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PERIGLACIAL SLOPEWASH INVESTIGATIONS, BANKS ISLAND, WESTERN ARCTIC

Abstract

Three small run-off plots, located in north-central Banks Island, were used in a reconnaissance study of the hydrologic and geomorphic importance of downslope water movement during the summer of 1977. Positive correlations were observed between net radiation, sensible heat transfer, and run-off production. In addition, summer precipitation generated surface flow with low run-off coefficients.

Suspended and dissolved sediment concentrations in surface run-off were low suggesting that slopewash is not a major denudational process in this environment. Some support is given to the concept of partial area contribution to run-off in permafrost regions.

INTRODUCTION

Slopewash is the term commonly applied to two sets of processes. First, surface wash is the downslope transport of weathered material over the ground surface by running water. Second, subsurface wash is the group of processes associated with water movement through the regolith (YOUNG, 1972, pp. 62—70).

This paper describes a series of measurements made to monitor this process on Banks Island in the Western Canadian Arctic during the summer of 1977. Although a short note is already available (LEWKOWICZ *et al.*, 1978) this paper presents the results in more detail and within the context of other literature.

The existence of wash has been reported from most climatic zones but its effectiveness as a geomorphic agent is thought to vary considerably (YOUNG, 1974, p. 69). It is generally agreed however, that due to a sparse vegetation cover and high convectional rainfall intensities, wash is most important in hot, semi-arid regions (YAIR and KLEIN, 1973). It is surprising therefore, that in periglacial environments, which are often semi-arid in terms of total per annum precipitation, little attention has been paid to slopewash (FRENCH, 1976b, p. 141). Notable exceptions are the early work by A. JAHN (1961) on Spitsbergen, and more recently, by T. WILKINSON and B. T. BUNTING (1975) on Devon Island in the Eastern Arctic. It appears that most geomorphologists have concentrated their attention upon the relatively 'unique' periglacial processes such as either solifluction or frost action, or those processes related directly to permafrost and ground ice. In the last decade however, there has

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been a shift towards fluvial processes and hydrology (e.g. CHURCH, 1972, 1974; DINGMAN, 1967; WOO, 1976); in this context, the role of water movement on slopes rather than in channels seems a logical extension.

Two theories exist relating to the hydrologic aspects of slopewash which may be applicable to periglacial areas. First, since the majority of these are underlain by permafrost, the simple Hortonian model of overland flow, in which infiltration capacity is exceeded by rainfall intensity (HORTON, 1945), may be appropriate. An alternative is the theory of partial area contribution to run-off, a model often thought realistic for humid environments (BETSON and MARIUS, 1969; DUNNE and BLACK, 1970; RAGAN, 1968). Concerning the latter model, the formation and subsequent ablation of large snowbanks on lee slopes and in gullies, results in certain Arctic localities remaining moist for much of the summer. Other localities, exposed to strong winter winds, have a relative lack of snow, and suffer summer desiccation.

STUDY AREA

The study was carried out in the Thomsen River lowlands of north-central Banks Island (latitude 73° 14′ N, longitude 119° 32′ W) (fig. 1) between May 25—July 25, 1977. This island, the fourth largest in the Canadian Arctic, lies totally within the zone of continuous permafrost. Records from Sachs Harbour, on the southwest corner of the island, provide the only long term climatic data. Typically, precipitation of less than 100 mm per annum is recorded with over half occurring as rain in the summer months of May through August (Meteorological Branch, Department of Transport). In 1977, however, there were significant departures from these long term records (tab. I).

In general, the topography of the north-central part of Banks Island is undulating with either convexo-concavo, or gentle, near-rectilinear slopes dominant. The underlying bedrock consists of sand and shale of Cretaceous and Tertiary age (THORSTEINSSON and TOZER, 1962) overlain by a veneer of surficial materials much reworked and redistributed by mass wasting processes.

Table I

Summer precipitation data for
Thomsen River and Sachs Harbour for 1977 and earlier years

	Thomson River (119°32′W; 73°14′N)		Sachs Harbour (125°20′W; 71°57′N)	
	1975*	1977	1955—60**	1977***
June	3.00 +1 Tr.	21.75 +9 Tr.	4.50	11.20 +5 Tr.
July	15.00 +1 Tr.	2.50 +5 Tr.	25.00	8.80 +3 Tr.

* Compiled by G.S.C. party under direction of T.J. Day (unpublished)
** Thompson, 1967
*** Station records
All data in mm.

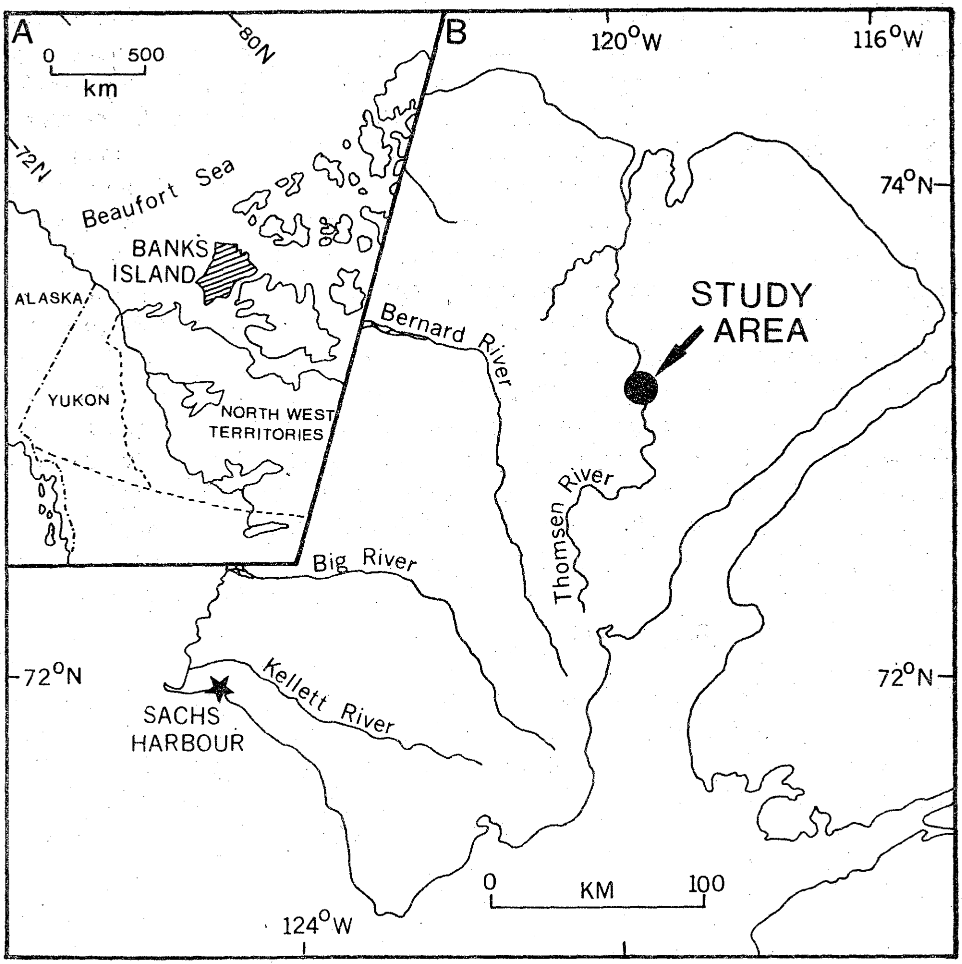


Fig. 1. Location map of Banks Island and the study area

METHODS

Three slopes of varying angle, aspect and microrelief were selected in the vicinity of the base camp. Slopes 1 and 2 (Pl. 1) were located in a shallow northeast—southwest trending valley drained by a small tributary of the Thomsen River. Slope 3 (Pl. 2) constitutes the west side of the Thomsen River Valley which, south of the base camp, assumes a relatively narrow and well defined form. A marked break of slope separates Slope 3 into a steep, upper section and a gentler, lower section.

Soil-slope relationships in this area are essentially the same as those described earlier from northwest Banks Island (French, 1971, pp. 723—25). Typically, silty sand and gravel veneer the summits and interfluves where scattered willow (*Salix* sp.), *Dryas* hummocks and isolated cushion plants (eg. *Saxifrage* sp.; *Silene* sp.) occur. In places, a poorly developed desert pavement is present. Immediately down slope, in lee slope and snowbank locations, a more continuous cover of *Dryas* hummocks and *Cassiope* sp. occurs. This may grade into poorly developed non-sorted stripes on extensive low angled (4—6°), near-rectilinear slopes. As slope angles continue to decrease towards the valley bottom, grassy meadow tundra develops, often with ice wedge polygons. At Slope 3 the accumulation of an extremely large snowbank during winter gives rise to a transition zone between upland and meadow tundra which TEDROW (1974, p. 66) refers to as the Polar Desert Tundra Interjacence.

Exposures of bedrock in the area are rare. The slopes studied are completely mantled, either by sandy gravel (Slope 1) or silty gravelly colluvium (Slopes 2 and 3). They are probably underlain by shale of the Christopher Formation (personal communication, J.-S. VINCENT, July 1977).

On each of the three slopes a run-off plot was delineated with lawn edging. As the snow ablated, the edging was advanced up the line of maximum slope. The first plot was located, before the thaw commenced, on an exposed relatively snow-free part of Slope 1 which possessed an average angle of 5°. On Slope 2, the plot covered a concave section of the slope immediately below the crest and ranged between 4° to 9° in angle. On Slope 3, the plot extended across the marked break of slope. Details of the three plots are summarised in Table II and the slope profiles and plot locations illustrated in figure 2.

At the downslope exit to each plot a surface flow collector was installed (fig. 3). This apparatus consisted of a copper trap box, open upslope, with an outlet pipe connected to a calibrated collecting pan by a length of flexible tubing. The surface wash which was collected was analysed for suspended sediment by the use of an Ostrem filter pump in the field and the reweighing of filter papers in the laboratory.

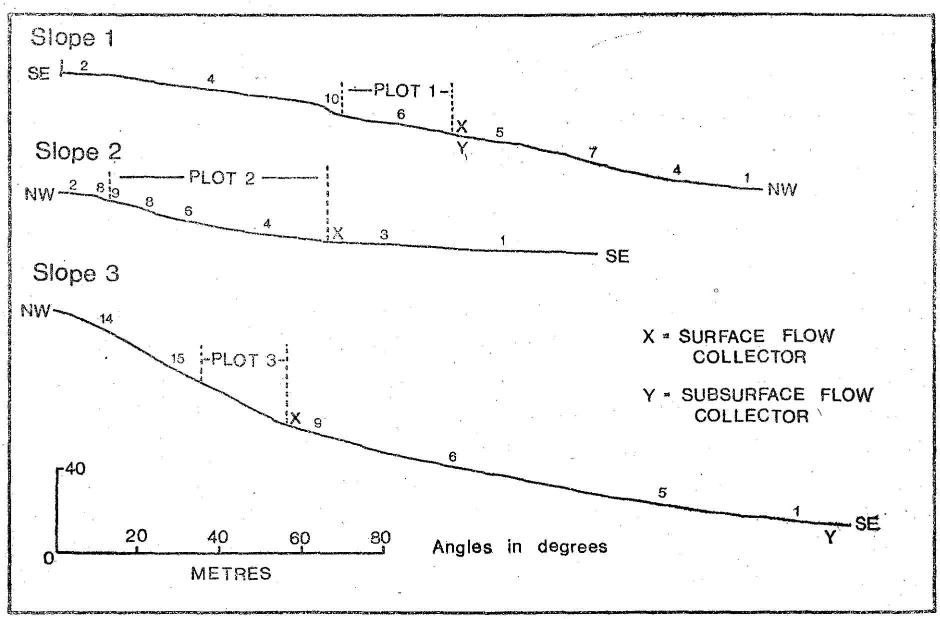


Fig. 2. Slope profiles and plot locations of slopes 1, 2, and 3

Table II

Dimensions and characteristics of run-off plots

A – DIMENSIONS

	Length (m)	Av. width (m)	Area (m²)	Av. angle	Aspect	Position on slope
Plot 1	28.7	5.2	149.6	5°12′	SE	Exposed/interfluve
Plot 2	54.1	7.2	387.5	5°19′	NW	Valleyside
Plot 3	18.8	1.4	26.6	14°18′	SE	Valleyside

B – SURFACE CHARACTERISTICS

	Vegetation cover (%)	Surficial materials	Micro-relief	Soil series*
Plot 1	10–20	Sandy gravel	*Dryas* hummocks, frost fissures, lag gravel	Storkerson, Polar desert
Plot 2	60–80	Silty colluvium	*Dryas* hummocks, *Cassiope* sp., intra-vegetational-wash lines	Bernard, Upland tundra
Plot 3	20 Upper	Sandy colluvium	*Dryas*	Regosol/Polar desert tundra interjacence
	90 Lower	Silty colluvium	*Carex* sp., *Salix* sp., mosses	Kellett, Meadow tundra

* After Tedrow and Douglas, 1964; Tedrow, 1974.

Solute concentrations were also measured in the field using a portable conductivity meter, giving values in micromhos/cm which were subsequently transformed into mg/l of dissolved solids.

Subsurface wash was monitored at plots 1 and 3. Instrumentation consisted of a series of copper gutters placed horizontally within the active layer at depths varying between 5 and 50 cm (Pl. 4). Each gutter was backfilled and connected by flexible piping to collecting containers downslope. In this way, water movement at depth, as the frost table descended, was recorded.

A number of snow sampling pits were dug adjacent to each plot. Average density values were obtained by sampling at 3–4 localities within the pit. At the same time, the spatial extents and thickness of the snowpacks were recorded. These measurements were repeated at intervals throughout the ablation period enabling the estimation of the water equivalents of the snowpacks. The position of the frost table was also monitored and the frost table topography (i.e. the subsurface catchement) mapped. In addition, net radiation, air temperatures and precipitation were measured continuously throughout the period of study.

RESULTS

LIMITATIONS

There are several problems related to the validity of any short term process study. First, a theoretical difficulty arises from the nature of geomorphic processes whose responses are often non-linear and dependent upon threshold values. Such thresholds are particularly evident in hydrologic studies. Second, the results from a small-area study, such as this, are of limited significance unless they can be utilised to make predictions over an area larger than that of the study itself. Third, any predictions derived from the results of a single season study are hazardous; even if the climatic inputs are near average for the year, the possibility remains that an event with a high recurrence interval is more important than the more frequent events of lower magnitude.

On a more specific level, there are additional weakness or limitations. First, the distinction between surface and subsurface flow may not be clear under certain conditions. For example, in vegetated areas such as at plot 3, water seeping through the surface organic mat was not recorded by the surface flow collectors, yet could not be regarded as true subsurface wash. In future studies it might be appropriate to recognise a transitional flow type which might be described as 'intra-vegetational-wash'. The occurrence of non-sorted stripes, formed by the growth of vegetation along seepage lines, in many parts of the island (e.g. see FRENCH, 1976b, p. 188) suggests that this type of wash may be important. Second, the insertion of the subsurface flow gutters in late May, at a time when the active layer was still frozen, involved considerable disturbance to the adjacent soil. Undoubtedly, this influenced the amount of sediment movement through the active layer and probably the solute concentration also. For these reasons, the subsurface flow data are thought to be unreliable or, at best, of uncertain accuracy. The re-installation of the guttering at new sites in late July, when the active layer had thawed and insertion was relatively easy, should lead to new data being of greater reliability.

A number of assumptions associated with the study also need careful assessment. For example, an assumption of the surface flow investigation is that the snowpack contributory area is the same as that of the surface topography of the plot. As regards subsurface flow, an assumption is that the contributory area is determined by the frost table configuration. Since the surface and subsurface catchments need not be the same, direct comparison of data may not be valid. In an attempt to overcome this, data were converted to discharge per unit width of plot in the calculation of the run-off coefficients. Another assumption relates to the calculation of the water equivalents of the snowpacks: lateral homogeneity of the snowpacks was assumed yet ice lenses and density differences were apparent, particularly in the upper layers.

The limitations outlined above suggests that (1) surface wash was more accurately measured than subsurface wash and (2) a longer period of study is required before results of a definitive nature can be reported. In spite of these conclusions, the 1977 data provide the first approximation of slopewash activity on Banks Island and a brief discussion is warranted.

SLOPEWASH ACTIVITY AND NET RADIATION

As might be expected, there was a clear correlation between net radiation, air temperature and surface wash. For example, at plot 1 two hydrographs were obtained between May 30, at the commencement of surface flow, and June 2, when the thin snowpack had ablated completely (fig. 3). Total surface flow was 0.97 m^3 which constituted only 9 % of the original water equivalent of the snowpack on the plot (10.3 m^3). Thus, a significant amount of snow ablated without causing surface run-off.

The response of surface flow to snowmelt was not of a simple linear nature since a lag period was apparent on all three plots. On plot 1, regression of surface flow against net radiation using a number of different lag times revealed a lag of 2.5 hours

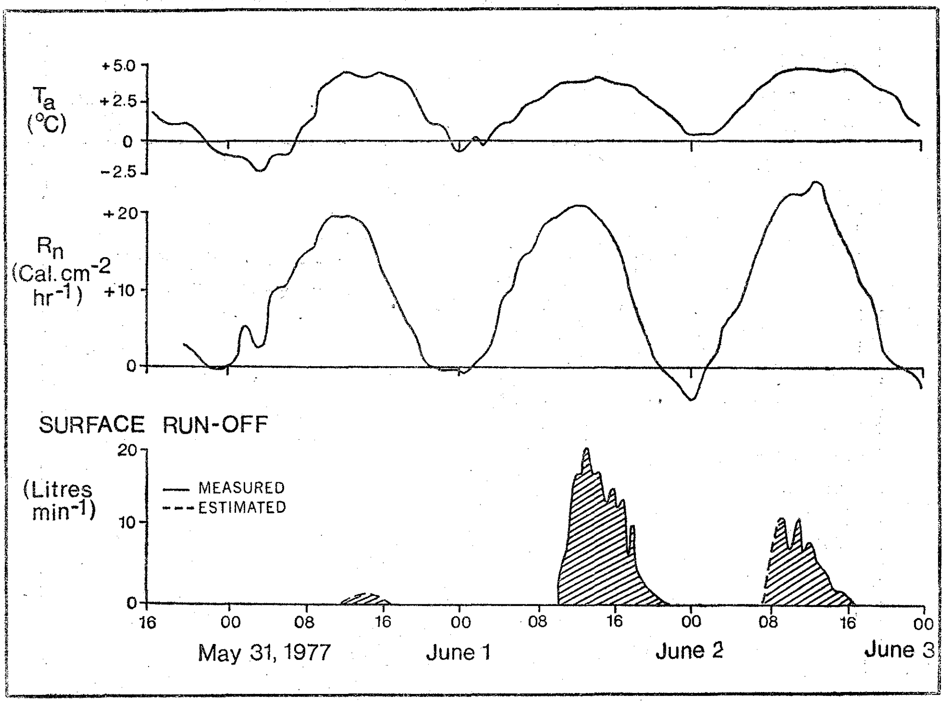


Fig. 3. Relationship between surface run-off, net radiation (R_n) and air temperature (T_a) at Plot 1, May 30—June 2, 1977

to be the most appropriate explaining 66 % of the variability. At plot 2, 12 hydrographs were obtained between June 1 and June 17 during the period of snowpack ablation; lag times varied from 1.7 to 7.0 hours. Where necessary gaps in the surface flow record were filled by the use of regression against lagged net radiation.

A typical day was June 11 when a lag of 3 hours occurred between peak net radiation and air temperature values. Surface flow however, commenced approximately 2 hours prior to peak net radiation and eventually peak 5 hours later with a maximum of 13.85 litres per minute. Surface flow represented 53 % of the estimated changes in water equivalent that occurred on the plot that day.

The daily lag time recorded between maximum net radiation and overland flow was attributed primarily to the passage of water through the snowpack. On June 11 at plot 2 for example, Rhodamine dye was placed upon the plot immediately below the ablating snowpack and the ground surface velocity was estimated at approximately 1.3 cm/second. Using this value, only 14 minutes out of the 3 hour lag time occurring that day could be attributed to the time taken for water to pass over the ground surface from the snow front to the collector.

Subsurface flow measurements are considerably less precise than those for surface flow. In general, short term trends in the hydrograph patterns are not recognisable. One set of data illustrates the type of information obtained.

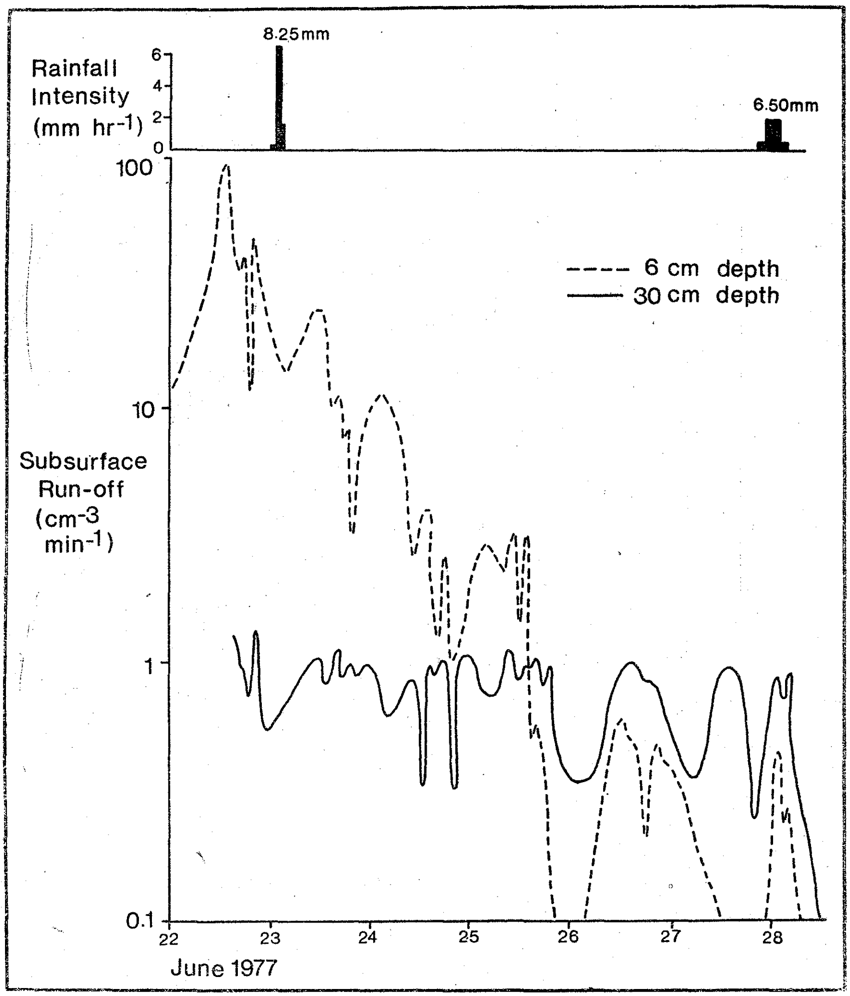
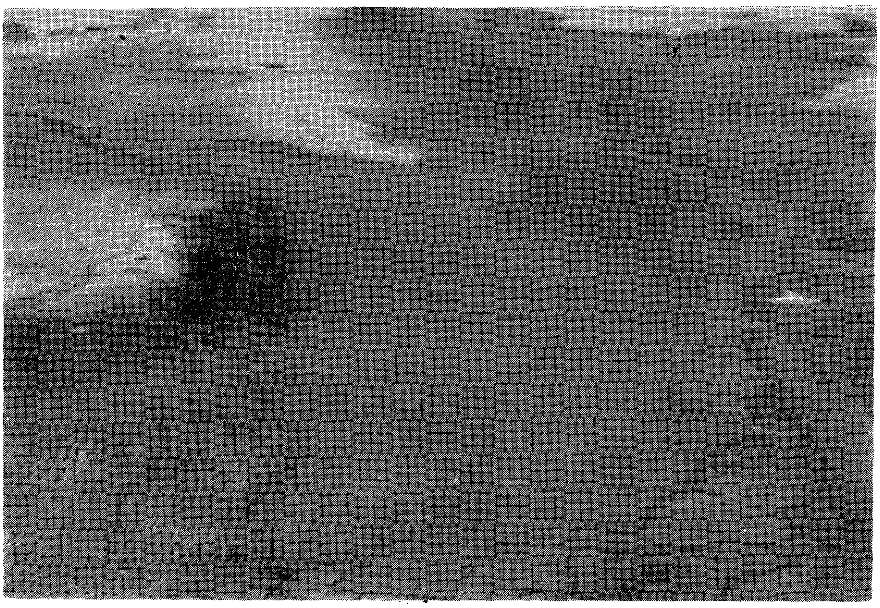
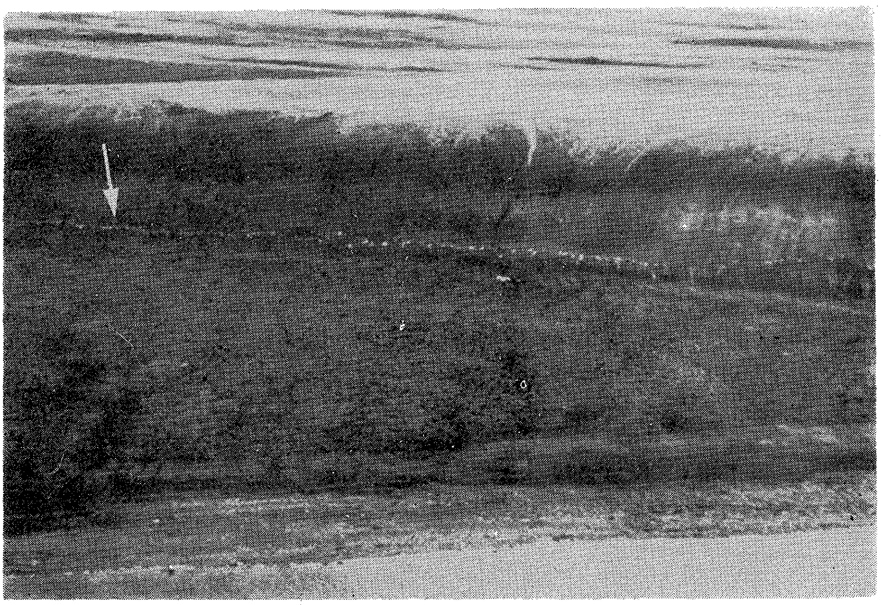


Fig. 4. Subsurface flow values recorded at Plot 3 at depths of 6 cm and 30 cm, June 22—June 28, 1977

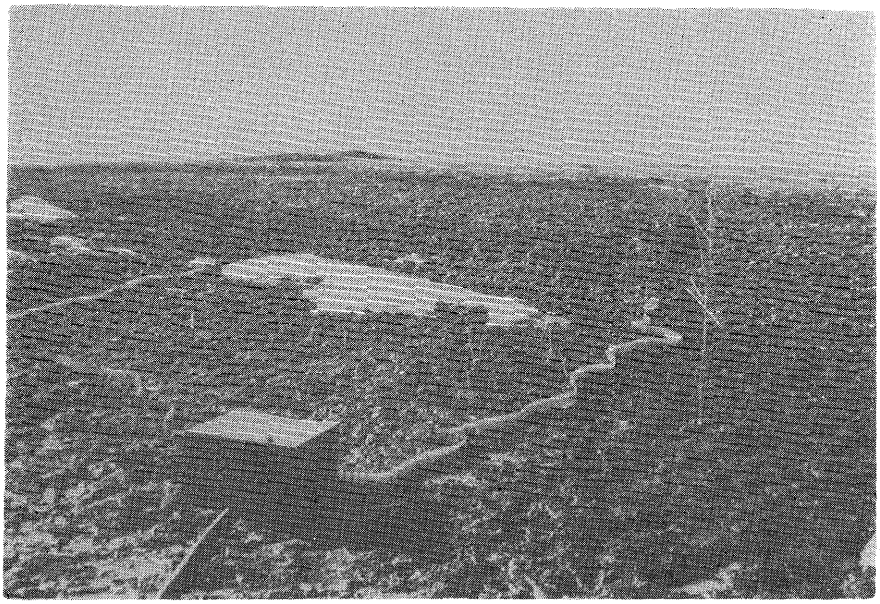
At plot 3 continuous subsurface flow was recorded between June 22 and June 28 at depths of 6 cm and 30 cm (fig. 4). At the 6 cm depth a steeply falling hydrograph pattern emerged with no obvious diurnal rhythm. The decline was attributed to a reduction in the supply of water from the snowpack as it ablated. At a depth of 30 cm, flow amounts were approximately one order of magnitude smaller with



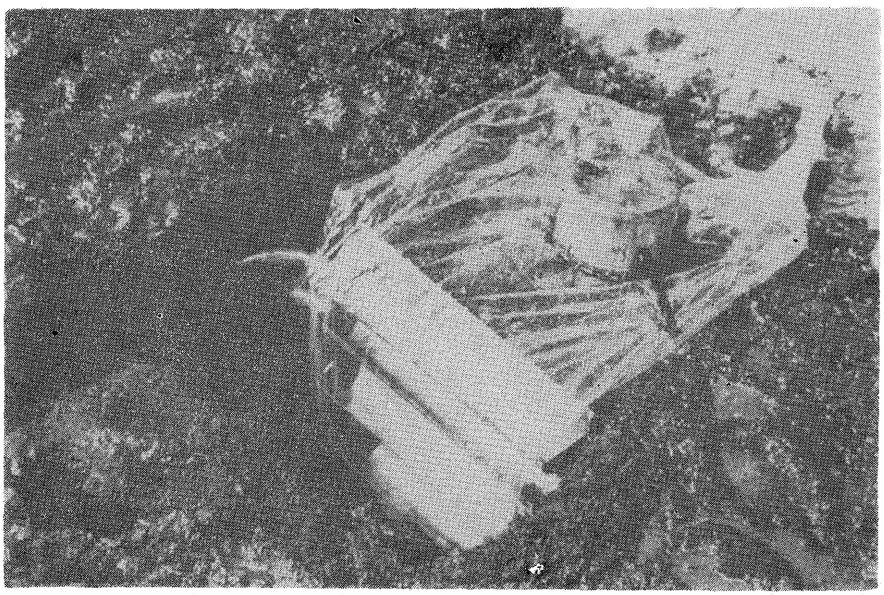
Pl. 1. Oblique air view of slope 2. Note the gravelly summit surface, nonsorted stripes on the slopes beneath, and ice wedge polygons in the meadow tundra of the valley bottom. Slope 1 is at the top right of the picture. Photograph taken in mid July 1977



Pl. 2. Oblique air view of slope 3 showing the marked break of slope between the upper steeper and lower, gentler part of the slope. Note the layer of wind blown sediments (arrow) deposited at the downslope edge of the former snowbank which existed at this locality until late June. Photograph taken in mid July 1977



Pl. 3. View upslope of Plot 1 showing surface flow collector in place, run-off plot delimited by lawn edging, and ablating snowpack. Photograph taken June 2, 1977



Pl. 4. Subsurface flow instrumentation being installed at Plot 1. Note the disturbance caused by the excavation of the pit at a time when the active layer was still frozen. Photograph taken May 29, 1977

a maximum flow of 0.41 cm³/minute recorded as compared to 94 cm³/minute at 6 cm depth. Moreover, no rising, falling or diurnal trends were visible, suggesting a slow continuous percolation of water through the lower zones of the active layer.

SUMMER PRECIPITATION AND SLOPEWASH HYDROLOGY

Although snowmelt is thought to be the major source of water for surface flow, the effects of summer precipitation may also be important (e.g. COGLEY and MCCANN,

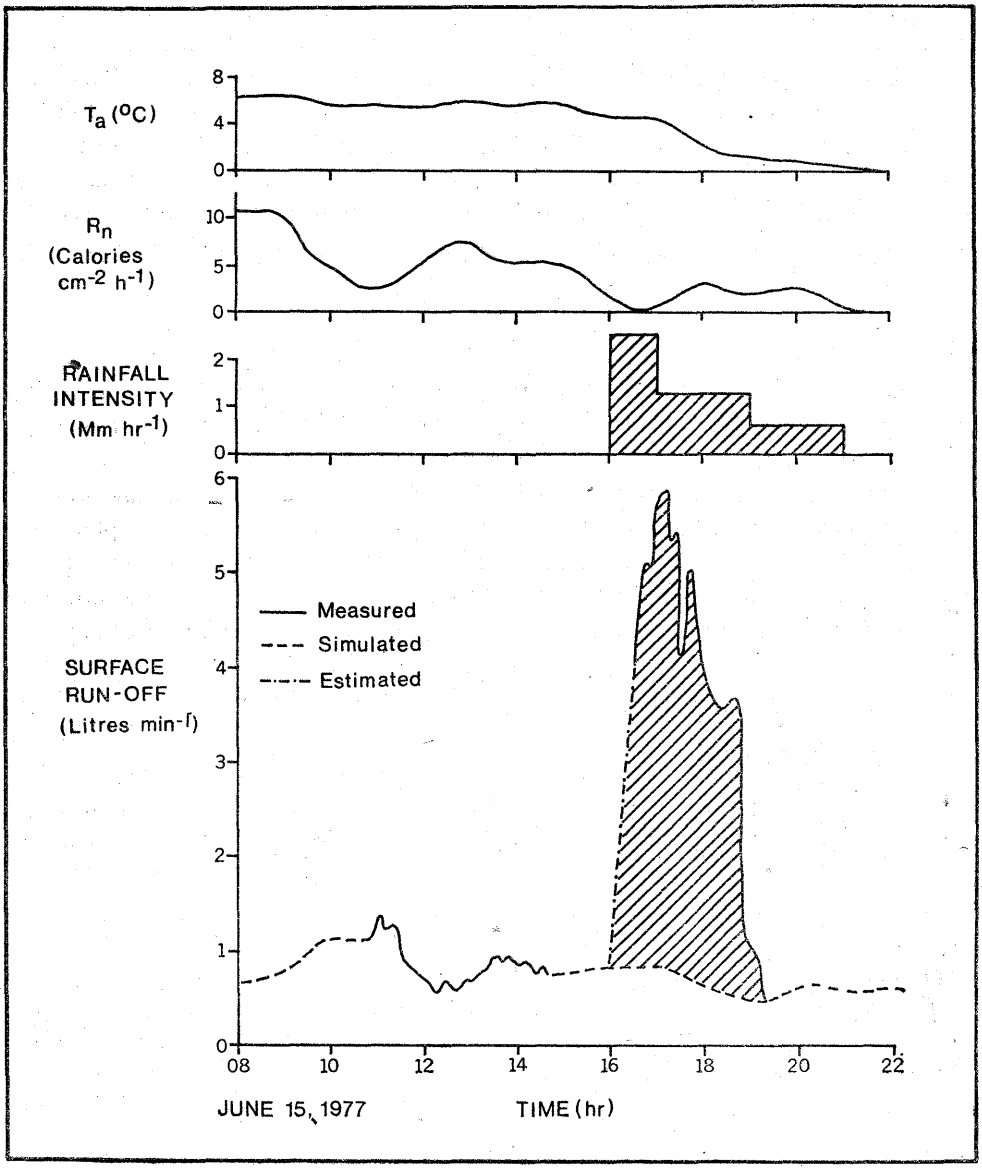


Fig. 5. Relationship between storm rainfall and surface flow at Plot 2, June 15, 1977

To simulate surface flow the following equation was used: surface flow = 0.06 R +0.48, where R is lagged two hours, n = 25, and $r^2 = +0.55$

1976). On June 15, storm precipitation of 6.25 mm in 5 hours was recorded in the hydrograph at plot 2 (fig. 5). Analysis of this information enables some assessment of the hydrologic importance of such events as regards surface flow. The hydrograph was separated by regression against lagged net radiation into run-off thought to be the result of snowmelt (a component equivalent to 'base flow') and that derived from the storm. Run-off due to the storm totalled 640 litres, giving a storm run-off coefficient of 26.5%.

It might be assumed that the plot source area for the surface run-off resulting from the storm rainfall would consist of the snowbank itself and the saturated area between it and the surface flow collector. On June 15, these sections of the plot accounted for 85% of its area. As the run-off coefficient was less than one third of this value, it follows that rain falling on the snowbank either failed to cause run-off or that the water was lost from the plot, the latter as evaporation or increased sub-surface flow. The rapid response time of run-off to precipitation and the equally rapid fall off at the end of the storm suggests that most water was stored in the snowbank.

GEOMORPHIC CONSIDERATIONS

The measurement of suspended and solute loads in the surface flow enables an assessment of the role of surface wash in effecting landscape modification under periglacial conditions.

Denudation estimates were calculated by multiplying the total flow volumes with the mean concentrations and averaging these values over the total plot areas (tab. III). Suspended sediment concentrations gave denudation estimates of 0.92 gm/m²/yr and 10.04 gm/m²/yr for plots 1 and 2 respectively. Solute concentrations gave denudation estimates of 0.8 gm/m²/yr at plot 1 and 2.38 gm/m²/yr at plot 2.

Table III

Suspended and dissolved sediment concentrations and denudation estimates

A — SUSPENDED SEDIMENT

	Number of samples	Mean concentration (p.p.m.)	S.D.	Total flow volume* (litres)	Denudation estimate (gm/m²/yr)
Plot 1	17	130	15.4	964	0.92
Plot 2	36	110	6.1	35,400	10.04
Plot 3	13	111	11.5	n.d.	n.d.

B — DISSOLVED SEDIMENT

	Number of samples	Mean conductivity (micro-mhos/cm)	S.D.	Mean concentration, dissolved solids (p.p.m.)	Denudation estimate (gm/m²/yr)
Plot 1	16	296.8	86.0	127.8	0.82
Plot 2	33	64.3	30.0	26.1	2.38
Plot 3	11	145.0	88.2	58.9	n.d.

* Includes simulated values where actual data are missing.

It must be stressed that these values do not necessarily represent total denudation on the plots, as no account is taken of other sediment inputs and outputs to the plots, notably solifluction and wind-blown particles (see Pl. 2). The latter are thought to be very important in this part of Banks Island (PISSART, VINCENT and EDLUND, 1977). Furthermore, it is assumed that total slopewash activity was restricted to the period of measurement, and that subsurface sediment transport was zero. Finally, the effects of any late summer storms in August are not included. On the other hand, it may be significant that the maximum denudation of 10 gm/m^2/yr is in broad agreement with that of 12 gm/m^2/yr reported by A. JAHN (1961, p. 17) from Spitsbergen beneath a snowbank location. Clearly, additional data is required before the proper significance of these values can be assessed.

Assuming the denudation values reported in this paper are typical, it is instructive to compare the role played by slopewash with other mass-wasting processes, notably solifluction. On Banks Island, rates of solifluction movement have been monitored at Sachs Harbour for a number of years (e.g. FRENCH, 1974) and data is now available over a 6 year period (tab. IV). The slopes being monitored are of low angle (2—4°), underlain by sandy gravelly colluvium and reasonably similar, therefore, to the slopes monitored for slopewash in the present study. Calculations indicate the approximate volume of material moved by solifluction. Given that the mean value for movement near the surface is 1.2 cm/yr, and assuming that movement in the upper 50 cm is, on average, half the surface rate, a volumetric downslope movement of approximately 30 cm^3/cm/yr is indicated. Alternatively, if the maximum thickness of the active layer is assumed to be 75 cm and if average movement in this zone is assumed to be one quarter of the surface rate, then the total volumetric downslope movement is approximately 22 cm^3/cm/yr. These values are of the same order of magnitude as those recorded from other permafrost environments (see YOUNG, 1974, tab. II).

Direct comparison of the slopewash and solifluction data for Banks Island requires transformation of the slopewash data from a mass to a volume measure.

Table IV

Average subsurface movement on low angled slopes, Sachs Harbour, 1969—1975, (see French, 1974, 1976a)*

Depth	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Total average movement, 1969—75
3	9.2	8.1	11.5	7.1	2.6	6.3	7.47
8	6.9	6.6	11.1	6.8	2.5	5.8	6.60
15	6.0	6.3	10.3	7.3	0.7	4.5	5.85
30	5.5	5.1	9.5	6.8	1.0	3.6	5.25
Total av. movement, 1969—75	6.9	6.5	10.6	7.0	1.7	5.0	6.29
Annual av. movement, 1969—75	1.15	1.08	1.77	1.16	0.28	0.84	1.05

* All values in cm.

If the highest slopewash denudation estimate is considered (i.e. 10.04 gm on plot 2) and assuming a dry bulk density of 1.5 gm/cm^2, denudation by slopewash appears to be at least two orders of magnitude less than that by solifluction. Again, further data is required, of a more comprehensive nature and of greater accuracy, before this tentative assessment can be confirmed.

CONCLUSIONS

Both hydrologic and geomorphic implications follow from this study.

The amounts of slopewash recorded were small compared to the total amounts of moisture originally available on the run-off plots in the form of snow. Therefore, attention must be focused upon other means of moisture removal in periglacial environments, notably sublimation and evaporation. Likewise, the low run-off coefficients obtained, for both snowmelt and storm-derived-run-off, indicate that Hortonian overland flow did not occur. If these data are typical, they provide tentative support for the concept of partial area contribution to run-off in periglacial environments.

From the geomorphic viewpoint, the data presented suggest that slopewash is not a major process fashioning the landscape. Because of sublimation losses much of the periglacial landscape may experience little or no denudation by slopewash activity at the time of spring melt. Only at snowbank locations does slopewash denudation achieve significant proportions. Even there, the available evidence suggests that total denudation is dominated by other mass-wasting processes, notably solifluction.

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