Occurrence and recurrence of aufeis in an upland taiga catchment

C.W. SLAUGHTER

Institute of Northern Forestry, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Fairbanks, Alaska 99701, USA

As a stream freezes, streamflow is impeded by thickening of the surface ice and accumulation of frazil and bottom ice on channel sides and floor. As flow is restricted, unfrozen water is subjected to increasing hydraulic pressure; this may be relieved by release of water to the surface through cracks in the ice cover or through zones of weakness at stream borders. Water released at the ice surface rapidly loses heat as it flows over the existing ice cover, and subsequently freezes. Recurring episodes of water release and freezing can result in major ice accumulation in, and adjacent to, stream channels. Water held in storage as aufeis may comprise up to 40 per cent of total winter streamflow in an upland subarctic catchment.

Aufeis was observed during 1969-80 in a subarctic drainage basin (lat. 65°N). Volume of aufeis accumulation was determined at selected locations. Spring ablation and melt were monitored at several sites over two periods of spring break-up. At one downstream site, aufeis occurred annually for at least seven years; occurrence of aufeis was intermittent during the same years at two upstream locations. Ice volume at the downstream site varied from year to year, but distribution over local areas was relatively consistent. Exposure of the site and the contributing catchment affects aufeis persistance; a south-facing, first-order basin has been consistently ice-free several weeks earlier than a nearby north-facing, first-order catchment.

Lorsqu'un cours d'eau gèle, l'écoulement de l'eau est ralenti par l'épaississement de la glace formée en surface et l'accumulation de frasil et de glace sur les côtés et sur le fond du lit du cours d'eau. A mesure que cesse l'écoulement, l'eau pas encore gelée est soumise à une pression hydraulique croissante; l'écoulement peut reprendre lorsque des fissures dans la couverture de glace ou des zones de moindre résistance laissent passer de l'eau le long des bords du cours d'eau. L'eau libérée en surface perd rapidement de la chaleur en s'écoulant sur la couverture de glace déjà constituée et se solidifie. Des épisodes répétés de libération d'eau et de congélation de celle-ci peuvent donner lieu à d'importantes accumulations de glace dans les lits des cours d'eau et à proximité de ceux-ci. L'eau prise sous forme d'aufeis peut retenir jusqu'à 40 pour cent du débit hivernal total d'un bassin hydrographique de hautes-terres subarctiques.

De 1969 à 1980, on a observé la présence d'aufeis dans un bassin-versant subarctique (lat. 65° N). On a déterminé le volume d'accumulation de l'aufeis en des endroits précis. On a aussi observé l'ablation et la fonte qui ont eu lieu au printemps en plusieurs endroits pendant deux périodes de débâcle. En un site situé en aval, il y a eu annuellement, pendant au moins sept ans, formation d'aufeis; par contre, en deux sites d'amont la formation d'aufeis a été intermittente pendant ces mêmes années. Dans les sites d'aval, le volume de glace variait d'une année à l'autre, mais localement, la distribution de la glace était assez uniforme. Le type d'exposition du site et le bassin-versant d'où vient l'apport d'eau déterminent la persistance de l'aufeis; un bassin de premier ordre exposé au sud a été constamment libre de glaces plusieurs semaines avant un bassin de premier ordre exposé au nord.

Proc. 4th Can. Permafrost Conf. (1982)

Introduction

An accumulation of ice which is superimposed on the frozen surface of a stream, river, or sector of landscape is generally termed aufeis (Grey and MacKay 1979), or simply "icing" (Carey 1973). Grey and MacKay prefer to reserve "aufeis" as the designation for ice which forms over an existing ice cover on rivers and streams (and presumably over adjacent flood plains if the ice accumulation fills and overtops the stream channel). Although not restricted to northern latitudes, aufeis is commonly associated with permafrost-dominated terrain. Aufeis is thus more common in northern regions.

Comprehensive reviews of aufeis (or icing) have been provided by Carey (1973) and Grey and MacKay (1979). Kane *et al.* (1973), Kane and Carlson (1977), and Kane (1981) have summarized current knowledge of mechanisms of the formation of aufeis. Carlson (1979), and Grey and MacKay speculated on the engineering consequences of aufeis formation. In Alaska, Sloan *et al.* (1975) observed and documented locations of aufeis activity along the entire route of the trans-Alaska pipeline.

Aufeis generally forms when water in, or adjacent to, a stream channel rises above the level of an existing ice cover. Such water flows over existing ice, losing heat and gradually freezing (at a rate dependent on ambient air temperatures, rates of flow, and gradient of surface ice) to produce a thickened ice cover. In central Alaska, Carlson and Kane (1973) and Kane *et al.* (1973) monitored aufeis

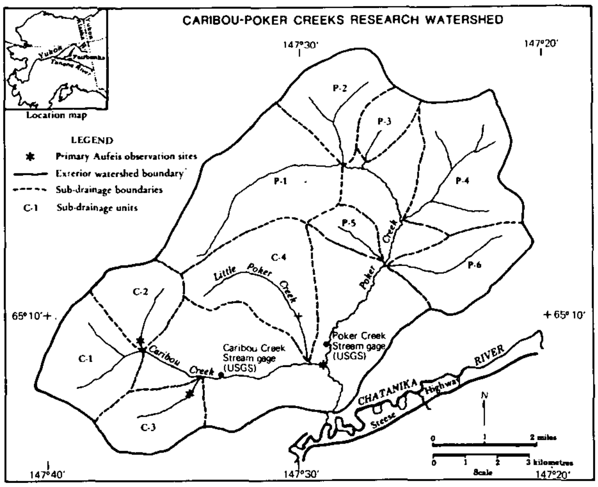

FIGURE 1. Location of Caribou-Poker Creeks Research Watershed.

formation on small streams and demonstrated that episodes of aufeis formation occurred in response to restriction of available flow area in a stream course. Such restriction could be by freezing from top, bottom, and/or sides, development of anchor ice in the stream, and by surface-ice depression subsequent to increase in snowpack and/or aufeis. Such restriction leads to an increase in piezometric head or pore-water pressure of the water flowing down-valley in the unfrozen channel and in the associated aquifer, respectively. As winter progresses, continued constriction of the available unfrozen channel and aquifer commonly results in continuing, episodic accumulation of aufeis. As the piezometric head exceeds the existing ice surface at a given site, unfrozen water will reach the ice surface through any available conduit. The course may be through vertical tension or contraction cracks which develop in the stream-ice cover, along narrow unfrozen zones around the stems of woody plants, or along lateral conduits leading water away from the stream channel and into the snowpack on the adjacent floodplain (Benson 1978).

This paper describes the occurrence of aufeis at several locations within a subarctic research basin in central Alaska (lat. 65°10'N., long. 147°30'W.) over a number of years. These observations were not necessarily systematic, save for several specific, time-restricted studies.

The Study Area

Observations of aufeis were made in the 106-km^2 Caribou-Poker Creeks Research Watershed, 45 km north of Fairbanks, Alaska. The research watershed (Figure 1), established in 1969, is an Experimental Ecological Reserve and has been the locale for a number of hydrologic and environmental studies (Slaughter and Lotspeich 1977). The catchment is developed in the Birch Creek Schist of the Yukon-Tanana Uplands where elevations range from 210 to 826 m. Permafrost underlies about 30 per cent of the research area, and virtually all of the valleys and stream courses. Streamflow continues the year around (although stream channels do freeze completely at some points). Average annual streamflow at a U.S. Geological Survey stream gauge (drainage area 23.8 km^2) on Caribou Creek is 0.135 m^3/s, over ten years of record (U.S. Geological Survey 1979). Average winter streamflow at that same location is estimated at 0.05 m^3/s for the period November through March.

Methods

Aufeis was observed in the spring of both 1970 and 1971 by Kane and Slaughter (1973). Repetitive leveling at three valley cross-sections yielded the accumulation information for that year. Kane *et al.* (1973) and Kane and Carlson (1977) have reported other aspects of that work. Information on aufeis accumulation was collected on a more casual basis, mostly through photography and individual field notes, through 1974. Benson (1978) measured aufeis accumulation at the confluence of Caribou and Poker creeks in 1975 and 1976, using aerial photographs and plane-table mapping. Lotspeich (*pers. commun.* 1977); Lotspeich and Slaughter (1981), and Helmers (*pers. commun.* 1976) made numerous observations of aufeis conditions at the confluence of Caribou and Poker creeks, incidental to other tasks. More recently, in 1979 and 1980, ablation of aufeis at stream-gauging sites in subbasins C-2 and C-3 was monitored by time-lapse photography.

Results

Specific Studies

Only the work of Kane and Slaughter (1973) and Benson (1978) was specifically directed toward aufeis. Kane and Slaughter monitored aufeis activity during the winter and spring of 1969-1970 at locations near the mouth of sub-basins C-1, C-2, and C-3 (*see* Figure 1). These catchments have drainage areas of 6.7, 5.2, and 5.7 km^2 respectively. Weekly ice accumulation was measured by repetitive leveling along pre-established cross-valley transects. Seasonal patterns of aufeis accumulation and ablation are displayed in Figure 2. Maximum accumulation was reached in late March to mid-April, depending on location. Aufeis formation was

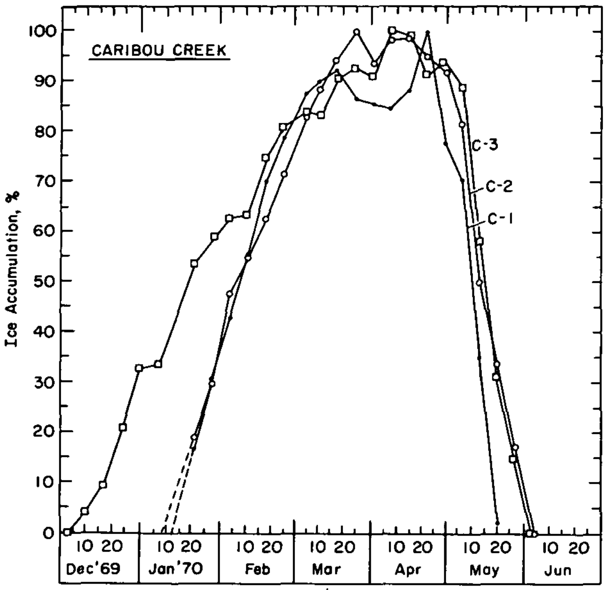

FIGURE 2. Aufeis accumulation and ablation during winter 1969–1970. (*Adapted from* Kane and Slaughter 1973).

initiated almost a month earlier in sub-basin C-3, which is largely underlain by permafrost.

Hand-held aerial photography (35 mm taken from a helicopter) was obtained of the complete watershed stream course, including the C-1, C-2, and C-3 valleys, on 23 April, 1970, after ablation of the seasonal snowpack but while the bulk of aufeis remained intact. Information on icing distribution obtained from these images was transferred to 1:16,000-scale vertical photography. The surface area of ice existing on 23 April was then estimated at 0.78 km^2. Based on the measured cross-sections and other observations a mean ice depth of 0.9 m was assumed; this, applied to the estimated surface area, yielded an estimated ice volume of 7.10 x 10^5 m^3. This estimate is probably conservative, since some aufeis ablation occurred during the snowmelt period preceding 23 April, 1970. Nonetheless, it is an indication of the magnitude of water which was stored as ice. That amount of ice comprised an estimated 40 per cent of total winter discharge, and 4 per cent of the estimated annual water yield for the entire 106 km^2 research watershed.

These measurements were to have been repeated in 1971; however, there was no aufeis accumulation at any of these three measurement points in spring 1971.

Several years later, Benson (1978) undertook a study of the seasonal snowpack which included observations of aufeis in the valleys of Caribou and Poker creeks. Benson obtained hand-held aerial photographs of 15.7 km of stream course in the lower catchment valleys on 21 April and 10 May, 1975, following snowmelt but while major aufeis accumulations persisted. Ten km of the stream reach photographed was overlain by aufeis. He also prepared a plane-table map of the aufeis surface in the immediate vicinity of the Caribou–Poker creeks confluence in spring of both 1975 and 1976, allowing estimation of aufeis volume. Benson emphasized that the initial aufeis volume estimate for 1975, 650,000 m^3, was conservative because it did not include the entire watershed. He repeated this estimation procedure in spring 1976, incorporated field observations in areas of the watershed which had not been included in the aerial photography, and summarized total volume estimates for three years (Table 1).

TABLE 1. Estimates of total aufeis in Caribou–Poker Creeks Research Watershed (Benson 1978)

	Surface area of aufeis	Volume of aufeis
	m^2	m^3
1970	7.8 x 10^5	7.1 x 10^5
1975	1.0 x 10^6	8.0 x 10^5*
1976	1.0 x 10^6	8.0 x 10^5

*Upgraded from initial estimate (6.5 x 10^5 m^3)

Miscellaneous Observations

Field notes and photography by A.E. Helmers, F.B. Lotspeich, the author, and other occasional observers, along with published work previously cited, allow reconstruction of a chronological summary of aufeis in Caribou–Poker Creeks Research Watershed. Many recent references are to the confluence of Caribou and Poker creeks, because of increased research activity in the lower reaches of the basin. Year-by-year observations are summarized below. A more detailed chronology is presented for one year (1974), to illustrate the progression of aufeis accretion and ablation.

1969—Extensive aufeis was observed in April in the valley below the Caribou–Poker creeks confluence and up-valley in both streams, as well as in the C-4 (Little Poker Creek) valley. It was possible to travel continually on aufeis for at least 6.5 km up the Poker Creek valley, and the aufeis was similarly continuous for at least 5 km up the Caribou Creek valley.

1970—Observations of extensive aufeis in subdrainages C-2 and C-3 of the Caribou Creek headwaters were summarized earlier (Kane and Slaughter 1973). Further downstream, aufeis was evident at the stream-gauging station on Caribou Creek on

18 February, 1970, and was widespread in the Caribou Creek valley on 16 April, 1970.

1971—Very little icing activity was noted in 1971. The measurement transects in sub-drainages C-1, C-2, and C-3 were monitored, but no aufeis developed at those sites. Lotspeich (*pers. commun.* 1977) indicated "no significant icing" in the lower Caribou Creek valley.

1972—According to field notes and photograhs taken 8 May, 1972, there was no aufeis formation in sub-drainages C-2 and C-3, or at the confluence of Caribou and Poker creeks. Although snowmelt was complete by 8 May, any significant ice accumulation should still have been evident, based on earlier experience with ablation periods (*see* Figure 2).

1973—Ice formed in the stream channels of Caribou and Poker creeks but did not exceed the bankfull level at the confluence.

1974—The 1973–74 winter saw major aufeis accumulation, particularly in the vicinity of the Caribou and Poker creeks confluence:

31 January: Fresh aufeis is developing at the Caribou–Poker creeks confluence, but the levels are still within the stream channel.

28 February: Fresh, active aufeis development. The ice level has overtopped stream banks and is spreading onto the adjacent floodplain.

19 March: Fresh aufeis formation, evidenced by liquid water on ice surface. Ice surrounds the lab trailer (Figure 3) and envelops burlap "fencing" which had been erected in an attempt to protect the trailer from ice encroachment. No evidence of aufeis formation in the lower channels of sub-drainages C-1 or C-2.

29 March: Fresh aufeis development is again evident around the lab trailer; two steps are inundated, indicating that ice is more than 50 cm thick over the ground surface at that point.

10 April: Hand-held aerial photography shows extensive aufeis development in the lower Poker Creek valley and in the Caribou Creek valley up to sub-drainage C-3. There is no indication of aufeis formation in the C-1 or C-2 valleys.

22 April: Snowmelt has begun on south-facing slopes; some ablation of the aufeis around the lab trailer is evident.

7 May: Hand-held aerial photography shows that south-facing slopes are almost snow-free, but north-facing slopes are still snow-covered. Major aufeis is still evident in the lower Poker Creek valley, upstream to, and within, the valley of sub-drainage P-4.

30 May: Ice still bridges Poker Creek in some areas; all out-of-channel aufeis in the vicinity of the lab trailer has melted.

1975—Aufeis accumulation was similar to 1974. On 6 February fresh aufeis development was evident at the Caribou–Poker creeks confluence; nearly 3 m of ice was drilled in the stream channel before free water was reached. Water in the channel confined under pressure rose to the surface through the drill hole. By 6 March, aufeis had surrounded the lab trailer and extended across the floodplain on both sides of Poker Creek. By 21 March, the aufeis accumulation had increased to the base of the lab trailer door, over 100 cm above ground surface. Drilling required 3.5 m of auger stem to reach liquid water in the stream channel (Figure 4).

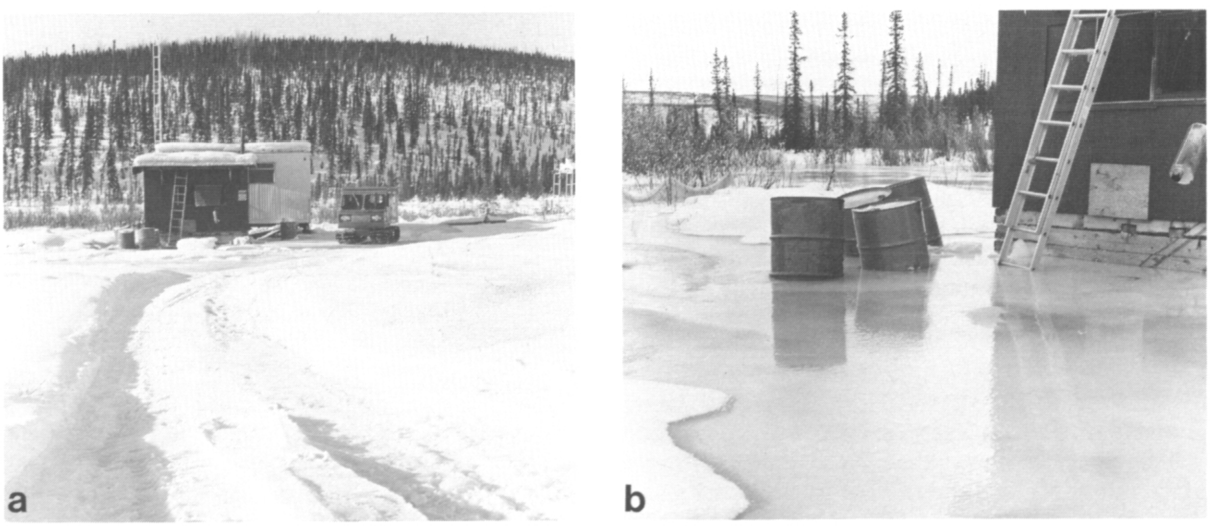

FIGURE 3.**a** Fresh aufeis at the confluence of Caribou and Poker creeks, 19 March 1974. **b** Detail at corner of building shown in **a**.

FIGURE 4. Drilling through aufeis at the confluence of Caribou and Poker creeks, 21 March 1975.

1976—Aufeis activity seemed to repeat the 1974 and 1975 pattern. By 15 January, aufeis had already filled and overtopped the channels of Caribou and Poker creeks at their confluence, and had spread over the floodplain to surround the lab trailer. On 9 April, aufeis had accumulated around the trailer up to the door level and occupied the entire floodplain in the vicinity. Aufeis levels did not rise above the 9 April level; accumulation approximately equalled that in 1975. At break-up (April and early May), ice and water surrounded the trailer and toolshed and occupied the entire floodplain (Figure 5).

1977—No photos available. Field notes from hydrologists of the U.S. Geological Survey indicate extensive aufeis formation in Caribou Creek valley on 4 February, 1977; aufeis build-up was massive in the Poker Creek valley. In May 1977, major aufeis remained at the Caribou–Poker creeks confluence, with silt accumulations over the aufeis. The Poker Creek stream gauge was still surrounded by ice on 29 June, 1977.

1978—No ground photos available. Field notes from hydrologists of the U.S. Geological Survey indicate that aufeis was so extensive and deep at the Poker Creek stream gauge on 2 June, 1978, that they had to remove the roof of the recorder shelter to gain access. Although field notes mention some remaining "shore ice" at the Caribou Creek gauge, the gauge was activated on 2 June, 1978. A LANDSAT image for 12 May, 1978, shows snow cover completely gone and major aufeis accumulations remaining in the Caribou–Poker Creek valleys.

1979—New stream-gauging stations (Parshall flumes) had been installed on C-2 and C-3. Aufeis development was minor in the C-2 drainage. The channel itself was ice-filled, but there was little aufeis development away from the channel. Aufeis was locally massive in the C-3 (north-facing) channel. Aufeis was over 100 cm thick at the Parshall flume site and well exceeded bank-full channel capacity. By 25 April, snowmelt runoff was active. Aufeis accumulation was massive at the Caribou–Poker creeks confluence, covering the entire floodplain.

By 1 May 1979, seasonal snowpack ablation was virtually complete, with minor ice accumulations remaining along the C-2 stream channel through the first week of May and, at C-3, into June. Break-up again saw stream channels choked with ice and meltwater flowing out of channel at the Caribou–Poker creeks confluence.

1980—Aufeis accumulation in the C-2 valley exceeded the 1979 levels but was still relatively minor compared with 1970. Ice was over bank-full, extending laterally several metres on both sides of the channel. By 29 April, with seasonal snow gone, ice remained only in, and adjacent to, the channel. Aufeis accumulation in the C-3 valley was greater than in 1979, completely inundating the Parshall flume and recorder. Ice thickness was estimated at 2+ m at the site, and it overtopped the channel and filled the local valley for more than 100 m up-

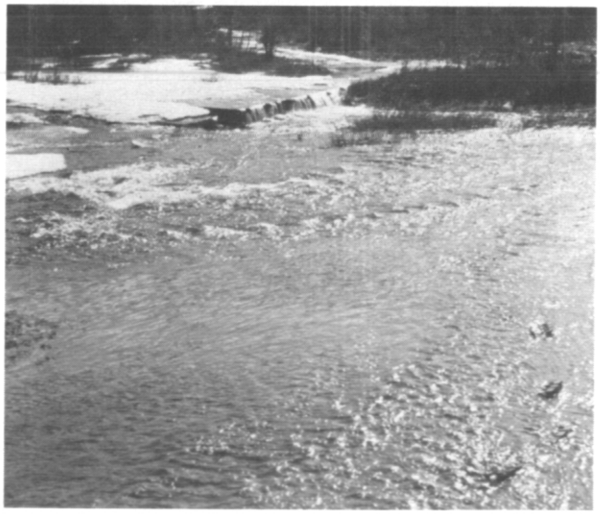

FIGURE 5. Meltwater and ice covering flood-plain at the confluence of the Caribou and Poker creeks during spring break-up.

stream; major ice remained on 12 June, 1980. At the Caribou-Poker creeks confluence, aufeis again filled the entire channel of both creeks, inundating the local floodplain. The areas of accumulation were similar to previous years.

TABLE 2. Subjective rating of aufeis accumulation, Caribou-Poker Creeks Research Watershed, Alaska, 1969–1980

Year	Location		
	C-2	C-3	Confluence of Caribou and Poker creeks
1969	no observation	no observation	major
1970	major	major	major
1971	none	none	none
1972	none	none	none
1973	minor	minor	minor
1974	none	minor	major
1975	minor[1]	minor[1]	major
1976	minor[1]	minor[1]	major
1977	minor[1]	minor[1]	major
1978	minor[1]	minor[1]	major
1979	minor	major	major
1980	minor	major	major

[1]The rating may be biased because close observation was lacking. Permanent stream-gauging stations were installed in 1978–79, allowing better observations.

Discussion

A subjective rating of aufeis development at the three primary observation points, by year, is provided in Table 2. Aufeis in this subarctic catchment tends to recur in the same locations year after year. Aufeis does not occur at the same relative magnitude at all locations in any given year, nor does aufeis occur every year at any one site.

Sloan *et al.* (1975) monitored aufeis along the route of the trans-Alaska oil pipeline and concluded that icings tend to recur at the same locations. In interior Alaska, south of the Yukon River, they stated that "narrow channel icings form on the small streams of the uplands." The aufeis accumulations in Caribou-Poker Creeks Research Watershed are apparently similar to those observed by Sloan *et al.* They also noted that "some of the smaller icings did not form annually, and all icings varied in areal extent and thickness from year to year." The observations for Caribou-Poker Creeks Research Watershed concur with this finding.

Carlson and Kane (1973) and Kane (1981) concluded that, in central Alaska, aufeis accumulates from sub-permafrost groundwater sources, not from water yielded from the active layer. This agrees with the author's observations of maximum aufeis development in mid-winter to early spring (January–March), well after most of the active layer refreezes. Water from taliks or thawed zones of sub-channels may also contribute to aufeis development.

Aufeis activity seemed to accelerate following pronounced warming periods. This was evident in 1973–74, 1977, 1978, and, most recently, in 1981. Following an intense warm spell (official Fairbanks temperature reached 9°C in January 1981), accelerated aufeis activity was observed at the confluence of Caribou and Poker creeks. This reinforces Kane's (1981) similar observation—that periods of increased ice accumulation follow relatively warm periods.

Of what value are these observations? Even casual observers in the north will have noticed aufeis, perhaps remarking about "natural skating rinks." Aufeis persisting in a valley can influence:

(i) the phenology of riparian vegetation;
(ii) streamside wildlife habitat;
(iii) the primary productivity in the aquatic system;
(iv) the quantity, quality, (aufeis is derived from groundwater or baseflow, which may have different chemical constituents from snowmelt or summer storm runoff), and timing of early summer streamflow;
(v) the stability of stream channels and perhaps local micro-drainage patterns on the floodplain; and
(vi) human use of valleys.

Engineers, transportation planners, and resource managers should be aware of the practical problems imposed by aufeis both on the building and maintenance of roadways, buildings, pipelines, or research instruments. Veldman (*pers. commun.* March 5, 1981) noted that aufeis dictated the elevation of some river-crossing structures along the trans-Alaska pipeline. In a totally different setting, Weyer (*pers. commun.* March 5, 1981) noted that icings provided initial evidence that groundwater flow was affecting a mining development on Baffin Island.

The ability to simply predict where aufeis is likely to occur would be useful, but such prediction now is most often based on past experience in the area. As one example of this need, an experienced hydrologist in the U.S. Geological Survey (with the author's help) selected the site for a permanent stream-gauge on Poker Creek where it was not likely to "ice up." The following year the water-level recorder was removed from the instrument shelter by chainsaw, encased in a block of ice; over 2.5 m of aufeis had built up at that site. A better predictive ability would have been most useful!

These observations show, as did Sloan *et al.* (1975), not only that aufeis does tend to recur, but also that one or two seasons of experience in a given place may not be adequate. Observations during three consecutive years (1971-1973) at the confluence of Caribou and Poker creeks gave other scientists enough confidence in the site to pick it as the locale for a laboratory trailer (*see* Figure 3) and water-quality monitoring station (Lotspeich *et al.* 1976). The site has been the scene of massive aufeis development during each of the eight subsequent years.

If aufeis is *ever* observed at a given location, it can be expected to recur at that same place in the future. As in the case of the C-2 drainage of this study (*see* Table 2), however, recurrence may be on a minor scale, even though nearby sites have massive aufeis development during the same year.

References

BENSON, C.S. 1978. Studies on the seasonal snow cover of the Caribou-Poker Creeks Research Watershed during the winters of 1974-75 and 1975-76. Final report. Geophys. Inst., Univ. Alaska, College, Alaska. 38 p.

CAREY, K.L. 1973. Icings developed from surface water and ground water. Cold Regions Science of Engineering Monograph III-D3. U.S. Army Cold Regions Res. and Eng. Lab., Hanover, N.H. 65 p.

CARLSON, R.F. 1979. A theory of aufeis and bed erosion. *In*: Can. Hydrol. Symp.: 79-Cold Climate Hydrol., Natl. Res. Counc. Can., Ottawa, pp. 197-205.

CARLSON, R.F. AND KANE, D.L. 1973. Hydraulic influences on aufeis growth. *In*: First Can. Hydraul. Conf., Proc. Univ. Alberta, Edmonton, Alberta, pp. 165-175.

GREY, B.J. AND MACKAY, D.K. 1979. Aufeis (overflow ice) in rivers. *In:* Can. Hydrol. Symp.: 79-Cold Climate Hydrol., Natl. Res. Counc. Can., Ottawa, pp. 134-165.

KANE, D.L. AND SLAUGHTER, C.W. 1973. Seasonal regime and J. Civil Eng. (*in press*).

KANE, D.L. AND CARLSON, R.F. 1977. Analysis of stream aufeis growth and climatic conditions. *In*: Proc., 3rd Natl. Hydrotech. Conf., Can. Soc. for Civil Eng., Quebec, pp. 656-670.

KANE, D.L., CARLSON, R.F., AND BOWERS, C.E. 1973. Groundwater pore pressures adjacent to subarctic streams. *In*: Proc. North Amer. Contrib., 2nd Int. Conf. Permafrost, Natl. Acad. Sci., Washington, D.C., pp. 453-458.

KANE, D.L., AND SLAUGHTER, C.W. 1973. Seasonal regime and hydrological significance of stream icings in central Alaska. *In:* Proc. The Role of Snow and Ice in Hydrol., Banff, Alberta, Canada. UNESCO/WMO/IASH, pp. 528-540.

LOTSPEICH, F.B., JACKSON, R.L., AND HELMERS, A.E.. 1976. Climatological and water quality data, Caribou-Poker Creeks Research Watershed. AERS Working Paper No. 30 (CERL NO. 014). Arct. Environ. Res. Stn., U.S. Environ. Prot. Agency, College, Alaska. 41 pp.

LOTSPEICH, F.B. AND SLAUGHTER, C.W. 1981. Preliminary results of a study on the structure and functioning of a taiga research watershed. Inst. Water Resour., Univ. Alaska, Fairbanks, Alaska (*in press*).

SLAUGHTER, C.W. AND LOTSPEICH, F.B. 1977. Caribou-Poker Creeks Research Watershed. Arct. Bull. vol. 10, pp. 182-188.

SLOAN, C.E., ZENONE, C., AND MAYO, L.R. 1975. Icings along the trans-Alaska pipeline route. Open-File Report 75-87. Geol. Surv., U.S. Dep. Inter., Anchorage, Alaska. 39 p.

U.S. Geological Survey. 1979. Water resources data for Alaska. Water-Data Report AK-79-1, Anchorage, Alaska. 365 p.