961, p. 4.

7. ——————————, "Method for Predicting River and Lake Ice Formation," Journal of Applied Meteorology, Vol. 3, 1964, p. 38.

8. Bunge, William W. Jr., and Bryson, Reid A., "Ice on Wisconsin Lakes," Pt. 1, No. 13, Report to the University of Wisconsin Lakes Investigations Committee, U. of Wisconsin, Madison, 1956, Ch. 111.

9. Ragotzkie, Robert A., "Compilation of Freezing and Thawing Dates for Lakes in North Central United States and Canada," Technical Report, No. 3, University of Wisconsin, Dept. of Meteorology, September, 1960, 61 pp.

(a) "Opening Date" (Break-up),

(b) "Closing Date" (Freeze-up).

(c) "First Movement" (Freeze-up).

In Japan, Arakawa,[10] listed over five centuries of "freezing dates" and "omiwatari" (rupturing of the ice, two to three days after an ice cover is established, due to thermal expansion and contraction) for Lake Suwa. No mention was however made regarding the precise definition of "freezing dates."

It is readily conceivable that there exist both national and international variations regarding definitional criteria for break-up and freeze-up dates.

In addition, numerous studies (e.g. Arakawa,[11] Eriksson,[12] and Bunge and Bryson[13]) have neglected to define these terms precisely.

With this state of affairs, not only is the validity of the individual studies somewhat reduced, but also comparisons between their findings are rendered difficult.

These records however, especially those that go back to the pre-instrumental era, are of invaluable climatological significance.

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10. Arakawa, H., "Fujwhara on Five Centuries of Freezing Dates of Lake Suwa in Central Japan," Archiv fur Meteorologie, Geophysik und Bioklimatologie, Serie B, Vol 6, 1954, pp. 152 - 166.

11. Ibid.

12. Ericksson, J. V., "Ice Cover and Break-up in Sweden's Inland Lakes," in SIPRE Report 12, Vol. 11, "Annotated Bibliography on Snow, Ice, and Permafrost," U.S. Army Corps of Engineers, p. 228.

13. Bunge, William W. Jr., and Bryson, Reid A., ibid.

If suitable methods are applied to standardize them, their importance can be preserved. Catchpole et al[14] have suggested content analysis as a method for the identification of the dates of first freezing and first breaking from the historical records. Similar methods can be applied to the more recent records as kept by the Canadian Meteorological Service.

4.3 Listing of Definitions by Canadian Meteorological Service

The first attempt at recording break-up and freeze-up dates by the Meteorological Branch of Canada was initiated by Burbidge and Lauder in 1957 (cir. 2939).[15] They commented that:

> It has been very difficult to arrive at any universal definitions of the terms "Break-up" and "Freeze-up." In most cases "Break-up" is considered to be the date when the ice moves in a river, or clears from the shores of a lake, and this was the definition accepted and applied herein. "Freeze-up" can be defined as the date when ice forms and begins to grow, but can sometimes be listed as the time when skim ice or slush

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14. Catchpole, A.J.W., Moodie, D.W., and Kaye, B., "Content Analysis: A Method for the Identification of Dates of First Freezing and First Breaking from Descriptive Accounts," Reprinted from The Professional Geographer, Vol. XX11, No. 5, September, 1970, pp. 252 - 257.

15. Burbidge, F.E., and Lauder, J.R., "A Preliminary Investigation into Break-up and Freeze-up Conditions in Canada," Meteorological Branch, Department of Transport, Canada, cir. 2939, Tec. 252, July 1957.

ice first forms. In the opposite extreme, some observers do not believe that the "Freeze-up" is official until the ice is thick enough to walk on with safety. In this study all three definitions of "Freeze-up" are considered, but in the preparation of maps, the date of first ice formation has been used.

In this preliminary report, there appears to be two definitions for break-up and three for freeze-up.

In 1959 however, the Meteorological Branch published an official list of break-up and freeze-up dates for 87 rivers and 113 lakes, bays and harbours.[16] In the abstract of this publication, the following reference was made regarding the definitions of break-up and freeze-up:

> The information on break-up indicated the date on which the ice first moved or showed signs of breaking, and also the date on which the water was entirely clear of ice. Similarly for freeze-up, the date on which ice first formed and the date on which the body of water was completely frozen over was listed.

Within the text of the publication however, the following standard definitions of break-up and freeze-up were given for both rivers and lakes. Two dates were supplied for each event.

First Break-up Date
"First appearance of breaks or movement of the ice."

Second Break-up Date
"Complete clearing of ice from the water."

First Freeze-up Date
"First appearance of ice in the fall."

Second Freeze-up Date
"Complete ice coverage."

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16. Meteorological Branch, Department of Transport, Canada, "Break-up and Freeze-up Dates of Rivers and Lakes in Canada," cir. 3156, Ice - 2, January, 1959.

In addition however the dates contained in 20 of the freeze-up, and 35 of the break-up tables were obtained using criteria other than the definitions stipulated above. In some cases however, the departure from the standard definition merely involved neglect of either the initial or the terminal definition.

Alternative definitional criteria for first break-up date:

a. Fort Simpson on Liard R., N.W.T., Norman Wells on MacKenzie River, N.W.T.
"initial movement of ice."

b. Ft. Good Hope on MacKenzie R., N.W.T.
"initial breaking of ice."

c. Smokey Falls on Mattagami R., Ont.
"on which the ice was broken and commencing to move freely."

d. McMurray on Clearwater R., Alta.
"first movement of the ice."

e. The Pas on Saskatchewan R., Man.
"on which the ice began to break."

f. Swift Current on Swift Current Creek, Sask.
"on which the ice first moved."

g. North Bay on L. Nipissing, Ont., Trenton on Trent R., Ont. Saskatoon on South Saskatchewan R., Sask.
"on which the ice began to break-up."

h. Dawson on Yukon R., Y.T.
"on which the river ice began to break."

i. Whitehorse on Yukon R., Y.T
"on which the river ice commenced to break-up."

Alternative definitional criteria for second Break-up date.

a. Churchill on Churchill R., Man.
"river ice essentially clear."

b. Chatham on Miramichi, N.B.
"river was more or less clear of ice."

c. Ottawa on Rideau R., Ont.
"the dates of peak water flow at which time the river is usually clear of ice."

d. Lake Ecorses, Que., Lake Megantic, Que.,
"on which the lake was clear of ice."

e. Winnipeg on Red. R. Man., Cambelltown on Restigouche R., N.B., Quebec on St. Lawrence R. Que.
"on which the river was clear of ice."

f. Kapuskasing on Kapuskasing R., Ont.
"on which the river was completely clear of ice."

g. Lake Alex, Chicontimi, Que.
"complete clearing of the lake."

In addition, a number of dates based upon highly vague criteria were given. It is confusing to determine what phase of the process they refer to. These are as follows:

a. Peace River on Peace R., Alta
"on which the ice moved out of the river."

b. Lake Christina, Grand Forks, B.C.
"on which the lake opened."

c. Kimberly on Elk R., B.C.
"dates of spring break-up."

d. Quesnel on Fraser R., B.C.
"the opening of the channel."

e. Selkirk on Red R., Man.
"'break-up' of ice."

f. Southbank on Francois L., B.C.
"on which the lake 'broke-up'."

g. Yellowknife on Gt. Slave Lake, N.W.T.
"ice break-up dates."

h. Penticton, Okanagan L., B.C.
"no appreciable ice."

In a limited number of cases, these events were dated using criteria involving navigation. They are listed as follows:

a. Amundsen G on Holman Island, N.W.T.
"The approximate times when the ice was well broken and spread over a large area so that small boats could be used without hinderance or danger."

b. Fort Resolution, Great Slave L., N.W.T.
"are approximate only, being derived from boat arrivals and other happenings."

c. Chicoutimi on Saguenay R., Que.
"opening of the Chicoutimi Harbour to navigation."

d. Churchill on Churchill R., Man.
"opening of the harbour at Churchill to navigation."

e. Fredericton on Saint John R., N.B.
"opening dates of the Saint John River to navigation."

f. Three Rivers to Montreal on St. Lawrence R., Que.
"on which the river was considered sufficiently clear for navigation."

g. Charlottetown Harbour, P.E.I.
"on which the first ship entered Charlottetown Harbour."

h. The Pas, Grace L., Man.
"operation of float-equipped aircraft began."

i. Yellowknife, Great Slave L., N.W.T.
"on which the first boat arrived at Yellowknife."

j. Kenora, L. of the Woods, Ont.
"opening of navigation on the lake."

k. Port Arthur and Port William Harbours, L. Superior, Ont.
opening of navigation in Port Arthur and Fort William Harbours. Ice conditions at the time of opening vary only slightly from year to year and are indicated as being - - - "A clear channel 200 feet wide extending from the harbour out to open water with the harbour otherwise plugged with ice to the Welcome Islands (4 to 6 miles from shore) with drifting ice to Thunder Cape and Pie Island (9 to 15 miles from shore)."

Alternative definitional criteria for first freeze-up date:

a. Hope on Fraser R., B.C.
(i) "drifting ice appeared."
(ii) "fast ice beginning to form."

b. Amundsen G., Holman Island, N.W.T.
"first formation of ice."

c. L. St. John, Que.
"ice first formed on the lake."

d. Chatham on Miramichi R., N.B.
"the initial formation of ice."

Alternative definitional criteria for second freeze-up date.

a. Athabasca on Athabasca R., Alta., Winnipeg on Red. R., Man.
"complete freeze-over of the river."

b. Deer Lake, Deer L., Nfld., Chicoutimi
L. Kenogami, Que., Banff, L. Minnewanka, Alta.,
L. Winnipeg (South of the Narrows) Man.
Whitehorse on Yukon R., Y.T.
"completely frozen over."

c. Montreal, L. St. Louis, Que.
"complete freeze-over except for a narrow channel which often remains open."

d. Cornerbrook, Humber Arm, Nfld.
"on which the Humber Arm from Lark Harbour to Humbermouth was frozen over."

As in the case of break-up, the following dates, based upon highly vague definitional criteria, were supplied:

a. Kimberly on Elk R., B.C.
"approximate dates of freeze-up, the stage of the process being unspecified."

b. Pagwa on Pagwachuan R., Ont.
"dates, obtained from elderly trappers, Indians etc., are approximate only."

c. Baker Lake, Baker L., N.W.T.
" dates of 'freeze-up'."

d. Charlottetown, Charlottetown Harbour, P.E.I.
"dates on which the harbour buoys are lifted because of the formation of slush ice."

e. Grand Forks, Christina L, B.C.
"on which the lake "froze'."

f. Resolute, Resolute B. N.W.T.
"dates are approximate."

Similarly, dates relating to navigation or ice trafficability, were given. These are as follows:

a. Athabasca on Athabasca R., Alta.
"time when the ice was safe for crossing on foot."

b. Churchill on Churchill R., Man.
"the closing of Churchill Harbour to navigation."

c. Fredericton on Saint John R., N.B.
"the closing of Saint John River to navigation."

d. Three Rivers to Montreal on St. Lawrence R., Que.
"on which the Channel was closed to navigation."

e. Yellowknife, Great Slave L., N.W.T.
"on which the last boat of the season departed from Yellowknife."

f. Port Arthur and Fort William Harbours, L. Superior, Ont.
The closing dates of navigation in Port Arthur and Fort William Harbours. Ice conditions at the time of closing may vary greatly from very little ice to a considerable amount. Average ice conditions are indicated as being "about 8 inches of ice in the Kaministiquia R. and 6 to 8 inches of ice in Port Arthur Harbour."

In 1964, another publication (cir. 4116 Ice-17)[17] of break-up and freeze-up dates in Canada was released by the Meteorological Branch. In it was contained data from 274 locations relating to 97 rivers and 231 other bodies of water.

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17. Allen, W.T.R., "Break-up and Freeze-up Dates in Canada," Meteorological Branch, Department of Transport, Canada, cir. 4116, Ice 17, Oct. 1964.

Break-up and freeze-up dates are defined in the following manner:

Break-up Dates
There is no universally recognized definition of the term "break-up." However, it may be thought of as a process which extends over a period of days or weeks, commencing when the ice in a river or lake begins to move, break, or deteriorate; and ending when the water is completely free of all ice. The first date (1) given in the tables, therefore, marks the beginning of the process. In the case of rivers, it is usually evidenced by a definite breaking or movement of the ice brought about by the weakening of the ice due to initial melting, currents, and a rise in water level due to runoff. The date of this initial ice movement is reported. On lakes, where there is normally a lack of currents, and ice movement depends to a large extent on wind action, the ice may melt in situ, exhibiting little movement. In this event, the approximate date on which the first signs of deterioration occured, is recorded. Visual evidence of initial deterioration is given by surface melting of the ice, the appearance of a narrow lead of open water along the shore, or open water areas offshore. Where the body of water does not freeze over completely during the course of a winter, and there is a varying ice coverage throughout the winter, the date of the commencement of the break-up has little significance.

The second date (2) under "Break-up" is the date on which the body of water is first observed to be entirely clear of ice, and remains clear thereafter. This date marks the end of the break-up process. Many bodies of water in northern Canada do not become completely free of ice during the short summer season. In this event, the date of minimum ice coverage is given. When the percentage of open water present on this date is known, it is given in brackets after the date. Otherwise, the occurence of incomplete clearing is indicated by means of a footnote.

Freeze-up dates
There is no universally recognized definition of the term "freeze-up". However, it may also be thought of as a process extending over a period of days or weeks. It commences with the appearance of ice crystals on the water surface, and ends when the body of water is completely frozen over, except perhaps in the occasional case of isolated areas which may remain open all winter due to the effect of rapids, waterfalls, or other natural or man-made causes. This final stage of the process will be referred to as "freeze-over".

The first date (1) given under "Freeze-up" is the date on which ice was first observed on the water surface, and remained thereafter. Ice may have formed and melted again one or more times prior to the date indicated, and if these occurences are reported by the station, they are mentioned in a footnote.

The second date (2) given under "Freeze-up" is the date of freeze-over, i.e., the date on which the water was first observed to be completely frozen over. There are many bodies of water in southern Canada, especially southern British Columbia, which rarely freeze over completely. If reported by the station, the date of maximum ice coverage, followed by the percentage of ice cover in brackets is given. Otherwise incomplete freeze-over is indicated by means of a footnote.[18]

Apart from these specified definitions, however, there appear in the text of the publication, 39 alternative definitional criteria for break-up dates and 18 for freeze-up dates.

Alternative definitional criteria for Break-up I:

a. <u>Atlin, B.C.</u>
"ice moving."
"

b. <u>Fort Mcpherson, N.W.T.</u>
(i) "ice broke"
(ii) "ice went out"

c. <u>Roberval, Que.</u>
"on which the water level began to rise, indicating start of spring runoff."

Alternative definitional criteria for Break-up II:

a. <u>Cape Young, N.W.T.</u>
"Ice broke away from shoreline."

b. <u>Chapais, Que.</u>
"some ice still remaining."

c. <u>Fort Providence, N.W.T.</u>
"Date last drift ice from Great Slave Lake seen."

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18. Allen, W.T.R., pp 2-3

d. Hall Beach, N.W.T.
"the first occasion on which the water, as seen from the station was ice free."

e. Prince Albert, Sask.
"river was clear of ice except for floating pieces."

Apart from these, several other definitions that referred to neither of the specified break-up processes, or which were inadequately defined, were given. These are as follows:

a. Aklavik, N.W.T.
(i) "ice went out of river".
(ii) "shore ice breaking".
(iii) "ice going out".
(iv) "Liard going out".
(v) "Mackenzie coming down".
(vi) "ice cracked three miles above settlement".
(vii) "ice running".

b. Boiestown, N.B.
"ice-run records for the Boiestown area. The dates presumably refer to a time when the ice is broken and moving downstream."

c. Cambridge Bay, N.W.T.
(i) "water on ice".
(ii) "lake throwing water".
(iii) "Dease straight ice still solid".
(iv) "Dease straight opened up".
(v) "water on ice".
(vi) "bay clear of ice".
(vii) "three to four inches of water on bay ice".
(viii) "bay ice breaking rapidly".

d. Fort St. John, B.C., Kimberly, B.C., Lethbridge, Alta., Summerside, P.E.I., Resolute, N.W.T.
"approximate dates".

e. Fort Simpson, N.W.T.
"movement of ice above the mouth of the Liard River".

f. Grand Forks, B.C.
"lake 'opened'".

g. Holman, N.W.T., Isachsen, N.W.T., Resolute, N.W.T., Medicine Hat, Alta., Wabowden, Man., Wagner, Alta., Plaster Rock, N.B.
"'Break-up' (undefined)".

h. Mayo, Y.T.
(i) "river out".
(ii) "river ice moving".

i. Mont Joli, Que.
"ice last seen".

j. Lake Ontario at Point Petre, Ont.
"ice last observed".

k. Smokey Falls, Ont.
"on which the ice was broken and starting to move freely over and through the dam at Smokey Falls".

l. Southbank, B.C.
"date Broke-up".

m. Holman, N.W.T.
"conditions when ice well broken and spread over large area".

In addition the following navigational dates were substituted for the specified break-up dates:

a. Cambridge Bay, N.W.T.
"first boat from King William Island".

b. Charlottetown, P.E.I.
"on which the first ship entered Charlottetown Harbour".

c. Fort William, Ont., Trois Rivieres, Que.
"opening of navigation".

d. Kenora, Ont.
"on which lake open to navigation".

Alternative definitional criteria for Freeze-up I:

a. Aklavik, N.W.T.
"first ice on river" .

b. Bagotville, Que.
"appreciable ice formation".

Alternative definitional criteria for Freeze-up II:

a. Aklavik, N.W.T.
"river frozen across".

b. Sault Ste. Marie, Ont.
"partial clearing and refreezing after these dates".

As in the case of break-up, several other definitions that were vague and that did not refer to either freeze-up process were found. These are as follow:

a. Atlin, B.C.
"lake 'closed'".

b. Fort Mcpherson, N.W.T.
"ice 'set fast'".

c. Fort St. John, B.C., Horton R., N.W.T.
Kimberly, B.C., Lethbridge, Alta., Resolute, N.W.T.,
Septiles, Que., Shepherd Bay, N.W.T., Shingle Point, N.W.T.,
Yorkton, Sask.
"approximate dates".

d. Grand Forks, B.C.
"lake 'froze'".

e. Holman, N.W.T., Resolute, N,W,T.,
Wagner, Alta., Plaster Rock, N.B.
"'freeze-up' (indefined)".

f. Mayo, Y.T.
(i) "river almost full of ice".
(ii) "river closed".

g. Mont Joli, Que.
"ice first seen".

h. Lake Ontario at Point Petre, Ont.
"ice first observed".

i. Southbank, B.C.
"date froze".

In addition, the following navigational and ice trafficability dates were used instead of the specified freeze-up dates.

a. Cape Harrison, Nfld., Clyder R., N.W.T.
Frobisher Bay, N.W.T.
"ice safe for men on foot".

b. Charlottetown, P.E.I.
"on which harbour buoys were lifted because of the formation of slush ice".

c. Fort William, Ont., Trois Rivieres, Que.
"closing of navigation".

d. Yellowknife, N.W.T.
"last boat arrival".

The most recent publication on break-up and freeze-up dates of water bodies in Canada was issued by the Meteorological Branch in 1971 (CLI -1-71).[19] This report contains all the information presented in the two previous publications (cir. 3156 and cir. 4116) and recent data up to the 1969-70 ice season. The following additional data are also given:

1. Dates regarding ice trafficability.

2. Dates of other specified events relating to freeze-up and break-up.

3. Information on water bodies that do not freeze over or clear completely.

4. Information on ice thickness.

This publication contains information received from 318 stations, reporting on 458 water bodies, not all different. In addition, data for 13 locations along the St. Lawrence Seaway in Ontario and Quebec are also included.

In this case, the data are arranged in such a way that there are not any specified definitions of break-up or freeze-up. Instead, the dates of the various events in the formation and disintegration of

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19. Allen, W.T.R., and Cudbird, B.S.V., "Freeze-up and Break-up Dates of Water Bodies in Canada," Canadian Meteorological Service, CLI -1-71, Toronto, 1971, 144 pp.

ice are given approximately in the order in which they occur during the ice season. These are as follows:

a. First Permanent Ice
"The dates in this column are those on which new ice first formed on the water surface and did not melt completely again until its final deterioration during break-up of the following year."

b. Complete Freeze-Over
The date given is the earliest date on which the water body was reported to be completely covered by ice, or was completely covered except for small open areas in rapids or near waterfalls, or near the outlets of power or industrial plants, which normally remain ice-free all winter. Such localized open water areas will normally comprise less than 5 per cent of the visible surface of the water body.

c. Incomplete Ice Coverage
Many water bodies in southern Canada, and especially southern British Columbia, have little or no ice during the winter, or in many years do not freeze-over completely. This column provides information, when available, on the extent of the ice coverage on the water body in these cases where the freeze-over was not complete.

Furthermore, a number of coded specifications describe the extent of incomplete ice coverage (See Appendix 11A).

d. Ice Safe for Traffic
When the information is available, this column normally contains a date on which the ice sheet was considered, in the opinion of the observer or other local persons, to be safe for use by various types of traffic or was first used by such traffic.

The significance of this date is further coded by the type of traffic for thich the ice was used. (See Appendix 11A).

e. Other Date with Respect to Freeze-up
"The dates given in this column apply to specific events associated with or brought about as a result of the freeze-up process, or refer to various descriptions of the ice conditions as given in the original reports."

The event or conditions referred to by the date is given by the coded specifications given in Appendix 11A.

f. Maximum Ice Thickness
"The greatest reported thickness attained by level, undisturbed portions of the ice sheet during the winter season are presented."

A further subdivision is used to indicate the ice thickness, the method of determination, and the units in which the thickness are originally reported (See Appendix 11A).

g. Ice Unsafe for Traffic
When the information is available, this column normally contains a date on which the ice was considered, in the opinion of the observer or other local persons, to be unsafe for use by various types of traffic; or was last used by such traffic.

Additional specifications indicate the type of traffic for which the ice was used (See Appendix 11A).

h. First Deterioration of Ice
The information on the deterioration of ice presented in this column is intended to be the earliest date during the final thawing period of the winter season (if more than one occurred), on which there were definite indications that the ice was beginning to melt. This date marks the beginning of the break-up process, which may be manifested by a definite movement of the ice, or the formulation of cracks, leads or open water areas in the ice, all the result of weakening of the ice due to melting. On most lakes, where there is very little current to move the ice, initial evidence of melting may be the the formation of pools of melt water on the ice surface.

i. Water Clear of Ice
The date given is the earliest date on which the water was reported to be completely free of all floating ice, and remained so until the following freeze-up. Some reports indicated that the water was clear of ice except for a few scattered pieces.

j. Incomplete Ice Clearance
Many water bodies in northern Canada often do not become

completely ice-free during the short summer season. This column provides information, when available, on the extent of the clearing of ice from the water body when the clearing was not complete. A date, when given, is either the date of maximum open water, or the date on which a given extent of open water occurred.

Again coded specifications are used to describe the extent of incomplete clearing of the ice (See Appendix 11A).

In addition, the extent of incomplete clearing in tenths of the water surface free of ice, is given (See Appendix 11A). In the case of salt water bodies, only the clearing of the sea ice is estimated. The presence of ice of land origin (ice bergs, growlers, etc.) if any, is not taken into account.

k. Other Date Relating to Break
"The dates given in this column apply to specific events associated with or resulting from the break-up process, or refer to various descriptions of the ice conditions as given in the original reports."

The event or condition referred to by the date is given by a list of coded specifications (See Appendix 11A).

In this last publication, alternative definitional criteria do not appear. Instead of specifying events and giving alternative criteria, the Meteorological Branch arranged the data under 11 headings and 84 sub-headings. This in fact turns out to be the greatest number of definitions allotted to both events thus far.

Upon examining the standard instructions for observing break-up (form no. 63 - 2360)[20] and freeze-up (form no. 63 -

20. Meteorological Branch, Department of Transport, Canada, "Report on Break-up and Water Bodies," Form No. 63 - 2361, (Rev. 69).

2361),[21] as stipulated by the Meteorological Branch, one discovers that the following dates are the most important ones requested.

<u>Break-up (Form no. 63 - 2360)</u>
1. The earliest date on which there were definite indications that the ice was beginning to melt.

2. The date on which the water body was observed, or reliably reported, to be finally clear of all ice.

<u>Freeze-up (Form no. 63 - 2361</u>
1. The earliest date on which new ice of any amount, formed anywhere on the water surface.

2. The first date on which ice formed and did not consequently melt.

3. The earliest date on which the water body was observed, or reliably reported, to be completely covered by ice.

None of the Meteorological Branch publications however, attempted to specdifically list all these dates. Moreover, there seem to be variations of definitions referring to initial freeze-up date and final freeze-up date. Similarly for initial break-up and final break-up. This is clearly obvious from the following table (Table 4.1).

It is evident from the following table, that in some cases even the stipulated definitions of break-up and freeze-up have changed from one publication to the next.

In the case of Break-up I the 1959 and 1964 definitions seem to agree with each other. The 1971 report however stipulates that this process occurs "during the final thawing period." The 1957 publication

21. Ibid, "Report on Freeze-up of Water Bodies," Form No. 63 - 2360, (Rev. 69).

Table 41 Specified Break-up and Freeze-up Events in the Meteorological Records

EVENT	Year of Publication			
	1957	1959	1964	1971
Break-up 1	The date when ice moves in a river or clears from the shores of a lake.	First appearance of breaks or movement of the ice.	The date on which the ice begins to move, break, or deteriorate.	The earliest date during the final thawing period when there were definite signs of melting.
Break-up 2	None	Complete clearing of ice from the water.	The date on which the body of water is first observed to be entirely clear and remains clear thereafter.	The earliest date on which the water was reported to be completely free of all floating ice and remains so until the following freeze-up.
Freeze-up 1	The date when ice forms and begins to grow or when skim or slush ice first forms.	The first appearance of ice in the fall.	The date on which ice was first observed on the water surface and remained thereafter.	The date on which new ice formed on the water surface and did not melt completely again.
Freeze-up 2	The date ice is thick enough to walk on with safety.	The date of complete ice coverage	The date on which the body of water is first observed to be completely frozen over.	The earliest date on which the water body was reported to be completely covered by ice.

on the other hand does not differentiate between break-up 1 and break-up 2.

As for break-up 2, the 1964 and 1971 reports specify final clearing of the water body, whereas the 1959 report does not.

Similarly for freeze-up 1, there is agreement between the 1964 and 1971 reports. But they are different from both the 1957 and 1959 reports. The 1964 and 1971 data refer to the second freeze-up date given above (form No. 63-2361) while the 1957 and 1959 data refer to the first.

Finally, in the case of freeze-up 2 the 1964 and 1971 data are again similar. The 1959 data however does not specify whether it is the "earliest date" of complete freeze-over. On the other hand the 1957 data relates to ice trafficability conditions.

4.4 Sources of Data

One essential characteristic of accurate and meaningful data collection whether it be climatological or otherwise is uniform and standardized observational personnel. Different observers with diverse backgrounds and interests introduce a fair amount of subjectivity into the recorded data (See Ch.111),which in turn militates against the desired uniformity.

This fact has been the case with the Meteorological Records of break-up and freeze-up dates. In the 1957 report, information was received from the following sources:[22]

22.Burbidge, F.E., and Lauder, J.R., p 2.

1. Directory of Hinterland Aerodnomes, published by the R.C.A.F..

2. "Dates of Break-up and Freeze-up of Rivers and Lakes in Canada," (unpublished), by W.T.R. Allen.

3. Northern Transportation Company, N.W.T..

4. Canadian Pacific Airlines, Northern Alberta and N.W.T..

In the 1959 report it was mentioned that data was obtained from a wide variety of sources including station meteorological records, newspaper files, power companies, public utility companies, harbour commissions, transportation companies, church missions, R.C.M.P., other governmental agencies, and many private companies and individuals.[23]

The 1964 report however is the most elaborate, as far as information on the source of data goes. For the 328 sites listed in it, 295 different sources of data are given. A list of these sources of information are given in Appendix 11B.

Finally, the 1971 report contains all information presented in the previous publications, and recent data up to the 1969 - 70 ice season. One would therefore expect the sources of data to be as equally diversified as in the previous reports.

4.5 Site Specification

Site conditions are an important feature of climatological observations. In order to obtain comparable sets of data observation sites should be standard and uniform. However, within the publications of break-up and freeze-up dates by the Meteorological Branch, little or no mention is made of site conditions. Only once was it mentioned that these events are observed "in the immediate vicinity of meteorological stations."[24]

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23. Meteorological Branch, (abstract).

24. Meteorological Branch, (abstract).

Furthermore, site conditions are not defined. Site conditions for break-up and freeze-up are known to vary considerably. Because of local effects that are induced mainly by river or lake morphology break-up or freeze-up patterns vary from site to site and from year to year.[25] Also man-made conditions such as sewer outlets and river or lake damming can create site peculiarities.

The meteorological records on break-up and freeze-up also contain evidence of changes in site for a particular station. The following are some of the site changes noticed:

1. Saguenay R. at Chicoutimi, Que. (cir. 3156, p. 23).
2. Amundsen G. (King's Bay) at Holman Island, N.W.T. (cir. 3156, p. 72).
3. Georgian B. (North Channel) at Gore Bay, Ont. (cir. 3156, p. 77).
4. Ottawa, Ottawa R., Ont. (cir. 4116, p. 117).
5. Winnipeg, Red R., Man. (cir. 4116, p.181).

Because of the fact that there are no designated observers, and no specified site conditions, it is suspected that there are a lot more changes in site than those recorded.

Finally, the network of observational stations has been noted to change continuously. Ever since observations on break-up and freeze-up began, stations have been continuously added or or deleted. The following table summarizes these changes.

In Table 4.2, the high value of 106 for the number of stations deleted (1961 - 1970) could be due to missing dates for this

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25. Williams, G.P., "Break-up and Control of River Ice," N.R.C., Div. of Bldg. Research, Ottawa, 1970, p. 1.

Table 4.2 Changes in Network Pattern:
Break-up and Freeze-up Dates Canada.

Years	No. of Stations	no. of Stations Added	no. of Stations Deleted
Pre 1900	15	5	0
1901 - 1910	19	4	0
1911 - 1920	25	6	1
1921 - 1930	40	16	0
1931 - 1940	72	32	0
1941 - 1950	138	66	4
1951 - 1960	306	172	71
1961 - 1970	386	151	106

period. The values for the earlier decades however present a justifiable case of station network changes.

4.6 Missing Dates

Missing dates are a common feature of the meteorological records of break-up and freeze-up dates. This arises mainly from the lack of any designated observers for these events. Routine and continuous reports are therefore lacking. Part of this shortcoming can also be attributed to the array of definitions for each event; a date for one definitional criteria is usually substituted by another.

The accompanying table gives an example of missing dates, as contained in the most recent meteorological publication (CLI -1 - 71).[26] It presents a summary of missing dates that fall under the following definitional criteria:

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26. Allen, W. T. R., and Cudbird, B. S. V., 1971, 144 pp.

Table 4.3: Missing Dates of Break-up and Freeze-up, Canada

Total No.	First Permanent Ice		Complete Freeze Over		First Deterioration of ice		Water Clear of ice	
of Possible Dates	No. of Dates Missing	Percent Missing	No. of Dates Missing	Percent Missing	No. of Dates Missing	Percent Missing	No. of Dates Missing	Percent Missing
6229	3635	52	3213	46	3581	51	2796	40

1. First permanent ice.
2. Complete freeze over.
3. First deterioration of ice.
4. Water clear of ice.

These were selected because they appear to be the events specified by the Meteorological Branch (Forms no. 63-2361 and 63-2360).

It is readily apparent that about half the possible number of dates is missing in all four cases. Most of these however are substituted by alternative definitional criteria. This therefore reverts back to the problem of different definitions dealt with in section 2.

4.7 Conclusion

It transpires from the preceding sections, that the records of break-up and freeze-up, as published by the Meteorological Branch, Canada, and as encountered in some of the academic literature are highly inconsistent as far as definitional criteria go. This can be attributed mainly to the complexity of both processes (See Ch. V) and the inefficient methods of observation.

Each process extends over a period of days or weeks, with no systematic progression of events. This time duration is due mainly to the reversible nature of both processes. Mainly because of variable weather conditions the freeze-up and break-up process is usually reversed several times during a particular season. This gives rise to a series of cycles or part-cycles, depending on what stage of the process reversal occurred.

Furthermore, within each cycle or part-cycle, there are several component phases that extend along a continuum, for each process, Different descriptions are usually attached to these several phases by the different observers. Usually an isolated description is taken to refer to the integral process "break-up" or "freeze-up". Because of these factors, an array of definitions is usually encountered for each process.

Standardized definitions, even when given, as by the Meteorological Branch, are difficult to isolate, especially with untrained observers, because of perceptual problems (See Ch. 111). This brings us to the problem of economic costs. Highly trained observers, employed on a full-time basis at all stations, and following standardized procedures can very likely obtain accurate records. Cost factors will however militate against this, especially in isolated northern communities. It must not also be forgotten that these events occur only once during the year.

Cheaper observational methods, at least in the long run, such as systematic aerial photography, may yield as accurate, if not better, records. This will however introduce a change in observational procedure. Hence the continuity of records will be affected.

This just happens to be one of the disadvantages of technological progress. In all progressive societies perfection is constantly being sought after. In the wake of this search, there inevitably follows change. Methods of recording break-up and freeze-up dates, among other climatological data collecting techniques, need to be updated. The internal consistency of some forms of data may be affected, but at least they will be more worthwhile.

CHAPTER V

Statistical Evidence of Inhomogeneity

5.1 Preliminary Remarks

The processes of break-up and freeze-up are, like temperature and precipitation, significant and observable physical events. The factors that control the observation of these natural phenomena though are more numerous and complex. However, they can be conveniently summarized under the following two general headings:

(1) Climatological

(2) Hydrological

Climatological factors by nature extend homogeneously over broad geographical areas.

Hydrological factors on the other hand, though spatially heterogeneous by nature, maintain an element of permanence and consistency (Ch. 2). Similar physical and environmental conditions can therefore be expected to exist over extended geographical areas from year to year.

As a result it would be reasonable to assume that stations within appropriately defined geographic regions, recording specified break-up and freeze-up events, ought to concur in both sense and magnitude (Murray Mitchell, 1953).[1]

On the basis of the afore-mentioned hypothesis, the dates of break-up and freeze-up at adjacent stations should consist of a rela-

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1. Mitchell, J. Murray, "Observed Secular Temperature Trends," Journal of Meteorology, Vol. 10, August 1953, pp. 244 - 261.

tively homogeneous series. The objective of this study is to examine the degree to which the dates recorded by The Canadian Meteorological Service (CL1 - 1 - 71)[2] satisfy this assumption. The pursuit of this objective will lead through several phases.

5.2 Definition of Break-up and Freeze-up

Since the terms break-up and freeze-up can take on a series of meanings or can refer to any one of several phases of each process (See Ch. 4), it is essential to specify each term. A listing of the processes and their appropriate definitions that are to be examined are presented in the following table.

TABLE 5.1

DEFINITION OF PROCESSES

Process	Definition
Freeze-up I	.First Permanent Ice
Freeze-up II	.Complete Freeze-over
Break-up I	.First Deterioration of Ice
Break-up II	.Water Clear of Ice

5.3 Selection of Stations

In order to carry out any meaningful test of relative homogeneity comparative sets of data are basically essential. Spatial comparability has already been outlined and satisfied on the basis of assumption (5.1). As for temporal comparability, it has been found through a close and systematic scrutiny of the meteorological records, that a time-span

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2. Allen, W. T. R., and Cudbird, B. S. V., "Freeze-up and Break-up Dates of Water Bodies in Canada," Canadian Meteorological Service, CL1 - 1 - 71, Toronto, 1971.

of fourteen years (1956 to 1969) offers the most viable length of period. This is due mainly to the varying periods of coverage, and missing dates. Additional stations with longer records are also analysed in order to verify the results obtained by using a small sample size.

5.4 Network Specification

As has been mentioned already, this study is seeking a measure of spatial homogeneity for break-up and freeze-up dates. In order to test for such, it is necessary to have a network of stations that are linearly related. A map of Canada therefore with the selected stations (See Fig. 5.2) is divided into what can be appropriately termed hydro-climatic regions (See Fig. 5.5 and 5.6). This is done separately for rivers, and lakes. The boundaries for these regions are established on the basis of similiarity of regional climate (See Fig. 5.4) and location within the same drainage basin (See Fig. 5.3). As for rivers, major drainage divides are the main criteria used to delimit each region. This is similarly done for lakes. In the latter instance however, proximity of stations is also taken into consideration. Coastal stations are not included because of a lack of available data.

5.5 Data Acquisition

The data that are to be analysed herein, are extracted from the records of the Canadian Meteorological Service (CL1 - 1 - 71).[3] This publication gives the date of the month, for each particular year, that a specific break-up or freeze-up event occurs.

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3. Allen, W. T. R., and Cudbird, B. S. V., op. cit..

The dates are converted into numerical terms, namely the days' of the calendar year. These comprise the raw data to be analysed. Leap years are taken into account. The years that are to be analysed here have already been mentioned (Sec. 5.3).

5.6 Statistical Analysis

The dates of break-up and freeze-up as previously defined are extracted from the Meteorological records (CL1 - 1 - 71). These are then coded (See Appendix 3) and subjected to statistical analysis. The method of analysis used is the simple correlation technique from which r (the product moment correlation coefficient) is derived. This is done using pairs of observations within each hydro-climatic region, for each type of water body.

Correlation analysis seems to be the most meaningful statistical tool that can be used here. Apart from being simple and easy to manipulate, it serves as a valid test of homogeneity or association between two comparable series of observations, provided that the basic assumptions are satisfied (Conrad,[4] Gregory,[5] and MacKay[6]).

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4. Conrad, V. and Pollak, L. W., Mèthods in Climatology, 2nd. ed. rev., Harvard University Press, Cambridge, Massachusetts, 1950, Ch. VIII.

5. Gregory, S., Statistical Methods and the Geographer, Longmans, 1963, Ch. 11.

6. MacKay, D. K., "River and Ice Conditions in the Nelson River Drainage System," Geographical Paper No. 34, Geogr. Br., Dept. of Mines, Ottawa, 28 pp..

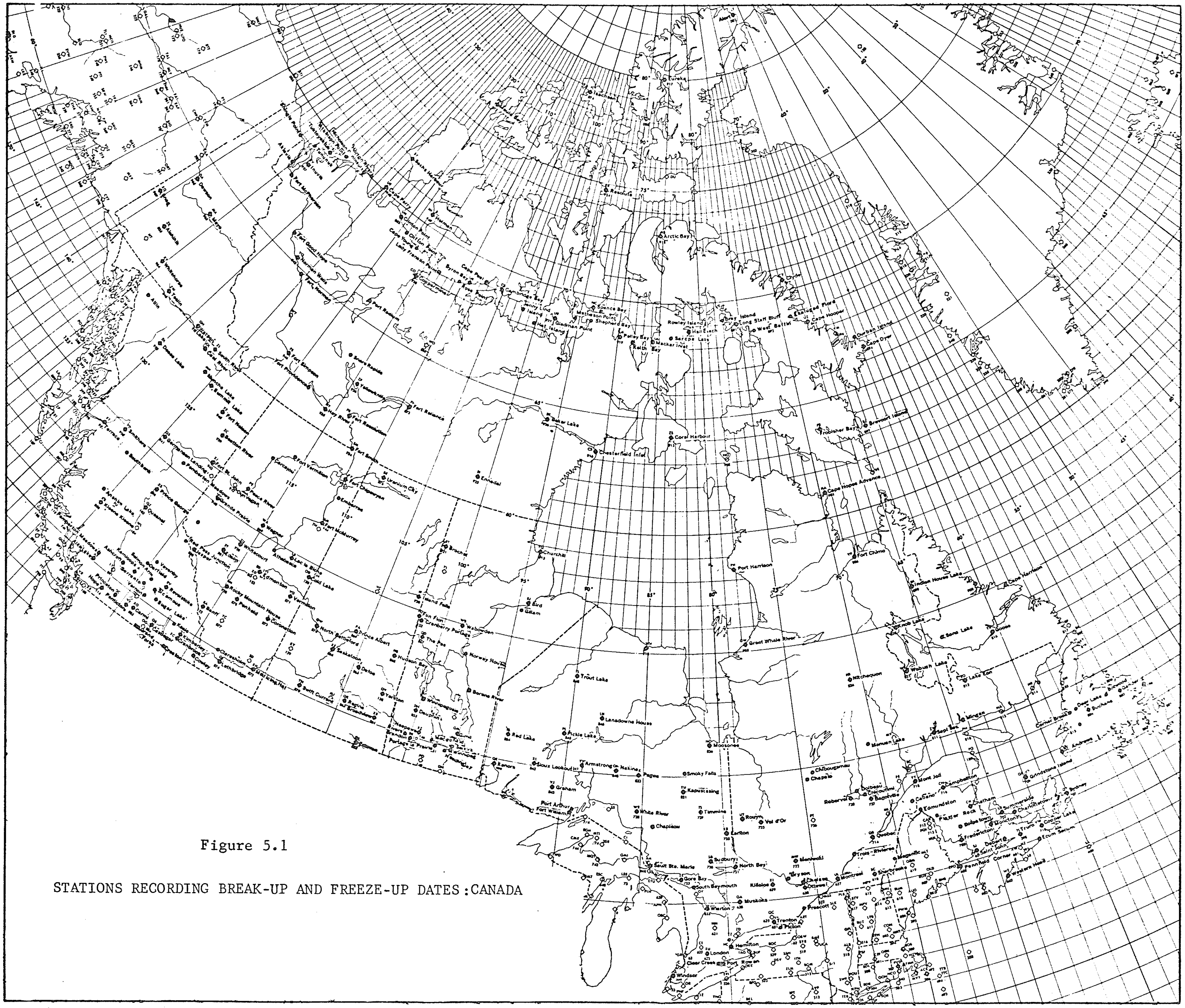

Figure 5.1

STATIONS RECORDING BREAK-UP AND FREEZE-UP DATES:CANADA

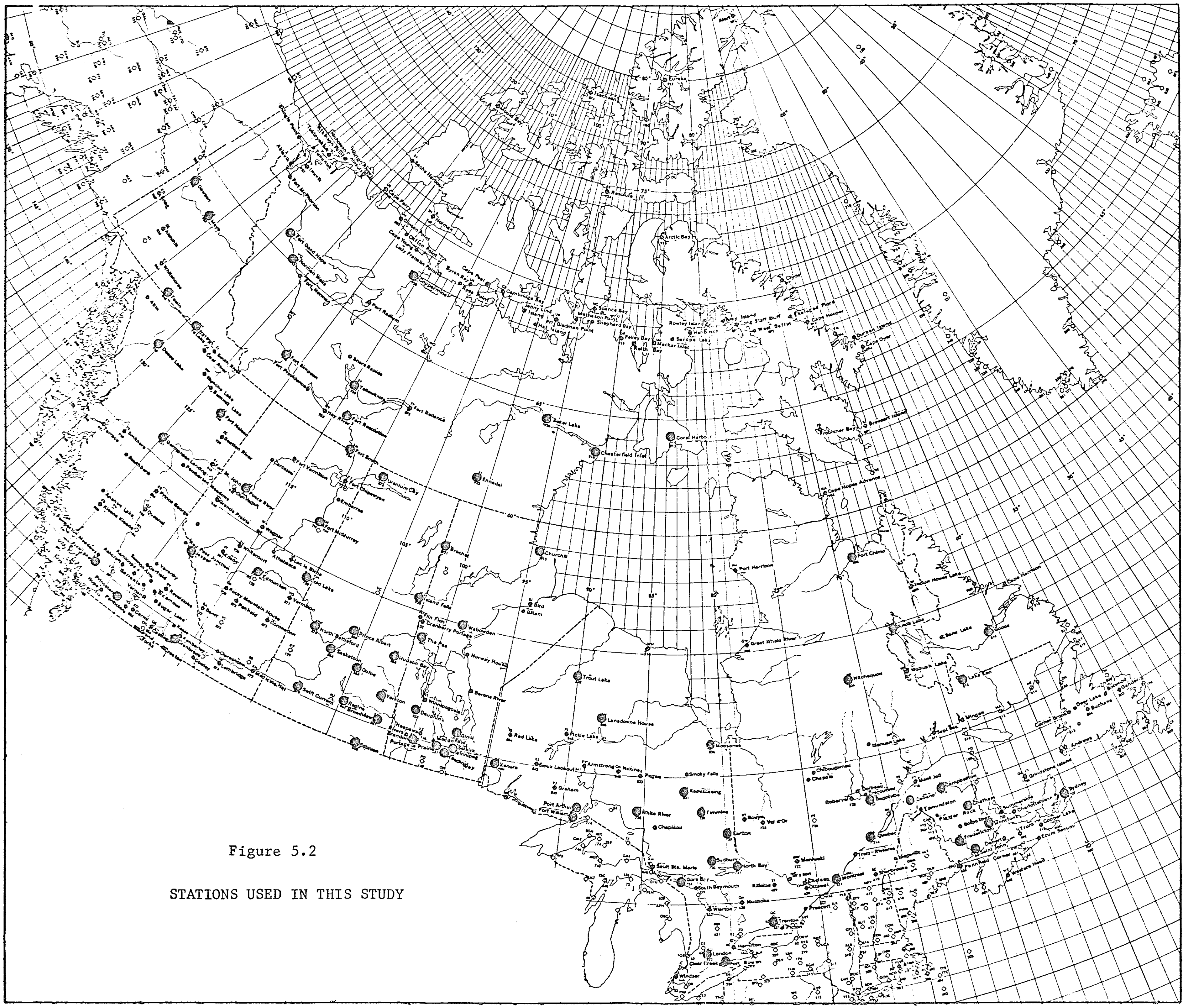

Figure 5.2

STATIONS USED IN THIS STUDY

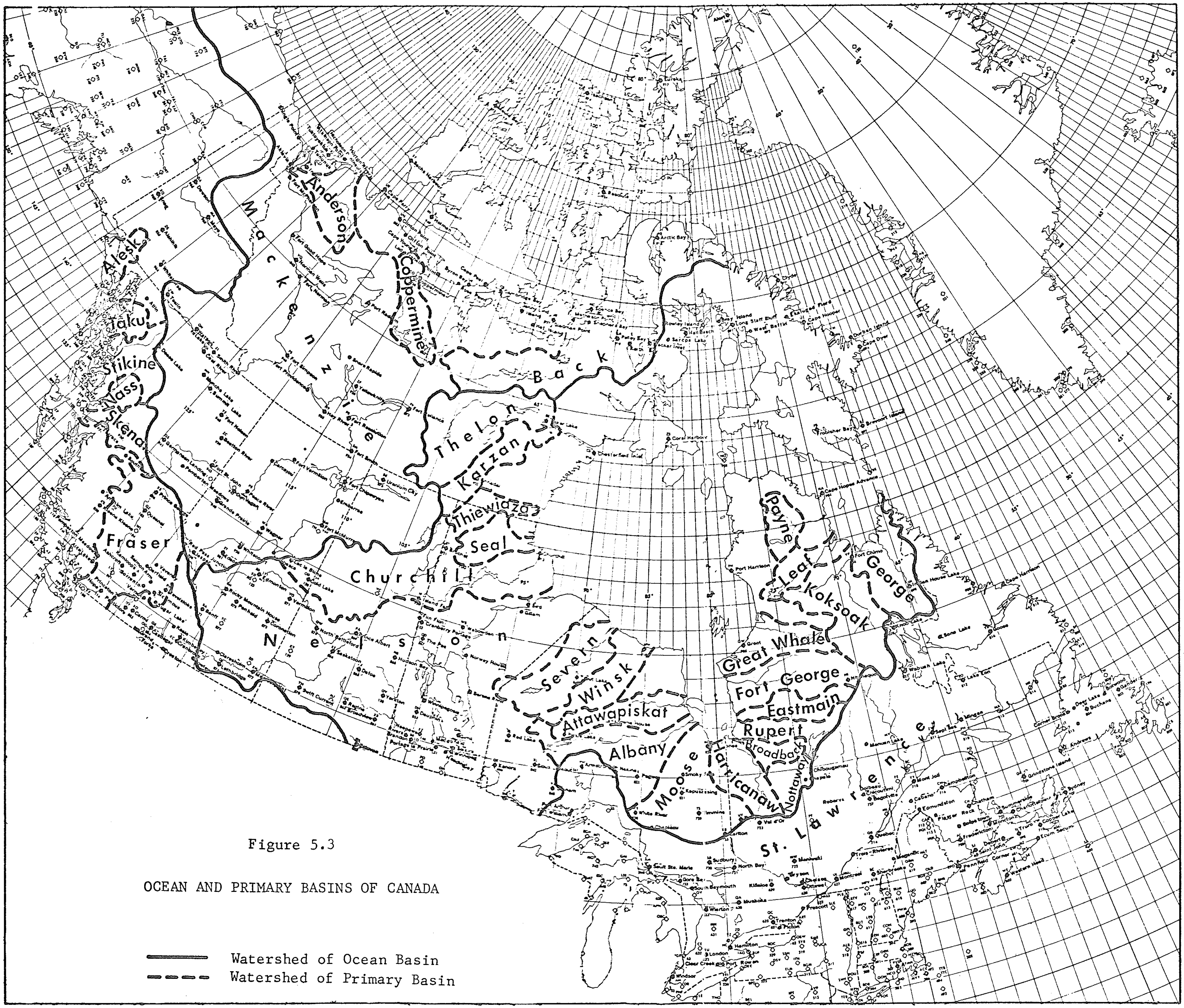

Figure 5.3

OCEAN AND PRIMARY BASINS OF CANADA

Source: MacKay, D.K., "Characteristics of River Drainage and Runoff in Canada," Geogr. Bull., Vol.8, No. 3, 1966, p 218.

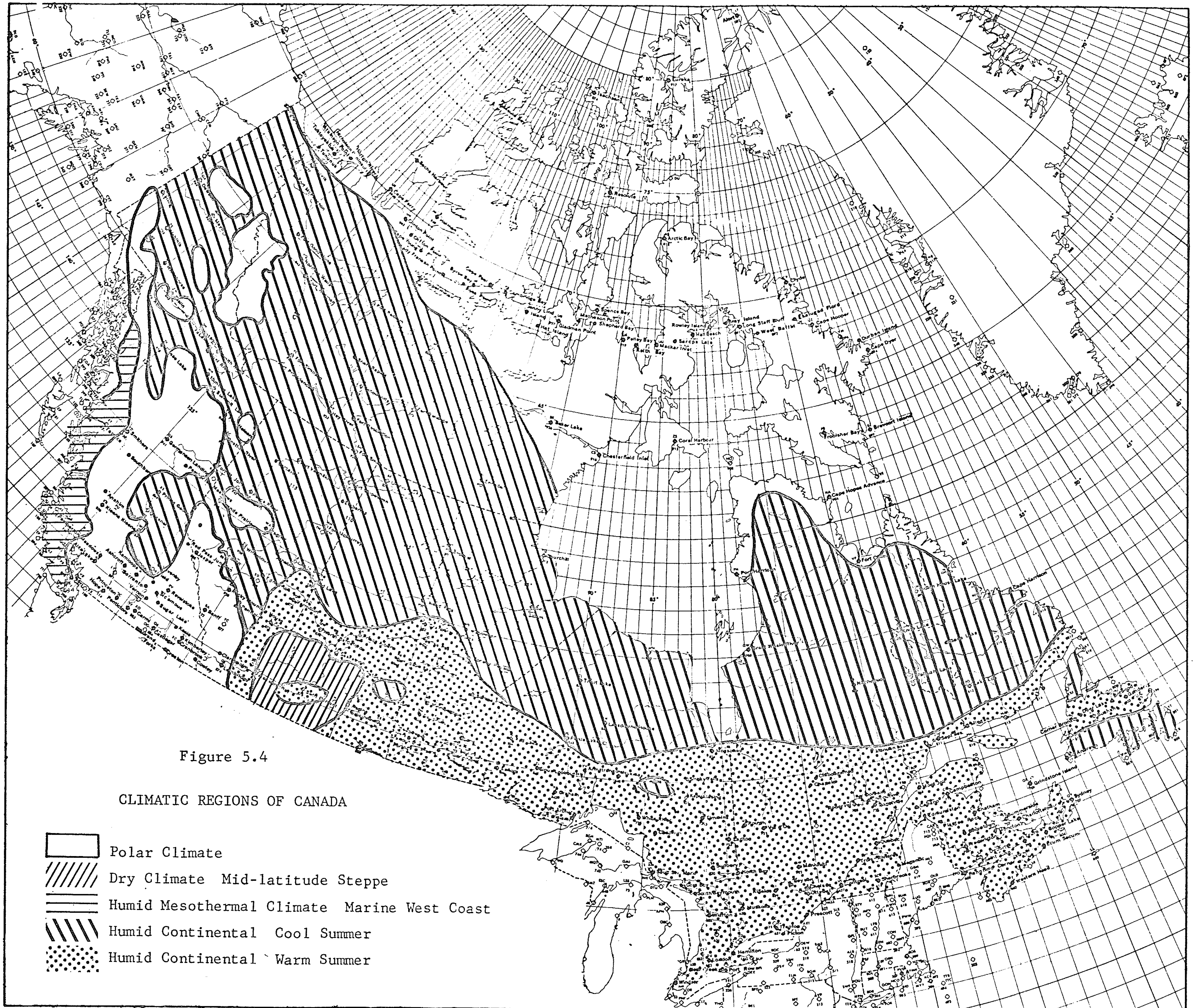

Figure 5.4

CLIMATIC REGIONS OF CANADA

Source: "Atlas of Canada," Dept. of Mines and Tech. Surveys, Geogr. Branch, Ottawa, 1957, p30.

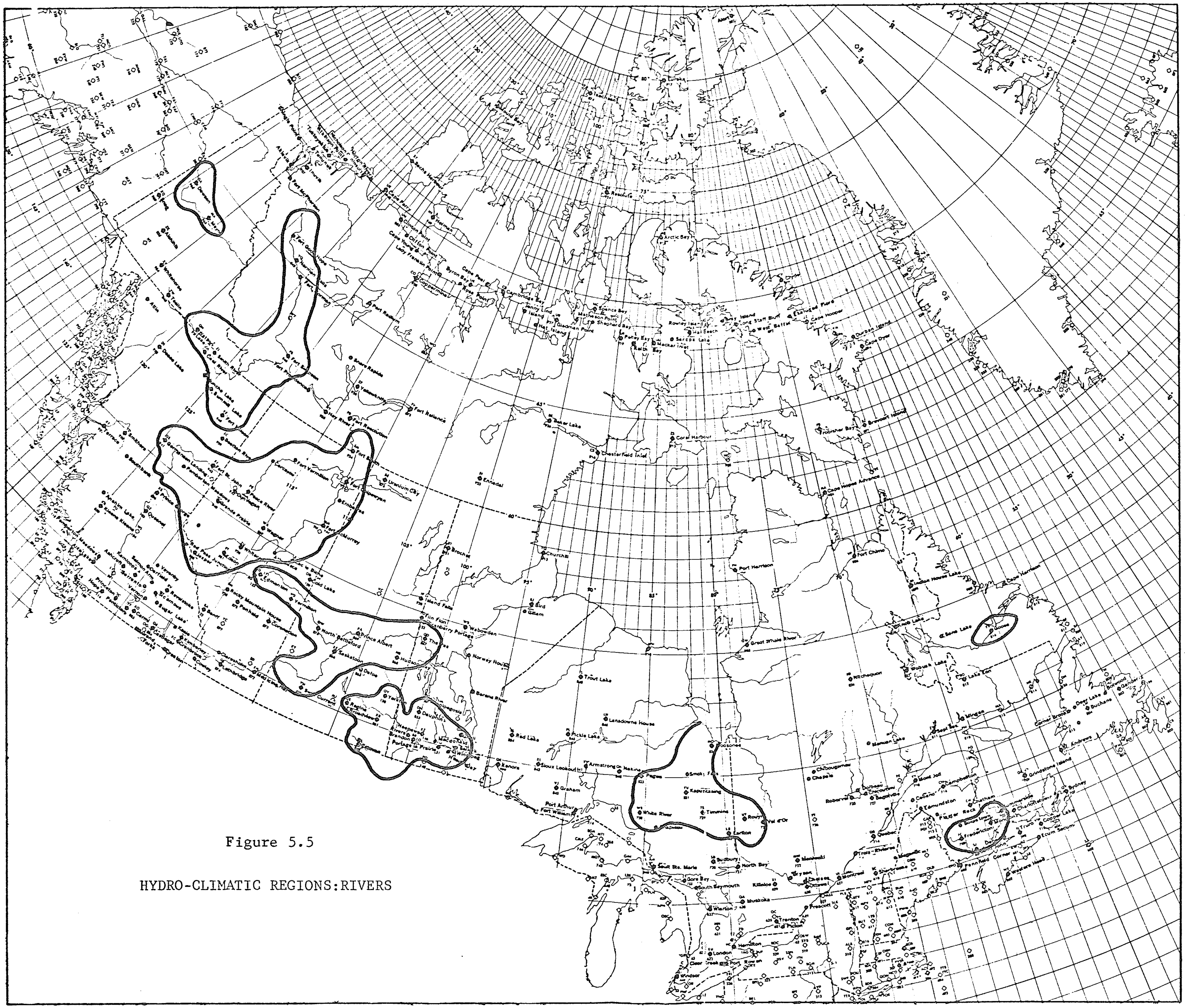

Figure 5.5

HYDRO-CLIMATIC REGIONS:RIVERS

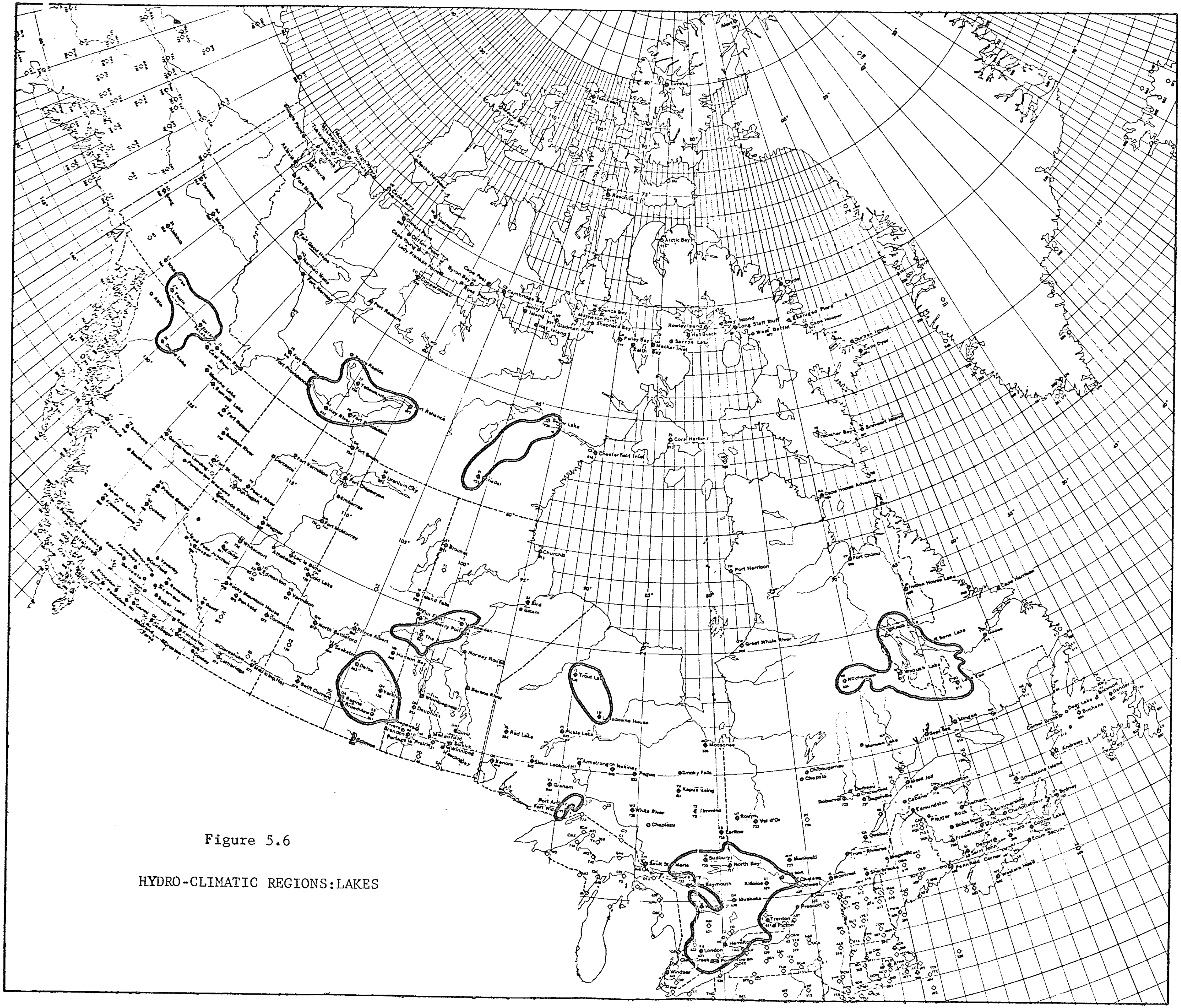

Figure 5.6

HYDRO-CLIMATIC REGIONS:LAKES

It is assumed that the data for pairs of stations fits the model for the bivariate normal distribution. Thus a linear relationship can be expected between stations (Steele and Torre)[7]. This is justified by the fact that the event of break-up or freeze-up at each station, is independent of that at any other station. Furthermore, each event, at each particular site, is considered as a random occurrence. Finally it is assumed that pairs of observations should covary or correlate significantly, in that they are related to a third common random variable, namely hydrologic and climatic conditions.

The model for correlation analysis can be expressed mathematically in the following manner:

$$r = \frac{1}{n-1} \sum \underline{x_i\ y_i} \qquad (5.1)$$

where

r = sample correlation coefficient

n = sample size

and $\underline{x_i\ y_i}$ = standardized deviations of observations (dates) from their means. Similarly for the population, the correlation coefficient ρ (rho) has the same definition and interpretation as the sample correlation r. Thus by analogy with

(5 - 1),

$$\rho \triangleq \frac{1}{N} \sum_{i=1}^{N} \underline{x_i}\ \underline{y_i} \qquad (5-2)$$ [8]

7. STEEL, Robert G. D. and TORRIE, J. H., Principles and Procedures of Statistics, McGraw Hill Book Co. Inc., New York, 1960, Ch. 10.

8. WONNACOTT, Ronald J. and WONNACOTT, Thomas H., Econometrics John Wiley and Sons, Inc., New York, 1970, Ch. 5.

where $\underline{x_i}$, $\underline{y_i}$ are appropriately standardized population values, and N is the population size.

To test whether pairs of observations are significantly correlated, that is whether they form a relatively homogeneous series the student's t - distribution is used. The test has the following mathematical expression:

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

when r = sample correlation coefficient n = sample size. The null hypothesis can be stated as

$$Ho: \rho = o.*$$

Acceptance of the null hypothesis means that there is no linear relationship between pairs of variables (stations). Rejection of the null hypothesis gives the opposite result. At the five percent level of significance, and with n-2**(12) degrees of freedom, the critical r- value is found to be 0.53 (Fisher and Yates)[9]. Since we are seeking a measure of the positive linear relationship between pairs of stations, only those r- values $\geq$ 0.53 are considered as significantly correlated.

The following tables gives a summary of the r-values for the several pairs of stations examined and the percentage of those that correlate significantly.

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* ρ = population correlation coefficient.

** n = sample size (14 years).

9. FISHER, K. A. and YATES, F., Statistical Tables for Biological Agricultural and Medical Research, 4th ed., Oliver and Boyd, Edinburgh, 1953, p. 54.

TABLE 5-2

SUMMARY OF CORRELATION ANALYSIS

Water Body	Pairs of Stations	No. Significant	Percentage(%)
Rivers	123	51	41.5
Lakes	62	29	46.8
Total	185	80	43.2

TABLE 5-3

PERCENTAGE OF STATIONS SIGNIFICANTLY CORRELATED: RIVERS.

Process	Pairs of Stations	No. Significant	Percentage(%)
Freeze-up 1	31	9	29.0
Freeze-up 11	28	7	25.0
Break-up 1	28	16	57.1
Break-up 11	36	19	52.8

TABLE 5-4

PERCENTAGE OF STATIONS SIGNIFICANTLY CORRELATED : LAKES

Process	Pairs of Stations	No. Significant	Percentage(%)
Freeze-up 1	11	2	18.2
Freeze-up11	19	8	42.1
Break-up 1	7	2	28.6
Break-up 11	25	17	68.0

In order to validate the results presented in tables 5-2, 5-3, and 5-4, a further number of pairs of stations, where the data permits, with longer (20 years and over) periods of record are examined. Stations are again selected on the basis of comparable periods of observations and proximity to stations similarly located.

This selection of stations however does not lend itself to the type of regional classification mentioned previously (5.4). Station networks that are approximately similar are however established. The boundaries for these are derived using the same type of criteria as was adopted earlier (5.4). Because of the fewer number of stations, both rivers and lakes are grouped within the same hydro-climatic regions (See Fig. 5.7).

Twenty eight pairs of stations for both rivers and lakes are examined. This is also done for the different stages of each process as outlined in section 5.1. However, only seven of the pairs of stations dealt with here belong to the group analysed earlier. (Table 5.2).

The following table summarizes the results of the present analysis.

TABLE 5-5

Correlation Analysis for Stations with long records (20 years and over): Rivers and Lakes

Process	No. of Pairs of Stations	No. Significant	%age	Previous %age	No. Belonging Previous Hydro-Climatic Regions	No. Significant
Freeze-up 1	3	2	66.6	23.6	1	1
Freeze-up 11	6	2	33.3	33.5	2	1
Break-up 1	7	4	57.1	42.9	3	2
Break-up 11	12..	12	100.0	60.4	1	1
Total	28	20	71.4	40.1	7	5

The results presented in table 5-5 are very much in agreement with those mentioned earlier (tables 5-2, 5-3 and 5-4). For each process, similar percentages of stations correlate significantly. The discrepancies between previous and present results for Freeze-up 1 and Break-up 2 can be due to differences in sample size and the different pairs of stations considered. The latter observation would seem to suggest regional variations of accuracy of recording these dates. Also, out of the five stations belonging to the previous hydro-climatic regions (5.4) that correlate significantly here, three of these had produced similar results in the previous analysis.

From the foregoing, one can safely assume that the small sample sizes considered earlier (Tables 5-2, 5-3, and 5-4) do not statistically invalidate the results obtained.

5.7 Summary and Conclusions

The results presented in the previous section (5.6) show that, on an over-all basis, only about fifty percent of the pairs of stations examined, correlate significantly. From a statistical point of view, this percentage can even be lower, if the confidence level (0.05) is reduced (Sec. 5.6).

Correlation analysis of break-up and freeze-up dates presents statistical evidence of inhomogeneity among break-up and freeze-up dates for Canadian stations. On the other hand, in certain cases (Freeze-up 11 and Break-up 11), the dates for lakes show a closer relationship than those for rivers (Tables 5-3 and 5-4). This could be due to the elimination, in some cases, of the hydrological control, namely water flow which

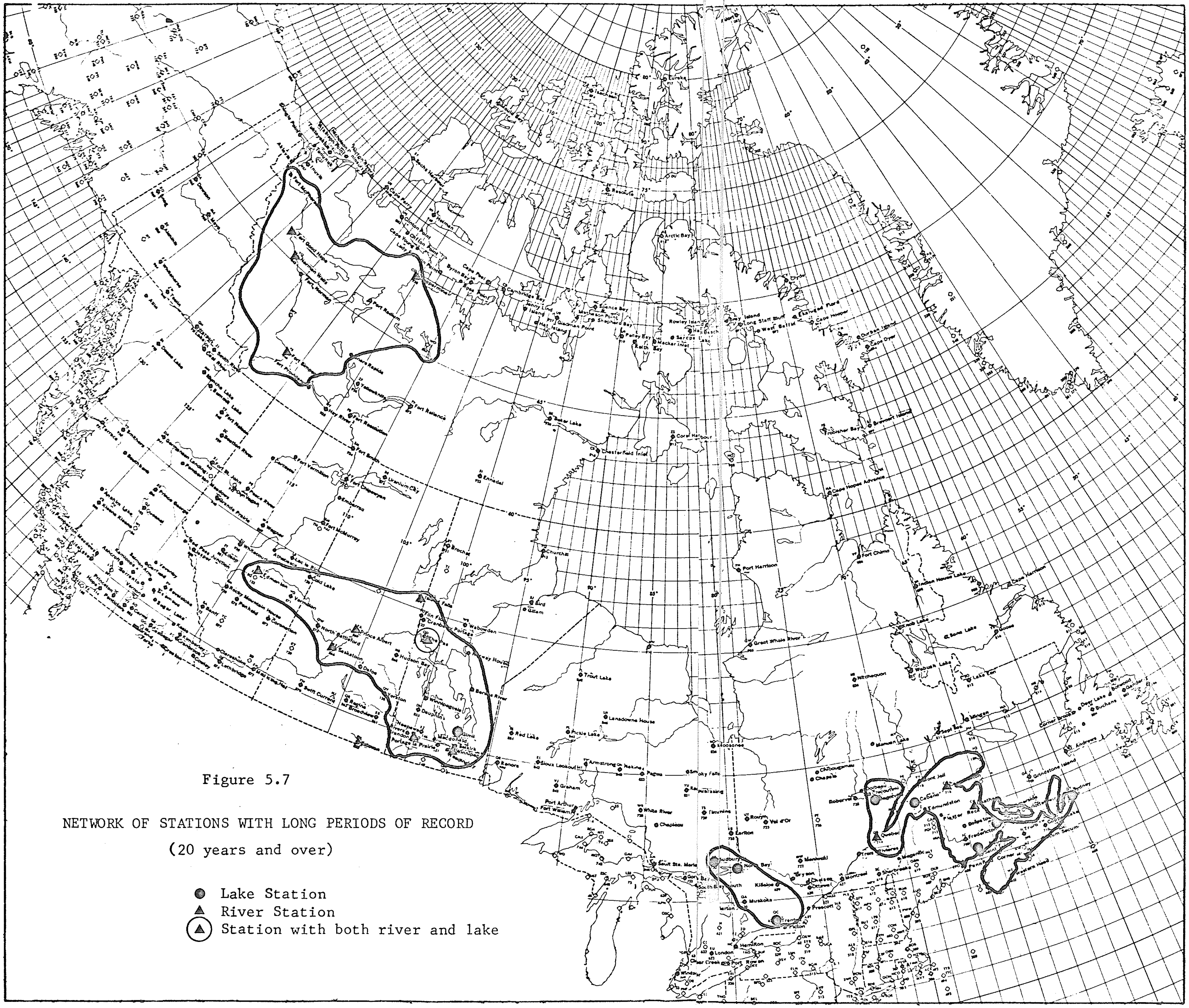

Figure 5.7

NETWORK OF STATIONS WITH LONG PERIODS OF RECORD
(20 years and over)

- Lake Station
- River Station
- Station with both river and lake

tends to complicate perception of the processes.

The evidence as presented in tables 5-3, 5-4, and 5-5 would also seem to suggest that the accuracy of the recorded dates depends on the extent of their tangibility. This is particularly true in reference to Break-up 11 (water clear of ice.) This is an easily perceived process, when compared to Freeze-up 1 (First Permanent Ice) or Break-up 1 (First Deterioration of Ice).

In concluding, one can state that there is a substantial verification of inhomogeneity of break-up and freeze-up dates among Canadian stations. It would not therefore be entirely unreasonable to suspect a significant amount of systematic observational error.

CHAPTER VI

Conclusion

6.1 Summary

The previous chapters have attempted to outline the inconsistencies inherent in the break-up and freeze-up data as recorded by the Canadian Meteorological Service. A wide range of applied research has utilized these dates. Very little attention however has been devoted to examining their validity.

There are numerous problems associated with recording break-up and freeze-up dates. These are due mainly to the nature of the physical processes (Ch. 11), observational problems (Ch. 111), and variations of definitional criteria (Ch. 1V). As a result of these, two main sources of error are incorporated into the recorded data.

The first type of error is related to the inter-play between the environment and the observer; there is a certain amount of variance between the natural date and the recorded date. This can be appropriately referred to as random measurement error. The second type of error is associated with the differences among observers, and the varying definitional criteria adopted, at the different stations. These can be conveniently grouped under the heading of systematic observational error.

These sources of error render a certain measure of inaccuracy to the observed dates of freeze-up and break-up, especially for purposes of spatial and temporal comparability.

Statistical analyses of these dates show that in a large number of cases, there tends to be a certain degree of inhomogeneity among neighbouring stations (Ch. V). As was mentioned previously, a significant portion of this incoherence can be attributed to measurement problems arising from the intengible nature of the physical processes, definitional problems and observer subjectivity.

Problems of measurement, when recording data of this nature are to be expected. But if standardized methods of data collection are adopted error variance can be substantially reduced.

6.2 Recommendations

With reference to the problems and inconsistencies outlined previously, a number of improvements and innovations can be recommended. These are suggested as a means of acquiring more reliable and meaningful dates of freeze-up and break-up for Canadaan stations.

The major area of improvement seems to concern definitional criteria. Standard definitions as have been attempted already (Forms Nos. 63-2360 and 63-2361),[2] should be established and adhered to.

These should also be so designed as to make their perception as tangible and conspicuous as possible, in relation to the observational methods used. Mechanical definitions, as suggested by

1. Meteorological Branch, Dept. of Transport, Canada, "Report on Break-up of Water Bodies," Form No. 63 - 2360, (Rev. 69).

2. Ibid, "Report on Break-up of Water Bodies," Form No. 63 - 2361, (Rev. 69).

MacKay[3] (See Ch. 111) offer a viable alternative.

Methods of data collection also seem to be deficient in a number of respects. Observation personnel could be uniformly trained, so as to reduce observer subjectivity. Also representative and amenable station sites should be selected and maintained. The times of recording data should also be standardized. It would seem as if the early morning, just after sunrise, and the late afternoon, just before sunset, could be appropriate times.

Other more sophisticated, but more costly observational procedures could also be adopted. Remote sensing, employing time-lapse aerial photography could be useful in this respect. Critical stages of each process that could be easily detected by the air-borne scanners should however be established. Infra-red photography in particular, could be advantageously employed here. The use of this type of measurement technique would at least reduce the effect of the subjective human element.

6.3 Suggestions for Future Research

A number of extensions to the present research can be easily suggested. This study is essentially a macro - scale one. Its limited scope militates against detailed discussion.

Micro - scale studies of the variability and complexity of break-up and freeze-up conditions, and the problems of data collection along a particular stretch of a river or lake can be justifiably attempted. The effect of local conditions on break-up and freeze-up dates can

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3. MacKay, D. K., "Trends and Factors Affecting Break-up and Freeze-up Dates in the Nelson River Drainage System," Geographical Paper No. 35, Geogr. Br., Dept. of Mines and Tech. Surveys, Ottawa, 1962, pp. 2-3.

be adequately investigated with a study of this nature.

The results of the present research seem to indicate a regional variation in the accuracy of break-up and freeze-up dates. The more accurate dates seem to be coincident with areas of concentrated population (See Figs. 5-5, 5-6, and 5-7). This type of situation could also result from the nature of the physical factors.

The rapidity of freezing or breaking which can be due to latitudinal climate or hydrologic factors, can also affect the accuracy of the recorded dates: the shorter the time extent of the process, the less will be the chances of encountering observational error. Hydrologic factors will be particularly important during break-up; the flood wave can be expected to travel at a faster rate in circular basins as opposed to linear ones.[4]

When longer periods of records become available statistical analyses that can examine the internal consistency of the data at each station can also be performed. This type of data analysis, where stations are singularly considered will not only facilitate regional comparisons of accuracy and reliability, but will also give a measure of the magnitude of the inconsistencies encountered, if any.

A final viable research topic that can be undertaken regarding break-up and freeze-up dates is separating systematic observational error from random measurement error (See Ch. 1). This can be easily manipulated through an analysis of variance technique. The different stations can be appropriately delineated as the treatments.

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4. Gray, D. M., editor, "Handbook on the Principles of Hydrology," Canadian National Committee for the International Hydrological Decade, Ottawa, 1970, Sec. Vll, .3.2.1.

APPENDIX 1

Field Observations

The following tables give a detailed account of field observations of freeze-up during the fall of 1971 and break-up for the spring of 1972. The observation site was along the Red River near the University of Manitoba, upstream from the junction with the Assiniboine. The time that field observations were made was the late afternoon (between 4 and 5 p.m.). At relevant times however, such as when initial freeze-up was approaching, early morning observations were made so as to record the effect of conditions occuring the previous night.

Occasional checks were also made along the Assiniboine River, near the Maryland Bridge and its junction with the Red, for comparable purposes.

In certain instances, where their effect was important, weather conditions were also briefly described.

Table 1.a: Daily Observations of Freeze-up, 1971

Date	Observational Reports
Nov. 1st	No signs of freeze-up. Snow lying on the banks. Rippling of the water still fairly strong. Thin films of ice (or snow?) on the Assiniboine where branches protruded in areas of stagnant water (Freeze-up 1?).
" 2nd	Same conditions as on the previous day.
" 3rd	Same conditions prevail for the Red. Floating ice of the frazil type begins to appear (Freeze-up 1 definite).

Table 1.a: Daily Observations of Freeze-up, 1971 continued

Nov. 4th	Conditions for the Red unchanged.
" 5th	Same conditions of the Red as the previous day. Weather conditions: gusting winds, cold (15^{o} - $20^{o}F$), and snowing.
" 6th	Same conditions as on the previous day. Weather conditions: cold and sunny.
" 7th	First time the Red freezes to a great extent. Thin films of ice continuosly forming and being destroyed by water turbulence. Assiniboine - complete freeze-over (Freeze-up 11), and snow-covered.
" 8th	Floating ice from upstream observed at site. Ice cover established at the edges. Weather conditions: sunny and warmer.
" 9th	First time freeze-up 11 observed (early morning). Skim ice cover prevailed. By the afternoon this was broken up. Pancake frazil ice float rapidly down the river. Rafted ice piled up at the sides from frictional effects.
" 10th	Greater concentration of ice floes. Formation of pancake ice from collision among frazil floes. Ice piled up at the sides.
" 11th	Warmer temperature conditions. Some melting, with fewer ice floes. Assiniboine still frozen over.
" 12th	Continuing warm temperatures. Very few ice floes. Appreciable fall in river level. Stranded ice floes on banks.
" 13th	Same conditions prevail. Assiniboine still completely frozen over.
" 14th	Same conditions continue to exist.
" 15th	Continuing warm weather conditions. Almost complete clearing of the Red. Only one or two isolated ice floes observed. Some ice still perched at sides, with some calving.

Table 1.a: Daily Observations of Freeze-up, 1971 continued

Nov. 16th	Warm weather conditions continue. River clear of ice in the middle. Very little ice left at sides.
" 17th	Continuing warm. Little or no ice at the sides. Light snowfall. Assiniboine still completely frozen over.
" 18th	Colder temperatures. But same conditions as previous day.
" 19th	Colder weather conditions with snowfall. Middle of the Red still ice-free. Snow accumulation at the sides. Assiniboine completely frozen over.
" 20th	Colder temperatures. Floating films of skim and frazil ice appear again. Assiniboine remains frozen over.
" 21st	Cold weather continues. Pancake ice floes are prevalent. Extension of the ice shelf from the sides inward.
" 22nd	Weather conditions: cold and windy. Skim ice and frazil floes continuosly being broken up. Piling of ice floes at the sides.
" 23rd	Sunny and warmer weather conditions. Very little floating ice. Sides still frozen over. Assiniboine remains completely frozen over.
" 24th	Red almost completely frozen over. A few open areas persist. Snowfall adding to ice cover.
" 25th	Red frozen over from bank to bank in some areas; a few open areas persist at others, especially in the middle.
" 26th	Open areas are now reduced. First time compression ridges are seen.
" 27th	Open areas in the middle down to a minimum.
" 28th	Continuing cold. Difficult to say whether open areas in middle are ice-covered due to reflectance from the snow.

Table 1.a: Daily Observations of Freeze-up, 1971 continued

Nov. 29th	Same conditions as previous day.
" 30th	Complete freeze-over clearly perceptible.
Dec. 1st.	Complete freeze-over prevails on both the Red and the Assiniboine. N.B. Observations were terminated on this date. Cold weather conditions continued and the observer was convinced that a firm ice-cover was established.

Table 1.b: Daily Observations of Break-up, 1972

Date	Observational Reports
March 12th	Warm weather conditions. Only signs of melt around drainage outlet.
" 13th	Continuing warm, some melt at the sides. Run-off from the banks observed (Break-up 1?).
" 14th	Warm weather continues. Ice cover surface begins to darken.
" 15th	Warm and cloudy. Increased darkening of snow surface. A mottled appearance sets in. More melt water at the sides.
" 16th	Warm, sunny and windy. Mottled appearance more pronounced. Amount of melt water at sides increases.
" 17th	Sunny with temperatures above freezing. Ice cover very dark and dappled. More melt water collects at the sides.
" 18th	Above freezing temperatures continue. Ice cover overlain by a bit of melt water.
" 19th	Warm and cloudy. More melt water on the surface of the ice cover.

Table 1.b: Daily Observations of Break-up, 1972

March	20th	Ice cover completely covered by melt water.
"	21st	Cooler weather. Some refreezing of melt water.
"	22nd	Warmer weather, melting resumes, a lot of melt water at the sides.
"	23rd	River level has risen. Ice cover afloat, but not moving.
"	24th	Cloudy and cooler weather. Some refreezing at the sides.
"	25th	River ice broke. Ice cracked, but no movement. Same conditions on Assiniboine.
"	26th	Same conditions on Red. Assiniboine ice broken and moved in a few places.
"	27th	Cooler weather with snowfall. Red blanketed by snowfall. Melt water only visible at edges.
"	28th	Warmer weather. More melt at the sides. River level rises.
"	29th	Windy. River level extremely high. Ice cover afloat but not moving.
"	30th	Same conditions as previous day.
April;	1st	Same conditions except for a higher river level.
"	2nd	Cooler weather sets in. Melt still prevails at the sides.
"	3rd	Below freezing temperatures. Some refreezing at the sides.
"	4th	Same conditions as on the previous day.
"	5th	Same, except for a rising river level.
"	6th	Warmer weather. Melting on surface resumes.
"	7th	Same conditions as on previous day.

Table 1.b: Daily Observations of Break-up, 1972 continued

April 8th	Surface melt extremely prevalent.
" 9th	Warmer. Extremely dark color of ice.
" 10th	Warm and windy. Quite a bit of surface melt.
" 11th	Same, except for a higher river level.
" 12th	First movement of the ice. River clear of ice at the observation site, but still ice covered by rafted ice at upstream and downstream locations.
" 13th	Same conditions, except for a higher water level.
" 14th	Same, except ice cover shoved and broken up a little more. Ice thickness - 8 - 12 inches.
" 15th	River ice begins to move. Ice floes floating rapidly, overturning, colliding and disintegrating.
" 16th	River level extremely high. Fewer ice floes. Quite a bit of floes trapped by vegetation at sides.
" 17th	One or two ice floes seen. Assiniboine still ice-covered, with no movement. Probably due to the higher level of the Red.
" 18th	Continuing warm weather and same conditions.
" 19th	Red completely clear at observation site. (Break-up 11). Assiniboine ice held up by jams.
" 20th	Red River clear. Flood wave at its peak. A few ice floes still persist on the Assiniboine.
" 21st.	Both Red and Assiniboine completely clear of ice except for ice slabs that were trapped at the sides. River level falling.
" 22nd	River level continues to fall. This was the last day of observations. The observer was convinced that all ice floes from upstream had already passed the observation site.

APPENDIX 11 A

The following are the coded specifications that further describe the character of selected definitions of break-up and freeze-up dates referred to previously (Ch. 1V).

Specification of Date Relating to Extent of Incomplete Ice Coverage

"0. No ice (or no appreciable ice) formed during the winter."

"1. Water body did not freeze over completely - date of maximum ice coverage unknown."

"2. Water body did not freeze over completely - date of maximum ice coverage."

"3. Water body did not freeze over completely - date on which given ice coverage (not necessarily maximum ice coverage) occurred."

"4. Date of complete freeze over unknown - date on which given ice coverage occurred."

"5. Ice present along shoreline only."

"6. Water body said to be "open" throughout the winter."

Extent of Ice Coverage

"0. Less than 1 tenth, but not zero."

"1. 1 tenth."

"2. 2 tenths."

"3. 3 tenths."

"4. 4 tenths."

"5. 5 tenths."

"6. 6 tenths."

"7. 7 tenths."

"8, 8 tenths."

"9. 9 tenths or more, but not 10 tenths."

Type of Traffic for which Ice was used

"0. Ice not used, or unsafe for traffic."

"1. Ice considered safe for use as road or runway - type of vehicle not specified."

"2. Ice considered safe for very light traffic (pedestrians, dog teams, snowmobiles or ski-doo type, etc.)."

"3. Ice considered safe for light vehicles (automobiles, jeeps, large snowmobiles, light trucks, etc.)."

"4. Ice considered safe for light aircraft (Cessna, Beaver, Otter, Norseman, etc.)."

"5. Ice considered safe for heavy equipment (heavy trucks, tractors, DC3 or heavier aircraft."

"6. Ice first used by very light traffic (pedestrians, dog team, snowmobiles of ski-doo type, etc.)."

"7. Ice first used by light vehicles, up to 6,000 lbs. (automobiles, jeeps, heavier snowmobiles, light trucks)."

"8. Ice first used by light aircraft up to 7,500 lbs. (Cessna, Beaver, Otter, Norseman, etc.)."

"9. Ice first used by heavy equipment, over 10,000 lbs. (heavy trucks, tractors, DC3 or heavier aircraft)."

Specification of Other Data Relating to Freeze-up

"0. 'Freeze-up', body of water 'froze', or 'frozen' - terms undefined."

"1. Water body closed to navigation."

"2. New ice formed, but later melted or cleared completely."

"3. Buoys lifted due to formation of new ice."

"4. Water body said to be 'closed' - term undefined."

"5. Last ship of season left harbour."

"6. Appreciable ice formation."

"7. Complete freeze over with subsequent partial or complete clearing, followed later by second complete freeze-over."

"8. Drifting ice first observed."

"9. Ice said to be 'running'."

"A. Ice said to be 'set fast'."

"B. Last float-equipped aircraft departed."

Indicator for Maximum Ice Thickness

"0. Inches - Unknown."

"1. Inches - Estimation."

"2. Inches - Measurement."

"3. Feet - Unknown."

"4. Feet - Estimation."

"5. Feet - Measurement."

Type of Traffic for which Ice was Used

"0. Ice not used, or unsafe for traffic."

"1. Ice considered unsafe for use as road or runway - type of vehicle not specified."

"2. Ice considered unsafe for very light traffic (pedestrians, dog team, snowmobiles of ski-doo type, etc.)."

"3. Ice considered unsafe for light vehicles (automobiles, jeeps, larger snowmobiles, light trucks, etc.)."

"4. Ice considered unsafe for light aircraft (Cessna, Beaver, Otter, Norseman, etc.)."

"5. Ice considered unsafe for heavy equipment (heavy trucks, tractors, DC3 or heavier aircraft)."

"6. Ice last used by very light traffic (pedestrians, dog teams, snowmobiles of ski-doo type, etc.)."

"7. Ice last used by light vehicles, up to 6,000 lbs. (automobiles, jeeps, heavier snowmobiles, light trucks)."

"8. Ice last used by light aircraft, up to 7,500 lbs. (Cessna, Beaver, Otter, Norseman, etc.)."

"9. Ice last used by heavy equipment, over 10,000 lbs. (heavy trucks, tractors, DC3 or heavier aircraft)."

Specification of Date Relating to extent of incomplete clearing of Ice

"0. No clearing (or no appreciable clearing) of ice."

"1. Water body did not clear completely - date of maximum open water unknown."

"2. Water body did not clear completely - date of maximum open water."

"3. Water body did not clear completely - date on which given extent of open water (not necessarily maximum extent) occurred."

"4. Date water body clear of ice unknown - date on which given extent of open water occurred."

Extent of incomplete Ice clearance

"0. Less than 1 tenth, but not zero."

"1. 1 tenth."

"2. 2 tenths."

"3. 3 tenths."

"4. 4 tenths."

"5. 5 tenths."

"6. 6 tenths."

"7. 7 tenths."

"8. 8 tenths."

"9. 9 tenths or more, but not 10 tenths."

Specification of Other Date Relating to Break-up

"0. 'Break-up', ice 'broke', or 'broken', or ice 'gave way' - terms undefined."

"1. Water body open to navigation."

"2. Partial clearing or melting of ice with subsequent refreezing."

"3. Water body cleared temporarily, but ice reformed, or drift ice reappeared later."

"4. Water body said to be 'open' - term undefined."

"5. First ship of season entered harbour."

"6. Ice said to be 'moving'."

"7. Date refers to 'ice run'."

"8. Ice 'moved out' or 'went out'."

"9. Ice moving at the Ramparts (Fort Good Hope, N.W.T.)."

"A. Channel open."

"B. Drifting ice last observed."

"C. Ice broken and moving freely over dam."

"D. First landing of float-equipped aircraft."

APPENDIX 11 B

The following list gives the sources of information regarding break-up and freeze-up dates referred to earlier (Ch. 1V). Where the observation agent has supplied data for more than one station, the number is indicated in brackets. Also, where the observer is of local concern, the place of observation is indicated.

1. Telecommunications Branch, D.O.T. (69)
2. R.C.A.F. (29)
3. Meteorological Branch (92)
4. Hudson's Bay Company, N.W.T. (5)
5. Federal Elective Corporation (31)
6. Saguenay Shipping Limited
7. Consolidated Paper Corporation (2)
8. District Warden, Banff National Park, Alta.
9. Conservation Office, Berens River, Man.
10. Miramichi Salmon Association, Boiestown, N.B.
11. Anglo-Newfoundland Development Co., Botwood, Nfld.
12. City of Brandon Water Works Department, Man.
13. Roman Catholic Mission, Brochet, Man., and Fort Good Hope and Holman, N.W.T. (3)
14. Gatineau Power Company, Que. (2)
15. Fraser Companies Limited Que. and N.B. (3)
16. Mr. J. F. J. DeGrace, Cambellton, N.B.

17. U. S. Army (6)

18. Nordair Ltd. (3)

19. Fecteau Arien Transport, Chapais, Que.

20. District Marine Agent, D.O.T., P.E.I.

21. Charlottetown Experimental Farm, P.E.I.

22. North Shore Leader, Newcastle, N.B.

23. Fisheries Research Officer, Chatham, N.B.

24. Trans-Canada Air Lines, Que.

25. Price Bros. and Co. Ltd., Que. (4)

26. Department of Resources and Hydro, Que.

27. National Harbours Board, Churchill, Man. (2)

28. Cove Fisheries, Clear Creek, Ontario

29. Canadian National Telegraphs (4)

30. Fisheries Officer, Cold Lake, Alta.

31. J. Brian Bird, Southampton Island, Q.P., N.W.T.

32. Bowaters Paper Company Limited, Nfld. (2)

33. Canadian Aviation Electronics Ltd., Man.

34. Canadian Pacific Airlines (3)

35. Personal diary, Mrs. T. Locke, Dauphin, Man.

36. Royal Canadian Corps of Signals (10)

37. St. Lawrence Corporation Limited, Dolbeau, Que.

38. Original Edmonton weather records, Alta.

39. Edmonton City Power Plant, Alta.

40. Edmonton Journal, Alta.

41. Trans-Air Limited (2)

42. Abasand Oil Co. Ltd., Alta. (2)

43. Diaries of Mr. J. Goodall, Fort Simpson, N.W.T.

44. B. C. Forrest Service, B. C. (2)

45. Manitoba Water Resources Department (2)

46. Churchill River Power Co. Ltd., Inland Falls, Sask.

47. Mrs. C. Phillips, Kamloops, B.C.

48. City of Kamloops, B.C.

49. Spruce Falls Power and Paper Co. Ltd., Ont. (2)

50. Ontario Department of Lands and Forests (4)

51. McGill University, Sub-Arctic Research Laboratory, Knob Lake, Que.

52. Menihek Power Company, Knob Lake, Que.

53. City of Lethbridge Power House, Alta.

54. Resident Engineer, Fanshawe Dam, London, Ont.

55. Aluminum Company of Canada, Manua Lake, Que.

56. Lake Megantic Pulp Co., Megantic, Que.

57. Staff of McLaughlin Road Reservoir, Moncton, N.B.

58. Imperial Oil Limited, Norman Wells, N.W.T.

59. North Bay "Nugget," North Bay, Ont.

60. Ontario Hydro (2)

61. Manitoba Telephone System

62. Gatineau Boom Company, Ottawa, Ontario

63. Superintendent Engineer, Rideau Canal, Ottawa, Ont.

64. Various local residents of Pagwa, Ont.

65. Peace River local newspaper, Alta.

66. Royal Canadian School of Artillery, Picton, Ont.

67. Personal diary of local citizens, Port Radium, N.W.T.

68. Mr. Bert Crockett, Port Rowan, Ont.

69. District Marine Agent, Prescott, Ont.

70. City of Prince Albert Fire Department, Sask.

71. Mr. D. F. Allen, Nukko Lake, B.C.

72. Marine Services, D.O.T., Que. (2)

73. City of Regina Power Plant, Sask.

74. "L'Etoile du Lac," Dec. 10, 1953, Roberval, Que.

75. Saint John City Water Department, N.B.

76. Saskatoon Municipal Water Works, Sask.

77. Iron Ore Company of Canada, Septiles, Que.

78. Sherbrooke University, Que.

79. Northwest Territories Power Commission, Snare Rapids, N.W.T.

80. Bell Telephone Company of Canada

81. St. Lawrence Seaway Authority

82. Austin Airways Limited, Sudbury, Ont.

83. Kiwanis Club, Swift Current, Sask.

84. Superintendent of Utilities, The Pas, Man.

85. Manitoba Department of Mines and Natural Resources

86. Trenton Courier-Advocate, Ont. (2)

87. Belleville Public Water Works, Ont.

88. Lock keepers of Trent Canal, Trenton, Ont.

89. Quebecair Inc.

90. Nova Scotia Power Commission and Marine Services, D.O.T.

91. Alberta Department of Highways (2)

92. White Pass and Yukon Railway, Y.T.

93. White River Air Services, Ont. (3)

94. Abitibi Power and Paper Co. Ltd., White River, Ont.

95. Provincial Fish Hatchery, Wiarton, Ont.

96. Mr. R. J. Fleming, Lighthouse keeper, Winnipegosis, Man.

97. Northern Transportation Co. Ltd., Yellowknife, N.W.T.

APPENDIX 111 A

Data Analysis

The following series of tables list the data that has been coded and subjected to correlation analysis (See Ch V). They give the date of the month and the day of the year that the specified break-up or freeze-up events have occured.

The period of record extends from 1956 to 1969. Those r-values ≥ 0.53 are considered as significant.

Data Set 1A Freeze-up I Yukon Territory - Rivers

	Dawson-Klondike R.		Mayo-Stewart R.	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	Oct. 10	284	Oct. 08	282
57	Nov. 03	307	" 21	294
58	Oct. 10	283	" 07	280
59	" 08	281	" 09	282
L 60	Nov. 01	306	" 10	284
61	" 01	305	" 07	280
L 62	" 04	308	" 10	283
63	" 06	310	" 18	291
L 64	" 10	315	" 26	300
65	Oct. 15	288	" 21	294
66	" 23	296	" 10	283
67	Nov. 05	* 309	" 14	287
L 68	" 01	306	" 17	291
69	Oct. 16	289	" 16	289

(r = 0.4569)

Data Set 2A Break-up I Yukon Territory - Rivers

	Dawson-Klondike R.		Mayo-Stewart R.	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	May 04	125	May 15	136
57	Apr 23	113	" 01	121
58	May 10	130	" 08	128
59	Apr 28	118	" 04	124
L 60	" 18	109	" 12	133
61	May 11	131	" 19	139
62	Apr 20	110	" 08	128
63	May 15	135	" 22	142
L 64	" 01	122	" 18	139
65	" 03	123	" 12	132
66	Apr 25	115	" 13	133
67	" 29	119	" 12	132
L 68	" 27	118	Apr 25	116
69	May 07	127	" 12	102

(r = 0.18841)

Data Set 2B Break-up II Yukon Territory - Rivers

	Dawson-Klondike R.		Mayo-Stewart R.	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	May 09	130	May 20	141
57	Apr 29	119	" 07	127
58	May 25	145	" 22	142
59	" 04	124	" 15	135
L 60	" 10	131	" 20	141
61	" 11	131	" 22	142
62	" 02	122	" 13	133
63	" 31	151	Ju. 01	152
L 64	" 12	133	May 22	143
65	" 11	131	" 17	137
66	" 06	126	" 22#	142
67	" 08	128	" 20	140
L 68	" 04	125	" 07	128
69	" 10	130	" 12	132

(r = 0.7869)

Data Set 3A Freeze-up I Mackenzie River (Liard) Basin

	Watson Lake		Fort Nelson		Fort Simpson		Fort Good Hope	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	*Oct. 05	279	Oct. 12	286	Oct. 06	280	Oct. 13	287
57	* " 08	281	Nov. 06	310	" 21	294	" 16	289
58	* " 08	281	" 07	311	" 24	297	" 22	295
59	* " 04	277	" 09	313	" 12	285	" 10	283
L 60	" 12	286	" 05	310	" 10	284	" 19	293
61	" 08	281	" 02	306	" 11	284	" 10	283
62	" 07	280	" 12	316	" 28	301	Nov. 03	307
63	" 05	278	" 05	309	" 26	299	Oct. 25	298
L 64	* " 12	286	Oct. 30	304	" 28	302	" 28	302
65	" 12	285	" 20	293	" 30	303	" 18	291
66	" 24	297	" 17	290	" 18	291	" 23	296
67	" 25	298	" 24	297	" 18	291	" 17	290
L 68	" 19	293	" 23	297	" 25	299	" 20	294
69	Nov. 04	308	" 18	291	" 17	290	" 24	297

Matrix of r- values

	Watson L.	Fort Nelson	Fort Simpson	Fort Good Hope
Watson L.	-	-0.5927	0.0083	0.1982
Fort Nelson	-	-	0.1823	0.1484
Fort Simpson	-	-	-	0.6739

Data Set 3B Freeze-up II Mackenzie River (Liard) Basin

	Watson Lake		Fort Simpson		Norman Wells		Fort Good Hope	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Oct. 18	292	Oct. 23	297	Oct. 29	303	Oct. 30	304
57	" 27	300	Nov. 15	319	Nov. 16	320	Nov. 16	320
58	Nov. 30	334	" 16	320	" 14	318	" 15	319
59	" 30	334	" 15	319	" 04	308	" 02	306
L 60	" 16	321	" 25	330	" 16	321	" 09	314
61	" 19	323	" 02	306	" 05	309	" 02	306
62	" 20	324	" 27	331	" 19	323	" 16	320
63	" 12	316	" 19	323	" 15	319	" 12	316
L 64	" 22	327	" 20	325	" 19	324	" 22	327
65	" 09	313	Dec. 01	335	" 06	310	" 24	328
66	" 14	318	Nov. 15	319	" 21	325	" 14	318
67	" 09	313	" 27	331	" 13	317	" 12	316
L 68	" 18	323	" 18	323	" 22	327	" 16	321
69	" 28	332	" 16	320	" 12	316	" 08	312

Matrix of r- values

	Watson L.	Fort Simpson	Norman Wells	Fort Good Hope
Watson L.	-	0.3320	0.2803	0.0865
Fort Simpson	-	-	0.5343	0.7202
Norman Wells	-	-	-	0.6310
Fort Good Hope	-	-	-	

Data Set 4A   Break-up I   Mackenzie River Basin

Year	Watson Lake		Fort Simpson		Norman Wells		Fort Good Hope	
	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Apr. 26	117	May 05	126	May 21	142	May 19	140
57	May 03	123	" 07	127	" 21	141	" 16	136
58	" 05	125	" 14	134	" 20	140	" 19	139
59	Apr. 26	116	Apr. 25	115	" 15	135	" 11	131
L 60	May 01	122	May 19	140	" 23	144	" 23	144
61	" 02	122	" 13	133	" 22	142	" 22	142
62	" 08	128	" 01	121	" 10	130	" 10	130
63	" 14	134	" 09	129	" 27	147	" 24	144
L 64	" 12	133	" 02	123	" 24	145	" 22	143
65	" 02	122	" 08	128	" 15	135	" 15	135
66	" 01	121	" 08	128	" 19	139	" 15	135
67	Apr. 20	110	" 04	124	" 21	141	" 18	138
L 68	" 10	101	Apr. 15	106	Apr. 22	113	" 09	130
69	" 13	103	" 14	104	" 12	102	" 23	143

Matrix of r- values

	Watson L.	Fort Simpson	Norman Wells	Fort Good Hope
Watson L	-	0.6739	0.7572	0.2808
Fort Simpson	-	-	0.8490	0.4051
Norman Wells	-	-	-	0.2939

Data Set 5A Freeze-up I Slave Athabasca River Basin

	Jasper		Fort McMurray		Fort Smith	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Oct. 14	288	*Nov. 04	309	Oct. 20	294
57	" 07	280	" 15	319	Nov. 06	310
58	Nov. 16	320	Oct. 11	284	" 12	316
59	" 04	308	*Nov. 05	309	Oct. 11	284
L 60	" 02	307	" 16	321	" 21	295
61	Oct. 19	292	Oct. 05	278	" 21	294
62	Nov. 17	321	Nov. 14	318	" 18	291
63	" 11	315	*Oct. 27	300	Nov. 15	319
L 64	" 10	315	" 25	299	" 17	322
65	" 12	316	Nov. 03	307	Dec. 01	335
66	" 14	318	Oct. 29	302	Oct. 27	300
67	" 26	330	Nov. 01	305	Nov. 07	311
L 68	Dec. 01	336	" 03	308	" 25	330
69	*Nov. 28	332	Oct. 23	296	Oct. 19	292

Matrix of r- values

	Jasper	Fort McMurray	Fort Smith
Jasper	-	0.1101	0.3010
Fort McMurray	-	-	0.0836

Data Set 6A Break-up I Athabasca (Peace) River Basin

Year	Germansen Landing		Peace River	
	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	May 01	122	Apr. 28	119
57	Apr. 19	109	" 12	102
58	" 26	116	" 14	104
59	" 23	113	" 16	106
L 60	" 23	114	" 20	111
61	" 28	118	" 16	106
62	" 25	115	" 17	107
63	" 23	113	" 19	109
L 64	" 15	106	" 14	105
65	" 05	95	" 05	95
66	" 24	114	" 30	120
67	" 27	117	" 22	112
L 68	" 15	106	" 14	105
69	" 16	106	" 05*	95

$(r = 0.74)$

Date Set 7A Freeze-up I Saskatchewan River Basin

Year	Swift Current		Saskatoon		Prince Albert		Hudson Bay	
	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Oct. 29	302	Oct. 29	303	Nov. 08	313	Oct. 30	304
57	Nov. 14	318	Nov. 10	314	" 08	312	" 22	295
58	" 15	319	" 12	316	" 06	310	Nov. 12	316
59	" 03	307	" 03	307	" 05	309	Oct. 29	302
L 60	" 08	313	" 07	312	" 04	309	" 20	294
61	" 15	319	Oct. 23	296	" 03	307	" 25	298
62	" 07	311	Nov. 22	326	" 15	319	Nov. 15	319
63	" 10	314	" 09	313	" 04	308	" 13	317
L 64	Dec. 12	347	" 17	322	" 13	318	" 13	318
65	Nov. 08	312	" 08	312	" 05	309	" 04	308
66	" 01	305	" 06	310	" 04	308	Oct. 31	304
67	" 25	329	" 21	325	" 01	305	Nov. 05	309
L 68	" 13	318	" 26	331	" 06	311	" 02	307
69	" 12	316	Dec. 22	356	Oct. 27	300	" 14	318

Matrix of r- values

	Swift Current	Saskatoon	Prince Albert	Hudson Bay
Swift Current	-	0.39	0.32	0.31
Saskatoon	-	-	0.16	0.56
Prince Albert	-	-	-	0.59

Data Set 7B Freeze-up II Saskatchewan River Basin

Year	Swift Current		North Battleford		Prince Albert		The Pas	
	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Dec. 04	339	Dec. 01	336	Dec. 01	336	Nov. 15	320
57	" 27	361	Oct. 22	295	Nov. 26	330	Dec. 01	335
58	Nov. 26	330	Nov. 11	315	" 20	324	Nov. 29	333
59	Jan. 04	369	Oct. 31	304	" 12	316	" 08	312
L 60	Nov. 09	314	Nov. 15	320	" 08	313	" 09	314
61	" 23	327	" 25	329	" 23	327	" 08	312
62	Dec. 29	363	Dec. 06	340	* " 17	321	" 13	317
63	" 13	347	Nov. 20	324	" 21	325	" 18	322
L 64	" 29	364	" 17	322	" 20	325	" 21	326
65	Nov. 16	320	" 14	318	* " 25	329	" 17	321
66	Jan. 22	387	" 04	308	" 11	315	" 04	308
67	Dec. 22	356	Dec. 04	338	" 20	324	" 28	332
L 68	Dec. 30	365	Nov. 11	316	Dec. 03	338	Dec. 03	338
69	Jan. 04	369	Oct. 16	289	Nov. 17	321	Nov. 18	322

Matrix of r- values

	Swift Current	North Battleford	Prince Albert	The Pas
Swift Current	-	-0.34512	-0.12437	0.02738
North Battleford	-	-	0.20143	-0.07481
Prince Albert	-	-	-	0.62080

Data Set 8B Break-up II Saskatchewan River Basin

Year	Swift Current		Saskatoon		Prince Albert		The Pas	
	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Apr. 08	99	Apr. 16	107	Apr. 24	115	May 03	124
57	" 03	93	" 09	99	" 10	100	*Apr. 09	99
58	" 10	100	Mar. 30	89	" 15	105	* " 20	110
59	Mar. 21	80	Apr. 11	101	" 15	105	" 29	119
L 60	" 31	91	" 04	95	" 20	111	May 03	124
61	Apr. 16	106	" 18	108	" 21	111	" 03	123
62	" 10	100	" 03	93	" 15	105	Apr. 20	110
63	" 09	99	" 13	103	" 14	104	" 25	115
L 64	" 14	105	* " 26	117	May 01	122	" 29	120
65	Mar. 27	86	" 05	95	Apr. 23	113	May 01	121
66	Apr. 14	104	" 29	119	May 06	126	" 16	136
67	" 06	96	* " 14	104	Apr. 13	103	Apr. 27	117
L 68	" 04	95	" 11	102	" 17	108	" 21	112
69	" 06	96	* " 22	112	" 23	113	May 11	131

Matrix of r- values

	Swift Current	Saskatoon	Prince Albert	The Pas
Swift Current	-	0.46028	0.40162	0.15921
Saskatoon	-	-	0171616	0.63228
Prince Albert	-	-	-	0.78365

Data Set 9A Freeze-up I Red Assiniboine River Basin

	Estevan		Brandon		Dauphin		Portage La Prairie	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Nov. 02	307	Nov. 15	320	Nov. 07	312	Nov. 10	315
57	Oct. 23	296	Oct. 26	299	" 08	312	" 08	312
58	Nov. 06	310	Nov. 15	319	" 14	318	" 18	322
59	" 03	307	" 07	311	" 03	307	" 04	308
L 60	" 03	308	" 10	315	" 09	314	" 10	315
61	" 03	307	" 01	305	" 02	306	" 03	307
62	" 10	314	" 20	324	" 15	319	" 07	311
63	" 10	314	" 17	321	" 05	309	" 15	319
L 64	" 16	321	" 15	320	" 18	323	" 16	321
65	" 08	312	" 08	312	" 08	312	" 08	312
66	" 03	307	" 07	311	" 01	305	Oct. 31	304
67	" 24	328	" 14	318	" 03	307	" 28	301
L 68	" 05	310	" 05	310	" 06	311	Nov. 06	311
69	Dec. 03	337	" 12	316	" 12	316	" 13	317

Matrix of r- values

	Estevan	Brandon	Dauphin	Portage La Prairie
Estevan	-	0.52816	0.27931	0.09418
Brandon	-	-	0.42042	0.38588
Dauphin	-	-	-	0.73982
Portage La Prairie	-	-	-	-

Data Set 9B Freeze-up II Red Assiniboine River Basin

	Estevan		Brandon		Dauphin		Portage La Prairie		Winnipeg	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Nov. 06	311	Dec. 04	339	Nov. 14	319	Nov. 22	327	Nov. 23	328
57	" 01	305	" 20	354	" 21	325	" 28	332	Dec. 11	345
58	" 13	317	Nov. 16	320	" 18	322	" 24	328	Nov. 20	324
59	" 05	309	" 19	323	" 06	310	" 24	328	" 05	309
L 60	" 07	312	Dec. 12	347	" 12	317	" 27	332	" 10	315
61	" 07	311	Nov. 11	315	" 02	306	" 28	332	" 08	312
62	" 16	320	" 20	324	Dec. 05	339	Dec. 08	342	Dec. 07	341
63	" 14	318	" 17	321	Nov. 19	323	Nov. 23	327	Nov. 20	324
L 64	" 19	324	" 19	324	" 18	323	" 20	325	" 19	324
65	" 11	315	" 09	313	" 08	312	" 30	334	Dec. 11	345
66	" 07	311	" 16	320	" 01	305	" 03	307	Nov. 23	327
67	" 27	331	" 17	321	" 14	318	" 27	331	" 17	321
L 68	" 08	313	" 07	312	" 16	321	Dec. 03	338	" 21	326
69	Dec. 12	346	" 13	317	" 12	316	Nov. 21	325	" 15	319

Matrix of r- values

	Estevan	Brandon	Dauphin	Portage La Prairie	Winnipeg
Estevan	-	0.37979	0.14432	-0.03839	-0.016239
Brandon	-	-	0.26474	0.04421	0.19409
Dauphin	-	-	-	0.57243	0.49212
Portage La Prairie	-	-	-	-	0.25328
Winnipeg	-	-	-	-	-

Data Set 10B Break-up I Red Assiniboine River Basin

	Brandon		Dauphin		Portage La Prairie		Winnipeg	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Apr. 01	92	Apr. 15	106	Mar. 26	86	Apr. 02	93
57	Mar. 28	87	Mar. 28	87	" 27	86	" 01	91
58	" 24	83	" 27	86	Apr. 05	95	Mar. 31	90
59	Apr. 12	102	Apr. 11	101	" 08	98	Apr. 08	98
L 60	" 08	99	Mar. 28	88	" 08	99	" 12	103
61	" 16	106	Apr. 17	107	" 14	104	" 14	104
62	Mar. 25	84	Mar. 23	82	Mar. 25	84	Mar. 24	83
63	Apr. 09	99	Apr. 10	100	Apr. 11	101	Apr. 09	99
L 64	" 12	103	Apr. 10	101	" 14	105	" 12	103
65	" 01	91	Mar. 26	85	Mar. 21	80	Mar. 25	84
66	" 07	97	Apr. 12	102	Apr. 11	101	Apr. 06	96
67	Mar. 29	88	Mar. 26	85	Mar. 28	87	" 08	98
L 68	Apr. 11	102	Apr. 05	96	Apr. 09	100	" 09	100
69	" 14	104	" 06	96	Apr. 05	95	" 15	105

Matrix of r- values

	Brandon	Dauphin	Portage La Prairie	Winnipeg
Brandon	-	0.72627	0.75275	0.83182
Dauphin	-	-	0.62675	0.57608
Portage La Prairie	-	-	-	0.78650
Winnipeg	-	-	-	-

Data Set 10B Break-up II Red Assiniboine River Basin

	Estevan		Brandon		Dauphin		Portage La Prairie		Headingly		Winnipeg	
Year	Date-Mo	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.
L 1956	Apr. 23	114	Apr. 15	106	Apr. 16	107	Apr. 19	110	Apr. 19	110	Apr. 04	95
57	" 12	102	" 04	94	Mar. 30	89	" 08	98	" 06	96	" 10	100
58	" 14	104	" 01	91	" 30	89	" 19	109	" 14	104	" 14	104
59	" 01	91	" 20	110	Apr. 13	103	" 16	106	" 16	106	" 12	102
L 60	" 19	110	" 13	104	" 21	112	" 19	110	" 19	110	" 19	110
61	" 23	113	" 22	112	" 17	107	" 22	112	" 23	113	" 24	114
62	" 20	110	" 12	102	Mar. 23	82	" 10	100	" 08	98	" 10	100
63	" 09	99	" 18	108	Apr. 11	101	" 15	105	" 16	106	" 18	108
L 64	" 15	106	" 17	108	" 11	103	" 18	109	" 16	107	" 17	108
65	Mar. 17	76	" 10	100	Mar. 31	90	" 07	97	" 13	103	" 05	95
66	Apr. 06	96	" 19	109	May 04	124	" 16	106	" 23	113	" 15	105
67	" 13	103	" 11	101	Mar. 28	87	* " 07	97	" 12	102	" 14	104
L 68	" 18	109	" 15	106	Apr. 12	103	" 19	110	" 19	110	" 15	106
69	" 19	109	" 25	115	" 09	99	" 18	108	" 25	115	" 20	110

Matrix of r- values

	Estevan	Brandon	Dauphin	Portage La Prairie	Headingly	Winnipeg
Estevan	-	0.18209	0.12352	0.56156	0.27756	0.43832
Brandon	-	-	0.59675	0.46813	0.75526	0.49104
Dauphin	-	-	-	0.63971	0.79041	0.38449
Portage La Prairie	-	-	-	-	0.77144	0.56005
Headingly	-	-	-	-	-	0.55306

Data Set IIA Freeze-up I Moose River Basin

	Earlton		Moosonee		Timmins		Rouyn		White River	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Nov. 23	328	Nov. 10	315	Nov. 13	318	Nov. 12	317	Nov. 16	321
57	" 27	331	" 20	324	" 24	328	" 24	328	" 20	324
58	* " 20	324	" 14	318	" 24	328	" 23	327	" 22	326
59	" 25	329	" 03	307	Oct. 21	294	" 10	314	" 06	310
L 60	Dec. 07	342	" 24	329	Dec. 04	339	Dec. 02	337	" 26	331
61	" 14	348	" 17	321	Nov. 20	324	Nov. 21	325	Dec. 08	342
62	" 10	344	" 03	307	Dec. 06	340	Dec. 10	344	" 04	338
63	" 02	336	" 27	331	Nov. 25	329	Nov. 25	329	Nov. 25	329
L 64	Nov. 26	331	" 15	320	" 15	320	" 18	323	" 28	333
65	" 29	333	" 05	309	Oct. 12	285	" 08	312	" 14	318
66	Dec. 10	344	Oct. 31	304	Nov. 04	308	" 02	306	" 05	309
67	Nov. 10	314	Nov. 05	309	" 06	310	" 08	312	" 20	324
L 68	" 12	317	" 15	320	" 09	314	" 13	318	Dec. 02	337
69	Dec. 01	335	" 15	319	Dec. 09	343	" 15	319	" 12	346

Matrix of r- values

	Earlton	Moosonee	Timmins	Rouyn	White River
Earlton	-	0.07655	0.32029	0.38090	0.15932
Mossonee	-	-	0.49304	0.49304	0.49649
Timmins	-	-	0.74866	0.74866	0.71158
Rouyn	-	-	-	-	0.54686

Data Set IIB Freeze-up II Moose River Basin

	Earlton		Kapuskasing		Timmins		Rouyn	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Nov. 30	335	Nov. 17	322	Nov. 17	322	Nov. 17	322
57	Dec. 04	338	" 23	327	" 25	329	" 26	330
58	" 08	342	" 26	330	" 28	332	" 27	331
59	" 02	336	" 10	314	" 03	307	" 15	319
L 60	" 13	348	" 26	331	Dec. 07	342	Dec. 05	340
61	" 16	350	" 20	324	" 15	349	Nov. 29	333
62	" 12	346	Dec. 08	342	" 08	342	Dec. 14	348
63	" 11	345	Nov. 27	331	" 01	335	Nov. 28	332
L 64	" 03	338	Dec. 01	336	Nov. 27	332	" 19	324
65	" 18	352	Nov. 12	316	Dec. 27	361	" 15	319
66	" 14	348	" 11	315	". 10	344	" 15	319
67	" 07	341	" 07	311	" 03	337	" 18	322
L 68	" 20	355	" 15	320	Nov. 15	320	" 21	326
69	" 04	338	" 14	318	Dec. 12	346	" 21	325

Matrix of r- values

	Earlton	Kapuskasing	Timmins	Rouyn
Earlton	-	-0.00155	0.47848	0.22727
Kapuskasing	-	-	0.05440	0.80000
Timmins	-	-	-	0.19037

Data Set 12A Break-up I Moose River Basin

	Earlton		Kapuskasing		Moosonee		Timmins		Rouyn	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Apr. 03	94	Apr. 24	115	Apr. 20	111	Mar. 16	76	Apr. 19	110
57	Mar. 31	90	" 17	107	" 25	115	" 15	74	" 10	100
58	*Apr. 06	96	" 29	119	May 06	126	" 30	89	" 20	110
59	" 08	98	" 25	115	" 02	122	Apr. 04	94	" 12	102
L 60	" 15	106	" 25	116	Apr. 30	121	" 04	95	" 20	111
61	" 11	101	May 03	123	May 04	124	Mar. 15	74	" 20	110
62	" 01	91	Apr. 27	117	Apr. 28	118	Apr. 09	99	" 15	105
63	" 12	102	" 26	116	" 24	114	" 06	96	" 19	109
L 64	" 29	120	May 04	125	" 25	116	Mar. 15	75	" 25	116
65	" 10	100	Apr. 27	117	" 19	109	" 14	73	" 20	110
66	" 10	100	" 20	110	" 28	118	Apr. 01	91	" 18	108
67	Mar. 08	67	* " 15	105	" 17	107	Mar. 26	85	" 10	100
L 68	Apr. 12	103	* " 14	105	" 13	104	" 20	80	" 18	109
69	" 08	98	" 26	116	" 21	111	" 22	81	" 26	116

Matrix of r- values

	Earlton	Kapuskasing	Moosonee	Timmins
Earlton	-	0.61036	0.26277	-0.10810
Kapuskasing	-	-	0.57644	-0.06060
Moosonee	-	-	-	0.36221
Timmins	-	-	-	-

Data Set 12B Break-up II Moose River Basin

	Earlton		Kapuskasing		Moosonee		Timmins		Rouyn		White River	
Year	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.
L 1956	Apr. 25	116	Apr. 27	118			Mar. 23	83	Apr. 25	116	Apr. 24	115
57	" 06	96	" 20	110			" 21	80	" 17	107	" 14	104
58	" 20	110	May 06	126			Apr. 01	91	" 30	120	" 22	112
59	" 19	109	" 04	124	M		" 09	99	" 28	118	" 24	114
L 60	" 20	111	Apr. 28	119			" 10	101	" 25	116	" 22	113
61	* " 18	108	May 05	125			Mar. 26	85	" 25	115	" 25	115
62	" 08	98	Apr. 30	120			Apr. 13	103	" 21	111	May 05	125
63	" 17	107	" 28	118			" 12	102	" 27	117	" 01	121
L 64	May 02	123	May 05	126			" 05	96	May 02	123	Apr. 27	118
65	Apr. 15	105	Apr. 27	117			" 03	93	Apr. 25	115	" 17	107
66	" 14	104	" 25	115			" 09	99	" 28	118	" 15	105
67	" 01	91	" 20	110			Mar. 28	87	" 13	103	" 15	105
L 68	" 18	109	" 27	118			Apr. 06	97	" 30	121	" 15	106
69	" 18	108	May 01	121			" 02	91	May 01	121	" 28	118

Matrix of r- values

	Earlton	Kapuskasing	Timmins	Rouyn	White River
Earlton	-	0.71980	0.16226	0.84269	0.35529
Kapuskasing	-	-	0.27732	0.72840	0.59075
Timmins	-	-	-	0.39215	0.40909
Rouyn	-	-	-	-	0.30235

Data Set 14A Moncton-Fredericton

	Moncton		Fredericton	
	Break-up I		Break-up I	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	Apr. 12	103	Apr. 08	99
57	" 10	100	" 06	96
58	" 01	91	" 13	103
59	Mar. 24	83	" 17	107
L 60	Apr. 29	120	" 22	113
61	" 21	111	" 02	92
62	" 14	104	" 20	110
63	" 03	93	" 16	106
L 64	May 01	122	" 17	108
65	Apr. 15	105	Mar. 26	85
66	May 02	122	Apr. 19	109
67	Apr. 16	106	Mar. 29	88
L 68	" 20	111	" 21	81
69	" 20	110	" 21	80

<u>Data Set 14A BU I</u>

$$\left.\begin{array}{l}\text{Moncton}\\ \text{Fredericton}\end{array}\right\} r = -0.01612$$

Data Set 14B Moncton-Fredericton

	Moncton		Fredericton	
	Break-up II		Break-up II	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	May 03	124	* Apr. 17	108
57	Apr. 24	114	" 09	99
58	" 25	115	* " 20	110
59	" 28	118	" 19	109
L 60	May 10	131	" 30	121
61	Apr. 28	118	" 10	100
62	" 28	118	" 28	118
63	" 08	98	" 27	117
L 64	May 02	123	" 27	118
65	Apr. 24	114	" 18	108
66	May 08	128	" 28	118
67	Apr. 18	108	" 08	108
L 68	" 30	121	Mar. 27	87
69	" 25	115	" 28	87

<u>Data Set 14B BU II</u>

$$\left.\begin{array}{l}\text{Moncton}\\ \text{Fredericton}\end{array}\right\} r = 0.14113$$

Data Set 16A and 16B Goose (Town): One Location

	Goose - Churchill River				Goose - Goose River				Goose - Terrington Basin			
	BU I		BU II		BU I		BU II		BU I		BU II	
Year	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.
L 1956	May 19	140	June 05	157	May 13	134	May 29	150	May 08	129	June 06	158
57	Apr. 27	117	May 07	127	Apr. 19	109	" 01	121	" 07	127	May 09	129
58	May 13	133	* " 17	137	May 07	127	" 15	135	" 08	128	" 17	137
59	" 14	134	* " 24	144	" 09	129	" 11	131	" 23	143	" 25	145
L 60	" 03	124	" 13	134	Apr. 28	119	Apr. 30	121	Apr. 25	116	" 10	131
61	" 16	136	" 25	145	May 10	130	May 17	137	May 18	138	" 28	148
62	" 13	133	" 19	139	" 07	127	" 14	134	" 15	135	" 20	140
63	" 15	135	" 20	140	" 08	128	" 15	135	" 15	135	" 26	146
L 64	" 08	129	" 20	141	" 09	130	" 15	136	" 15	136	June 04	156
65	Apr. 25	115	Apr. 29	119	Apr. 19	109	" 05	125	" 04	124	May 06	126
66	May 05	125	May 30	150	" 28	118	" 21	141	" 12	132	" 28	148
67	" 02	122	" 13	133	" 30	120	" 07	127	" 13	133	" 22	142
L 68	" 09	130	" 26	147	May 07	128	" 21	142	" 23	144	June 02	154
69	" 03	123	" 19	139	*' " 03	123	" 19	139	" 04	124	May 22	142

Data Set 16A and 16B Goose

BU I Correlation Matrix

	Churchill River	Goose River	Terrington B.
Churchill River	-	0.9342	0.5100
Goose River	-	-	0.5443
Terrington Basin	-	-	-

BU II Correlation Matrix

	Churchill River	Goose River	Terrington B.
Churchill River	-	0.8592	0.87735
Goose River	-	-	0.84261
Terrington Basin	-	-	-

Data Set 17A Freeze-up I Yukon - B. C. Lakes

	Dease Lake		Watson Lake	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	Dec. 03	338	Oct. 11	285
57	Nov. 20	324	" 24	297
58	" 18	322	" 10	283
59	" 11	315	" 07	280
L 60	" 10	315	" 14	288
61	" 18	322	" 11	284
62	Dec. 02	336	" 14	287
63	Nov. 17	321	" 12	285
L 64	Dec. 05	340	" 06	280
65	Nov. 20	324	" 10	283
66	" 12	316	" 25	298
67	" 15	319	" 18	291
L 68	" 16	321	" 12	286
69	" 16	320	Nov. 06	310

r - −0.29132

Data Set 17B Freeze-up II Yukon - B. C. Lakes

	Dease L.		Teslin L.		Watson L.	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Dec. 06	341	Dec. 06	341	Oct. 31	305
57	" 18	352	" 21	355	Nov. 16	320
58	Nov. 26	330	Nov. 30	334	" 14	318
59	Dec. 23	357	Dec. 24	358	" 04	308
L 60	" 18	353	" 19	354	" 10	315
61	" 04	338	Nov. 29	333	" 03	307
62	" 22	356	Dec. 21	355	" 08	312
63	" 15	349	Nov. 24	328	" 03	307
L 64	" 15	350	" 30	335	" 12	317
65	" 05	339	Dec. 07	341	" 06	310
66	" 13	347	" 02	336	" 08	312
67	" 15	349	" 07	341	" 12	316
L 68	" 11	346	" 10	345	" 04	309
69	" 16	350	" 14	348	" 15	319

Matrix of r- values

	Dease Lake	Teslin Lake	Watson Lake
Dease Lake	-	0.65	0.12
Teslin Lake	-	-	0.22
Watson Lake	-	-	-

Data Set 18A Break-up I Yukon - B. C. Lakes

	Dease L.		Watson L.	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	May 19	140	May 11	132
57	" 19	139	" 05	125
58	" 15	135	" 12	132
59	" 10	130	" 04	124
L 60	" 09	130	" 10	131
61	" 25	145	" 14	134
62	" 25	145	" 08	128
63	" 25	145	" 04	124
L 64	" 25	146	" 10	131
65	" 15	135	" 01	121
66	" 03	123	" 05	125
67	" 16	136	" 12	132
L 68	Apr. 15	106	Apr. 15	106
69	May 06	126	" 10	100

r = 0.67

Data Set 18B Break-up II Yukon - B. C. Lakes

	Dease L.		Watson L.	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	May 26	147	May 25	146
57	" 30	150	" 23	143
58	June 02	153	" 29	149
59	May 18	138	" 14	134
L 60	" 29	150	" 23	144
61	June 04	155	" 29	149
62	May 30	150	" 21	141
63	June 07	158	" 30	150
L 64	" 12	164	June 03	155
65	" 04	155	May 20	140
66	" 04	155	" 29	149
67	May 30	150	" 21	141
L 68	June 13	165	" 18	139
69	" 02	153	" 18	138

r = 0.51

Data Set 19A Freeze-up I N. W. T. Lakes

	Fort Resolution		Yellowknife Long L.		Yellowknife Back Bay	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Oct. 13	287	Oct. 13	287	Oct. 12	286
57	" 04	277	" 17	290	" 17	290
58	Nov. 11	315	" 09	282	" 16	289
59	Oct. 08	281	" 07	280	" 16	289
L 60	" 30	304	" 17	291	" 17	291
61	" 10	283	" 07	280	" 08	281
62	Nov. 01	305	" 17	290	" 18	291
63	Oct. 29	302	" 30	303	" 18	291
L 64	" 30	304	" 17	291	" 25	299
65	" 28	301	" 10	283	" 18	291
66	" 26	299	" 16	289	" 19	292
67	" 02	275	" 12	285	" 12	285
L 68	" 27	301	" 17	291	" 29	303
69	" 19	292	" 10	283	" 11	284

Matrix of r - values

	Fort Resolution	Long Lake	Back Bay
Fort Resolution	-	0.32	0.50
Long Lake	-	-	0.49

Data Set 19B Freeze-up II N. W. T. Lakes

	Yellowknife - Frame		Yellowknife - Long L.		Yellowknife - Back B.	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Oct. 13	287	Oct. 14	288	Oct. 17	291
57	" 17	290	" 21	294	" 31	304
58	" 10	283	" 31	304	Nov. 13	317
59	" 07	280	" 11	284	Oct. 18	291
L 60	" 18	292	" 21	295	" 22	296
61	" 08	281	" 20	293	" 20	293
62	" 18	291	Nov. 01	305	Nov. 06	310
63	" 30	303	Oct. 31	304	" 18	322
L 64	" 19	293	" 26	300	" 01	306
65	" 18	291	" 29	302	" 02	306
66	" 18	291	" 20	293	Oct. 23	296
67	" 20	293	Nov. 01	305	Nov. 04	308
L 68	" 29	303	Oct. 29	303	" 03	308
69	" 12	285	Nov. 10	314	" 05	309

Matrix of r- values

	Frame L.	Long L.	Back Bay
Frame L.	-	0.36	0.51
Long L.	-	-	0.81

Data Set 20B Break-up II N. W. T. Lakes

	Yellowknife - Frame L.		Yellowknife - Long L.		Yellowknife - Back B.	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	June 01	153	June 04	156	June 11	163
57	May 23	143	May 25	145	May 25	145
58	June 08	159	June 10	161	June 14	165
59	May 27	147	May 29	149	" 04	155
L 60	" 29	150	" 31	152	" 03	155
61	June 03	154	June 06	157	" 10	161
62	May 17	137	May 21	141	May 26	146
63	" 30	150	June 02	153	June 05	156
L 64	" 27	148	May 30	151	" 07	159
65	" 25	145	" 27	147	May 29	149
66	June 02	153	June 01	152	June 08	159
67	" 03	154	" 05	156	" 09	160
L 68	May 26	147	" 01	153	" 01	153
69	" 29	149	May 30	150	" 02	153

Matrix of r- values

	Frame L.	Long L.	Back Bay
Frame L.	-	0.96	0.92
Long L.	-	-	0.92

Data Set 21B Freeze-up II Southern Saskatchewan Lakes

	Broadview		Wynard		Yorkton	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Nov. 07	312	Nov. 17	322	Nov. 24	330
57	Oct. 24	297	" 28	332	" 08	312
58	" 26	299	" 20	324	" 25	329
59	Nov. 11	315	" 12	316	" 07	311
L 60	" 09	314	" 10	315	* " 01	306
61	" 02	306	Oct. 25	298	" 10	314
62	" 13	317	Nov. 30	334	" 28	332
63	" 19	323	" 22	326	" 24	328
L 64	" 15	320	" 28	333	" 20	325
65	" 20	324	" 10	314	" 13	317
66	" 06	310	" 05	309	" 15	319
67	" 03	307	" 25	329	Dec. 10	344
L 68	" 11	316	Dec. 02	337	Nov. 08	313
69	Oct. 27	300	Nov. 10	314	Dec. 01	335

Matrix of r- values

	Broadview	Wynard	Yorkton
Broadview	-	0.00	-0.14
Wynard	-	-	0.29

Data Set 22B Break-up II Southern Saskatchewan Lakes

Year	Regina Date - Mo.	Regina Day - Yr.	Wynard Date - Mo.	Wynard Day - Yr.	Yorkton Date - Mo.	Yorkton Day - Yr.
L 1956	Apr. 28	119	May 09	130	May 10	131
57	" 06	96	" 01	121	Apr. 19	109
58	" 07	97	" 13	133	May 05	125
59	" 15	105	" 05	125	Apr. 25	115
L 60	" 15	106	" 05	126	" 28	119
61	" 14	104	" 05	125	" 29	119
62	" 05	95	Apr. 29	119	" 24	114
63	" 22	112	May 06	126	" 30	120
L 64	" 26	117	" 08	129	May 04	125
65	" 06	96	" 10	130	" 17	137
66	" 20	110	" 16	136	" 23	143
67	" 03	93	Apr. 29	119	Apr. 25	115
L 68	" 10	101	" 23	114	" 29	120
69	" 18	108	May 05	125	May 14	134

Matrix of r- values

	Regina	Wynard	Yorkton
Regina	-	.45	.41
Wynard	-	-	.71

Data Set 23A Freeze-up I Northern Manitoba Lakes

	The Pas - Grace L.		Wabowden	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	Oct. 28	302	Oct. 28	
57	" 23	296	" 21	
58	Nov. 10	314	Nov. 19	
59	Oct. 05	278	Oct. 27	
L 60	" 20	294	" 25	
61	" 23	296	" 26	
62	" 24	297	Nov. 01	
63	Nov. 04	308	" 18	
L 64	" 08	313	" 14	
65	" 05	309	" 01	
66	Oct. 24	297	Oct. 29	
67	" 26	299	" 27	
L 68	Nov. 04	309	Nov. 05	
69	" 17	321	Oct. 20	

$r = 0.42$

Data Set 23B Freeze-up II Northern Manitoba Lakes

	The Pas - Clearwater L.		Wabowden	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	Dec. 01	336	Nov. 16	321
57	Nov. 27	331	" 17	321
58	" 29	333	" 19	323
59	" 13	317	" 04	308
L 60	" 25	330	" 09	314
61	" 25	329	" 09	313
62	Dec. 05	339	" 16	320
63	" 03	337	" 21	325
L 64	Nov. 23	328	" 20	325
65	" 20	324	" 14	318
66	" 17	321	" 13	317
67	" 26	330	" 19	323
L 68	" 29	334	" 09	314
69	" 20	324	" 06	320

$r = 0.51$

Data Set 24A Northern Manitoba Lakes

	Brochet		Wabowden	
	Break-up I		Break-up I	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	June 01	153	May 23	144
57	May 23	143	" 05	125
58	June 01	152	" 25	144
59	" 03	154	" 14	134
L 60	" 02	154	" 21	142
61	" 03	154	" 19	139
62	" 04	155	" 02	132
63	May 17	137	" 09	129
L 64	" 24	145	" 16	137
65	" 26	146	" 23	143
66	June 10	161	" 24	144
67	May 24	144	" 10	130
L 68	Apr. 20	111	Apr. 23	114
69	*June 01	152	May 12	132

$$r = \frac{\text{BU I}}{0.81}$$

Data Set 24B Northern Manitoba Lakes

	Brochet		Wabowden	
	Break-up II		Break-up II	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	June 15	167	May 30	151
57	May 30	150	" 18	138
58	June 13	164	June 01	152
59	" 09	160	May 24	144
L 60	" 05	157	" 27	148
61	" 09	160	" 26	146
62	" 07	158	" 19	139
63	" 03	154	" 15	135
L 64	" 06	158	" 24	145
65	" 05	156	" 30	150
66	" 18	169	" 29	149
67	" 04	155	" 28	148
L 68	May 26	147	" 09	130
69	*June 15	166	" 29	149

BU II

r = 0.76

Data Set 25A N. W. T. (Hudson) Lakes

	Bake Lake		Ennadai Lake	
	Freeze-up I		Freeze-up I	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	Oct. 09	283	Oct. 14	288
57	" 18	291	" 06	279
58	" 17	290	" 04	277
59	" 08	281	" 04	277
L 60	" 19	293	" 18	292
61	" 05	278	" 07	280
62	" 17	290	" 22	295
63	" 10	283	" 28	301
L 64	" 15	289	" 18	292
65	" 13	286	" 20	293
66	" 19	292	" 19	292
67	" 21	294	" 19	292
L 68	" 25	299	" 25	299
69	" 22	295	" 17	290

FU I

r = 0.38

Data Set 25B N. W. T. (Hudson) Lakes

	Baker Lake		Ennadai Lake	
	Freeze-up II		Freeze-up II	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	Oct. 16	209	Oct. 18	292
57	" 29	302	" 23	296
58	" 28	301	" 31	304
59	" 13	286	" 08	281
L 60	" 21	295	" 19	293
61	" 07	280	" 08	281
62	" 24	297	" 29	302
63	" 21	294	Nov. 01	305
L 64	" 22	296	Oct. 27	301
65	" 15	288	" 22	295
66	" 27	300	" 20	293
67	" 27	300	" 24	297
L 68	Nov. 04	309	Nov. 03	308
69	Oct. 30	303	Oct. 18	291

BU II

r = 0.69

Data Set 26A N. W. T. (Hudson) Lakes

	Baker Lake		Ennadai Lake	
	Break-up I		Break-up I	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	July 08	190	July 05	187
57	" 03	184	June 18	169
58	June 26	177	" 24	175
59	" 18	169	" 26	177
L 60	" 24	176	" 24	176
61	" 30	181	" 30	181
62	July 04	185	" 19	170
63	June 20	171	" 25	176
L 64	" 25	177	" 18	170
65	" 15	166	" 15	166
66	" 14	165	" 26	177
67	July 02	183	" 26	177
L 68	June 20	172	" 15	167
69	May 29	149	" 16	167

$r_{\underline{\text{BU I}}} = 0.47$

Data Set 26B N. W. T. (Hudson) Lakes

	Baker Lake		Ennadai Lake	
	Break-up II		Break-up II	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	Aug. 02	215	July 17	199
57	July 29	210	" 19	200
58	" 31	212	" 08	189
59	" 12	193	" 05	186
L 60	" 17	199	" 01	183
61	* " 30	211	" 08	189
62	" 31	212	" 03	184
63	" 21	202	" 09	190
L 64	" 27	209	June 28	180
65	" 23	204	" 28	179
66	Aug. 01	213	July 17	198
67	July 28	209	" 09	190
L 68	Aug. 14	227	" 21	203
69	July 13	194	June 25	176

BU II

r = 0.71

Data Set 27A Northern Ontario Lakes

	Trout Lake		Lansdowne House	
	Freeze-up I		Freeze-up I	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	Nov. 08	313	Nov. 10	315
57	" 07	311	" 08	312
58	" 08	312	" 13	317
59	Oct. 15	288	Oct. 27	300
L 60	" 22	296	Nov. 07	312
61	" 26	299	Oct. 29	302
62	" 26	299	Nov. 03	307
63	Nov. 13	317	" 20	324
L 64	" 12	317	" 14	319
65	Oct. 28	301	" 06	310
66	" 30	303	Oct. 29	302
67	" 27	300	" 28	301
L 68	Nov. 03	308	" 30	304
69	Oct. 17	290	" 24	297

$$r_{\overline{\text{FU I}}} = 0.82$$

Data Set 27B Northern Ontario Lakes

	Trout Lake		Lansdowne House	
	Freeze-up II		Freeze-up II	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	Nov. 15	320	Nov. 16	321
57	" 32	326	" 10	314
58	" 30	334	" 22	326
59	" 09	313	" 03	307
L 60	" 11	316	" 11	316
61	" 09	313	" 07	311
62	" 16	320	" 08	312
63	" 24	329	" 26	330
L 64	" 19	324	" 19	324
65	" 09	313	" 07	311
66	" 10	314	" 02	306
67	" 19	323	" 07	311
L 68	" 20	325	" 13	317
69	" 17	321	Oct. 24	297

FU II

r = 0.62

Data Set 28A

	Trout Lake		Lansdowne House	
	Break-up I		Break-up I	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	May 18	139	May 05	126
57	" 24	144	" 06	126
58	June 01	152	" 11	131
59	May 22	142	" 18	138
L 60	" 21	142	" 08	129
61	" 24	144	" 11	131
62	" 23	143	" 03	123
63	" 10	130	" 07	127
L 64	" 17	138	" 09	130
65	" 23	143	" 13	133
66	" 21	141	" 16	136
67	" 06	126	Apr. 29	119
L 68	Apr. 15	106	" 29	120
69	May 10	130	May 15	135

BU I

r = 0.52

Data Set 29B Freeze-up II Thunder Bay

Year	Fort William Harbour		Port Arthur Harbour	
	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	*Dec. 01	336	*Dec. 17	352
57	" 14	348	Jan. 01	367
58	Nov. 30	334	Dec. 01	335
59	Dec. 19	353	" 19	353
L 60	Nov. 30	335	" 01	336
61	Dec. 08	342	" 11	345
62	" 08	342	" 11	345
63	" 12	346	" 12	346
L 64	Nov. 30	335	Nov. 30	335
65	Dec. 16	350	Dec. 16	350
66	" 02	336	" 02	336
67	" 22	356	" 22	356
L 68	" 14	349	" 14	349
69	Feb. 02	399	" 10	344

<u>FU II</u>

r = 0.26

Data Set 31A Freeze-up I Southern Ontario Lakes

	Killaloe		Gore Bay		London	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Nov. 15	320	Dec. 14	349	Nov. 30	335
57	" 28	332	Nov. 22	326	Dec. 30	364
58	" 23	327	" 30	334	" 01	335
59	Dec. 06	340	" 21	325	" 21	355
L 60	" 14	349	" 11	316	" 09	344
61	Nov. 30	334	Dec. 01	335	" 08	342
62	" 10	314	" 08	342	" 06	340
63	Dec. 12	346	" 02	336	" 02	336
L 64	" 07	342	" 08	343	" 01	336
65	" 02	336	" 15	349	" 07	341
66	" 08	342	" 13	347	" 10	344
67	" 20	354	" 23	357	Nov. 28	332
L 68	" 06	341	" 07	343	Dec. 07	342
69	Nov. 20	324	" 28	362	" 02	336

Matrix of r- values

	Killaloe	Gore Bay	London
Killaloe	-	-0.20	0.01
Gore Bay	-	-	-0.61

Data Set 31B Freeze-up 1I Southern Ontario Lakes

	Sudbury		North Bay		London	
Year	Date - Mo.	Day - Yr.	Date of Mo.	Day - Yr.	Date of Mo.	Day - Yr.
L 1956	Nov. 30	335	Dec. 05	340	Dec. 30	365
57	Dec. 02	336	" 02	336	Jan. 03	369
58	" 04	338	Nov. 30	334	Dec. 08	342
59	Nov. 27	331	" 26	330	" 21	355
L 60	Dec. 10	345	Dec. 10	345	" 11	346
61	" 15	349	" 15	349	" 11	345
62	" 11	345	" 12	346	" 10	344
63	" 14	348	" 10	344	" 15	349
L 64	" 01	336	" 03	338	" 07	342
65	" 16	350	" 07	341	Jan. 11	377
66	" 03	337	" 12	346	Dec. 24	358
67	Nov. 30	334	Nov. 28	332	" 04	338
L 68	" 30	335	" 30	335	" 09	344
69	Dec. 05	339	Dec. 01	335	" 03	337

Matrix of r- values

	Sudbury	North Bay	London
Sudbury	-	0.75	0.11
North Bay	-	-	0.11

Data Set 32A Break-up I Southern Ontario Lakes

	North Bay		Killaloe		Simcoe	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Apr. 20	111	Apr. 01	92	Mar. 12	72
57	" 05	95	" 08	98	" 25	84
58	" 18	108	" 11	101	" 28	87
59	" 20	110	" 16	106	Apr. 04	94
L 60	May 01	122	Mar. 28	88	Mar. 03	63
61	Apr. 24	114	Apr. 17	107	" 25	84
62	" 16	106	" 04	94	" 25	84
63	" 18	108	" 14	104	" 10	69
L 64	May 01	122	" 21	112	Apr. 05	96
65	Apr. 15	105	Mar. 18	77	Mar. 05	64
66	" 14	104	Apr. 01	91	" 25	84
67	" 14	104	Mar. 21	80	" 21	80
L 68	" 20	111	Apr. 05	96	" 14	74
69	" 17	107	" 21	111	" 07	66

Matrix of r- values

	North Bay	Killaloe	Simcoe
North Bay	-	0.28	0.00
Killaloe	-	-	0.43

Data Set 32B Break-up II Southern Ontario Lake

	Sudbury		North Bay		Killaloe		Gore Bay		London		Simcoe	
Year	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.
L 1956	Apr. 25	116	Apr. 30	121	Apr. 18	109	Apr. 24*	115	Mar. 25	85	Mar. 17	77
57	" 16	106	" 20*	110	" 21	111	" 19*	109	Apr. 02	92	" 31	90
58	" 29	119	" 29	119	" 24	114	" 29	119	" 09	99	Apr. 02	92
59	May 03*	123	" 30	120	" 26	116	May 02	122	" 10	100	" 06	96
L 60	" 07	128	May 03	124	" 25	116	Apr. 21	112	" 05	96	Mar. 06	66
61	Apr. 27	117	Apr. 26	116	" 27	117	" 26*	116	Mar. 30	89	" 29	88
62	" 25	115	" 22	112	" 18	118	" 18*	108	Apr. 01	91	" 31	90
63	" 28	118	" 28	118	" 18	118	" 23	113	" 09	99	" 15	74
L 64	May 05	126	May 11	132	May 04	125	May 04*	125	" 15	106	Apr. 08	99
65	Apr. 24	114	Apr. 26	116	Apr. 23	113	Apr. 15	105	Mar. 21	80	Mar. 13	72
66	" 29	119	" 24	114	" 22	112	" 21	111	Apr. 03	93	" 28	87
67	" 18	108	" 19	109	" 11	101	" 14	104	Mar. 30	89	" 24	83
L 68	" 26	117	May 01	122	" 20	111	May 01	122	Apr. 08	99	" 17	77
69	" 29	119	" 03	123	May 04	124	Apr. 30	120	" 10	100	" 19	78

Matrix of r- values

	Sudbury	North Bay	Killaloe	Gore Bay	London	Simcoe
Sudbury	-	0.82	0.63	0.62	0.58	-0.02
North Bay	-	-	0.64	0.79	0.61	-0.02
Killaloe	-	-	-	0.57	0.57	0.20
Gore Bay	-	-	-	-	0.76	0.36
London	-	-	-	-	-	0.36
Simcoe	-	-	-	-	-	-

Data Set 33A Freeze-up I Quebec Labrador Lakes

	Nitcheguon		Schefferville	
Year	Date of Month	Day of Year	Date of Month	Day of Yr.
L 1956	Nov. 10	315	Nov. 07	312
57	Oct. 30	303	Oct. 23	296
58	" 15	288	" 04	277
59	" 27	300	" 28	301
L 60	Nov. 04	309	" 26	300
61	" 08	312	" 21	294
62	Oct. 22	295	" 27	300
63	Nov. 12	316	" 30	303
L 64	Oct. 25	299	" 12	286
65	" 26	299	" 06	279
66	" 22	295	" 16	289
67	Nov. 06	310	Nov. 06	310
L 68	" 10	315	" 10	315
69	Oct. 20	293	Oct. 17	290

$r = 0.77$

Data Set 33B Freeze-up II Quebec Labrador Lakes

	Nitcheguon		Schefferville		Lake Eon	
Year	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.	Date - Mo.	Day - Yr.
L 1956	Nov. 13	318	Nov. 11	316	Nov. 15	320
57	" 08	312	" 03	307	" 07	311
58	Oct. 27	300	Oct. 07	280	Oct. 28	301
59	" 31	304	" 30	303	Nov. 14	318
L 60	Nov. 07	312	Nov. 03	308	" 10	315
61	" 09	313	" 07	311	" 12	316
62	" 09	313	Oct. 31	304	" 01	305
63	" 13	317	Nov. 02	306	" 19	323
L 64	Oct. 25	299	Oct. 31	305	Oct. 31	305
65	" 28	301	" 07	280	" 27	300
66	" 31	304	" 29	302	Nov. 14	318
67	Nov. 08	312	Nov. 06	310	" 15	319
L 68	" 11	316	" 12	317	" 17	322
69	Oct. 26	299	Oct. 23	296	Oct. 23	296

Matrix of r- values

	Nitcheguon	Schefferville	Lake Eon
Nitcheguon	-	0.75	0.74
Schefferville	-	-	0.75

Data Set 34B Break-up II Quebec Labrador Lakes

	Schefferville		Lake Eon	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	June 20	172	June 24	176
57	" 12	163	May 23	143
58	May 28	148	June 04	155
59	June 04	155	May 30	150
L 60	" 11	163	June 07	159
61	" 13	164	" 10	161
62	" 18	169	" 03*	154
63	" 12	163	" 06	157
L 64	" 17	169	" 18	170
65	" 16	167	" 14	165
66	" 12	163	" 15	166
67	" 06	157	" 07	158
L 68	" 18	170	" 16	168
69	" 13	164	" 14	165

$r = 0.57$

APPENDIX 111 B

Data Analysis (Longer Periods)

The following sets of data are an addendum to those given in Appendix 111 A. They give the same type of information except for longer periods (20 years and over) of coverage.

The time periods that these cover are of varying lengths. Significant r- values are indicated by asterisks (*).

Data Set 1 Freeze-up 1 Mackenzie River Basin

	Fort Good Hope		Fort Simpson	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
1931	Oct. 18	291	Oct. 25	298
L 32	" 16	290	" 16	290
33	" 19	292	" 20	293
34	" 27	300	" 26	299
35	" 20	293	" 20	293
L 36	" 08	282	" 29	303
37	" 28	301	Nov. 02	306
38	Nov. 01	305	Oct. 30	303
39	Oct. 11	284	" 14	287
L 40	" 24	298	" 23	297
41	" 13	286	" 23	296
42	" 23	296	" 24	297
43	" 29	302	" 27	300
L 44	" 27	301	" 27	301
45	" 26	299	" 26	299
46	" 25	298	" 25	298
47	" 22	295	" 29	302
L 48	" 18	292	" 21	295
59	" 17	290	" 26	299
50	" 23	296	" 21	294
51	" 18	291	" 16	289
L 52	" 26	300	Nov. 02	307
53	" 26	299	Oct. 25	298
54	" 21	294	Nov. 01	305
55	" 25	298	Oct. 22	295

Data Set 1 Freeze-up 1 Mackenzie River Basin (continued)

	Fort Good Hope		Fort Simpson	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1956	Oct. 13	287	Oct. 06	280
57	" 16	289	" 21	294
58	" 22	295	" 24	297
59	" 10	283	" 12	285
L 60	" 19	293	" 10	284
61	" 10	283	" 11	284
62	Nov. 03	307	" 28	301
63	Oct. 25	298	" 26	299
L 64	" 28	302	" 28	302
65	" 18	291	" 30	303
66	" 23	296	" 18	291
67	" 17	290	" 18	291
L 68	" 20	294	" 25	299
69	" 24	297	" 17	290

r = .57*

Data Set 2 Freeze-up 1 Quebec - N. B. Rivers

Year	Chatham		Quebec	
	Date of Month	Day of Yr.	Date of Month	Day of Yr.
L 1912	Dec. 13	348	Dec. 09	344
13	" 16	350	" 16	350
14	" 06	340	" 09	343
15	" 31	365	" 13	347
L 16	" 14	349	" 13	348
17	Nov. 28	332	Nov. 27	331
18	Dec. 01	335	Dec. 02	336
19	" 02	336	" 02	336
L 20	" 20	355	" 04	339
21	" 07	341	Nov. 26	330
22	" 08	342	Dec. 07	341
23	" 30	364	" 19	353
L 24	" 15	350	" 09	344
25	Nov. 30	334	" 11	345
26	Dec. 03	337	" 30	364
27	" 05	339	" 05	339
L 28	Nov. 30	335	" 04	339
29	Dec. 04	338	Nov. 29	333
30	" 13	347	Dec. 03	337
31	" 16	350	" 08	342
L 32	" 10	345	" 09	344
33	Nov. 15	319	Nov. 17	321
34	Dec. 07	341	Dec. 07	341
35	" 19	353	" 04	338
L 36	" 02	337	Nov. 17	322
37	" 03	337	Dec. 10	344
38	" 16	350	Nov. 29	333
39	" 15	349	Dec. 11	345
L 40	" 01	336	Nov. 29	334
41	" 11	345	Dec. 02	336
42	" 10	344	" 04	338
42	" 12	346	" 07	341
L 44	" 18	353	" 04	339
45	" 16	350	" 01	335
46	" 01	335	" 03	337
47	" 14	348	" 05	339
L 48	" 23	358	" 19	354
49	" 21	355	Nov. 27	331
50	" 20	354	Dec. 14	348
51	" 03	337	" 28	362
L 52	" 15	350	" 22	357
53	" 17	351	" 18	352
54	" 27	361	" 09	343
55	" 09	343	Nov. 30	334

r = 0.37*

Data Set 3 Freeze-up 1 Manitoba Lakes

	Gimili		The Pas	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
1949	Nov. 22	326	Oct. 21	294
50	" 16	320	" 30	303
51	" 03	307	" 21	294
L 52	" 22	327	" 27	301
53	" 25	329	Nov. 02	306
54	" 27	331	" 01	305
55	" 01	305	Oct. 29	302
L 56	" 15	320	" 28	302
57	" 24	328	" 23	296
58	" 20	324	Nov. 10	314
59	" 09	313	Oct. 05	278
L 60	" 11	316	" 20	294
61	" 08	312	" 23	296
62	" 10	314	" 24	297
63	" 19	323	Nov. 04	308
L 64	" 16	321	" 08	313
65	" 09	313	" 05	309
66	" 04	308	Oct. 24	297
67	" 13	317	" 26	299
L 68	" 08	313	Nov. 04	309
69	" 17	321	" 17	321

$r = 0.29$

Data Set 4 Freeze-up II Mackenzie River and Surrounding Area

	Year	Fort Good Hope Date-Mo.	Fort Good Hope Day-Yr.	Fort Simpson Date-Mo.	Fort Simpson Day-Yr.	Coppermine Date-Mo.	Coppermine Day-Yr.
	1931	Nov. 17	321	Dec. 04	338	Nov. 03	307
L	32	" 02	307	Nov. 17	322	Oct. 15	289
	33	" 02	306	" 23	327	" 25	298
	34	" 01	305	Dec. 02	336	Sept.27	270
	35	" 10	314	Nov. 26	330	Oct. 11	284
L	36	" 04	309	" 30	335	Sept.30	274
	37	" 21	325	" 30	334	Oct. 15	288
	38	" 18	322	" 24	328	" 13	286
	39	Oct. 27	300	" 29	333	" 06	279
L	40	Nov. 07	312	" 23	328	" 11	285
	41	" 04	308	" 18	322	Sept.24	267
	42	" 15	319	" 22	326	Nov. 05	309
	43	" 12	316	" 30	334	" 04	308
L	44	" 10	315	" 23	328	Oct. 22	296
	45	" 08	312	" 15	319	Nov. 01	305
	46	" 06	310	" 24	328	Oct. 10	283
	47	" 16	320	" 29	333	" 22	295
L	48	" 16	321	" 29	334	" 15	289
	49	" 27	331	Dec. 07	341	" 16	289
	50	" 02	306	Nov. 15	319	" 12	285
	51	" 14	318	" 20	324	" 20	293
L	52	" 28	333	Dec. 10	345	" 28	302
	53	" 06	310	Nov. 25	329	Nov. 07	311
	54	" 14	318	Dec. 07	341	Oct. 15	288
	55	" 09	313	Nov. 16	320	" 30	303
L	56	Oct. 30	304	Oct. 23	297	" 15	289
	57	Nov. 16	320	Nov. 15	319	Nov. 01	305
	58	" 15	319	" 16	320	" 04	308
	59	" 02	306	" 15	319	Oct. 22	295
L	60	" 09	313	" 25	330	" 28	302
	61	" 02	306	" 02	306	" 16	289
	62	" 16	320	" 27	331	Nov. 04	308
	63	" 12	316	" 19	323	Oct. 27	300
L	64	" 22	327	" 20	325	" 15	289
	65	" 24	328	Dec. 01	335	" 23	296
	66	" 14	318	Nov. 15	319	" 25	298
	67	" 12	316	" 27	331	" 30	303
L	68	" 16	321	" 18	323	Nov. 25	330

Matrix of r- values

	Fort Good Hope	Fort Simpson	Coppermine
Fort Good Hope	–	0.48*	0.37
Fort Simpson	–	–	0.06
Coppermine	–	–	–

Data Set 5 Freeze-up II Saskatchewan Rivers

	Year	Prince Albert		Island Falls	
		Date of Month	Day of Yr.	Date of Month	Day of Yr.
	1931	Nov. 14	318	Nov. 19	323
L	32	" 09	314	Oct. 30	304
	33	Oct. 27	300	Nov. 02	306
	34	Nov. 18	322	" 17	321
	35	" 30	334	" 02	306
L	36	" 04	309	Oct. 31	305
	37	" 16	320	Nov. 15	319
	38	" 05	309	" 14	318
	39	Oct. 26	299	Oct. 26	299
L	40	Nov. 07	312	Nov. 10	315
	41	" 07	311	" 16	320
	42	" 01	305	" 08	312
	43	" 20	324	" 13	317
L	44	" 15	320	" 13	318
	45	" 07	311	" 07	311
	46	" 16	320	" 08	312
	47	" 11	315	" 13	317
L	48	" 12	317	" 24	329
	49	" 20	324	" 20	324
	50	" 12	316	" 13	317
	51	" 01	305	" 02	306
L	52	" 24	329	" 22	327
	53	" 28	332	Dec. 21	355
	54	Dec. 01	335	Nov. 26	330
	55	Nov. 03	307	" 12	316
L	56	Dec. 01	336	" 12	317
	57	Nov. 26	330	" 22	326
	58	" 20	324	" 23	327
	59	" 12	316	" 04	308
L	60	" 08	313	" 10	315
	61	" 23	327	" 20	324
	62	" 17	321	" 15	319
	63	" 21	325	" 21	325
L	64	" 20	325	" 18	323
	65	" 25	329	" 13	317
	66	" 11	315	" 07	311

$r = 0.07$

Data Set 6 Freeze-up II Red - Assiniboine Rivers

	Brandon		Winnipeg	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
1943	Nov. 16	320	Nov. 15	319
L 44	" 12	317	" 29	334
45	" 14	318	" 08	312
46	" 24	328	" 17	321
47	" 16	320	" 13	317
L 48	" 19	324	" 19	324
49	" 30	334	" 22	326
50	" 20	324	" 19	323
51	" 16	320	" 01	305
L 52	" 20	325	" 25	330
53	Dec. 04	338	" 25	329
54	Nov. 26	330	" 28	332
55	" 12	316	" 12	316
L 56	Dec. 04	339	" 23	328
57	" 20	354	Dec. 11	345
58	Nov. 16	320	Nov. 20	324
59	" 19	323	" 05	309
L 60	Dec. 12	347	" 10	315
61	Nov. 11	315	" 08	312
62	" 20	324	Dec. 07	341
63	" 17	321	Nov. 20	324
L 64	" 19	324	" 19	324
65	" 09	313	Dec. 11	345
66	" 16	320	Nov. 23	327
67	" 17	321	" 17	321
L 68	" 07	312	" 21	326
69	" 13	317	" 15	319

$r = 0.27$

Data Set 7 Freeze-up II Atlantic Prov. Lakes

		Moncton		Sidney	
	Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
	1946	Nov. 30	334	Dec. 19	353
	47	" 28	332	" 06	340
L	48	Dec. 16	351	Jan. 11	376
	49	Nov. 28	332	" 10	376
	50	Dec. 21	355	" 08	373
	51	Nov. 30	334		
L	52	Dec. 03	338	Dec. 19	354
	53	" 18	352	" 19	353
	54	" 04	339	Jan. 23	388
	55	Nov. 23	327	" 29	394
L	56	Dec. 03	338	Dec. 20	355
	57	Jan. 04	370	Feb. 11	405
	58	Nov. 28	332	Dec. 02	336
	59	Dec. 15	349	" 23	357
L	60	" 09	344	" 11	346
	61	" 16	350	" 15	349
	62	" 14	348	" 18	352
	63	" 06	340	" 13	347
L	64	" 04	339	" 06	341
	65	Nov. 20	324	" 12	346
	66	Dec. 16	350	" 31	365
	67	" 01	335	" 17	351
L	68	Nov. 27	332	" 26	360
	69	Dec. 18	352	Jan. 02	368

$r = 0.38$

Data Set 8 Break-up I Mackenzie River Basin

	Year	Fort Good Hope Date-Mo.	Fort Good Hope Day-Yr.	Fort Simpson Date-Mo.	Fort Simpson Day-Yr.	Norman Wells Date-Mo.	Norman Wells Day-Yr.
	1942	May 05	125	Apr. 24	114	May 14	134
	43	" 07	127	" 26	116	" 15	135
L	44	" 21	142	May 15	136	" 21	142
	45	" 09	129	" 02	122	" 08	128
	46	" 12	132	" 03	123	" 12	132
	47	" 16	136	" 12	132	" 15	135
L	48	" 18	139	Apr. 29	120	" 19	140
	49	" 12	132	May 16	136	" 13	133
	50	" 12	132	" 06	126	" 10	130
	51	" 16	136	Apr. 30	120	" 15	135
L	52	" 15	136	May 09	130	" 16	137
	53	" 22	142	" 14	134	" 23	143
	54	" 18	138	" 12	132	" 20	140
	55	" 18	138	" 11	131	" 22	142
L	56	" 19	140	" 05	126	" 21	142
	57	" 16	136	" 07	127	" 21	141
	58	" 19	139	" 14	134	" 20	140
	59	" 11	131	Apr. 25	115	" 15	135
L	60	" 23	144	May 19	140	" 23	144
	61	" 22	142	" 13	133	" 22	142
	62	" 10	130	" 01	121	" 10	130
	63	" 24	144	" 09	129	" 27	147
L	64	" 22	143	" 02	123	" 24	145
	65	" 15	135	" 08	128	" 15	135
	66	" 15	135	" 08	128	" 19	139
	67	" 18	138	" 04	124	" 21	141
L	68	" 09	130	Apr. 15	106	Apr. 22	113
	69	" 23	143	" 14	104	" 12	102

Matrix of r- values

	Fort Good Hope	Fort Simpson	Norman Wells
Fort Good Hope	-	0.44*	0.35
Fort Simpson	-	-	0.73*

Data Set 9 Break-up I Manitoba Saskatchewan Rivers

	Saskatoon		Brandon		The Pas	
Year	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.
1942	Apr. 07	97	Apr. 05	95	Apr. 23	113
43	" 09	99	" 14	104	" 22	112
L 44	Mar. 30	90	Mar. 29	89	May 05	126
45	" 26	85	Apr. 01	91	Apr. 20	110
46	" 27	86	" 15	105	May 02	122
47	Apr. 18	108	" 21	111	" 06	126
L 48	" 11	102	" 11	102	Apr. 16	107
49	" 17	107	" 20	110	May 02	122
50	" 08	98	" 10	100	Apr. 25	115
51	" 06	96	" 12	102	" 20	110
L 52	" 20	111	" 08	99	" 26	117
53	" 18	108	" 15	105	May 12	132
54	" 10	100	" 02	92	Apr. 20	110
55	" 15	105	" 19	109	May 07	127
L 56	" 15	106	" 01	92	Apr. 23	114
57	" 06	96	Mar. 28	87	" 06	96
* 58	Mar. 28	87*	" 24	83*		
59	" 31	90	Apr. 12	102	Apr. 25	115
L 60	Apr. 02	93	" 08	93	" 17	108
61	" 12	102	" 16	106	" 25	115
62	" 03	93	Mar. 25	84	" 16	106
63	" 06	96	Apr. 09	99	" 21	111
L 64	" 25	116	" 12	103	" 25	116
65	Mar. 31	90	" 01	91	" 16	106
66	Apr. 25	115	" 07	97	May 07	127
* 67	M		Mar. 29	88	Apr. 22	112
L 68	Apr. 09	100	Apr. 11	102	" 16	107
69	Mar. 15	74	" 14	104	" 28	118

Matrix of r- vàlues

	Saskatoon	Brandon	The Pas
Saskatoon	–	0.36	0.32
Brandon	–	–	0.55*

Data Set 10 Break-up I Ontario Lakes

	Trenton		North Bay	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
1937	Mar. 26	82	Apr. 24	114
38	Apr. 22	112	May 07	127
39	" 18	108	" 04	124
L 40	" 11	102	Apr. 24	115
41	Mar. 26	85	" 26	116
42	Apr. 09	99	May 11	131
43	" 11	101	" 04	124
L* 44	M	-	Apr. 03	-
* 45	M	-	" 04	-
46	Apr. 09	99	May 02	122
47	" 27	117	Apr. 20	110
L 48	Mar. 25	85	" 24	115
49	Apr. 09	99	May 06	126
50	Mar. 08	67	Apr. 19	109
51	" 20	79	" 28	118
L 52	" 12	72	" 13	104
53	" 23	82	" 21	111
54	" 18	77	" 19	109
55	Apr. 05	95	May 09	129
L 56	Mar. 22	82	Apr. 20	111
57	" 26	85	" 05	95
58	Apr. 11	101	" 18	108
* 59	M	-	" 20	-
L 60	Mar. 24	84	May 01	122
61	" 22	81	Apr. 24	114
62	" 24	83	" 16	106
63	" 15	74	" 18	108
L* 64	M	-	May 01	-
65	Mar. 21	80	Apr. 15	105
66	" 29	88	" 14	104
67	" 24	83	" 14	104
L 68	" 27	87	" 20	111
69	" 28	87	" 17	107

r = .52*

Data Set 11 Break-up II Alberta - Saskatchewan Rivers

	Edmonton		Prince Albert		Island Falls	
Year	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.
1899	Apr. 18	108	Apr. 12	102		
L 1900	" 15	106	" 21	112		
01	" 26	116	" 18	108		
02	" 16	106	" 25	115		
03	" 14	104	" 21	111		
L 04	" 08	99	" 07	98		
05	" 13	103	" 14	104		
06	" 25	115	May 11	131		
07	" 20	110	Apr. 21	111		
L 08	May 06	127	May 08	129		
09	Apr. 05	95	Apr. 01	91		
10	" 20	110	" 18	108		
11	" 12	102	" 15	105		
L 12	" 15	106	" 15	106		
13	" 20	110	" 19	109		
14	" 10	100	" 09	99		
15	" 18	108	" 19	109		
L 16	" 13	104	" 30	121		
17	" 10	100	" 11	101		
18	" 12	102	" 16	106		
19	" 23	113	" 29	119		
L 20	" 16	107	" 21	112		
21	" 26	116	" 22	112		
22	" 23	113	" 22	112		
23	" 29	119	" 28	118		
L 24	" 09	100	" 14	105		
25	" 14	104	" 18	108		
26	" 18	108	" 27	117		
27	" 25	115	" 24	114		
L 28	" 25	116	" 25	116		
29	" 04	94	" 12	102		
30	" 11	101	" 12	102	Apr. 30	120
31	" 14	104	" 17	107	May 07	127
L 32	" 26	117	" 21	112	" 16	137
33	" 11	101	" 18	108	" 22	142
34	" 20	110	" 23	113	" 14	134
35	" 20	110	" 21	111	" 11	131
L * 36	M	-	" 16	107	" 07	128
* 37	M	-	" 15	105	" 17	137
38	Apr. 12	102	" 21	111	" 05	125
39	" 15	105	" 21	111	" 08	128
L 40	" 08	99	" 14	105	" 01	122

Data Set 11 Break-up II Alberta - Saskatchewan Rivers (continued)

	Edmonton		Prince Albert		Island Falls	
Year	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.
1941	Apr. 21	111	Apr. 22	112	May 11	131
42	" 10	100	" 15	105	" 19	139
43	" 04	94	" 13	103	" 02	122
L 44	" 19	110	" 18	109	" 29	150
45	" 11	101	" 10	100	" 01	121
46	" 12	102	" 21	111	" 25	145
47	" 24	114	" 28	118	" 16	136
L 48	" 11	102	" 09	100	" 10	131
49	" 18	108	" 22	112	" 20	140
50	" 07	97	" 14	104	" 05	125
51	" 10	100	" 13	103	Apr. 29	119
L 52	" 07	98	" 20	111	May 08	129
53	" 05	95	May 02	122	" 21	141
* 54	M	-	Apr. 10	100	" 03	123
* 55	M	-	" 18	108	" 17	137
L* 56	M	-	" 24	115	" 15	136
57	Apr. 12	102	" 10	100	" 07	127
* 58	M	-	" 15	105	" 31	151
59	Apr. 08	98	" 15	105	" 24	144
L 60	" 17	108	" 20	111	" 22	143
61	" 16	106	" 21	111	" 23	143
62	" 20	110	" 15	105	" 18	138
* 63	M	-	" 14	104	" 12	132
L 64	Apr. 25	116	May 01	122	" 17	138
65	" 09	99	Apr. 23	113	" 16	136
66	May 08	128	May 06	126	" 26	146

Matrix of r- values

	Edmonton	Prince Albert	Island Falls
Edmonton	-	0.68*	0.43*
Prince Albert	-	-	0.48*

Data Set 12 Break-up II Red - Assiniboine Rivers

	Brandon		Winnipeg	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
1942	Apr. 12	102	Apr. 08	98
43	" 24	114	" 19	109
L 44	" 08	99	Mar. 23	83
45	" 13	103	" 25	84
46	" 22	112	Apr. 14	104
47	" 30	120	" 18	108
L 48	" 15	106	" 10	101
49	" 26	116	" 23	113
50	" 16	106	" 10	100
51	" 18	108	" 18	108
L 52	" 15	106	" 13	104
53	" 23	113	" 16	106
54	" 14	104	" 08	98
55	" 26	116	" 23	113
L 56	" 15	106	" 04	95
57	" 04	94	" 10	100
58	" 01	91	" 14	104
59	" 20	110	" 12	102
L 60	" 13	104	" 19	110
61	" 22	112	" 24	114
62	" 12	102	" 10	100
63	" 18	108	" 18	108
L 64	" 17	107	" 17	108
65	" 10	100	" 05	95
66	" 19	109101	" 15	105
67	" 11	101	" 14	104
L 68	" 15	106	" 15	106
69	" 25	115	" 20	110

r = 0.57*

Data Set 13 Break-up II Atlantic Provincial Rivers

	Cambellton		Chatham		Quebec	
Year	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.
L 1912	May 25	146	Apr. 16	107	Apr. 17	108
13	" 08	128	May 04	124	" 27	117
14	Apr. 23	113	Apr. 15	105	" 13	103
15	" 21	111	" 13	103	" 22	112
L 16	" 27	118	" 21	112	" 22	113
17	" 28	118	" 22	112	" 22	112
18	" 23	113	" 11	101	" 18	108
19	" 25	115	" 19	109	" 17	107
L 20	" 21	112	" 04	95	Mar. 28	88
21	" 19	109	" 08	98	Apr. 15	105
22	May 03	123	" 29	119	" 30	120
23	Apr. 27	117	" 27	117	" 19	109
L 24	" 25	116	" 20	111	" 11	102
25	May 10	130	May 01	121	May 01	121
26	Apr. 26	116	Apr. 21	111	Apr. 11	101
27	" 30	120	" 19	109	" 27	117
L 28	May 02	123	" 23	114	" 13	104
29	Apr. 29	119	" 12	102	" 19	109
30	" 06	96	" 11	101	" 06	96
31	" 18	108	" 14	104	" 19	109
L 32	" 22	113	" 26	117	" 14	105
33	" 24	114	" 18	108	" 20	110
34	" 23	113	" 25	115	" 20	110
35	" 26	116	Mar. 24	83	Mar. 30	89
L 36	" 23	114	Apr. 17	108	Apr. 21	112
37	" 20	110	" 17	107	" 16	106
38	May 02	122	" 29	119	May 03	123
39	Apr. 30	120	" 26	116	Apr. 28	118
L 40	" 18	109	" 19	110	" 15	106
41	" 25	115	" 21	111	" 22	112
42	May 07	127	" 27	117	May 02	122
43	Apr. 26	116	" 23	113	Apr. 23	113
L 44	" 10	101	" 07	98	" 02	93
45	" 23	113	" 19	109	" 07	97
46	May 08	128	" 24	114	" 18	108
47	Apr. 24	114	" 22	112	" 12	102
L 48	" 15	106	" 06	97	" 09	100
49	" 22	112	" 19	109	" 19	109
50	" 12	102	" 06	96	" 11	101
51	" 26	116	" 15	105	" 19	109
L 52	" 08	99	" 12	103	" 07	98
53	" 20	110	" 12	102	" 18	108
54	" 22	112	" 15	105	" 18	108
55	" 21	111	" 22	112	" 16	106

	Cambellton	Chatham	Quebec
Cambellton	–	.52*	.54*
Chatham	–	–	.72*

Data Set 14 Break-up II Atlantic Prov. Lakes

	Sidney		Moncton		St. John	
Year	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.	Date-Mo.	Day-Yr.
1947	Apr. 17	107	Apr. 26	116	Apr. 14	104
L 48	" 07	98	" 20	111	Mar. 20	80
49	" 30	120	" 21	111	Apr. 17	107
50	Mar. 17	76	" 21	111	Mar. 19	78
51	Apr. 19	109	" 22	112	" 24	83
L 52	Mar. 29	89	" 04	95	Feb. 09	40
53	Apr. 11	101	" 22	112	Mar. 01	60
54	" 07	97	" 25	115	Apr. 20	110
55	" 24	114	May 04	124	" 19	109
L 56	" 26	117	" 03	124	" 16	107
57	Mar. 22	81	Apr. 24	114	Mar. 16	75
58	Apr. 20	110	" 25	115	Apr. 13	103
59	" 17	107	" 28	118	" 15	105
L 60	May 09	130	May 10	131	May 03	124
61	Apr. 09	99	Apr. 28	118	Apr. 06	96
62	May 02	122	" 28	118	May 01	121
63	Apr. 24	114	" 08	98	Apr. 22	112
L* 64	May 11	132	May 02	*123	M	-
65	Apr. 16	106	Apr. 24	114	Apr. 17	107
66	May 14	134	May 08	128	May 08	128
67	Apr. 10	100	Apr. 18	108	Apr. 10	100
L 68	Mar. 27	87	" 30	121	" 17	108
69	Apr. 20	110	" 25	115	" 16	106

	Sidney	Moncton
Sidney	-	.50*
Moncton	-	-

Data Set 15 Break-up II Ontario Lakes

	Sudbury		Trenton	
Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
1945	Apr. 04	94	Mar. 23	82
46	" 08	98	Apr. 11	101
47	" 25	115	" 05	95
L 48	" 24	115	" 01	92
49	May 09	129	" 14	104
50	Apr. 26	116	Mar. 31	90
51	" 28	118	Apr. 05	95
L 52	" 20	111	Mar. 20	80
53	" 26	116	Apr. 05	95
54	" 21	111	" 08	98
55	May 10	130	" 15	105
L 56	Apr. 25	116	" 02	93
57	" 16	106	" 01	91
58	" 29	119	" 16	106
59	May 03	123	M	-
L 60	" 07	128	Apr. 08	99
61	Apr. 27	117	" 11	101
62	" 25	115	" 04	94
63	" 28	118	" 07	97
L 64	May 05	126	M	-
65	Apr. 24	114	Mar. 26	85
66	" 29	119	Apr. 05	95
67	" 18	108	Mar. 30	89
L 68	" 26	117	Apr. 08	99
69	" 29	119	" 15	105

$r = 0.56$*

Data Set 16 Break-up II Quebec Lakes

		Bagotville		Cabano	
	Year	Date of Month	Day of Yr.	Date of Month	Day of Yr.
	1930	Apr. 28	118	Apr. 23	113
	31	May 13	133	" 30	120
L	32	" 14	135	May 07	128
	33	" 06	126	" 02	122
	34	" 15	135	" 02	122
	35	" 05	125	Apr. 25	115
L	36	" 10	131	May 05	126
	37	" 01	121	" 01	121
	38	" 17	137	" 09	129
	39	" 17	137	" 07	127
L	40	" 07	128	" 05	126
	41	" 03	123	" 03	123
	42	" 22	142	" 18	138
	43	" 10	130	" 07	127
L	44	Apr. 14	105	Apr. 14	105
*	45	May 14	-	M	-
	46	" 25	145	May 21	141
	47	" 12	132	" 06	126
L	48	" 04	125	Apr. 29	119
	49	" 17	137	May 06	127
	50	Apr. 28	118	Apr. 22	112
	51	May 08	128	May 07	127
L	52	Apr. 29	120	Apr. 24	114
	53	May 05	125	May 02	123
	54	" 04	124	" 04	124
	55	" 13	137	" 07	127

$r = .89*$

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