Seasonal regime and hydrological significance of stream icings in central Alaska

Douglas L. Kane and Charles W. Slaughter

Institute of Water Resources, University of Alaska, College, Alaska, U.S.A.
and
U.S. Army Cold Regions Research and Engineering Laboratory, Fairbanks, Alaska, U.S.A.

ABSTRACT: Many streams in Arctic and sub-Arctic regions are characterized by accumulations of ice in the channel and nearby floodplain during the winter months. Field data on the rates of growth of this icing and on various climatic factors has been collected at a small research watershed near Fairbanks, Alaska. The volume of icing growths is estimated from aerial photographs. Hydrologic implications are derived by comparing the volume of these icings with other elements of the hydrologic cycle. Discussion on how the hydrologic cycle is modified by these ice accumulations is also included.

RESUME: De nombreux cours d'eau des régions arctiques et sub-arctiques sont caractérisés par des accumulations de glace, dans le chenal et dans la plaine d'inondation environnante, pendant les mois d'hiver. Les données sur les taux d'accroissement de ces glaces et sur les facteurs climatiques ont été recueillies dans un petit bassin de recherches près de Fairbanks en Alaska. On estime le volume d'augmentation de la glace au moyen de photographies aériennes. On fait alors des déductions hydrologiques en comparant le volume de ces glaces à d'autres éléments du cycle hydrologique. On discute aussi de la manière dont le cycle hydrologique est modifié par ces accumulations de glace.

INTRODUCTION

Large masses of seasonal ice in stream channels and in valley flood plains are found in northern regions. Such masses are not restricted to the typical surface ice that forms on open bodies of water with a downward progression of the freezing front. Another icing phenomenon occurs when channel water is restricted and forced to flow over the original ice cover. This water then freezes, and with subsequent overflows, ice reaches thicknesses of 2 to 3 metres or more and may extend for several kilometres in the horizontal plane. A clear understanding is lacking of the physical processes responsible for this icing formation.

Such stream "icings", sometimes termed "naleds" in the Russian literature, have been noted often but studied little. Carey (1970) has provided a comprehensive bibliography on the subject; the majority of his references are Russian, and most deal with attempts to control icing rather than with study of the phenomenon itself.

LOCALE

The points selected for monitoring are near the outlets of three subdrainages of the Caribou-Poker Creeks Research Watershed, north of Fairbanks, Alaska (Fig. 1). These basins are under study as one phase of a sub-Arctic environmental research program as described by Slaughter (1971).

The three basins selected, subdrainages C-1, C-2, and C-3 of Caribou Creek, have drainage areas of approximately 6.7, 5.2, and 5.7 km^2 (2.6, 2.0, and 2.2 mi^2) respectively, with east, south, and northeast drainages in that order. Permafrost (perennially frozen ground) exists in each basin in varying amounts, but is most prevalent in subdrainage C-3 and least common in subdrainage C-2.

Near-surface geology of the region is dominated by Birch Creek Schist. South-facing slopes are commonly mantled by wind-deposited silts, whereas valley bottoms are characterized by locally derived gravels often overlain by shallow peat or muck deposits. Soils underlying areas of observed icing activity in Caribou Creek are mapped as Saulich, Ester, or Karshner silt loams (Rieger, et al., 1971), each of which is underlain by permafrost at shallow depth. Vegetative cover of north-facing slopes is dominated by black spruce (*Picea mariana*) and alder (*Aluns crispa*); south-facing, non-permafrost slopes support communities of birch (*Betula papyrifera*), aspen (*Populus tremuloides*), alder, and white spruce (*Picea glauca*). Valley floors are commonly occupied by a shrub complex dominated by blueberry (*Vaccinium sp.*) and willow (*Salix sp.*).

PROCEDURE

Monitoring of icing behavior was approached by repetitive elevation measurements along designated cross-sections. One cross-section line was located across the lower valley of each basin in the fall of 1969. Stations were established at 3-m (10-ft) intervals, for repeated elevation determination. Beginning with initiation of icing build-up, measurements were taken at approximately weekly intervals throughout the winter of 1969-1970.

Near each cross-section, air temperature was recorded by thermographs throughout the winter. Snow depth and density were measured at monthly intervals at selected points in the basins. Streamflow was measured by the U. S. Geological Survey in a stream reach free from icing, at a point on Caribou Creek having a drainage area of 23.3 km^2 (9.0 mi^2). Following snowpack disappearance in the spring, selected portions of the research watershed were photographed from the air using a hand-held camera.

RESULTS

Data on ice build-up obtained by these methods are presented in Figures 2, 3, and 4. Weekly accumulation or depletion (cross-sectional area of ice along the survey line) is plotted as percentage of maximum accumulation in Figure 2. The maximum measured cross-sectional area of ice for C-1, C-2, and C-3 was 61.0 m^2, 63.5 m^2, and 100.8 m^2 (655 ft^2, 683 ft^2, and 1084 ft^2), respectively. As indicated on Figure 2, formation of icing in subdrainage C-3 began about a month prior to that in C-1 and C-2. By the end of March, 1970, the icing has reached approximately 95% of its maximum growth; about 80% of the accumulation had occurred by the end of February.

The surveyed ice surface profile at the mouth of subdrainage C-3, four times during the winter, is shown in Figure 3 (with 40:1 vertical scale exaggeration). In Figure 4, incremental and total ice accumulations are shown from the beginning of ice growth through March 25, 1970, for one point at the C-3 site. Accumulation increments were measured on a 10-cm (4-in) diameter ice core extracted from the icing, March 25. By comparing these increments with level observations, the period during which accumulation occurred at that point could be determined.

Times of maximum ice build-up generally coincide at the three locations. Maximum icing formation occurred from mid-winter to early spring, long after freeze-up in this area. During the 1969-70 winter, below-freezing mean daily air temperatures prevailed in the watershed after mid-October. Air temperatures at one location, near the cross-section in subdrainage C-3 are shown in Figure 5.

Melt of the accumulated ice occurred fairly rapidly and uniformly. Ice was essentially gone from the cross-section in subdrainage C-1 by the third week of May, and from the cross-sections in C-2 and C-3 by early June. Areal distribution of these ice accumulations was not measured directly. An attempt was made, however, to map ice distribution following almost complete ablation of the seasonal snowpack. On a helicopter flight, April 23, 1970, hand-held oblique photographs of the valleys of the watershed were obtained. By utilizing this type of photography, on which ice was readily discernible, ice distribution was sketched on 1:16,000 vertical photographs of the area. This resulted in a visual depiction of ice in the basin. The pattern of ice distribution along the main-stem of Poker Creek is shown in Figure 6. With ice delineated on vertical photographs, the surface area of icing was determined graphically; this yielded a surface area of 0.78 km^2 (0.30 mi^2) for the entire watershed. Although this technique is admittedly crude, it nevertheless is useful for considering the extent and hydrologic role of icing. Some ablation had occurred at the time of this survey; it is considered minor, with little diminution of areal extent of ice prior to photography.

DISCUSSION

Classifications

Icings such as those discussed here have been observed often in permafrost-dominated regions. The Caribou-Poker Creeks icings are apparently typical of those found in other areas of Alaska, and in Northern Eurasia. Bol'Shakov (1966) has provided a classification scheme for use in condidering icing, based on physical and geological indicators. The categories suggested are not necessarily mutually exclusive. Icing observed in Caribou Creek has characteristics of each of Bol'Shakov's four major icing types: surface water (river and stream), groundwater (suprapermafrost water), subterranean water (springs), and subterranean water (interpermafrost and subpermafrost). Johnson (1950) distinguished three major types of icing: river icing, ground icing (water source from above permafrost), and spring icing (water source from below permafrost). The Caribou Creek icings observed also appear to be a combination of the latter types.

From a practical standpoint, the most useful classification would be a simple distinction between icing primarily formed by winter-long contribution of groundwater, and that formed by water from fall runoff and suprapermafrost (active layer) sources.

In the current study, major icing activity occurred in mid to late winter. Although measurements of ground freezing regime are not available at the study locations, it is presumed that the active layer was generally refrozen by this time, at least on north-facing slopes and in valley bottoms. Below-freezing temperatures at ground level prevailed from early October, 1969 at the 485 m (1600 ft) elevation in subdrainage C-2, and from late September, 1969 at the same elevation in subdrainage C-3. Water temperature records indicated complete freezing in the streams (C-1, C-2, C-3) by November, 1969.

The active layer (zone of seasonal thawing and freezing over permafrost) is shallow in undisturbed sites in the area; in 1971, maximum thaw depth in the main valley of Caribou Creek was found to be about 60 cm (Rickard, unpublished data). Other Alaskan investigations have shown that, on undisturbed sites, the active layer is completely refrozen to contact with permafrost by mid-winter (Rickard and Brown, unpublished data). These considerations indicate that a large share of the water contributing to icings in this area is from sub-permafrost groundwater sources.

No measurements are available on depths of permafrost in the study area, nor has a detailed study been made of permafrost distribution. Such information would be of great value in analysis of this question of water source for icing development.

Hydrologic Significance

The hydrologic role of icings is two-fold. Firstly, the icing indicates sources of sub-surface water yield. The probable role of these features as indicators of groundwater sources has been noted by Hopkins, et al. (1955), Tolstikhin and Obidin (1936), Shvetsov and Sedov (1940), and Müller (1947), among others. Consistent emphasis has been placed on the role of groundwater in icing development, whether it is defined as water from above permafrost (Straub and Johnson, 1949; Johnson, 1950; Rumiantsev, 1966) or from below permafrost (Chekotillo, 1941; Shvetsov and Sedov, 1940). That water from both above and below permafrost may be important is recognized by Mudrov (1962) and Bol'Shakov (1966), among others. Secondly, the icing itself constitutes a means of water storage and delayed water yield during the ablation season. The influence on water yield from upland basins is primarily in terms of timing. Icing persists long after disappearance of snow cover. In the absence of precipitation, melt of this stored ice constitutes the major addition to base flow of upland streams following melt of the snowpack. Contribution of meltwater from permafrost melt is considered negligible (Dingman, 1971).

A preliminary assessment of the significance of this stream icing in the hydrologic regime of Caribou Creek can be accomplished through several simple calculations. The total yearly runoff volume for the entire Caribou-Poker Creeks drainage complex was estimated by taking published discharge for Caribou Creek (Geological Survey, 1971), deriving runoff per unit area, and applying that figure to the total watershed. The water content of the snowpack at maximum accumulation was taken as 5 cm (2 in), based on snow survey data for the area (Soil Conservation Service, 1970). Application of this assumed average to the entire basin yielded an estimated snowpack volume (Table 1). Winter (December - March) streamflow was estimated in the same manner as that for the entire water year. Volume of water in storage as stream icing was estimated, by utilizing the previously described estimate of areal ice distribution and an assumed mean icing depth of 0.9 m (3 ft). Quantities of water so estimated are given in Table 1. Water stored as icings is only 4% of the estimated yearly runoff volume. However, this storage amounts to almost 40% of estimated streamflow for the winter months - an appreciable portion of basin yield.

The potential influence of delayed release of this water can also be estimated. If one assumes that melt takes place over a four week period (Fig. 2), the estimated 710,000 m^3 (576 acre-ft) of ice would yield an average flow of 0.28 m^3/sec (9.8 cfs) during the month. This would be yielded largely after spring snowmelt runoff, and so it would comprise a noticeable augmentation of late spring streamflow.

Table 1

Estimated volumes of water, 1970 water year, for composite Caribou-Poker Creeks Basin

	1000 x m^3	Acre-feet
Icings (assume average depth 0.9 metres)	710	576
Runoff (water year)	17,700	14,400
Runoff (December, January, February, March)	1820	1475
Snow Accumulation (water content 5 cm)	5360	4340

Associated Effects

Two other, unstudied, effects of the icing phenomenon should be mentioned. During the spring, the presence of these ice masses in valleys causes diversion of meltwater from single-channel streamflow to dispersed flow. Channels develop (or are maintained during icing formation) under and in the ice mass, as well as on the surface. Location and extent of such channels, as well as amount of flow carried at any given time, presents a difficult problem which was not approached in this study. Meltwater can be yielded through such channels, as well as over the ice surface. Water has been observed moving as "sheet flow" over smooth stretches of ice during early melt periods. These conditions make measurement of runoff during the ablation season virtually impossible by conventional means.

The presence of icing may have significant effects on seasonal progression of biotic development. Valley floors and stream channels under icings are maintained at or below freezing temperatures well into early summer, relative to adjacent slopes. Spring vegetative development may well be retarded, with initiation of growth impeded by low temperature at the ground surface and by physical presence of ice. Aquatic organisms may be affected, again by the physical presence of ice, by maintenance of low water temperatures, by ice in channels, and by meltwater near 0°C being yielded to streamflow. These considerations are speculative at this time, but do suggest opportunity for detailed research.

The adverse effects of icing on man-made structures such as bridges and culverts has often been documented (Carey, 1970). A similar problem occurs with stream gauging stations. Development of a major stream icing in the control section interferes with rating curves and prevents or impedes current meter measurements; such icing development has substantially delayed the time of spring opening of the stream gauge in Caribou Creek (and other locations), due to the physical problems of removing or melting ice from/around the stilling well and from the control section.

SUMMARY

Stream icings are phenomena characteristic of cold environments. Although these features have often been observed, and much effort has been expended on control of icings where they constitute problems to man's activities, knowledge of factors governing occurrence and regime of stream icing is notably lacking. The hydrologic significance of icing is seen primarily in terms of temporary water shortage. Water involved in icing formation is diverted from winter streamflow; this same water is released from storage by melt in late spring, augmenting streamflow after peak snowmelt runoff.

Due to the high density of ice and concentration of icing in and adjacent to stream channels, the hydrologic role of icing differs markedly from that of a seasonal snowpack. Water yielded by melt of icing is largely available for streamflow, and does not contribute moisture to the soil mantle away from stream channels as does snowpack meltwater. In the current study, stream icing in a sub-Arctic, upland watershed constituted 4% of yearly runoff volume, but amounted to nearly 40% of winter streamflow. Melt occurred over a four-week period, largely following ablation of the seasonal snowpack.

It should be emphasized that this study reports only one year of observations. Experience in the area has shown that icing tends to recur in the same locations year after year, but does not necessarily occur in any given year or location. The relation of icing occurrence and regime to local climate, geology, groundwater regime, permafrost distribution, and related site factors needs detailed investigation. The occurrence and behaviour of stream icing in other Arctic and sub-Arctic regions are not discussed in this paper; such observations and treatment of the role of icing in regional hydrologic analyses would be welcome. Research on these and associated questions is vital to obtaining full understanding of the icing phenomenon.

ACKNOWLEDGMENT

The assistance of personnel from the Alaska Field Station, USACRREL, and from the Ft. Wainwright Detachment , U. S. Army Meteorologic Support Activity, in field observations is gratefully acknowledged. SP4 R. E. Koutz, USACRREL, assisted with data analysis. Dr. R. F. Carlson, Institute of Water Resources, University of Alaska, was most helpful in critically reviewing this manuscript.

REFERENCES

BOL'SHAKOV, S.M. (1966). Naledi kak otritsatel'noe fiziko-geologicheskoe yavlenie. (Icing as a negative physical and geological phenomenon.) Komitet po zemlianomu polotnu. Bor'ba s nalediami na zheleznykh i avtomobil'nykh dorogakh, No. 7, pp. 72-83. Moscow: Transport. Translated for USACRREL, 1969, by U.S. Army Foreign Science and Technology Center, FSTC-HT-23-413-68.

CAREY, K.L. (1970). Icing occurrence, control and prevention: an annotated bibliography. Special Report 151, U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL), 57 pp.

CHEKOTILLO, A.M. (1941). Oblast' velekikh naledei; naledei Vostochnoi Iakutii. (Region of the great icing: icings of eastern Yakutie.) Isvestiia Akademii Nauk SSSR, Seriia Geologicheskaia, No. 1, pp. 94-113 (as cited by Carey (1970)).

DINGMAN, S.L. (1971). Hydrology of the Glenn Creek watershed, Tanana River basin, Central Alaska. Research Report 297, U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL), 114 pp.

GEOLOGICAL SURVEY, USDI. (1971). Water resources data for Alaska. Water Resources Division, USGS, Anchorage, Alaska, 263 pp.

HOPKINS, D.M., KARLSTROM, T.N.V. et al. (1955). Permafrost and groundwater in Alaska. USGS, Professional Paper 264-F, pp. 113-146.

JOHNSON, L.A. (1950). Investigations of airfield drainage, Arctic and sub-Arctic regions. Supplement to Part I. Field reconnaissance and analysis. St. Anthony Falls Hydraulics Laboratory, University of Minnesota, for Corps of Engineers, U.S. Army, St. Paul District, 57 pp.

MUDROV, IU.V. (1962). Morfologiia i genezis naledei v TSentral'nom Zabaikel'e. (Morphology and genesis of icings in Central Transbaikaliya.) In Voprosy geograficheskogo merzlotovedeniia i perigliatsial'noi morfologii, pp. 173-183. Moscow: Moskovskii Gosudarstvennyi Universitet. Translated for USACRREL, 1969 by U.S. Army Foreign Science and Technology Center, FSTC-HT-23-489-68 (as cited by Carey (1970)).

MÜLLER, S.W. (1947). Permafrost or permanently frozen ground and related engineering problems. J.W. Edwards, Inc., Ann Arbor, Michigan, 231 pp.

RIEGER, S., FURBUSH, C.E., SCHOEPHORSTER, D.B., SUMMERFIELD, H., JR., and GEIGER, L.C. (1971). Soils of the Caribou-Poker Creeks experimental watershed, Alaska. (Interim Report.) Soil Conservation Service, USDA, Palmer, Alaska, 14 pp.

RUMIANTSEV, E.A. (1966). Dinamika nalednogo protsessa. (The dynamics of the icing process.) Komitet po zemlianomu polotnu. Bor'ba s nalediami na zheleznykh i avtomobil'nykh dorogakh, No. 7, pp. 84-97. Moscow: Transport. Translated for USACRREL, 1969, by U.S. Army Foreign Science and Technology Center, FSTC-HT-23-683-68 (as cited by Carey (1970)).

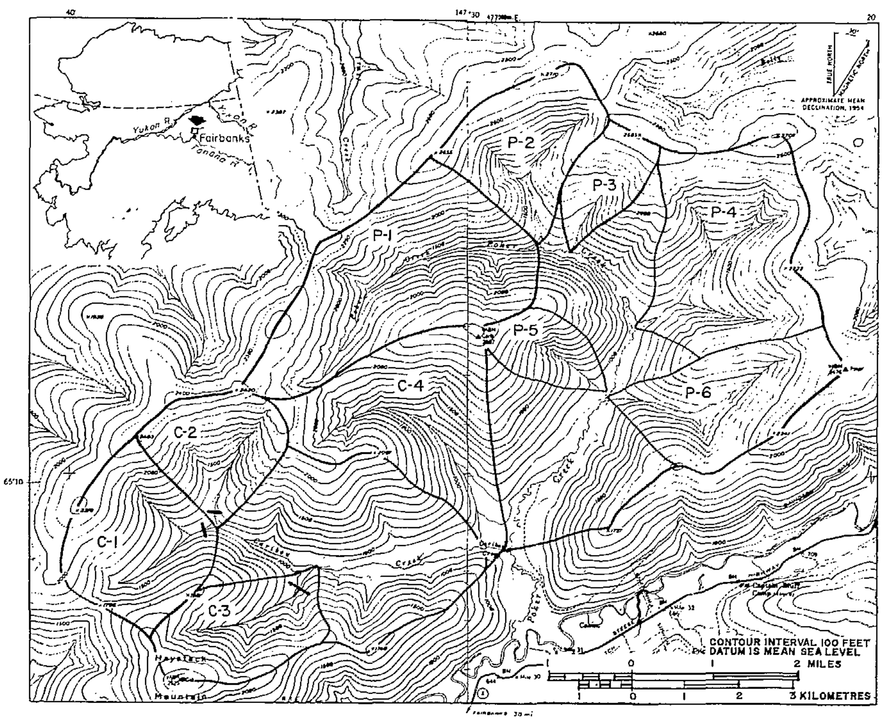
SHVETSOV, P.F., and SEDOV, V.P. (1940). Akademiia Nauk SSSR Comptes Rendus (Doklady). (Origin of the extensive aufeis on the Taskhaiakhtaich Range.) (Text in English), New Ser., Vol. 26 (4): pp. 380-384 (as cited by Carey (1970)).

SLAUGHTER, C.W. (1971). Caribou-Poker Creeks research watershed, Interior Alaska: Background and current status. Special Report 157, U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL), 11 pp.

SOIL CONSERVATION SERVICE, USDA. (1970). Summary of snow survey measurements for Alaska. SCS, Palmer, Alaska, 101 pp.

STAUB, L.G., and JOHNSON, L.A. (1949). Arctic and subarctic hydrology in Encyclopedia Arctica, Vol. IX, ed. by V. Stefanson (unpublished), 60 pp.

TOLSTIKHIN, H.E., and OBIDIN, N.I. (1936). Naledi Vostochnogo Zabaikal'ia. (Icing of the Eastern Zabaikal.) Izvestiia Gosudarstvennogo Geograficheskogo Obshchestva, Vol. 68, No. 6, pp. 844-877. Translated from Russian to Japanese by South Manchurian Railway Co., 1939; translated from Japanese to English (detailed summary) by HQ, 500th Military Intelligence Group, APO 613, Doc. No. 38174, 24 pp., 15 April, 1948 (as cited by Carey (1970)).



CARIBOU-POKER CREEKS RESEARCH WATERSHED
Tanana River Basin, Alaska

Fig. 1. Location of icing observation lines in Caribou-Poker Creeks research watershed, Interior Alaska

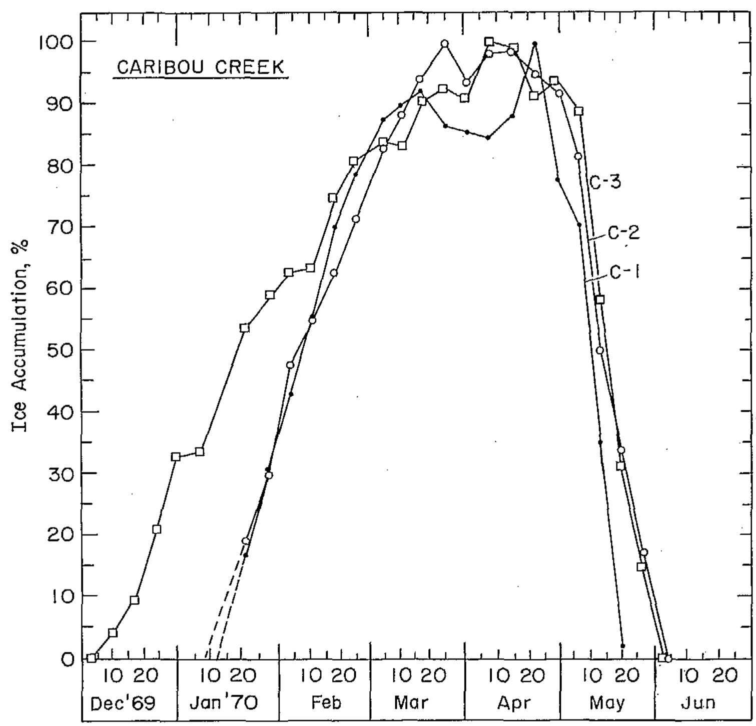


Fig. 2. Icing accumulation, as percentage of maximum seasonal accumulation

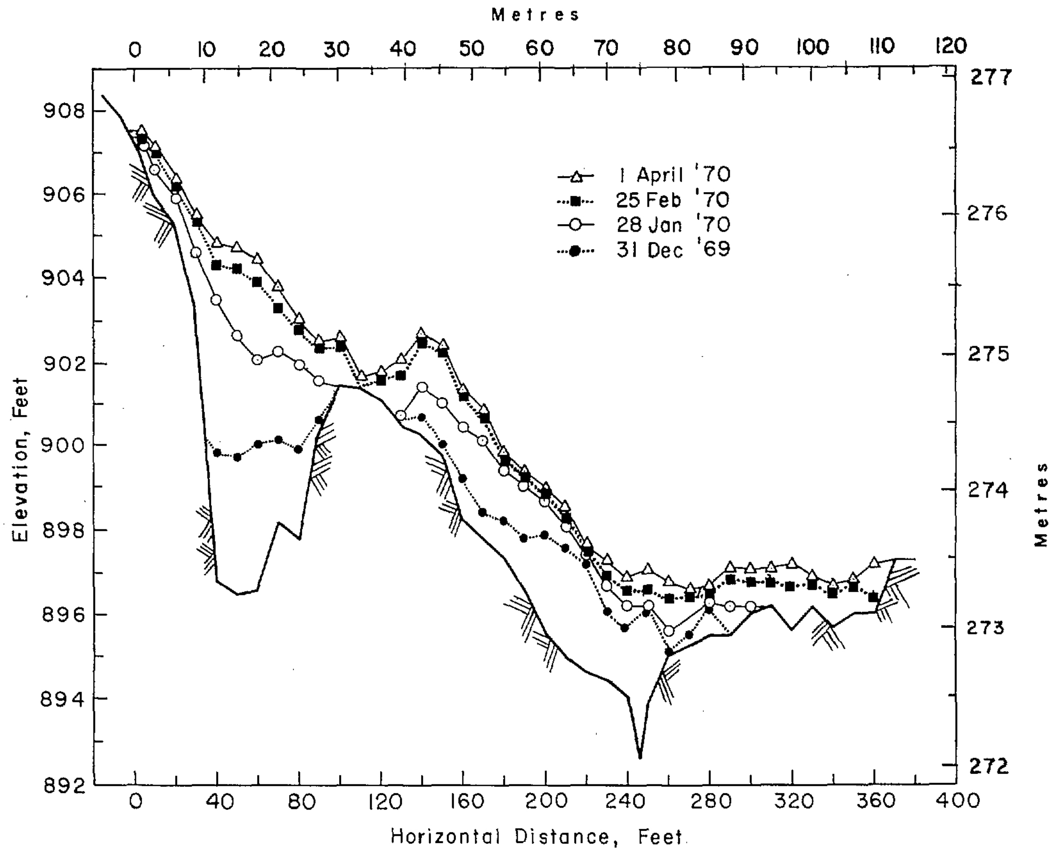


Fig. 3. Repetitive ice surface profiles, cross-section in subdrainage C-3
(40:1 vertical exaggeration)

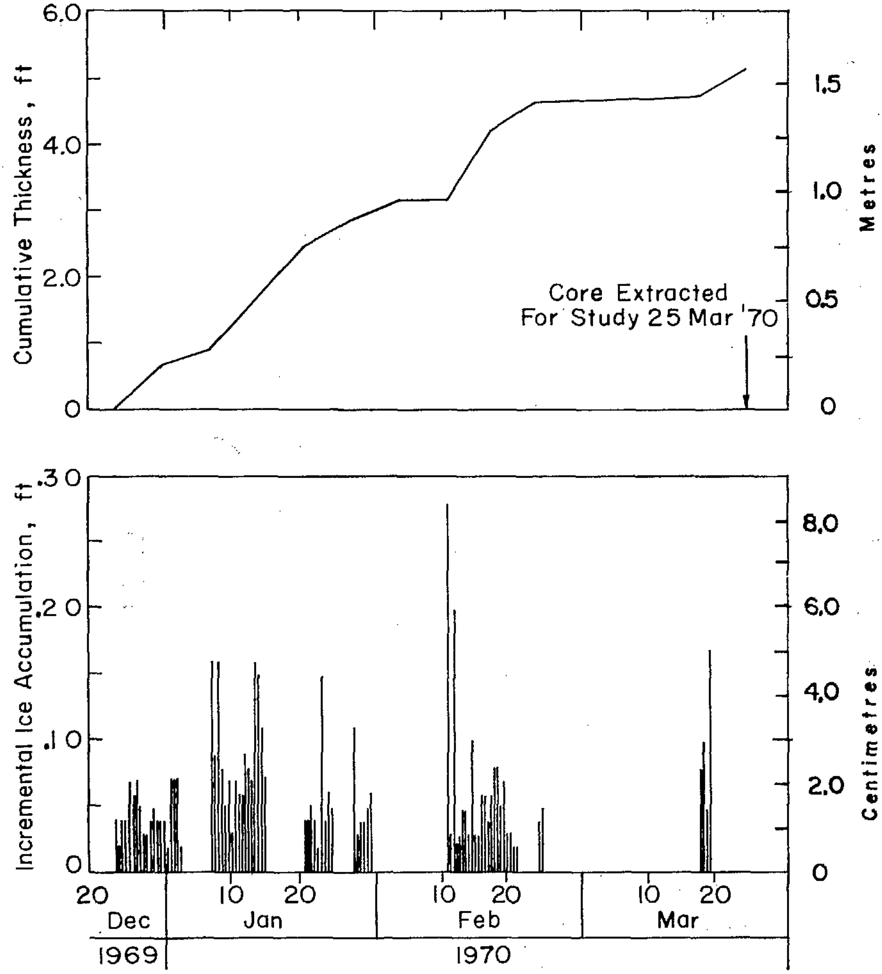


Fig. 4. Incremental accumulation, as determined by core analysis, for a point on the cross-section in subdrainage C-3

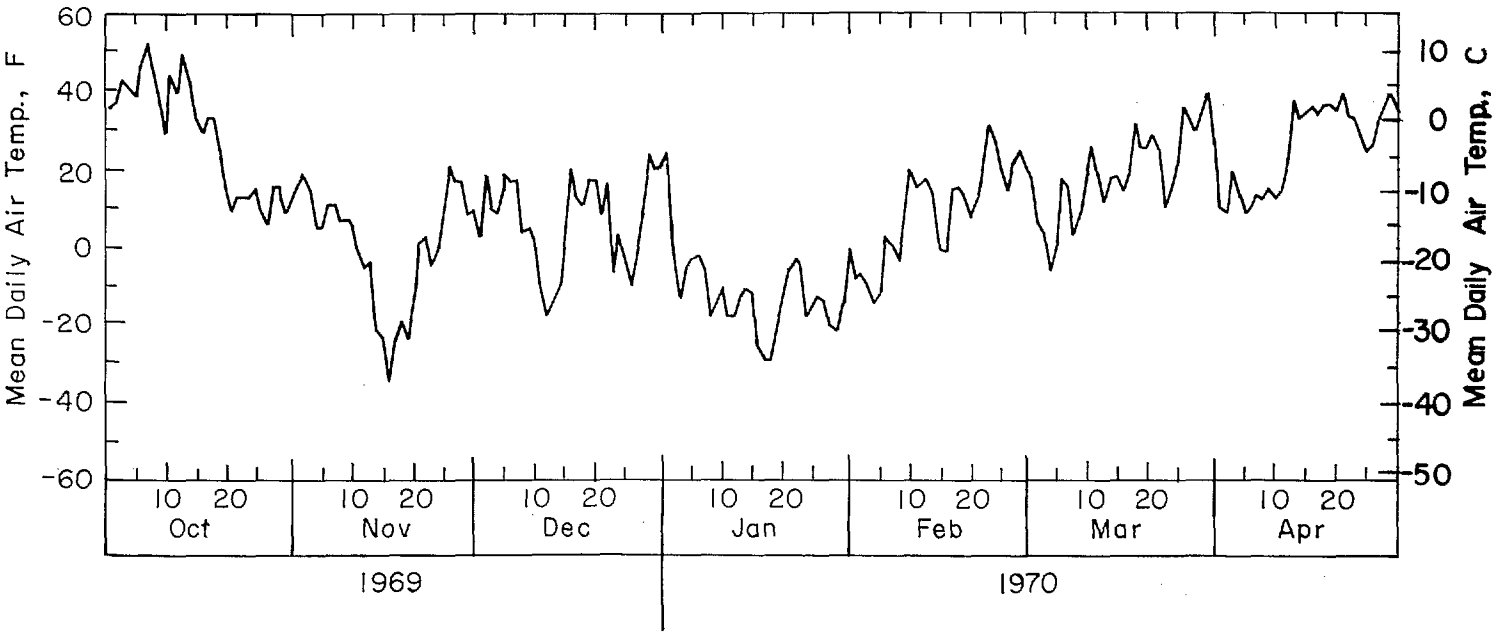


Fig. 5. Mean daily air temperature near the cross-section in subdrainage C-3
Winter 1969-70

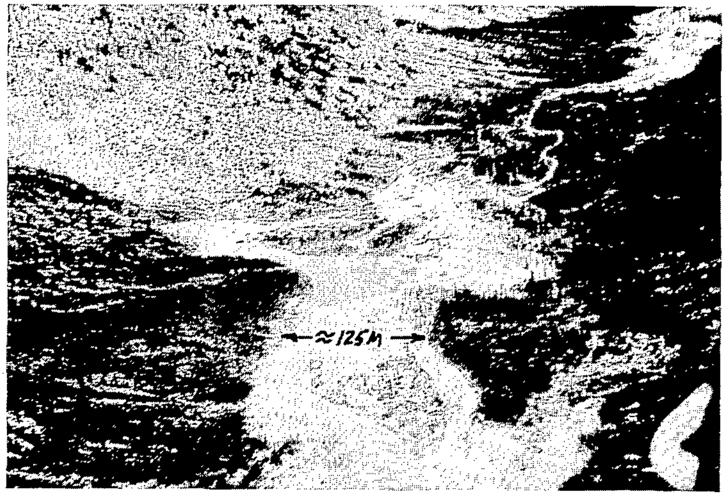


Fig. 6. Pattern of ice distribution along main-stem of Poker Creek

DISCUSSION

C.R. Neill (Canada) - In temperate parts of the world, good correlations have been developed between the hydraulic geometry of stream channels and their hydrologic regime. For example, in the U.S.A. and the U.K., it has been found that the bankfull condition generally corresponds approximately to the median annual flood.

I have heard that in Alaska the annual floods of some streams occur while they are in a frozen condition and therefore cannot be carved out by the flow. Thus, the channel size is anomalously small in relation to flood discharges. Can you comment?

D.L. Kane (U.S.A.) - It is true that the annual spring flood does occur when the rivers are still filled with ice. In this situation the ice diverts flow out of the existing channels and the river develops new channels to handle the flow. This creates an anomalous condition if the hydraulic situation is compared with more southerly rivers.