# Arctic Stream Processes—an Annotated Bibliography

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2065

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*By* KEVIN M. SCOTT

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# ARCTIC STREAM PROCESSES—AN ANNOTATED BIBLIOGRAPHY

By KEVIN M. SCOTT

## ABSTRACT

This bibliography selectively summarizes investigations to date (1978) dealing with the physical processes of streams in the Arctic. The specialized annotations include aspects of stream processes described in subordinate parts of general papers on the arctic environment and therefore not evident in author-abstract bibliographies. Foreign contributions—Canadian, Scandinavian, and Russian—are summarized, in the case of Russian literature primarily by means of papers in translation journals.

Until 1970 the role of streams in development of the arctic landscape was commonly considered subordinate to that of glacial and frost-related processes. This conclusion changed, however, with the findings of the many new studies begun in response to oil and gas discoveries in the late 1960's. The conclusions of these studies, made to provide both the engineering data for resource development and the information to assess the impacts of that development, were in general agreement that stream processes throughout most of the Arctic were significantly more important than previously had been thought.

## INTRODUCTION

The study of arctic stream processes is largely a product of the 1970's. Permafrost, or perennially frozen ground, and the problems encountered in construction on permafrost have a long history of study. Some landscape processes in the Arctic have been studied intensively, several more so than their temperate-zone counterparts. For example, formation of patterned ground by both frost action and ice wedges has attracted many investigators, as have the oriented lakes on the coastal plain of northern Alaska. Stream processes, by contrast, were not a popular subject for investigation in the Arctic before 1970. McCann, Howarth, and Cogley (1972) noted that, in four books on the geomorphology of cold regions that appeared between 1967 and 1969, only a total of nine pages was devoted to streams and stream processes—equivalent to barely 0.5 percent of the total contents.

Since that time (the late 1960's) all aspects of the arctic environment have been increasingly studied, but none more so than stream processes. This was due to several factors:

1. Researchers increasingly realized that fluvial processes were dominant in sculpting the arctic landscape, particularly so in the vast expanses of treeless barrens. Also, some of the highly visible processes in landscape formation that previously were intensely studied proved to be of minor interest once assessment of landscape response to man-induced change began.
2. Planning studies preparatory to resource development revealed that transportation corridors and pipelines could in many areas be routed most practically along stream valleys and flood plains. Rates and processes of erosion, scour depths, levels of design flooding, the hydraulics of streams in permafrost areas—all subjects little considered in pre-1970 arctic studies—were now of practical interest.
3. In Russia, Canada, and the United States, agencies concerned with water resource development have proposed a number of projects to divert the flow of rivers in permafrost areas to more populous regions. Many of the problems that will need to be considered before the utilization of arctic and subarctic water resources relate to interactions of permafrost with streams, lakes, and proposed reservoirs.
4. Additionally, because of the characteristically brief runoff season in the Arctic, the streams and their biota would be very sensitive to impacts from certain types of construction during the summer.

This literature survey evolved from a summary of background information for a study of permafrost effects on a group of streams in the vicinity of the Alaskan Pipeline on the north slope of the Brooks Range (Scott, 1978). Most of the papers listed in this bibliography were located by manual library search techniques because existing bibliographic compilations and data banks such as WRSIC (Water Resources Scientific Information Center) did not cover the subject of arctic streams sufficiently. The reasons for the lack of previous coverage of the subject include a lack of demand as explained above and the fact that many significant papers appeared in symposia proceedings, which were not fully indexed, and in resource-agency publications which, particularly in Canada, had very limited distribution.

Both the field study (Scott, 1978) and this bibliography were inspired by the late Don M. Culbertson. Several individuals, including Gertrude B. Sysak of the U.S. Geological Survey and Yvonne Wilson of the University of California, Irvine, provided helpful counsel during the course of the literature survey.

## DESCRIPTION OF THE BIBLIOGRAPHY

This bibliography is selective. The main criterion for inclusion of a paper was an affirmative answer to the question, "Can the paper possibly be useful to a person concerned with arctic stream behavior?"

Although the geographic focus of the literature reviewed is the Arctic, it also could be described as being "areas of permafrost" or "cold regions." Each of these terms can be rigorously defined and only locally will the areas so defined coincide. For purposes of a literature survey, however, the differences are not significant.

The arctic environment is aptly described as fragile. Significant streamflow commonly occurs only during the summer months in delicate balance with factors like solar radiation, vegetation, character of beds and banks, and ground-water conditions. Consequently, papers on these and similar topics where the conclusions may be relevant to stream processes are included in the bibliography. Likewise, papers on arctic lakes are included because lakes are an alternative to streams and shallow alluvial aquifers as sources of water supply, and those dealing with solifluction and similar processes are summarized because of their obvious bearing on erosion and streambank processes.

Much of the literature pertinent to streams in the Arctic comes from research in other areas. For example, subjects such as water-temperature effects on sediment transport and ice effects on streamflow are known in large part from research on temperate-zone streams. Alpine mudflows are analogs of their lesser-known arctic counterparts; and, much of the study of periglacial phenomena derives from large areas of the middle latitudes where the features are relicts of previous geologic intervals of cold climate. Also, the effects of frost action in cohesive streambank material are known in part from laboratory studies.

A weakness common to most summaries of arctic topics is inadequate coverage of the Russian literature. This compilation is no exception; however, the lack is partly remedied by two translation journals—*Soviet Hydrology: Selected Papers* and *Soviet Geography*—and the translation of the Russian journal *Vodnye Resursy* (Water Resources). The first of these sources is particularly valuable and contains many papers pertinent to arctic stream processes.

The annotations are arranged alphabetically by author (senior-author name in cases of multiple authorship). They are not necessarily synonymous with abstracts, in that no attempt is made to summarize conclusions not concerning stream processes. In only several designated instances is all or part of the author's abstract used in preference to the annotation written specifically for this summary. For the sake of brevity, geographic terminology in the titles of the publications is not repeated in the annotations. Geologic names are used as they appeared in the original sources and thus their use herein does not constitute acceptance by the U.S. Geological Survey.

The index to the bibliography keys the papers to both geographic and subject categories. Papers are listed under more than one subject area when appropriate. The index was compiled from the annotations and not the original publication, and therefore is only as complete as the information in the references and annotations.

## BIBLIOGRAPHY

**Abramov, R. V.**, 1957, Nishi vytaivaniya (Thaw-out niches): Priroda, v. 46, no. 7, p. 112-113, 2 figs.

Toward the end of summer, at the time of maximum development of the active layer, thermo-erosional niches develop in the sandy banks of the lower Lena River near the arctic coast of Siberia. Approximately 10 days after niching begins, with the niches at their maximum stage of stage of development, collapse of the overhanging banks occurs with a noise that can be heard 1.5 km away. This sequence of events is characteristic of the lower Lena River along its course above the Arctic Circle.

If vegetation prevents complete separation of the collapsed block, turf covers the bank like a "tablecloth hanging from a table." Complete separation occurs when the roots become dry and brittle, and then break.

This paper is significant primarily because of the indicated timing of the niching process in late summer. Elsewhere, thermo-erosional niching is reported to be a process associated with the breakup flooding of spring or, less commonly, with runoff from summer storms.

**Allen, C. R., O'Brien, R. M. G., and Sheppard, S. M. F.**, 1976, The chemical and isotopic characteristics of some northeast Greenland surface and pingo waters: Arctic and Alpine Research, v. 8, p. 297–317, 5 figs., 5 tables, 49 refs.

Water samples from Scoresby Land, northeast Greenland, from glacier, meltwater, stream, and pingo sources in the Delta Dal; from pingo sources in the Suchert Dal and on Traill Island; and from adjoining fiords were analyzed for their principle solute ions and for their deuterium and oxygen-18 contents. It was concluded that all waters discharging from the pingos are of recent meteoric origin, and that waters discharging from a group of related pingos do not necessarily have a common aquifer source.

**Ambler D. C.**, 1974 Runoff from a small Arctic watershed, *in* Permafrost hydrology, proceedings of workshop seminar, 1974: Ottawa, Canadian National Committee, International Hydrological Decade, p. 45–49, 3 figs., 1 table, 3 refs.

Hydrologic study of a sparcely vegetated, 29.4 km$^2$ watershed on Ellesmere Island at latitude 80°30′ N. is summarized. Runoff was recorded from June 18, the beginning of spring snowmelt, throughout the summer of 1973. Peak runoff occurred within 10 days after melting began.

In the discussion following oral presentation of this paper, it was noted that pronounced diurnal changes in discharge occurred. Peak flow usually occurred at 2400–0100 hours, and low flows were recorded about 13 hours later.

**Anderson, D. M.**, 1973, Water movement in frozen soil: a résumé of developments reported at the Second International Conference on Permafrost (abs.): EOS Transactions, American Geophysical Union, v. 54, p. 1090.

"More than forty papers dealing with the physics, physical chemistry, distribution, and flow mechanics of water in permafrost were presented***. Water movement in frozen soil is analogous in general to that in unfrozen soil, but in frozen soil, flow is confined primarily to unfrozen interfaces at mineral and organic matter surfaces. Soil water movement is readily induced by application of gradients in all component soil water potentials. Movement may occur in both liquid and vapor phases as mass movement or diffusive flow. The degree of pore saturation and ice content are additional, governing variables that must be specified in treating this problem. Although markedly influenced by variations in local permeability, ground water flow is substantial both in alluvium and bedrock and finds surface expression in freshwater springs, icings, pingos and solifluction features." (Quoted from author's abs.)

**Anderson, D. M., Reynolds, R. C., and Brown, Jerry,** 1964, Bentonite debris flows in northern Alaska: Science, v. 164, p. 173–174, 1 fig., 9 refs.

Channels developed by debris flows of bentonite-rich shale occur on steep banks of the Colville River near Umiat. The channels are U-shaped, 1 to 2 m deep and from 8 to 10 m wide, and are flanked by levees. Material is believed to be derived from headward parts of associated gulleys, and movement is triggered when the surface layer hydrates and swells, with loss of strength and consequent viscous flow.

The flows are active during the summer from bluffs 125 m in height. Much of the material is supplied to the channel of the Colville River at the foot of the bluffs.

The channels may be sufficiently distinctive to permit the identification of unstable, bentonitic slopes that will pose a widespread construction hazard. Similar features have been described at Franklin Bluffs overlooking the Sagavanirktok River, at Schrader Lake, and in the St. Elias Mountains.

**Anderson, G.S., and Hussey, K. M., 1962,** Alluvial fan development at Franklin Bluffs, Alaska: Iowa Academy of Science Proceedings, v. 69, p. 310–322, 8 figs., 5 refs.

Alluvial fans occur along the base of the Franklin Bluffs, a west-facing escarpment along the Sagavanirktok River. An age sequence of fan development was established, with examples to show how fan characteristics change in an arctic climate. Mudflow channels were common on a number of the fans.

**Anderson, G. S., and Hussey, K. M., 1963,** Preliminary investigation of thermokarst development on the North Slope, Alaska: Iowa Academy of Science Proceedings, v. 70, p. 306–320, 9 figs., 45 refs.

Thermokarst is a term applied to "karst-like" topography formed in permafrost regions that have had extensive thaw, like the North Slope. The term encompasses features described as thaw lakes, pits, sinks, basins, and gullies. Thermokarst features occurring in the Northern Foothills section of the North Slope include ice-wedge intersection pools, thermokarst ravines, "speckled topography" and beaded streams, in which each "bead" has formed at the intersection of two or more ice wedges.

**Anderson, J. C.,** 1974, Permafrost-hydrology studies at Boot Creek and Peter Lake watersheds, N.W.T., *in* Permafrost hydrology, proceedings of workshop seminar, 1974: Ottawa, Canadian National Committee, International Hydrological Decade, p. 39–44, 3 figs., 2 tables, 4 refs.

Two small (31 and 46 km$^2$) watersheds located within the zone of continuous permafrost on the east side of the Mackenzie River delta were studied in 1972 and 1973. Each basin contains many small lakes and is developed on glacial drift. Boot Creek occurs at the northern edge of the taiga vegetation zone; the Peter Lake drainage basin is in the tundra zone.

The snowpack attained its maximum water equivalent in early May, followed by snowmelt runoff in late May and early June over a period of 2 to 4 weeks. A high percentage (85 percent) of the "available" water (snowpack plus subsequent precipitation) on May 1 appeared as runoff by June 10 in 1973.

Midsummer storms resulted in ratios of direct runoff to precipitation of 0.05 or less. Recession limbs showed a slope change (on semilogarithmic plot) apparently reflecting a shift from base flow plus interflow (direct runoff was negligible) to only base flow. The low runoff ratios and the large decay constant values were related to terrain conditions—an increasingly thick thawed layer during the summer, widespread occurrence of peaty soil and moss, and the presence of lakes and depressions.

The cooler wetter weather of August and late summer brought an increased response of runoff to precipitation, possibly due to increased base flow caused by the thawing of permafrost in response to infiltrating storm precipitation. Freezeup usually occurred by late October.

**Anderson, J. C., and Durant, R. L.,** 1976, Hydrologic reconnaissance, Thomsen River basin, Banks Island, District of Franklin: Geological Survey of Canada Paper 76–1A, p. 221–227, 6 figs., 1 table, 1 ref.

Hydrologic processes were observed during the 1975 runoff season. Suspended-sediment samples were obtained but the results were not yet available at the time of this preliminary report. Hardness was found to increase during recession of the spring flood.

**Anderson, J. C., and MacKay, D. K.,** 1974, Progress of hydrologic studies at Boot Creek and Peter Lake watersheds, N.W.T., during 1973, *in* Hydrologic aspects of northern pipeline development, 1974: Environmental-Social Committee Northern Pipelines (Canada), Task Force on Northern Oil Development Report no. 74–12, p. 209–223, 4 figs., 2 tables, 9 refs.

Maximum runoff from the two small, instrumented watersheds east of the Mackenzie River delta typically occurs during the spring snowmelt period. Direct runoff from summer storms is minimal—less than 5 percent of precipitation. Water balance calculations for one basin revealed a sizable storage depletion in 1972–3.

**Antonov, V. S., Ivanov, V. V., and Nalimov, Y. V.,** 1972. Types of breakup of rivers in Siberian arctic and sub-arctic zones, *in* The role of snow and ice in hydrology, proceedings of Banff symposia, September 1972: International Association of Scientific Hydrology Publication, v. 1, p. 541–546, 1 fig.

Four main types of breakup are described. A map shows the reaches of major rivers that are characterized by each breakup type.

**Arnborg, Lennart,** 1955, Hydrology of the glacial river Austurfljót: Geografiska Annaler, Series A.,. 37, p. 185–201, 9 figs., 8 tables, 4 refs.

The hydrology of this Icelandic river was defined by two partial years (1951–1952) of stream-gaging records. Diurnal discharge variation was regular, with minimums at 8 a.m. and maximums at 6 p.m. Several jökulhlaups were measured, each with a markedly different hydrograph but with a gradual rise and a rapid recession—the reverse of floods from precipitation.

**Arnborg, Lennart, Walker, H. J., and Peippo, Johan,** 1966, Water discharge in the Colville River, 1962: Geografiska Annaler, Series A, v. 48, p. 195–210, 9 figs., 6 tables. 9 refs.

"This report *** presents hydrological characteristics of the surface drainage in an area of continuous permafrost on the Artic Slope. Water discharge was determined for the river delta during the whole hydrological year, which in 1962 lasted from May 25 to about October 20. During this period the discharge started from zero and reached about 6,000 $m^3/s$ during the flood at the beginning of June. The total water discharge during the year was $16 \times 10^9$ $m^3$ with an average of 26 $l/s/km^2$ for the hydrological year or 10 $l/s/km^2$ for the entire year." (Quoted from authors' abs.)

**Arnborg, Lennart, Walker, H. J., and Peippo, Johan,** 1967, Suspended load in the Colville River, Alaska, 1962; Georgrafiska Annaler, Series A, v. 49, p.131–144, 12 figs., 4 tables, 5 refs.

"*** In 1962, load per unit volume increased at a more rapid rate than discharge such that the peak sediment load preceded peak discharge. Grain size varied positively with discharge although other variables, especially position of sampling point in relation to source area, caused local differences.

One of the most striking characteristics of arctic rivers is the great concentration of activity in a short period of time. Although the Colville River flows for over 4 months of the year much of the discharge and suspended load transport occur during the first few weeks of the season. In 1962, the three-week period just preceding, accompanying and immediately following breakup, was a time of flooding. Forty-three percent of the annual discharge ($16 \times 10^9$ $m^3$) and 73 percent of the total suspended inorganic load ($5.8 \times 10^6$ tons) were carried onceanward during that period of time." (Quoted from authors' abs.)

Maximum suspended-sediment concentration, 800 mg/L, was reached 1.5 days before the pre-breakup peak discharge of June 4. Much sediment was derived from gullied mudbars. Breakup flooding was accompanied by much bank erosion and formation of thermo-erosional features. Peak concentration of 1650 mg/L was reached 2 days prior to the peak flow of June 14. During the summer, fluctuations in concentration corresponded closely with stage. Suspended-sediment concentrations ranged between 20 and 100 mg/L The correlation of concentration and discharge on both rising and falling stages suggested that the sediment was locally derived.

**Benninghoff, W. S.,** 1974, Macrobiology and ecology in polar deserts, *in* Smiley, T. L., and Zumberge, J. H., eds., Polar deserts and modern man: Tucson, University of Arizona Press, p. 91–97, 1 table, 15 refs.

Polar deserts have many features in common with lower-latitude deserts—discontinuities of vegetation cover, short growing and reproduction seasons, and expressions of drought stress. Differences in detail are apparent.

Vascular plants of the tundra are almost exclusively perennials. Annuals are rare. Woody perennials consist of low bushes, recumbant and matlike. Perennial herbs have most of their biomass underground, with root, rhizome, or bulb-storage organs.

Sensitivities of some polar ecosystems to changes in climate, atmospheric chemistry, or atmospheric pollution levels are such that the ecosystems could be used as indicators of global change. Individual species, or even entire specialized ecosystems, could be extinguished by man-induced changes in the lower latitudes.

Polar ecosystems have little diversity. The extreme diversity of the physical environment is reflected as side ecotypic variation by many species and by innumerable recombinations of the available species. Ecosystems are relatively unstable, in that environmental forcing functions are detected quickly and old couplings are broken and replaced by new ones. This situation results in a boom and bust biological economy and makes management difficult. This is the reason that the tundra ecosystem has been characterized as fragile. Over wider areas and longer time intervals, however, strong survival power is evident—it's a matter of scale. Relative to warm desert and wet tropical ecosystems, the polar ecosystems are less resilient but not more fragile.

Instability of soils because of permafrost beneath and frost action above provides distinctive environmental stresses for the biological system. Adaptations to these stresses are in the form of underground organs, and the ability to live on the "floating" surfaces of heavy, flowing soils.

Why are polar landscapes important? We don't know how to maintain them in a natural state in contact with man nor do we know how to maintain them domestically. Our choice, therefore, is to try to protect them and preserve their impressive esthetic values. Harmonious human activity need not be detrimental.

**Black, R. F.**, 1969a, Thaw depressions and thaw lakes, a review: Biuletyn Peryglacjalny, v. 19, p. 131–150, 61 refs.

The paper reviews the status of knowledge in North America of thaw depressions and thaw lakes of permafrost regions. Little new information is presented. Suggestions for future study are made.

Thaw depressions are caused by thaw of ice wedges. Thaw lakes are formed in part by thaw of permafrost, but the large lakes are too deep to be accounted for solely in this manner.

**Black R. F.**, 1969b, Geology, especially geomorphology, of northern Alaska: Arctic, v. 22, p. 283–299, 100 refs.

Geomorphological investigations in northern Alaska are usefully summarized, focusing particularly on past and desirable future trends in research as they concern the U.S. Naval Arctic Research Laboratory at Barrow. The discussion centers primarily on permafrost problems, but a history of investigations of oriented arctic lakes is included. The discussion of oriented lakes is more comprehensive but less recent than that in Brown and Sellman (1973).

**Black, R. F., and Barksdale, W. L.**, 1949, Oriented lakes of northern Alaska: Journal of Geology, v. 57, p. 105–118, 5 figs., 2 tables, 10 refs.

The degree of orientation of the lakes, which occur in an area of over 25,000 mi$^2$ in the Arctic Coastal Plain, is surprisingly uniform. The long-axis orientation ranges from N.9° W. to N. 21° W., and the deviation in any one locality is commonly less than 3° and rarely over 5°. The lakes are as large as 9 × 3 mi (14.4 x 4.8km) and as much as 20 ft (6m) or more in depth. Some drained lakes were as much as 60 ft (18m) in depth. The orientation of the lakes is ascribed to former winds at right angles to the presently prevailing east-west pattern and parallel to the long axis of the lakes.

**Blake, W., Jr.**, 1974, Periglacial features and landscape evolution, central Bathurst Island, Distirict of Franklin: Geological Survey of Canada Paper 74–1, pt. B, p. 235–244, 11 figs., 16 refs.

In this study of glacial and periglacial features, processes described include ther-

moabrasion of lake shores, formation of beaded drainage, and local drainage development.

**Bögli, A.**, 1960, Kalklösung and Karrenbildung (Limestone solution and karren formation): Zeitschrift für Geomorphologie, Supp. Band 2, p. 4–21, 5 figs., 18 plates, 39 refs.

Limestone solution is dependent to a high degree on the velocity of reaction, which rises with temperature and further depends on the presence of free carbon dioxide. Both temperature and carbon dioxide are high in the tropics and low in the Arctic. Although the solubility of carbon dioxide increases as temperature decreases, that of carbonate decreases, with the net result that the rate of solution is small.

**Bogoslovskiy, P. A., Veselov, V. A., Ukhov, S. B., Stotsenko, A.V., and Tsvid, A. A.**, 1966, Dams in permafrost regions, *in* International Conference on Permafrost, Lafayette, Ind., 1963, Proceedings, National Research Council Publication no. 1287, p. 450–455, 5 figs., 23 refs.

Principles of dam construction on permafrost, based on dams built in the U.S.S.R. since 1792, are discussed. Both "warm" and "cold" methods are described. In the Russian experience, spillways and water outlets have been the weakest points in any hydroelectric power plant "until recently."

**Brewer, M. C.**, 1958a, Some results of geothermal investigations of permafrost in northern Alaska: Transactions of the American Geophysical Union, v. 39, p. 19–26, 10 figs., 1 table, 4 refs.

The distribution of permafrost in the Barrow, Cape Simpson, Umiat, and Shaviovik River areas is described.

Lakes deeper than about 7 ft (2.1m) do not freeze to the bottom and may have an underlying unfrozen zone several hundred feet in thickness. The best year-round source of fresh water in the Arctic is an uncontaminated lake or stream with a minimum depth of 7 ft (2.1m).

A thermal profile through ice and water of the Colville River at Umiat is nearly vertical (constant temperature) beneath the ice, differing markedly from the lake profiles at Barrow and Umiat. Mixing by turbulence prevents development of a gradient in the river. The turbulence also accounts for the heavy concentration of ice crystals in the water (to a depth of 12 ft (3.6m) in 1953) beneath river ice in early fall.

Permafrost temperatures are modified beneath shallow streams, like the Shaviovik River, that usually freeze to the bottom. The Shaviovik River had introduced 3°C of warming in the permafrost to a depth of 135 ft (41m).

**Brewer, M. C.**, 1958b, The thermal regime of an Arctic lake: Transactions of the American Geophysical Union, v.39, p. 278–284, 10 figs., 6 refs.

Annual changes in the thermal regime of several shallow lakes on the Arctic Coastal Plain near Barrow are defined. The lakes are either 2 to 3 or 6 to 9 ft (.6 to .9m or 1.8 to 2.7m) deep. Shallow lakes can often provide a suitable summer water supply, but only deeper lakes could provide water throughout the year. Lakes more thna 6 to 7 ft (1.8 to 2.1m) deep do not freeze completely during the winter.

**Brice, J. C.**, 1971., Measurement of lateral erosion at proposed river crossing sites of the Alaska pipeline: U.S. Geological Survey Open-File Report, 39 p., 17 figs.

Rates of lateral erosion of major rivers were determined by comparison of aerial photographs taken mainly in 1950 with those taken in 1969.

The paper is an example of the practical engineering value of geomorphic analysis of stream behavior. Study of the aerial photographs indicated that diversions of channels across a flood plain or low terrace surface are more probable along meandering rivers than along braided rivers. The amounts of lateral erosion were extremely variable, both among different rivers and longitudinally along channels of both braided and meandering rivers.

**Britton, M. E.,** 1966, Vegetation of the arctic tundra: Oregon State University Press, 64 p.,12 figs., 63 refs.

First published in 1957, this study discusses the cycle of development of thaw lakes and associated vegetation changes. Small thaw ponds initially form in the centers of ice-wedge polygons and gradually expand to form larger ponds and lakes. The lakes deepen, continue to expand concomitant with further thawing, and may coalesce with other lakes. Eventually a breach occurs, the lake is drained, and ice wedges and vegetation develop in the organic-rich lake sediment. All stages in the sequence are present on the arctic tundra. Many variations are possible—the lake may be only partly drained, for example, and the residual lake may then begin to erode its own terraces.

**Broscoe, A. J.,** 1972, Some aspects of the geomorphology of meltwater streams, Steele Glacier terminus, *in* Bushnell, V. C., and Ragle, R.H., eds., Icefield Ranges Research Project scientific results: American Geographic Society and Arctic Institute of North America, v. 3, p. 47–51, 2 figs., 3 tables, 1 ref.

Measurements of discharge, sediment load, and water quality are summarized. A sudden increase in discharge in one channel was ascribed to changes in the tunnel system of the glacier.

**Broscoe, A. J., and Thomson, S.,** 1972, Observations on an alpine mudflow, Steele Creek, *in* Bushnell, V.C., and Ragle, R. H., eds., Icefield Ranges Research Project scientific results: American Geographic Society and Arctic Institute of North America, v. 3, p. 53–60, 7 figs., 2 tables, 13 refs.

Mudflows occurred in channels on valley-side slopes of Steele Creek, southern Yukon, on July 11, 1967, in response to 2.19 in. (5.56cm) of rainfall in 36 hours. Boulders as large as 13 ft (3.95m) were included in the flows, from which rain and runoff washed the fine material to produce a surficial lag deposit similar to alluvial gravel.

Calculation of the head necessary to move the large boulder indicates that, because of the high slope, fluid forces of the mudflow could easily move material of that size.

**Brown, Jerry,** 1966, Soils of the Okpilak River region, Alaska: U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory Research Report 188, 49 p., 74 figs., 7 tables, 51 refs.

This comprehensive study of the soils of a small area at the northern margin of the eastern Brooks Range focuses on surficial and internal structures related to frost action. Approximately 55 types of soil conditions and surface features are described and mapped. Soil forming processes and their relation to the arctic environment are discussed.

**Brown, Jerry, Dingman, S. L., and Lewellen, R. I.,** 1968, Hydrology of a drainage basin on the Alaskan coastal plain: U.S. Army Cold Regions Research and Engineering Laboratory Research Report 240, 18 p., 6 figs., 9 tables, 26 refs.

A four-summer hydrologic record from a 1.6 km$^2$, drained-lake watershed at Barrow is analyzed. Hydrographs revealed that (1) lag times were generally from 3 to 10 hours, (2) recession constants were about 50 hours, but occasionally were as much as 160 hours, and (3) runoff from individual storms was between 1 and 70 percent. About 5 percent of thaw-season precipitation normally runs off. Assuming all winter precipitation runs off, about 50 percent of the measured annual precipitation becomes runoff to the Arctic Ocean.

**Brown, Jerry, and Sellmann, P. V.,** 1973, Permafrost and coastal plain history of arctic Alaska, *in* Britton, M. E., ed., Alaskan arctic tundra: Arctic Institute of North America Technical Paper no. 25, p. 31–47, 6 figs., 1 table, 127 refs.

Properties and processes relevant to permafrost on the Arctic Coastal Plain are summarized. Thermal and chemical properties, ice morphology and dynamics, Quaternary stratigraphy, and the influence of surface properties on permafrost are discussed.

**Brown, R. J. E.,** 1973, Ground ice as an initiator of landforms in permafrost regions, *in* Fahey, B.D., and Thompson, R. D., eds., Research in polar and alpine geomorphology: Proceedings Third Guelph Symposium on Geomorphology, 1973, p. 25–42, 12 figs., 62 refs.

This discussion of ground ice and landforms includes mention of drainage features such as beaded streams and the thaw lakes resulting from degradation of permafrost.

**Brown, R. J. E.,** 1974, Distribution and environmental relationships of permafrost, *in* Permafrost hydrology, proceedings of workshop seminar, 1974: Ottawa, Canadian National Committee, International Hydrological Decade, p. 1–5, 3 refs.

This general discussion covers the character and distribution of permafrost in Canada, and the effects of the following factors on permafrost: climate, relief, vegetation, snow cover, fire, glacial ice, and soil and rock type.

Within the zone of discontinuous permafrost, the boundary conditions are so sensitive that the north-facing banks of even a small stream may be underlain by permafrost at the point where the south-facing bank is free of permafrost.

**Brunskill, G. J., Campbell, P., Elliott, S. E. M., Graham, B.W., Dentry, W. J., and Wagemann, R.,** 1975, The chemistry, mineralogy, and rates of transport of sediments in the Mackenzie and Porcupine River watersheds, N.W.T. and Yukon, 1971–73, unpublished report, 63 p., 6 figs., 16 tables, 103 refs.

Measurements of suspended sediment, particulate carbon, particulate nitrogen, particulate phosphorus, and discharge are reported from a variety of large and small streams in the Mackenzie Valley and northern Yukon. Suspended-sediment transport rates varied between 0.2 and 11.5 metric tons /km$^2$/yr for small (less than 10,000 km$^2$) watersheds, and 36 to 126 metric tons /km$^2$/yr for large (over 15000 km$^2$) river basins. The magnitude of annual transport rates of each of the above components was related by regression to watershed and precipitation factors. Differences in transport rates between large rivers, small rivers, and a group of lake-controlled rivers are explained. Effects of disturbances will be concentrated largely in the smaller watersheds.

**Bryan, M. L.**, 1972, Variations in quality and quantity of Slims River water, Yukon Territory: Canadian Journal of Earth Sciences, v. 9, p. 1469–1478, 3 figs., 6 tables, 25 refs.

Variations in water quality and discharge for several 24-hour periods in 1970 reflected the ablation pattern of the upstream glacier and a shift in glacial drainage believed caused by ice movements. Inverse correlation between flow and water quality was considered to be the result of decreased proportions of glacial meltwater.

**Büdel, Julius,** 1972, Typen der Talbildung in verschiedenen klimamorphologischen Zonen (Varieties of erosion in different climato-geomorphological zones): Zeitschrift für Geomorphologie, Supp. Band 14, p. 1–16, 6 figs., 12 refs.

In nonglaciated polar regions, erosion is facilitated by development of an *Eisrinde*–a "rind" or ice-rich surface layer, which in Spitsbergen has a thickness of 0.5 to 1.5 m. The work of streams is facilitated because bedrock is already mechanically reduced by the action of ground ice. Thus the rivers of polar regions are able to deepen their beds "very quickly." The process is operable even on wide flood plains, so that they "penetrate without steps in the longitudinal profile quickly back to the heart of the mountains." In Spitsbergen, the post-glacial erosion rate over the last 10,000 years is 1 to 3 m per 1,000 years—a very high rate ascribed to the *Eisrinde* effect.

**Burdykina, A. P.**, 1970, Breakup characteristics in the mouth and lower reaches of the Yenisey River: Soviet Hydrology: Selected Papers, no. 1, p. 42–52, 4 figs., 13 tables, 10 refs. (English edition published by the American Geophysical Union).

Breakup in the lower reaches of the Yenisey River is related to a large number of factors which reflect the diverse hydrometeorological conditions of the stream and are a function of its great meridional extent. Regressions with factors measuring the thermal state of the air masses, radiation, time of approach of the flood wave, rate of rise in river stage, and depth of snow cover were analyzed to forecast the breakup time at a series of points. The average prognostication error in a 5-year test period (1963– 67) was 2 days, with a ratio to the mean deviation of 0.35.

**Carlson, R.F.**, 1974, Permafrost hydrology: an Alaskan's experience, *in* Permafrost hydrology, proceedings of workshop seminar, 1974: Ottawa, Canadian National Committee, International Hydrological Decade, p. 51–57, 2 figs., 12 refs.

"Impending development in the north, particularly in permafrost regions, points to a need for a more extensive understanding of permafrost hydrology. Although the occurrence of permafrost itself is important to an understanding of hydrologic processes of northern regions, other important factors are low temperature, high latitude, large elevation differences, and an extremely sparse data network. When one is constructing models of understanding of the northern hydrologic systems, these factors must be kept in mind in conjunction with the particular problems of a region; whether they be of a mean value, extreme value, or time history nature. These considerations affect the understanding or modelling of each of the components of the hydrologic system: atmospheric, surface, soil, groundwater, and channel network. Although the problems are many, the major ones appear to be those dealing with stream crossings of northern rivers, both in terms of flow magnitude and of water level, and of a more complete understanding of bottom mechanics. Another important need is for a more complete understanding of mass and energy transport in engineered and natural soils. Some examples of research on a particular phenomenon can be shown in the areas of sparse data flood design, the design of stream crossings in the vicinity of large overflow icings, and a more complete understanding of soil-water movement in frozen soils. In summary, many features of the north must be kept in mind, certainly permafrost, but also other collaborative effects. But most importantly , the understanding of northern hydrologic problems must depend on input of a coordinated research, development, and design effort undertaken with the ultimate user in mind." (Quoted from authors' abs.)

**Carson, C. E.**, 1968, Radiocarbon dating of lacustrine strands in Arctic Canada: Arctic, v. 21, p. 12–26, 9 figs., 1 table, 12 refs.

Relict strands around oriented lakes yield radiocarbon dates of generally less than 3,500 years. The results suggest that lacustrine transgressive expansion reached a maximum near the end of the hypsithermal from 3,500 to 4,000 years ago.

**Carson, C. E., and Hussey, K. M.**, 1962, The oriented lakes of arctic Alaska: Journal of Geology, v. 70 p. 417–439, 14 figs., 6 tables, 21 refs.

Wind-controlled current systems and the morphology of oriented arctic lakes were studied. A combination of two main processes—basin subsidence by thaw and wind-oriented wave action—tends to produce the uniformly oriented basins. The lakes have sublittoral shelves on the east and west sides and a deeper central basin extending to the north and south ends. Easterly and westerly winds, nearly normal to the axis of orientation, produce wave action that deposits sediment on the east and west sides, forming the shelves, and erodes the north and south ends, thereby enlarging the lake and increasing the degree of orientation.

**Childers, J. M.**, 1972a, Flood surveys along proposed TAPS route, Alaska, July 1971: U.S. Geological Survey Basic Data Report, 16 p., 1 fig., 1 table, 22 refs.

Flood surveys at 13 sites along the northern segment of the pipeline route are described. Information presented includes drainage-basin characteristics, flood characteristics, bankfull-channel characteristics, and the maximum evident flood. Flood magnitude-frequency values at ungaged sites were estimated by previously developed multiple regressions with basin characteristics as the independent variables.

**Childers, J. M.**, 1972b, Channel erosion surveys along proposed TAPS route, Alaska, July, 1971: U.S. Geological Survey Open-File Report, 79 p., 62 figs., 1 table, 8 refs.

Preconstruction conditions are described at selected channel sites along the northern segment of the trans-Alaska pipeline from Prudhoe Bay to the Salcha River. Documentation included monumented cross sections, particle-size distributions, and large-scale aerial photography at times of low flow.

**Childers, J.M.**, 1974, Flood surveys along TAPS route, Alaska: U.S. Geological Survey Basic Data Report, 16 p., 1 fig., 1 table, 22 refs.

Flood surveys at 24 sites along the pipeline route are described. Content of the report is similar to that of Childers (1972a).

**Childers, J. M., and Lamke, R. D.**, 1973, Flood survey at proposed TAPS crossing of Yukon River near Stevens Village, Alaska: U.S. Geological Survey Open-File Report, 12 p., 4 figs., 1 table, 7 refs.

The peak discharge of the maximum evident flood at the crossing site was determined to be 25,200 m$^3$/s, coincident with the discharge at bankfull stage. That value compares with an estimate of the Standard Project Flood of 45,300 m$^3$/s. The stage-discharge relation was defined by two current-meter measurements (one of 17,800 m$^3$/s) and step-backwater computation. The basic hydraulic characteristics at the crossing site are presented.

A resurvey of the cross section in June 1973 (at the time of the high-flow measurement) showed no significant scour or fill compared with a preceding low-flow survey.

**Childers, J. M., Sloan, C. E., and Meckel, J.P.,** 1973, Hydrologic reconnaissance of streams and springs in eastern Brooks Range, Alaska—July 1972: US. Geological Survey Basic Data Report, 25 p., 20 figs., 2 tables, 6 refs.

Estimates of bankfull discharge and maximum evident flood peaks were made by slope-conveyance methods at 11 sites. Discharges of 2-year and 50-year average recurrence intervals were estimated from regressions of flood discharges versus the physical and climatic characteristics of the watersheds. Springs, mainly in limestone terrain, were measured and sampled.

**Chizhov, A. N.,** 1972, Characteristics of ice jam formation in mountain rivers: Soviet Hydrology: Selected Papers, no. 4, p. 284–289, 4 figs., 3 refs., (English edition published by the American Geophysical Union).

Intense ice jams as long as 50 km may form in mountain rivers and cause water rises as much as 10 to 12 m and accumulations of huge masses of ice. Jams on medium and large rivers completely fill the upper section of the channel with slush ice resembling a glacier tongue, below which the stream is confined in a tunnel. In alluvial valleys, jams cause overflow and flooding on terraces or flood plains. Most of the ice in a jam is not anchor ice, as frequently assumed, but slush consisting of primary crystals moved in suspension. Size and duration of jams are determined by the dynamic equilibrium between deposition and erosion of the ice accumulation and the hydraulic characteristics of the jammed reach.

**Church, M. A.,** 1972, Baffin Island sandurs: a study of arctic fluvial processes: Geological Survey of Canada Bulletin 216, 208 p., 99 figs., 40 tables, 243 refs.

The report is a comprehensive study of arctic stream processes in glacial-meltwater streams. Valley sandurs (valley trains) are the major postglacial physiographic features in much of the Canadian Arctic. Most sediment is transported mainly as bedload by runoff events from summer snowmelt periods and summer storms, but suspended-sediment and dissolved loads are important as well. Storm runoff is particularly effective, because the lack of vegetation and the frozen substrate result in a high runoff ratio. Extreme floods may be produced by sudden drainage of ponded water from ice margins. The major hydraulic adjustment to increasing discharge is made by stream velocity, indicating a change in bedform associated with the rapid increase of sediment transport that results in a sharp decline in flow resistance. Sandurs are areas of rapid aggradation, have approximately parabolic long profiles, and show downstream decreases in particle size. Because of reworking of glacial material, sediment yield bears no relationship to present primary rates of sediment production.

**Church, M. A.,** 1974a, Hydrology and permafrost with reference to northern North America, *in* Permafrost hydrology, proceedings of workshop seminar, 1974: Ottawa, Canadian National Committee, International Hydrological Decade, p. 7–20, 5 figs., 4 tables, 57 refs.

The article is a comprehensive summary of the hydrology of northern Canada and Alaska with emphasis on the effects of permafrost on surface water and ground water. Small-scale maps illustrate the distribution of permafrost, mean annual precipitation and the proportion falling as snow, mean annual evaporation from small lake surfaces, and mean annual runoff. Annual hydrographs of types of arctic streams are presented.

**Church, M. A.**, 1974b, On the quality of some waters on Baffin Island, Northwest Territories: Canadian Journal of Earth Sciences, v. 11 p. 1676–1688, 8 figs., 3 tables, 12 refs.

Water is generally very soft (total dissolved solids of 5 to 50 mg/L) in both the glaciated and nonglaciated Precambrian terrain of eastern and central Baffin Island. Diurnal and seasonal fluctuations in dissolved-solids concentration are related to sources and character of runoff.

**Church, M. A.**, 1977, River studies in northern Canada: reading the record from river morphology: Geoscience Canada, v. 4, p. 4–12, 5 figs., 18 refs.

This paper is an excellent general discussion of the regimen of northern rivers, particularly in reference to proposed resource development. Emphasis is placed on reconnaissance techniques to evaluate river behavior.

Proposed major projects in northern Canada will require far more extensive information than presently exists. Although conventional stream gaging will expand, morphologic information should be collected by regular survey of designated study reaches in a variety of rivers and in those of special interest—such as those with perennial springs, important fish migrations or spawning areas, or unusual stability problems.

**Church, M. A., and Ryder, J. M.**, 1972, Paraglacial sedimentation: a consideration of fluvial processes conditioned by glaciation: Geological Society of America Bulletin, v. 83, p. 3059–3072, 9 figs., 4 tables, 52 refs.

Drift is unstable in a proglacial or postglacial fluvial environment, resulting in increased sediment movement by "paraglacial" denudation and sedimentation. Sediment yield bears no relation to concurrent primary production of weathered debris. Areas discussed are Baffin Island, where postglacial valley alluvium is widespread and rapid sedimentation continues today, and south-central British Columbia, where rapid sedimentation during the paraglacial period contrasts sharply with the present.

Table 3 lists post-glacial and Holocene sediment-yield rates in various environments. Deduced paraglacial rates approach the magnitude of some of the most extreme recorded rates, such as those from badland topography or from areas underlain by loess.

**Cogley, J. G.**, 1972, Processes of solution in an arctic limestone terrain, *in* Polar geomorphology: Institute of British Geographers Special Publication no. 4, p. 201–211, 5 figs., 1 table, 7 refs.

Flow in a small drainage basin (2.3 $km^2$) in limestone terrain of Devon Island, Northwest Territories, peaked at 1.42 $m^3/s$ on July 2, 1970. Concentration of Ca and Mg reached a maximum of 102 mg/L (as $CaCO_3$) at a discharge of 0.067 $m^3/s$ on July 22. During a rainstorm flood in late July, the solute load (Ca and Mg) was greater than the suspended sediment load. Solute concentration also varied with the duration and distance over which solution occurred. Rainwater was a more effective solvent than snow meltwater.

**Cogley, J. G., and McCann, S. B.**, 1976, An exceptional storm and its effects in the Canadian High Arctic: Arctic and Alpine Research, v. 8, p. 105–110, 6 refs., 1 table, 4 figs.

The major storm of July 21–23, 1973, at Vendom Fiord, Ellesmere Island, resulted in high local precipitation (54.6 mm), but was not exceptional throughout the rest of the Queen Elizabeth Islands. At Vendom Fiord, storm runoff caused inundation of flood plains, movement of coarse alluvium, gully erosion, and rapid mass movements. The storm may have triggered a glacier outburst flood occurring from an ice-dammed lake 10 days later.

**Colby, B. R., and Scott, C.H.**, 1965, Effects of water temperature on the discharge of bed material: U.S. Geological Survey Professional Paper 462–G, 25 p., 19 figs., 1 table, 27 refs.

Changes in water temperature and viscosity affect bed-material discharge in three separate ways: (1) a change in thickness of the laminar sublayer affects the relation between mean velocity and effective shear on the bed; (2) the vertical distribution of sediment concentration is affected by changes in fall velocity; and (3) bed configuration and, therefore, resistance vary indeterminantly with temperature. The second effect is most important in an approximately doubling of bed-material discharge at 40°F as compared to 80°F.

**Cook, F. A.**, 1967, Fluvial processes in the High Arctic: Canadian Department of Energy, Mines and Resources, Geographic Bulletin, v. 9, p. 262–268, 3 figs., 3 tables, 11 refs.

Runoff processes were observed in the Mecham River drainage near Resolute, Cornwallis Island. The intense spring freshet from rapidly melting snow is responsible for the bulk of transport of weathered material in solution and as suspended-sediment load, a result in contrast to the generally underestimated role of snowmelt in the erosion of High-Arctic regions. Rare but heavy rainfalls during the short summer may also be effective.

**Cooper, R. H., and Hollingshead, A. B.**, 1973, River bank erosion in regions of permafrost, *in* Fluvial processes and sedimentation: Proceedings of Hydrology Symposium no. 9, University of Alberta, Edmonton, May 1973, p. 272–283, 5 figs., 1 table.

Four bank-erosion sites in the Yukon and Northwest Territories are described. Bank erosion was found to depend on the thermal regime within the banks, the effect of which is to make available an active layer that is unstable and actively erodible. This results in erosion rates that are more constant from year to year in comparison with nonpermafrost areas. The presence of shallow permafrost in banks tends to stabilize inherently unstable material.

**Corte, A. E.**, 1963, Particle sorting by repeated freezing and thawing: Science, v. 142, p. 499–501, 3 figs., 12 refs.

If a heterogeneous mixture of particles of various sizes is frozen and thawed repeatedly, the sorting of the particles is greatly improved. The movement of the particles depends on the amount of water between the ice-water interface and the particle, the freezing rate, the size distribution of the particles, and the orientation of the freeze-thaw plane.

Sorting generally increased the number of fine particles in the lower part of a layer and the number of coarse particles near the surface, leading to "vertical sorting." Gravels deposited by man in Alaska show sorting after 15 to 20 cycles of annual freezing and thawing. Experiments with conditions of lateral freezing, as with riverbanks and terraces, showed that the percentage of fine particles increased from the top down as well as laterally away from the freezing plane. The actual migration of particles in front of a freezing plane was experimentally demonstrated.

**Craig, P. C., and McCart, P. J.,** 1975, Classification of stream types in Beaufort Sea drainages between Prudhoe Bay and the Mackenzie Delta, N.W.T., Canada: Arctic and Alpine Research, v. 7, p. 183–198, 6 figs., 4 tables, 43 refs.

Streams are classified into the following categories: (1) Mountain streams originate in the Arctic Mountain Province and are large and cold (usually less than 10°C). Arctic char is the dominant fish species, and the density of benthic invertebrates is low (100 organisms/m$^2$). (2) Spring streams are small tributaries of mountain streams and originate from springs. Most are fresh with temperatures of 3° to 7°C. Arctic char dominate, and benthic invertebrates are common (10,000 organisms/m$^2$). (3) Tundra streams originate in the Foothills and Coastal Plain provinces. Water of tundra streams is stained brown, and has a lower pH, conductance, and calcium content than mountain or spring streams. Summer temperatures may exceed 16°C, and benthic invertebrates are of intermediate densities. Grayling spawn and are reared in tundra streams. All three types have only seasonal flow.

**Czeppe, Zdzislaw,** 1965, Activity of running water in south-western Spitsbergen: Geographia Polonica, v. 6 p. 141–150, 8 figs., 16 refs.

The importance of fluvial processes in Spitsbergen is assessed. The general theme of the paper is that fluvial processes are important in forming the Spitsbergen landscape and that they account for erosional features such as parallel rills and sharp-edged interfluves. Meltwater is vastly more important than storm rainfall. The greatest intensity of flow is achieved while the ground is still frozen, and sheet flow dominates. Running water is believed to act more as a denuding agent than as an erosional agent. Some forms of tundra microrelief previously thought to be the result of frost action are actually the product of running water.

**Davies, W. E.,** 1974, Geological and limnological factors of cold deserts, *in* Smiley, T. L., and Zumberge, J. H., eds., Polar deserts and modern man: Tucson, University of Arizona Press, p. 53–61, 7 figs., 19 refs.

Streams and lakes, mainly in the High Arctic, including Greenland, are discussed. Glacially fed rivers in northern Greenland contain about 50 mg/L of dissolved solids. Clear-water lakes with a high salt content are found throughout Greenland and the Canadian Arctic Islands. Salt content when the lakes are ice-free is relatively constant, and specific conductance is 200 to 700 $\mu$mho. These lakes, located near sea level, occur in depressions in terraces of marine silt.

**Day, T. J., and Anderson, J. C.,** 1976, Observations on river ice, Thomsen River, Banks Island District of Franklin: Geological Survey of Canada, Paper 76–1B, p. 187–196, 19 figs., 3 refs.

River ice was observed in order to assess the consequences of jamming, scour, and channel stability. Jamming in the area was minor and localized. Groove marks from grounding ice pans were common but were not important in bed scour. Scour holes from flow around grounded ice were as much as 1.0 m deep. Ice-push features were common. Indirect observations suggested that pools may not freeze to the bottom in winter.

**Day, T. J., and Egginton, P. A.**, 1976, River channel instability studies, District of Mackenzie: Geological Survey of Canada Paper 76–1C, p. 207–217, 12 figs., 2 tables, 6 refs.

Channel migration patterns and rates in three streams tributary to the Mackenzie River were studied by comparison of aerial photographs taken in the 1940's with those taken in 1972. The amount of lateral movement was seen to vary among the streams and longitudinally along each of the streams, but could only be grossly estimated. The maximum amount of erosion was estimated on Little Smith Creek, where as much as 39 m of erosion occurred on the outside bends of meanders over a 26-year interval.

**Day, T. J., and Gale, R. J.**, 1976, Geomorphology of some arctic gullies, Banks Island, District of Franklin: Geological Survey of Canada, Paper 76–1B, p. 173–185, 22 figs., 2 tables, 6 refs.

Gullies range from small features with V-shaped cross sections to larger features over 1 km long with U-shaped cross sections. Those described are developed both in sediment of an old meltwater channel and on an alluvial plain lateral to a stream channel. Frost-crack patterns are a significant control. North-south oriented gullies showed no asymmetry; east-west gullies showed steeper north-facing slopes, at odds with previous results from nearby areas. The cause of the asymmetry noted in this area is ascribed to preferential snow storage, reflecting prevailing winter winds. Dimensions of the gullies reflect both fluvial and periglacial processes.

**Day, T. J., and Lewis, C. P.**, 1977, Reconnaissance studies of Big River, Banks Island, District of Franklin: Geological Survey of Canada Paper 77–1A, p. 75–86, 10 figs., 3 tables, 3 refs.

The Big River system is divided, on the basis of morphology, into subreaches, the slopes of which are compared with statistically identifiable profile segments. The valley of the stream contains at least four discontinuous terrace surfaces and exhibits both a relict braided channel pattern and a subsequent paleochannel of meandering form.

**Dingman, S. L.**,1971, Hydrology of the Glenn Creek watershed, Tanana River basin, Central Alaska: U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory Research Report 297, 110 p., 23 figs., 55 tables., 115 refs.

The Glenn Creek watershed (0.7 $mi^2$) is representative of the lower elevations of the Yukon-Tanana uplands province of central Alaska. Shallow permafrost is present in poorly drained soils beneath 50 percent of the area; permafrost conditions correlate closely with vegetation. Relative insolation, measured in terms of equivalent latitude, was the major factor controlling the presence of permafrost.

The summers during which hydrologic data were collected (1964–67) included the driest, coolest, and second-wettest of the last 30 years. In the near-normal summer of 1964, about 6 in. (15.24 cm) of the normal annual precipitation of 12.3 in. (31.24 cm) was lost as evapotranspiration. Rainfall-runoff for individual storms ranged from 0.03 in. (0.76 mm) to 0.42 in. (10.67 mm), values correlating with antecedent stream discharge—a measure of watershed wetness at the start of the storm. Duration of the storm corresponded to the period of hydrograph rise. Surface runoff from the valley bottom was the dominant source of flow during rises. Recessions could be modeled by a simple exponential decay. Large recession constants are caused by regionally low evapotranspiration rates. Tunnel flow on mineral soil beneath the moss cover and typical ground-water flow provided a delayed source of runoff. Synthetic hydrographs can be constructed.

The results constitute the first detailed hydrologic data from the discontinuous permafrost zone in the North American taiga.

**Dingman, S. L.,** 1973, Effects of permafrost on stream flow characteristics in the discontinuous permafrost zone of central Alaska, *in* Permafrost, second international conference, Yakutsk, U.S.S.R., 1973: National Academy of Science, p. 447–453, 10 figs., 3 tables, 13 refs.

Two principal sources of runoff are apparent from the Glenn Creek watershed, 13 km north of Fairbanks. There is rapid runoff from overland flow that originates in the valley bottom and depends on antecedent conditions. There is often close correspondence between concurrent rainfall intensities and streamflow rates. This source rapidly depletes when rain stops, but flow continues for several days as water that has infiltrated moss on the north slopes of the watershed flows over impermeable mineral soil. Permafrost is a major indirect factor in stream behavior, acting to support a high water table in the valley bottom, so that overland flow dominates, by restricting groundwater flow to the stream channel, and by providing an impermeable surface beneath the moss on the north-facing slopes, allowing water infiltrating the moss to dominate the recession stages.

**Dingman, S. L.,** 1975, Hydrologic effects of frozen ground: literature review and synthesis: U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory Special Report 218, 55 p., 25 figs., 6 tables, 164 refs.

The report is a comprehensive synthesis of many important hydrologic effects of permafrost. Sections on ground water, runoff and streamflow, and erosion are included. The erosion section is restricted to surficial erosion and does not include lateral (bank) erosion or bed scour.

**Drury, W. M.,** 1956, Bog flats and physiographic processes in the upper Kuskokwim River region, Alaska: Contributions from the Gray Herbarium of Harvard University, 130 p., 23 figs., 135 refs.

The treeless bogs of the alluvial lowlands of Alaska are actually undermining the lowland forest by thawing at their banks. The bogs are similar to other "flats" of the far North in Eurasia and North America and are characterized by standing-water areas, an anastomosing pattern in which they surround islands and peninsulas of forest, and a surface pattern of ridges and clumps of trees. The separate processes of thawing and of rebuilding of the peat combine to mold the terrain of the alluvial lowlands. Variations in processes of bog formation, reforestation, and stream activity are shown to explain many features of the bogs. Detailed description of the bogs is both geological and botanical.

**Dunne, T., Price, A. G., and Colbeck, S. C.,** 1976, The generation of runoff from subarctic snowpacks: Water Resources Research, v. 12, p. 677–685, 11 figs., 2 tables, 13 refs.

A model of water movement through snowpacks was used to calculate the hydrographs resulting from daily waves of snowmelt on the tundra and boreal forest of Labrador. Results were compared with measured hydrographs under a variety of slope, cover, and snow conditions. The most critical factors controlling the hydrograph were found to be snow depth and melting rate.

**Dury, G. H.,** 1965, Theoretical implications of underfit streams, U.S. Geological Survey Professional Paper 452–C, 43 p., 39 refs., 15 tables, 106 refs.

Dury's estimates of discharge ratios for underfit streams are revised. Ratios range above 100:1 in some cases. Various explanations of underfit streams are discussed. Neither frozen ground nor temperature change provides a complete explanation. Changes in precipitation were likely changes in total, rather than seasonal, precipitation.

This paper is of interest because of the discussion of possible permafrost effects in causing underfit streams (by promoting high discharges through decreased ground permeability). The magnitude of increased runoff from this cause is not great enough to explain the increases in discharge needed without other factors being involved. Effects of permafrost alone could have increased total runoff in Black Earth Creek (Wisconsin) by no more than three times. In addition, underfit streams occur on the Gulf Coast of the United States where permafrost could not have occurred.

**D'yakonov, K. N.,** 1970, Effect of water reservoirs on the growth of forests on their banks: Soviet Hydrology: Selected Papers, no. 6, p. 570–580, 29 refs. (English edition published by the American Geophysical Union).

Considerable damage is inflicted on forests by lowland reservoirs, especially those in the taiga zone, in addition to the direct loss of flooded forest land. Detrimental effects are caused by rises in ground-water levels in a zone as much as 1200 m from the water's edge and relate to decreased oxygen content in the soil water. Tree species with a taproot system die in the first several years after this underflooding. Other flood-resistent species may be used to protect reservoir banks.Where trees are not killed, growth rate may be severely reduced and vulnerability to insects may be increased.

Near reservoirs in the forest-steppe zone (Novosibirsk, Kuybyshev) underflooding has only a slight adverse effect. The main loss is by erosion of reservoir banks by wind waves. The annual loss of forest land from this cause around the Novosibirsk Reservoir is 100 hectares.

**Eardley, A. J.,** 1938, Yukon channel shifting: Geological Society of America Bulletin, v. 49, p. 343–358, 3 figs., 6 plates, 10 refs.

There is much evidence of channel shifting on the lower Yukon River (between Tanana and Holy Cross). The yearly rate of recession, where the banks are of sand, is estimated at 6 ft (1.8m). Other local rates up to 120 ft (36.5m)/yr were based on historical evidence, and an average of the rates of lateral shifting as indicated in the examples described is 75 ft (22.8m)/yr. The amount of bank erosion by ice appears to be inconsequential.

Ice-jam-flood sedimentation causes bar and point-bar deposits to build to abnormal heights. Jams may raise water levels 40 ft (12.1m) in 3 days, remain for 2 or 3 days, and then subside rapidly. Normal stage variations on the lower Yukon River are not more than 10 ft (3m).

**Egginton, P.**, 1976, Hydraulic, morphologic, and morphometric studies of selected rivers along the route of the Mackenzie Highway: Geological Survey of Canada Paper 76–231, 2 figs., 1 table, 2 refs.

Three Mackenzie River tributaries with apparently unstable beds were surveyed and monitored through the summer of 1975. Hydraulic behavior of the streams was greatly influenced by the Mackenzie River, due to its later breakup and consequent damming of the tributaries with ice at their mouths.

**Emmett, W. W.**, 1972, The hydraulic geometry of some Alaskan streams south of the Yukon River: U.S. Geological Survery Open-File Report, 102 p., 32 figs, 24 photographs, 11 maps, 10 tables, 26 refs.

Bankfull stage, discharge, and other hydraulic characteristics were determined from surveys of channel geometry at 22 locations along the southern part of the trans-Alaska pipeline route. Combined with scattered information from gaging stations, the data describe and differentiate some channel and flow characteristics of each of two hydrologic areas, the Yukon Region and the South-Central Region. Use of average values of hydraulic and geometric properties was found to be a useful predictive procedure in the estimation of channel scour and bedload discharge.

**Ewing, K. J.**, 1972, Supraglacial streams of the Kaskawulsh Glacier, *in* Bushnell, V.C, and Ragle, R. H., eds. Icefield Ranges Research Project scientific results: American Geographic Society and Arctic Institute of North America, v. 3, p. 153–162, 10 figs., 9 refs.

Streams were categorized as (1) annual streams with shallow channels and (2) perennial streams with regularly spaced channels 1 m or more in depth and oriented generally parallel to glacier movement. Time lag in the variations in discharge and temperature increased downstream. Character of the supraglacial streams is related to many dynamic and static factors.

**Fahey, B. D., and Thompson, R. D., eds.**, 1973, Research in polar and alpine geomorphology: Proceedings of Third Guelph Symposium of Geomorphology, 343 p.

The following papers from this symposium volume are annotated: Brown, R. J. E., p. 25–42; Kerfoot, D. E., p. 60–72; McCann, S. B., and Cogley, J. G., p. 118–135; and Rampton, V. N., p. 43–59.

**Fahnestock, R. K.**, 1969, Morphology of the Slims River, *in* Bushnell, V. C.,and Ragle, R. H., eds., Icefield Ranges Research Project scientific results: American Geographic Society and Arctic Institute of North America, v. 1, p. 161–172, 7 figs, 4 tables, 20 refs.

The valley train of the Slims River was divided into three zones characterized by differences in slope, size of bed material, and flow characteristics. In 1965 the stream was regrading the valley train, that is, adjusting its slope to changes in load and discharge, and to the channel form of each zone. Subglacial drainage shifts in the source glacier have initially caused a major decrease in discharge of the Slims River and an increase in loess-forming, aeolian sediment.

**Ferrians, O. J., Kachadoorian, Reuben, and Greene, G. W.**, 1969, Permafrost and related engineering problems in Alaska: U.S. Geological Survey Professional

Paper 678, 37 p., 36 figs., 4 tables, 28 refs.

This paper is a comprehensive survey of permafrost distribution and associated design, construction, and maintenance problems in Alaska. Lack of knowledge about permafrost has resulted in greatly increased maintenance costs for a variety of structures and even in the abandonment of highways and railroads. The effects of surface water on permafrost are discussed, mainly in terms of drainage problems.

**Fuelner, A. J., and Williams, J. R.,** 1967, Development of a ground-water supply at Cape Lisburne, Alaska, by modification of the thermal regime of permafrost: U.S. Geological Survey Professional Paper 575–B, p. B199–B202, 3 figs., 8 refs.

A ground-water supply beneath Selin Creek, a small intermittent stream near the Arctic Coast, was developed by (1) removing tundra vegetation and surface alluvium to increase warming of the aquifer in summer, (2) constructing a reservoir from which warm water recharges the alluvium in summer, and (3) installing infiltration galleries downstream. Snow fences were erected to provide an insulating cover over the gallery.

**Feulner, A. J., Childers, J. M., and Norman, V. W.,** 1971, Water resources of Alaska: U.S. Geological Survey Open-File Report, 60 p., 18 figs., 4 tables, 192 refs.

Existing information on the availability and quality of both surface and ground water in Alaska is summarized. Comprehensive data are available only for parts of the South-Central and Southeast subregions and for the Tanana Basin in the Yukon subregion. Few data are available for areas north of the Arctic Circle.

**Forbes, D. L.,** 1975, Sedimentary processes and sediments, Babbage River delta, Yukon Coast: Geological Survey of Canada Paper 75–1, pt. B, p. 157–160, 1 fig., 7 refs.

The report updates a study of deltaic sedimentation at the joint outlet of the Babbage River and Deep Creek in Philips Bay. Scour holes as much as 7.5 m deep were sounded in delta channels. Probing in August 1974 revealed frozen substrate 0.5 to 2 m beneath the channel bottom. Suspended-sediment concentrations during breakup flooding varied from 50 mg/L on June 2, to less than 5 mg/L on June 6, and to a maximum of 300 mg/L 12 hours after the peak discharge occuring on June 8. The extent to which scour during the spring peak discharge is inhibited by a frozen channel perimeter remains an important unanswered question.

**Forbes, D. L.,** 1976, Sedimentary processes and sediments, Babbage River delta, Yukon coast: a progress report: Geological Survey of Canada Paper 76–1C, p. 165–168, 2 figs., 6 refs.

The objectives of the study, of which this paper is a preliminary report, are to measure sediment contributions from river and coastal sources and to describe Holocene sedimentary deposits, with an emphasis on facies distribution, morphology and depositional processes. An estimate of suspended-sediment discharge is made for the Babbage River (near mouth; drains Yukon Territory to Arctic Ocean) during the 1975 runoff season. Over 90 percent of the sediment discharge occurred during June.

**French H. M.,** 1974, Geomorphological processes and terrain sensitivity, Banks Island, District of Franklin: Geological Survey of Canada Paper 74–1, pt. A, p. 263–266, 4 tables, 3 refs.

Natural and man-induced thermokarst processes were investigated by means of boreholes and measurements of headwall retreat. Slumping related to extensive lenses of ground ice accounted for most of the thermokarst development.

**French, H. M.**, 1975, Pingo investigations and terrain disturbance studies, Banks Island, District of Franklin: Geological Survey of Canada Paper 75–1 pt. A, p. 459–464, 7 figs., 5 refs.

Gullying has developed rapidly since 1972 at the Sachs Harbour townsite in response to terrain disturbance by off-road vehicles. Stages in erosion are as follows: (1) water from melting snowbanks in early spring directly erodes small gullies; (2) ice wedges become exposed and in turn melt, causing rapid expansion of the gully system; and (3) in midsummer the gullies are widened through collapse of the banks, and water is ponded by slumped material.

**French H. M.**, 1976, Geomorphological process and terrain disturbance studies, Banks Island, District of Franklin: Geological Survey of Canada Paper 76–1A, p. 289–292, 4 figs., 1 table, 7 refs.

Previous studies reported by French (1974, 1975) are updated. Solifluctuation measurements in 1975 were concentrated on nonsorted stripes and low-angle slopes. Gullies developed near Sachs Harbour in 1973 and 1974 did not significantly increase in size because of the gradual 1975 breakup and the installation of culverts. Subsidence and gully development at a 1973 disturbed site near Big River emphasized the rapidity of thermokarst processes.

**French, H. M., and Egginton, P.**, 1973, Thermokarst development, Banks Island, western Canadian Arctic: *in* Permafrost, second international conference, Yakutsk, U.S.S.R., 1973: National Academy of Science, p. 203–212, 9 figs., 4 tables, 41 refs.

Thermokarst processes assume a regional importance in some areas of the High Arctic where soils with a considerable ice content are subject to climatic changes or the actions of man. Ground-ice slumping, for example, is one of the most rapid erosional processes now operating in the area.

Ground-ice mudslumps are localized mudflows that have excavated semicircular hollows. Rates of headwall retreat at two sites ranged form 0.08 to 0.14 m per day in July and August 1972. Total headwall retreat is approximately 7 to 10 m each summer, a range corresponding to data from other workers.

Where small north-south stream valleys are asymmetrical, the steep west-facing slopes are the sites of mudflows. The asymmetry is believed due to the indirect role of wind in determining the thickness of the active layer.

Melting of ice-wedge polygons leads to conical mounds known as cemetary mounds or baykjarakhs. Where some of the ice wedge remains, the mounds may be lower and then are called high-centered polygons. Badland topography may result.

**Fulwider, C. W.**, 1973, Thermal regime in an arctic earthfill dam, *in* Permafrost, second international conference, Yakutsk, U.S.S.R., 1973: National Academy of Science, p. 622–628, 7 figs., 1 table, 1 ref.

Temperature measurements in Cresent Lake Dam near Thule, Greenland, verify the design premise that the central part of the embankment would remain frozen and form an impervious core. Two winters were required to establish a stable thermal regime in the original dam, 3.6 m in height, and about the same for an embankment addition of 2.4 m. For an earthfill dam of greater height, construction in stages over several years may be necessary to insure natural freezeback of the core, if necessary before the impoundment of water.

This dam was constructed to provide water for Thule Air Base and essentially enlarged an existing lake. The entire fill was derived from local hillside borrow, and there was no differentiation in soil type. The top 0.3 m of the reservoir face was riprapped for protection against wave action. Thermocouples were installed in drillholes throughout the structure.

**Furbringer, W., and Walker, H. J.,** 1973, Structure and mineralogy of a sediment core from the Colville River delta, Alaska: Polarforschung, no. 2, 50–55, 5 figs., 13 refs.

A 1-m core from a bar off the mouth of the eastern branch of the Colville River in 1.6 m of water consists of layers of fine sand and silt, separated by thin layers of peat, woodchips, and elongated plant fragments. Clay-mineral analysis showed that montmorillonite is the most abundant clay mineral, with lesser amounts of kaolinite and illite and minor amounts of chlorite. Major heavy minerals include olivine, tourmaline, diopside, and hematite.

**Gagoshidze, M. S.,** 1969, Mud flows and floods and their control: Soviet Hydrology: Selected Papers, no. 4, p. 410–422, 10 figs., 2 tables, 11 refs. (English edition published by the American Geophysical Union).

Approximately 20 to 25 percent of the mountain and piedmont regions of the U.S.S.R. are subject to the destructive effects of mudflows. Structures designed to reduce damage include filter dams, elastic cable nets, fluid-addition systems, barriers, and retention dams.

Mudflows are defined as dense mud masses that are cohesive and structured and in which water serves no transporting function. Mud floods are fluid, turbulent, and noncohesive; water is the transporting medium. The latter category includes flash floods.

**Galay, V. J., Kellerhals, R., and Bray, D. I.,** 1973, Diversity of river types in Canada, *in* Fluvial processes and sedimentation: Proceedings of Hydrology Symposium no. 9, University of Alberta, Edmonton, May 1973, p. 272–283, 23 figs., 11 refs.

The report is a well-illustrated outline of a classification of Canadian rivers, in which ice regime is one of five groups of features used in the classification. In northern Canada, where breakup and spring snowmelt coincide, high stage combines with ice scour to produce distinctive features such as vegetation trim lines far above the highest levels reached during open-water conditions. Hanging ice dams below rapids may cause under-ice scour. Streams illustrated from arctic Canada are the Mountain River, Yukon Territory; the Athabasca River above Fort McMurray; and the stream entering Ekalugad Fjord, Baffin Island.

**Gaskin, D. A., and Stanley, L. E.,** 1973, Control of culvert icing, *in* Permafrost, second international conference, Yakutsk, U.S.S.R., 1973: National Academy of Science, p. 629–636, 7 figs., 1 table, 4 refs.

Reduced culvert icing by means of heated cables was investigated. The optimum location for the cable is near the bottom of the culvert, where the largest area can be melted without thawing the surrounding soil. Because icing observations near Fairbanks averaged 23 percent active icing days in a 145-day season, a flexible system utilizing a short-term cycle timer was tested, but with inconclusive results. A system with a long-term (24 hour) cycle timer would have the flexibility to adjust input energy levels to local conditions. An automatic system, using a temperature sensor and related controls to melt and maintain a hole of desired radius, performed well but may be too complicated in its present design for field use. A system consisting of a proportional controller with a thermistor temperature sensor and a simulated heat cable was investigated in the laboratory.

**George, Warren,** 1973, Analysis of the proposed little Chena River earthfill retention dam, Fairbanks, Alaska, *in* Permafrost, second international conference, Yakutsk, U.S.S.R., 1973: National Academy of Science, p. 636–648, 9 figs., 2 tables, 9 refs.

Only a few small dams have been built in the permafrost region of Alaska; consequently, the proposed flood-control structure on the Little Chena River near Fairbanks will have special design problems. It is planned for a height of over 31 m and a length of 1, 736 m between schist buttresses, and will temporarily store $128.5 \times 10^6$ $m^3$ of water. Although the permafrost temperature is marginal, the heat input from temporary and infrequent impoundments is not expected to be a problem. The design will attempt to preserve the integrity of the existing permafrost, probably by leaving surficial humus material in place and emplacing the fill only during the cold fall season, thereby allowing aggradation of the permafrost into the embankment prior to any impoundment. Heat adsorption and conduction to the structure will be minimized by spreading 1 m of coarse, light-colored rock on the surface. Present analysis shows no need for a cooling system, although provision will be made for its installation.

**Gerardi, I. A.,** 1973, Concerning the increase in the water supply of the Volga River and the diversion of part of the runoff of northern rivers to the south: Soviet Hydrology: Selected Papers, no. 6, p. 577–581, 1 fig. (English edition published by the American Geophysical Union).

Rivers on the southern slope of European Russia are subject to high rates of water utilization—rates that will exceed annual runoff in moderately dry years. Runoff from streams draining the arctic slope is considerably in excess of that needed for forecasted uses, including maintenance of a large fishing industry. It is assumed that a minimum of 46 to 50 $km^3$ of water can be diverted from northern rivers to the southern slope. A variety of specific diversion schemes is discussed. An eventual benefit of large-scale diversions may be the improvement of water quality in the Caspian Sea and the Sea of Azov.

**Gilfillian, R. E., Kline, W. L., Osterkamp, T. E., and Benson, C. S.,** 1972, Ice formation in a small Alaskan stream, *in* The role of snow and ice in hydrology, proceedings of Banff Symposia, September 1972: International Association of Scientific Hydrology Publication, v. 1, p. 505–513, 3 figs., 9 refs.

Freezeup in Goldstream Creek, a small subarctic stream near Fairbanks, is complex. Anchor ice and frazil ice particles changed the physical characteristics of the stream. Growth of frazil ice particles caused rejection of impurities to the water phase, thereby raising the conductivity of the water an amount proportional to the discharge of frazil ice. Increased sediment transport was caused by redistribution of anchor ice. Curves of temperature versus time during periods of supercooling were unlike those obtained in closed systems. Experiments on droplet freezing showed that the number of active ice nuclei at the highest nucleation temperature could account for the total production of frazil ice particles.

**Gill, Don,** 1972a, The point bar environment in the Mackenzie River delta: Canadian Journal of Earth Sciences, v. 9, p. 1382–1393, 9 figs., 1 table, 18 refs.

Sorting by fluvial and eolian processes on point bars creates coarse-textured deposits which have a lower water content and a higher soil temperature than deposits on other deltaic surfaces. Consequently, point bars are colonized by discrete plant associations dominated by balsam poplar (*Populus balsamifera*), well-developed stands of which are restricted to point bars.

**Gill, Don,** 1972b, Modification of northern alluvial habitats by river development: Canadian Geographer, v. 17, p. 138–153, 4 figs., 41 refs.

The article assesses the downstream effects of dams and diversions in the Arctic and sub-Arctic. Without the continued initiation of primary plant successions on floodplain and deltaic surfaces newly formed by annual floods, biological activity is greatly reduced. All river development that affects annual flooding should be assessed for this consequent loss of wildlife and recreational benefits.

The natural flow regime of northern rivers is characterized by extremely variable runoff. This variation is amplified in rivers that derive most of their flow from mountainous regions with low natural storage, and reduced in areas with large natural storage in lakes and organic terrain.

**Gill, Don,** 1972c, Modification of levee morphology by erosion in the Mackenzie River delta, Northwest Territories, Canada, *in* Polar geomorphology: Institute of British Geographers Special Publication no. 4, p. 123–138, 13 figs., 19 refs.

Levee morphology in an Arctic delta may be affected by wave action, ice abrasion, slumping and solifluction, and thermal degradation of perennially frozen sediment. These processes affect rates of levee retreat and rates of aggradation and progradation of slip-off slopes and point bars along shifting channels of the Mackenzie River delta.

Channel erosion at one site averaged 10 meters per year between 1952 and 1971. Other workers have measured similar rates, suggesting that thermo-erosional processes in arctic deltas may be relatively uniform through time.

**Giovinetto, M. B.,** 1974, Some aspects of climatology in polar barrens, *in* Smiley, T. L., and Zumberge, J. H., eds., Polar deserts and modern man: Tucson, University of Arizona Press, p.3–22, 17 figs., 8 tables, 64 refs.

The climatology of ice-free barrens in the Arctic and Antarctic is reviewed, focusing in particular on (1) the attenuation of winter air temperatures and (2) the relatively small variability of annual precipitation. The variability of precipitation is small compared to that in arid and semiarid coastal areas at lower latitudes.

**Golubev, G. N.,** 1976, Glaciers and river runoff: Water Resources (translation of Vodnye Resursy), v. 3, p. 894–898, 1 fig., 1 table, 10 refs.

This discussion of glaciers and runoff focuses on aspects of water supply and the role of glaciers in regulating seasonal runoff.

**Golubtsov, V. V.,** 1969, Hydraulic resistance and formula for computing the average flow velocity of mountain rivers: Soviet Hydrology: Selected Papers, no. 5, p. 500–511, 3 figs., 1 table, 26 refs. (English edition published by the American Geophysical Union.)

A modified Chezy equation is developed for mountain rivers (with slopes above 0.001) to account for the extreme roughness and the rapid increase of resistance with velocity.

**Gopchenko, Y. D.,** 1976, Problems of the theory of flash flood formation in the rivers of the permafrost zone: Soviet Hydrology: Selected Papers, v. 15, p. 91–94, 5 refs. (English edition published by the American Geophysical Union).

The paper is a mathematical treatment of runoff from permafrost terrain.

**Haddock, D. R., and Doehring, D. O.,** 1978, Modeling bedload transport in steep mountain streams of the Colorado Front Range (abs.): EOS, American Geophysical Union Transactions, v. 59, p. 1072.

Traditional bedload formulas overpredict sediment transport by orders of magnitude in this high-energy environment with a limited sediment supply (permafrost may have a similar effect in the Arctic). The assumption of unlimited sediment supply that underlies traditional formulas like those of Schoklitsch or Meyer-Peter and Müller may be the main cause of the overpredictions. As an alternative in this example, multiple linear regression equations are developed using independent variables such as discharge and drainage density.

**Harden, D., Barnes, P., and Reimnitz, E.,** 1978, Distribution and character of naleds: Arctic, v. 30, p. 28–40, 4 figs., 16 refs.

Satellite imagery and high- and low-altitute aerial photography of the North Slope of Alaska indicate that naleds (features formed during river icing) are widespread east of the Colville River but less abundant to its west. Where naleds occur, stream channels are wide and often braided. Their distribution can be related to changes in stream gradient and to the occurrence of springs. Large naleds, such as occur on the Kongukut River, often survive the summer melt season to form the nucleus of icing in the succeeding winter. Major naleds also are likely to significantly influence the nature of permafrost in their immediate vicinity. A map of naleds may serve as a guide to sources of perenially flowing water. (Author's abs.)

**Hardy, R. M., and Morrison, H. L.,** 1972, Slope stability and drainage considerations for arctic pipelines: National Research Council of Canada Technical Memo 104, p. 249–265, 10 figs., 5 refs.

Drainage and slope-stability problems will accompany the construction in permafrost of a "chilled" gas pipeline in which the temperature will be controlled at 15°C below freezing. The problems include erosion of right-of-way surfaces, ponding behind the impervious barrier created by the pipeline, potential slumping and sliding, icing, and liquifaction.

**Hare, F. K., and Hay, J. E.,** 1971, Anomalies in the large-scale annual water balance over northern North America: Canadian Geographer, v. 15, p. 79–94, 10 figs., 2 tables, 27 refs.

Published data for mean annual precipitation and runoff are inconsistent and lead to spurious estimates of eddy heat flux and evapotranspiration. Values of precipitation, particularly snowfall, are underestimated in Canada. The primary problem is undermeasurement of snowfall, not only because of the lack of suitable instruments, but because the open sites chosen for stations minimize snow-pitching. Russian studies have shown undermeasurement by as much as 33 percent. One Russian paper estimates that mean annual precipitation over the entire Soviet Union is 30 percent greater than previously supposed.

**Heinke, G. W., and Deans, B.,** 1973, Water supply and waste disposal systems for arctic communities: Arctic, v. 26, p. 149–159, 1 fig., 8 tables, 5 refs.

The discussion compares two existing methods of water supply and waste disposal—trucking and pipelines—for Frobisher Bay on Baffin Island, Northwest Territories. Any of a series of suggested improvements, up to the level of complete piped services, are feasible from an engineering and economic standpoint.

Advantages of trucking include low capital investment, independence from town layout, and a source of income for local residents. A big disadvantage of trucking is that much waste water must often be discharged directly on the ground. Trucking is also unreliable in storms, and lower quantities of water are available compared to a pipeline system. Also, operating costs are high, and the ability of the system in fighting fires is less. A pipeline system does not have the disadvantages of the truck system, but it does have a high capital cost and is strongly dependent on the layout of the community.

**Helldén, Ulf,** 1973, Limestone solution intensity in a karst area in Lapland, northern Sweden: Geografiska Annaler, Series A, Physical Geography, v. 55A, p. 185–196, 10 figs., 5 tables, 24 refs.

The chemical denudation rate—equivalent to 28 mm per 1000 years—is relatively high compared with results from other arctic areas and also with some results from non-arctic areas. Although constituent concentrations are relatively low—$CaCO_3$ concentrations in runoff are generally in the range of 25 to 55 mg/L—precipitation (27 inches (68.58cm) per year for 1965–72) and runoff are relatively high. Most chemical transportation occurs during snowmelt when the amount of water percolation is highest. The landscape is heavily karstified, and a well-developed underground drainage system is present.

**Henoch, W.E. S.,** 1974, Application of dendrochronology to some hydrological aspects of permafrost, *in* Hydrologic aspects of northern pipeline development: Environmental Social Committee Northern Pipelines (Canada), Task Force on Northern Oil Development Report no. 74–12, p. 51–69, 23 refs.

Dendrochronology is used to date geomorphic events that are caused or accelerated by ice in permafrost and to reconstruct past climate and predict future trends. Reconstruction of climatic variations calculated from ground-temperature profiles may be correlated and dated with temperature anomalies determined from tree rings.

**Hill, D. E., and Tedrow, J. C. F.,** 1961, Weathering and soil formation in the artic environment: American Journal of Science, v. 259, p. 84–101, 7 fig., 7 tables, 28 refs.

Examination of Arctic Brown soil profiles in northern Alaska indicated that chemical weathering of a low order is operating. Acid conditions in the surface layer facilitate solution of carbonates, which are redeposited in the profile. Oxidation of iron-bearing minerals; partial mobilization and translocation of iron, aluminum, and maganese; and weathering of feldspar to a claylike substance were also noted.

**Hjulström, Filip,** 1952, The geomorphology of the alluvial outwash plains of Iceland and the mechanics of braided rivers: International Geographic Congress, 17th, Washington, 1952, Eighth General Assembly Proceedings, p. 337–342, 8 refs.

Icelandic sandurs are briefly described, with emphasis on the braiding process.

**Ho, C. L., and Walker, H. J.,** 1976, Contribution of nutrients from sediments and interstitial water to Colville River system, Alaska: Geografiska Annaler, Series A, Physical Geography, v. 58, p.41–54, 8 figs., 6 tables, 31 refs.

The presence and movement of nutrients derived in part from fluvial sediment in the Colville River system are discussed. Sufficient inorganic N (0.875 × $10^6$kg) was transported to the Beaufort Sea in the spring of 1971 to constitute a significant input to the nearshore zone and help account for the abundance of fish.

**Holmes, G. W., and Lewis, C. R.,** 1965, Quaternary geology of the Mount Chamberlin area, Brooks Range, Alaska: U.S. Geological Survey Bulletin 1201–B, 32 p., 14 figs., 4 tables, 25 refs.

Glacial features and stratigraphy in the Franklin Mountains of the northeastern Brooks Range are described. Frost action and gravity processes have modified the glacial deposits proportional to their age. Four major Pleistocene glaciations and two minor (Holocene) fluctuations are represented.

The most obvious type of mass movement in the area is the earthflow, a sudden movement of saturated till or colluvium leaving a scar typically 5 to 10 ft (1.5 to 3m) deep, 50 to 100 ft (15.2 to 30.4m) wide, and several hundred feet long. The lower end is a lobe of blocks of soil, turf, and peat in a matrix of till or alluvium. Most flows extend to a lake or stream, where the material is subsequently transported by running water. High earthflow activity is presumably now related to a warming trend in the Arctic, and in the past may have been related to the warmer phases of the Quaternary.

**Holmes, G. W., Hopkins, D. M., and Foster, H. L.,** 1968, Pingos in central Alaska: U.S. Geological Survey Bulletin 1241–H, 40 p., 17 figs., 1 table, 35 refs.

Pingos in the Alaskan sub-Arctic are described. Nearly 300 pingos or pingolike mounds were located in central Alaska in the forested zone of discontinuous permafrost. They range in size from 50 to 1,450 ft (15.2 to 441.9 m) in diameter and 10 to 100 ft (3 to 30.4 m) in height and occur mainly near the bases of south- and southeast-facing slopes at the transition between the valley fill and slope deposits. Most are formed where subpermafrost or intrapermafrost water is likely to attain maximum hydrostatic head. Internal structure consists of ice masses crosscut by large ice wedges, the partial melting of which may explain the surface trench network.

**Hopkins, D.M.,** 1949, Thaw lakes and thaw sinks in the Imuruk Lake area, Seward Peninsula, Alaska: Journal of Geology, v. 57, p. 119–131, 6 figs., 2 plates, 4 refs.

The lakes and depressions are ascribed to subsidence caused by the thawing of permafrost. Soils of the region are ice-rich. The present large thickness of frozen ground is believed to be unstable under existing climatic conditions.

**Howard, C. D. D.,** 1974, Mackenzie gas pipeline, Alaska to Alberta, effects on the aquatic physical environment, *in* Environmental impact assessment of the portion of the Mackenzie Gas Pipeline from Alaska to Alberta: Environmental Protection

Board(Canada) Research Reports, v. 4, p. 177–202, 8 figs., 19 refs.

Flood frequencies and suspended-sediment concentrations were estimated for conditions before and after pipeline construction. Streams were classified on the basis of hydrologic behavior. The greatest potential increases in sediment concentration are in small, steep watersheds with much disturbance. The greatest potential for interference with natural stream processes is on the Yukon coast where gravel mining is planned. Use of the Universal Soil Loss Equation was the basis for conclusions on sedimentation.

**Howarth, P. J., and Bones, J. G.**, 1972, Relationships between process and geometrical form on High Arctic debris slopes, south-west Devon Island, Canada, *in* Polar Geomorphology: Institute of British Geographers Special Publication no. 4, p. 139–153, 4 figs., 2 tables, 16 refs.

Measurements of debris-slope profiles affected by different processes were made at several locations. Although there were significant differences in angle between slopes affected by different processes, there was little difference noted in geometric form between High Arctic and midlatitude slopes formed by similar processes. The debris-slope angles were similar to those previously measured on Spitsbergen.

**Hubbell, D. W. and Al-Shaikh Ali, K.**, 1961, Quantitative effects of temperature on flow phenomena in alluvial channels: U.S. Geological Survey Professional Paper 424–D, p. 21–23, 2 figs., 7 refs.

Under paired conditions equivalent except for water temperature, the concentration of total bed-material discharge could be either greater or less at low temperatures relative to high temperatures, depending on bedform. With ripples superimposed on ripples or dunes, concentration was greatest at high temperatures; no trend was apparent with dunes or a plane bed; and when antidunes were present, concentrations were greatest at low temperatures. Median diameter of the bed material in the experiments was 0.31 mm.

**Hudec, P. P.**, 1973, Weathering of rocks in arctic and sub-arctic environment, *in* Aitken, J. D. and Glass, D. J., eds, Symposium on the geology of the Canadian Arctic, Saskatoon, Canada, 1973: Proceedings, p. 313–335, 1 fig., 7 tables, 21 refs.

The following phenomena were observed during studies of the importance of frost action in weathering: (1) Water contained in most of the "frost"-sensitive argillaceous carbonate rocks did not freeze, even under extreme arctic temperatures; (2) most of this water is in an adsorbed state; (3) most rocks of this type tended to saturate under high humidity conditions alone; (4) the adsorbed water in these rocks is in a rigid state, as shown by increase in shear-wave velocity; (5) upon saturation in air, or in water, these rocks expand, and exert pressure if confined; and (6) "frost"-type weathering of rocks that tend to saturate with adsorbed water can be observed in climates where freezing is rare. Consequently, frost action is believed to be insignificant in the weathering of fine-grained sedimentary rocks. Such rocks weather by the expansive action of the rigid, adsorbed, non-freezable water, which induces tensional fatigue due to expansion and contraction on sorption and desorption. This action is enhanced by large temperature fluctuations. True frost action is active only in coarser-grained rocks that saturate by absorption.

**Hughes, O. L.**, 1974, Geology and permafrost in relation to hydrology and geophysics, *in* Permafrost hydrology, proceedings of workshop seminar, 1974: Ottawa, Canadian National Committee, International Hydrological Decade, p. 21–28, 2 figs., 11 refs.

The types, occurrences, and modes of formation of ground ice are surveyed. The following types are described, with examples from the Mackenzie River valley: segregated ice in till plains, glaciolacustrine plains, and moraines; ground ice in organic terrain; intrusive ice and the formation of pingos; aggradational ice, formed at the base of the active layer when the permafrost table is rising; and single-vein ice and ice wedges.

A potential for practical manipulation of permafrost exists. Year-round groundwater supplies for some communities are possible by thawing a "conduit" of permeable gravel connecting the available sources, located in the unfrozen alluvium of taliks or adjacent to river channels, with the community. Otherwise, pumping and intake facilities would have to be placed at the river bank, where damage from flooding and lateral erosion is a near certainty. The thawing technology could be readily adapted from procedures developed by the placer-mining industry.

**Hussey, K. M.,** 1962, Ground patterns as keys to photointerpretation of arctic terrain: Iowa Academy of Science Proceedings, v. 69, p. 332–341, 5 figs., 9 refs.

The angle of slope is the most important factor in determining the type of ground pattern. Other factors include soil texture, vegetation type, water availability, and thickness of the active layer. Equidimensional ground features such as circular frost scars, hummocks, ice-wedge polygons, and sorted stone nets develop on slopes of less than 2°. On slopes of 4°, the same patterns become elongated, and on slopes of 6°, they become alined and continuous, with stripes and the development of steps. Steps become pronounced on steeper slopes, and solifluction lobes characterize slopes over 8°. Consequently, it is possible to determine terrain conditions from photointerpretation of these features.

**Jahn, Alfred,** 1960, Some remarks on evolution of slopes on Spitsbergen: Zeitschrift für Geomorphologie, Supp. Band 1, p. 49–58, 7 figs., 13 refs.

Periglacial slopes are classified on Spitsbergen into the following divisions, with decreasing slope angle: (1) a zone of weathering rock walls (inclination above 40°) and rock slopes, covered by thin talus (25° to 40°); (2) a zone of dry talus cones and scree slopes (30° to 40°), and of humid slopes (from avalanches) with a 15° to 25° inclination; (3) a zone of solifluction terraces, from 3° to 25°; and (4) a zone of fluvial sedimentation, from 2° to 5°. The zones represent the four processes of weathering, gravity, solifluction, and slope wash. Measurements of slope wash resulting from snowmelt indicated active erosion and showed that the activity of rain and meltwater was an important process.

**Jansen, J. M. L., and Painter, R. B.,** 1974, Predicting sediment yield from climate and topography: Journal of Hydrology, v. 21, p. 371–380, 2 figs., 4 tables, 15 refs.

Linear regression models relating annual sediment yield with climatic and topographic variables are developed for rivers (drainage area greater than 5,000 km$^2$) in each of the world's major climatic zones. The global rate was calculated as $26.7 \times 10^9$ metric tons/yr. Polar climates were excluded, because they represent only 15 percent of the total land surface and include Antarctica, which is virtually erosion free. This exclusion, however, causes the global rate to be underestimated.

Two arctic rivers were included in the study: the Ob (7 metric tons /km$^2$) and Yenisei

(5 metric tons/km$^2$). Each drainage area is about 2,500,000 km$^2$.

**Jasper, J. N.,** 1974, Hydrologic studies at "Twisty Creek" in the Mackenzie Mountains, N.W.T., *in* Hydrologic aspects of northern pipeline development: Environmental-Social Committee Northern Pipelines (Canada), Task Force on Northern Oil Development Report no. 74–12, p. 259–281, 7 figs., 2 tables, 6 refs.

The percentage of runoff to precipitation for this small subarctic upland tributary to the Arctic Red River averaged 91 percent in 1973. About 80 percent of the total sediment yield occurred during peak flood events (less than 1 percent of the time). A heavy rainstorm in July yielded a peak flow of 16.99 m$^3$/s (2.45 m$^3$/s/km$^2$).

Bedload was only slightly less than suspended load in 1972—0.51 million kg versus 0.56 million kg. Bedload was greater than suspended load in 1973—4.87 million kg versus 4.57 million kg.

**Johnson, P. G.,** 1978, Rock glacier types and their drainage systems, Grizzly Creek, Yukon Territory: Canadian Journal of Earth Sciences, v. 15, p. 1496–1507, 10 figs., 10 refs.

Rock glaciers from three sources are described. (1) Those derived from moraines show evidence of periodic recent movement. Meltwater drainage through the features is slow, allowing deposition of the suspended sediment load; some flow may add to the ice core. (2) Talus-derived rock glaciers are morphologically more complex, but fewer flow episodes are evidenced. Drainage is slow and indicates movement of meltwater over an impermeable surface within the form. (3) Avalanche-derived rock glaciers are morphologically simple; extension from the toe of talus slopes is due to flow caused by ice incorporated during the avalanching.

**Johnston, G. H., and Brown, R. J. E.,** 1965, Stratigraphy of the Mackenzie River delta, Northwest Territories, Canada: Geological Society of America Bulletin, v. 76, p. 103–112, 7 figs., 1 table, 10 refs.

Drilling beneath a small lake near Inuvik penetrated 230 ft (70.1 m) of unfrozen sedimentary deposits above bedrock. The section, consisting of 180 ft (54.8 m) of deltaic silt and fine sand overlying 50 ft (15.2 m) of till and glaciomarine or estuarine deposits, was frozen throughout three holes drilled adjacent to the lake.

**Kachurin, S. P.,** 1962, Thermokarst within the territory of the U.S.S.R.: Biuletyn Peryglacjalny, v. 11, p.49–55, 1 fig., 1 plate, 19 refs.

The factors that control the development of thermokarst are discussed from a general standpoint.

**Kalyuzhnyy, I. L., Pavlova, K. K., and Teregulov, E. K.,** 1974, Laboratory instruments and apparatus for investigating the thermophysical interaction of water with a frozen peat deposit: Soviet Hydrology: Selected Papers, no. 5, p. 315–322, 5 figs., 8 refs. (English edition published by the American Geophysical Union).

Instruments are developed for measuring the unfrozen water content of frozen peat, the infiltration rate of water into frozen peat, and the rate of water migration toward a freezing front.

**Kamalov, B. A.,** 1969, Computation of flow in glacier-fed rivers: Soviet Hydrology:

Selected Papers, no. 4, p. 388–398, 3 figs., 2 tables, 15 refs. (English edition published by the American Geophysical Union).

Data from 51 glacier-fed rivers are analyzed to determine what watershed characteristics best correlate with discharge.

**Kane, D. L., Carlson, R. F., and Bowers, C. E.**, 1973, Groundwater pore pressures adjacent to subarctic streams, *in* Permafrost, second international conference, Yakutsk, U.S.S.R., 1973: National Academy of Science, p. 453–458, 5 figs., 8 refs.

During winter months when ice conditions exist and closed conduit flow occurs, fluctuating pressures develop in the system. The top surface of the water in the stream is usually in contact with a rigid lower ice surface that continually progresses downward. Pressure may cause aufeis formation that can fill the channel and extend on to the flood plain. In soil, the seasonal frost forms an impermeable barrier when the freezing front coincides with the unfrozen water, thereby confining the ground water. Large pressures caused by an aufeis confining layer gradually decrease away from the stream, and on balance act to increase bank storage during the winter season.

**Kane, D. L., and Slaughter, C. W.**, 1972, Seasonal regime and hydrological significance of stream icings in central Alaska, *in* The role of snow and ice in hydrology: Proceedings of Banff Symposia, September 1972, International Association of Scientific Hydrology Publication, v. 1, p. 528–540, 6 figs., 1 table, 16 refs.

Field data on the rates of icing growth and associated climatic factors were collected from small upland watersheds near Fairbanks. Icings contributed 4 percent of yearly runoff, mainly over a 4-week period after melting of the snowpack. Icing volume was equivalent to 40 percent of winter streamflow.

**Kane, D. L., and Slaughter, C. W.**, 1973, Recharge of a central Alaska lake by subpermafrost groundwater, *in* Permafrost, second international conference, Yakutsk, U.S.S.R., 1973: National Academy of Science, p. 458–462, 3 figs., 11 refs.

Piezometer and temperature data demonstrate that recharge of Isabella Creek bog lake, 0.02 $km^2$ in area and located 3 km north of Fairbanks, has occurred through the thawed zone under the lake. The lake is surrounded by permafrost. It is likely that many similar lakes in the zone of discontinuous permafrost have a hydrologic connection with subpermafrost aquifers. Thus, the thousands of lakes in the lowlands of central Alaska indicate a network of thawed zones and a presumably complex ground-water system.

In the vicinity of the lake, permafrost is present to a depth of 40–70 m, with an active layer as shallow as 0.2 m. Four piezometers at various depths indicated a difference in fluid potential with depth, verifying flow in a thawed transmission zone beneath the lake. Temperature gradients also indicated the presence of a thawed zone.

**Keevil, B. E., and Ramseier, R. O.**, 1974, Progress report on a study of oil pollution in ice-covered rivers, *in* Hydrologic aspects of northern pipeline development: Environmental-Social Committee Northern Pipelines (Canada), Task Force on Northern Oil Development Report no. 74–12, p. 283–296, 6 figs., 14 refs.

The behavior of oil under ice was examined by means of cold-room experiments and field observations of accidental oil spills. Oil released under ice separates into small globs 0.1 to 2.0 cm in diameter which coalesce at the ice-water interface and form a layer about 1.0 cm thick under smooth freshwater ice. In still water the oil layer becomes sandwiched into growing ice. Many accidental spills disappear quickly from sight and are not reported.

**Kennedy, B., and Melton, M. A.,** 1972, Valley asymmetry and slope forms of a permafrost area in the Northwest Territories, Canada, *in* Polar Geomorphology: Institute of British Geographers Special Publication no. 4, p. 107–121, 6 figs., 4 tables, 24 refs.

Asymmetry in maximum slope angle is found to reverse between (a) areas of more severe climate and low available relief, where north-facing slopes are significantly steeper, and (b) areas of milder climate and deeper valleys, where south-facing slopes are steeper. Slopes controlled by fluvial erosion show less response to differences in basal corrasion than to variations in aspect—results which differ from those of non-permafrost areas.

The presence of permafrost does not simplify the study of slope development. It adds to the complexity and variety of present-day processes. There is also no one form of asymmetry characteristic of permafrost areas, in spite of suggestions in the literature.

**Kerfoot, D. E.,** 1973, Thermokarst features produced by man-made disturbances to the tundra terrain, *in* Fahey, B. D. and Thompson, R. D., eds., Research in polar and alpine geomorphology: Proceedings of Third Guelph Symposium on Geomorphology, 1973, p. 60–72, 6 figs., 1 table, 11 refs.

Thermal erosion from flowing water is distinguished from thermokarst phenomena in this assessment of results from disturbance of tundra terrain by seismic lines and a winter road. On steep slopes severe gully erosion may be initiated. Generally, however, thermokarst subsidence is the most common result.

**King, C. A. M., and Buckley, J. T.,** 1968, The analysis of stone size and shape in arctic environments: Journal of Sedimentrary Petrology, v. 38, p. 200–214, 6 figs., 6 tables, 14 refs.

Lengths and shape of stones allowed recognition of various depositional environments in the recently deglaciated and isostatically uplifted tundra area of west-central Baffin Island. Mean grain size alone permitted differentiation of deltas, eskers, and ice-contact deposits. Roundness was found to differ significantly in the deposits of kames, eskers, and moraines.

**Konditerova, E. A., and Ivanov, L. V.,** 1969, Pattern of variation of the length of freely meandering rivers: Soviet Hydrology: Selected Papers, no. 4, p. 356–364, 5 figs. (English edition published by the American Geophysical Union).

Patterns of change in length of a 380 km meandering section of the Irtysh River (between Pavlodar City and Urlyutyb Village) show that, although segments of the river have varied in length by as much as 33 percent, the total length has remained relatively unchanged since 1904, indicating that the study section is in dynamic equilibrium. There is often a "key" meander, the deformation of which appears to control the deformation of other meanders.

**Krigström, Arne,** 1962, Geomorphological studies of sandur plains and their braided rivers in Iceland: Geografiska Annaler, Series A, Physical Geography, p. 328–346, 13 figs., 1 table, 21 refs.

The article is a comprehensive description of sandur morphology and processes based on Icelandic examples.

**Kuzin, P. L., and Reynin, P. V.,** 1972, Types of lake basins in West Siberia: Soviet Hydrology: Selected Papers, no. 6, p. 551–558, 4 figs., 2 tables, 11 refs. (English edition published by the American Geophysical Union).

Thermokarst lake basins account for as much as 70 to 90 percent of all the lake basins in the permafrost zone of West Siberia. They are shallow, and their bottoms are flat, frequently with small mounds produced by heaving at the center. Some contain funnels formed by melting of pure ice lenses and veins. Other deeper lakes as much as 30–60 m in depth may also be of thermokarst origin. Other types of lakes and lake-forming processes are discussed, and a classification of the lakes of West Siberia is presented.

**Lane, E. W., Carlson, E. J., and Hanson, O. S.,** 1949, Low temperature increases sediment transportation in Colorado River: Civil Engineering, v. 19, no. 9, p. 45–46, 4 figs.

A much larger sediment load is carried in the winter than during the summer (by as much as 2.5×) by approximately equal discharges in the Colorado River at Taylor's Ferry. Approximately 70 percent of the sediment load is composed of fine and very fine sand.

The effect of temperature varied with sediment size. For the range of 0.044 to 0.295 mm, the effect was very large. For that from 0.295 to 0.589 mm, the change in amount transported at different temperatures was negligible. The effects occurred predominantly in sizes under 0.3 mm.

**Leffingwell, E. deK.,** 1919, The Canning River region, northern Alaska: U.S. Geological Survey Professional Paper 109, 251 p., 33 figs., 35 plates, unnumbered tables, 78 refs.

The geography and geology of the region are surveyed. The study is not outdated in its treatment of subjects such as ground-ice occurrence and the formation of ice wedges. Included are sections on topographic-surveying techniques, a history of exploration in the area, general geology, and permafrost. The effects of permafrost on stream behavior are discussed briefly (p. 172).

**Levashov, A.A.,** 1966, Approximate determination of high flood frequency in rivers without hydrological observations: Soviet Hydrology: Selected Papers, p. 547–548, 1 fig. (English edition published by the American Geophysical Union).

Flood frequency is determined for ungaged streams in the Kola Peninsula by the ages of tree rings showing ice damage in pines from 200 to 300 years old. Darker tree rings were formed at the time of ice damage by flow of resin to the damaged area. It was found that significant overbank flooding occurred about every 25–30 years on one stream.

**Lewellen, R. I.,** 1972, Studies on the fluvial environment, Arctic Coastal Plain Province, northern Alaska: Published by the author, Littleton, Colorado, 2 v. (maps in v. 2), 282 p., 208 figs., 90 tables, 246 refs.

Drainage basins ranging in size from small polygon troughs to the Inaru River basin are described from the vicinity of Point Barrow. Hydrographs for two tundra streams are presented. Topics discussed include fluvial processes, soil processes, and Pleistocene and Holocene history. Effusively illustrated.

**Lewis, C. P., and McDonald, B.C.,** 1973, Rivers of the Yukon north slope, *in* Fluvial processes and sedimentation: Proceedings of Hydrology Symposium no. 9, University of Alberta, Edmonton, May 1973, p. 251–271, 9 figs., 4 tables, 23 refs.

Channel patterns of the streams range from well-developed meandering to braided. Estimation of dominant (channel-forming) discharges was complicated by inapplicability of standard resistance equations to gravel-bed rivers. Assessment of scour was complicated by clast imbrication, ice jams, spring flow over ice, and by permafrost. Air photographs indicate few areas of rapid channel migration over the last 16–20 years.

**Lewis, C. R.,**1962, Icing mound on Sadlerochit River, Alaska: Arctic, v. 15, p. 145–150, 5 figs., 7 refs.

Icing mounds result from upward arching of soil and ice associated with fields of aufeis. The mound described consisted of a sinuous ridge of soil-covered ground ice about 4 ft. (1.2 m) thick.

**Lifshits, F. A., Piguzova, V. M., and Ustinova, Z. G.,** 1966, Estimate of naled regulation of ground-water flow in the Chul'man River basin (southern Yakutiya): Soviet Hydrology: Selected papers, p. 135–141, 5 figs., 2 tables, 4 refs. (English edition published by the American Geophysical Union).

The relative contributions of icings and the total contribution of ground-water discharge to streamflow are calculated in a river basin in the zone of discontinuous permafrost. The basic theme of the study is the redistribution of the ground-water contribution from winter to summer through the mechanism of icings.

Most streams in the region have continuous winter flow. The spring breakup flood is brief—the average river stage is restored within several days and remains at that level until rains in June and July, at which time the contribution of icings to streamflow becomes important.

**Linell, K. A.,** 1973, Risk of uncontrolled flow from wells through permafrost, *in* Permafrost, second international conference, Yakutsk, U.S.S.R., 1973: National Academy of Science, p. 462–468, 6 figs., 2 tables, 4 refs.

Prevention of piping, erosion, and blowout under artesian pressure conditions requires proper installation of well casing. Consequences of uncontrolled flow could include a constantly enlarging thaw and erosion pit at the well, permafrost degradation in the area exposed to both subsurfaces and surface discharge, ice fog and ground icing in winter, development of frost mounds, and waste of water. If the permafrost is thaw-stable, without excess ice, the casing should be tightly installed through the permafrost zone. If the permafrost has a high ice content, or is thaw-unstable soil or rock, the casing must be tightly installed, and the maintenance of a frozen seal between the casing and the permafrost may be necessary.

A well in which flow could not be controlled was finally shut in by refreezing the entire thawed area by installing freeze probes and circulating refrigerant brines.

**Lisitsyna, K. N., and Aleksandrova, V. I.,** 1972, Sediment load of rivers in the

European USSR: Soviet Hydrology: Selected Papers, no. 2, p. 69–100, 4 figs., 7 tables, 23 refs. (English edition published by the American Geophysical Union).

The paper generalizes the spatial distribution of sediment-load characteristics for the European U.S.S.R. (without the Caucasus). Zones, or erosion regions, are delineated according to similarity of conditions and comparability of erosion rates. Sediment records, obtained from 585 stations (367 active) in the region, were extended in time and space using regressions of sediment-production rates with runoff, slope, weighted average of drainage-basin elevation, density of the river system, and the basin area covered by lakes and bogs.

Average annual sediment concentration in four "large" rivers in the White and Barents Sea basin ranged from 4 to 59 g/m$^3$, values generally lower than in any other zone. Sediment-production rates from the same four rivers ranged from 3 to 25 metric tons/km$^2$/yr, values comparable with many other rivers in other zones. The area above lat 60° N. had a particle-size composition of suspended sediment in which greater than 75 percent of fractions were less than 0.05 mm. Most other areas yielded coarser suspended sediment.

**Lissey, A.,** 1975, Groundwater flow in the permafrost active layer, Inuvik, N.W.T.: Geological Survey of Canada Paper 75–1, pt. B, p. 185–186, 1 fig., 2 refs.

Study of ground-water movement with piezometers in the active layer yielded hydraulic conductivities for peat and till soils. The annual pattern of rate and direction of ground-water movement is described.

**Livingstone, D. A.,** 1954, On the orientation of lake basins: American Journal of Science, v. 252, p. 547–554, 3 figs., 6 refs.

Oriented lakes of northern Alaska are shown to be the product of circulation produced by winds normal to their long axes.

**Lotspeich, F. B., and Helmers, A. E.,** 1974, Environmental guidelines for development roads in the subarctic: U.S. Environmental Protection Agency Report, EPA–660/3–74–009, 63 p., 42 figs., 20 refs.

Federal and State regulations are synthesized into a set of guidelines to protect the environment in construction of smaller, development-type roads. Illustrations of both good and poor engineering practice are given from the Fairbanks area.

Proper drainage is one of the most important factors. If drainage ditches must be used, runoff should be intercepted at frequent intervals to avoid build-up of erosive power. Runoff should be carried across the road to stable slopes. Designs such as open-type culverts, rolled grades, cross drains, or shallow ditches usually are suitable drainage structures and may reduce erosion as well.

Guidelines for constructing ice bridges are also included. Ice bridges across the Yukon are used as examples. On the Yukon River, a total ice thickness of 5 ft (1.5 m) was achieved by pumping water to the surface and cementing timbers laid sideways.

**Lundqvist, Jan,** 1969, Earth and ice mounds, *in* Péwé, T. L., ed., The periglacial environment: Montreal, McGill-Queen's University Press, p. 203–215, 1 fig., 18 refs.

Four principal types of mounds related to freezing and (or) thawing are distinguished: (1) pingos, (2) palsas, (3) earth hummocks, and (4) ice-cored bog hummocks.

**Lyubomirova, K. S.,** 1975, Floods in the USSR: Water Resources (translation of Vodnye Resursy), v. 2, p. 232–242, 17 refs.

In this summary of flood types and occurrences in the U.S.S.R. is a section on flooding caused by ice jams. Factors that control the formation and thickness of ice jams and the severity of the resulting flooding are described.

**McCann, S. B., and Cogley, J. G.,** 1972, Hydrologic observations on a small arctic catchment, Devon Island: Canadian Journal of Earth Sciences, v. 9, p. 361–365, 3 figs., 14 refs.

The paper is a summary of 1970 hydrologic data for "Jason's Creek," a sparsely vegetated, 2.3 $km^2$ watershed at lat 74° 40′ N. Snowmelt flooding for a 10–15 day period in June or early July was preceded by a few days of relatively low flow. Discharge then decreased in a roughly asymptotic fashion until freezeup in late August or early September. A diurnal lag time of 5 hours (2.2 $hr/km^2$) in the response of flow to energy inputs to the basin snowpack was noted. Response to summer rainstorms was rapid; duration of storm runoff was short.

Thickness of the active layer in the watershed is 0.5–0.6 m. Bedrock is till-mantled or frost-shattered limestone with intense solifluction.

**McCann, S. B., and Cogley, J. G.,** 1973, The geomorphic significance of fluvial activity at high latitudes, *in* Fahey, B. D., and Thompson, R. D., eds., Research in polar and alpine geomorphology: Proceedings of Third Guelph Symposium on Geomorphology, p. 118–135, 8 figs., 1 table, 23 refs.

The role of fluvial activity, both by rivers and by rillwash and sheetflow on slopes, has been underestimated in landscape development at high latitudes. Examples are cited from the Canadian High Arctic, and include Mecham River on Cornwallis Island and Jason's Creek on Devon Island. These landscapes appear "fluvial" when viewed from the air, as opposed to obviously periglacial landforms.

A good discussion of limestone solution appears on p. 126–128. Dissolved load was found to be 50–100 percent greater than suspended load, in contrast to the conclusions of Church (1972, p. 138), who stated that the distinctive property of arctic fluvial activity is the minor role of solution.

Fluvial activity is more important than just as a "cathartic." Many deeply entrenched, nonglacial valleys were observed, but their age is in doubt. Rill action and sheetwash are important, and may be more significant in terms of transport of material downslope than mass movement processes under present environmental conditions.

**McCann, S. B., Howarth, P. J., and Cogley, J. G.,** 1972, Fluvial processes in a periglacial environment, Queen Elizabeth Islands, N.W.T., Canada: Institute of British Geographers Transactions, no. 55, p. 69–82, 5 figs., 2 tables, 14 refs.

Discharge, suspended-sediment load, and dissolved-solute load were measured from the River Mecham on Cornwallis Island and a small stream, Jason's Creek, on Devon Island. The streams showed a diurnal response to snowmelt resembling the general response of the basin to a large input of water—a steep rising limb on the hydrograph and a more gently sloping recession limb. In the River Mecham sediment concentrations were as high as 570 mg/L during the spring flood, in which 90 percent of the annual runoff is concentrated in a 10 to 15 day period in early June. Some initial flow was over ice. Solute concentrations gradually increased from 30 to 50 mg/L to 70 to 100 mg/L for both streams, lower values than typical of streams draining limestone terrain in lower latitudes. The conclusion of Bögli (1960) that, although the solubility of carbon dioxide increases as temperature decreases, the rate of carbonate solution decreases, with a net effect of less solution, is supported.

The authors conclude that fluvial processes are more important as geomorphological agents in the periglacial environment than the scope and content of the literature suggests.

**McCloy, J. M.,** 1970, Hydrometeorological relationships and their effects on the levees of a small arctic delta: Geografiska Annaler, Series A, Physical Geography, v. 52, p. 223–241, 18 figs., 1 table, 23 refs.

The constructional and destructional processes affecting the levees of the Blow River delta, Yukon Territory, are discussed. In the constructional phase, levees in the upper deltaic plain may be raised by eolian deposition; those in the lower deltaic plain are augmented by log accumulations, which may cause discordant heights of paired surfaces. Destruction of levees in the upper deltaic plain was characterized by the collapse of thermo-erosional caverns. Erosion of levees on the lower deltaic plain was controlled by vegetation.

Visual observations indicated that peak suspended sediment concentration followed a flood peak, in contrast with the Colville River, where peak concentrations precede maximum flood stages. A peak concentration of 3,400 mg/L was measured. After thawing of banks by flow from a summer rainstorm, extensive bank slumping introduced much sediment into channels. Also, prior to the storm, the active layer in the channel banks had thickened and provided material that was readily eroded.

**McDonald, B. C., and Lewis, C. P.,** 1973, Geomorphical and sedimentologic processes of rivers and coast, Yukon coastal plain: Environmental-Social Committee Northern Pipelines (Canada), Task Force on Northern Oil Development Report no. 73–39, 66 figs., 8 tables, 46 refs.

The report is a comprehensive reconnaissance study of river and coastal environments of the Yukon coastal plain between the Mackenzie delta and Alaska. The main scientific conclusions of the study were:

1. Channel patterns range from fully meandering to braided.
2. The rivers appear to be slowly downcutting in response to uplift or decreased sediment supply.
3. Estimates of dominant (channel forming) discharges indicate that existing hydraulic formulas do not adequately describe the behavior of gravel rivers. They suggest, as well, that purely hydrologic methods of estimating flood discharges are unreliable, largely because of the absence of relative input data.
4. Flows causing appreciable bed scour, i.e. flows exceeding dominant discharge, can occur at any time during the open-water season.
5. Suspended-sediment concentrations vary greatly during open-water periods, and are directly correlated with discharge. Concentrations approaching 5,000 mg/L have been measured.
6. Assessment of bed scour is complicated by the influences of bed imbrication, ice jams, spring flow over ice, and frozen ground.
7. Lateral erosion my be locally severe, especially where fine-grained sediment is exposed to thermal niching and block slumping. At one such location the bank of the Babbage River retreated 2 m in 1 year. Ground-ice slumps in valley walls expand rapidly (more than 10 m in 1 year) and supply considerable sediment to the adjacent river, but are not common in the Yukon.
8. Permafrost has a variety of effects on both river hydrology and channel stability.

These include increasing the proportion of surface to total runoff, retarding bank erosion over short time spans, and adding to the relative importance of block slumping in channel migration.

**Macdougall, J. D., and Harriss, R. C.,** 1969, The geochemistry of an arctic watershed: Canadian Journal of Earth Sciences, v. 6, p. 305–315, 2 figs., 8 tables, 30 refs.

The clay mineralogy of soil and sediment samples from a small area of the Canadian Arctic Archipelago reflects a largely physical weathering regime. The geochemistry of sediment in terrestrial versus marine environments is discussed.

**McDowall, I. C.,** 1960, Particle size reduction of clay minerals by freezing and thawing: New Zealand Journal of Geology and Geophysics, v. 3, p. 337–343, 2 figs., 3 tables, 7 refs.

Congelifraction may be a major mechanism in the production of fine sediment in cold climates. Amount of size reduction depends on structure of the particular clay mineral. If bonding between basal planes of component sheets is strong, little size reduction by congelifraction occurs. If bonding is weak, freezing of water penetrating the basal planes causes rapid comminution.

**Mackay, J. R.,** 1961, Freeze-up and break-up of the lower Mackenzie River, Northwest Territories, *in* Raasch, G. O., ed., Geology of the Arctic, v. 2. p. 1119–1134, 3 figs., 7 tables, 25 refs.

Data on freezeup and breakup from as early as 1876 were analyzed to determine long-term trends in duration of the open season and the relation between early and late freezeups and breakups.

**Mackay, J. R.,** 1975, The stability of permafrost and recent climatic change in the Mackenzie Valley, N.W.T.: Geological Survey of Canada Paper 75–1, pt. B, p. 173–176, 2 figs., 25 refs.

Corresponding with global climatic trends, it is probable that mean annual ground temperatures in the Mackenzie Valley increased by as much as 3°C from the late 1800's to the 1940's, with possibly a 1°C decrease since that time. If true, the southern boundary of continuous permafrost was much farther south 100 years ago. Effects of temperature changes should be recognizable in a variety of features, such as thickness of the active layer, thermokarst activity, and variations in the activity of ice wedges, mass movements, and cryoturbation features. Evidence shows that extensive permafrost shifts have occurred, exceeding that of the last 100 years.

**Mackay, J. R.,** 1977, The stability of ice-push features, Mackenzie River, Canada: Canadian Journal of Earth Sciences, v. 14, p. 2213–2225, 10 figs., 2 tables, 37 refs.

The stability of ice-push features—tightly packed boulder pavements, loose boulder pavements, loose boulders, ice-push island buttresses, and rhythmically spaced boulder ridges—was studied between 1966 and 1975 by painting parallel lines across the features and subsequently measuring the changes. Boulder pavements in which the individual clasts are tightly packed were found to be the most stable features.

**MacKay, D. K., Sherstone, D. A., and Arnold, K. C.,** 1974, Channel ice effects and surface water velocities from aerial photographs of Mackenzie River break-up, *in*

Hydrologic aspects of northern pipeline development: Environmental-Social Committee Northern Pipelines (Canada), Task Force on Northern Oil Development Report no. 74–12, p. 71–107, 19 figs., 21 refs.

Surface-water velocities were mapped from aerial photographs for application to the distribution of river scour, the movement of spilled oil, and general hydrographic studies. The effects of channel ice were also analyzed from aerial photographs, and the results are relevant to navigation, highway and pipeline crossing, and settlement location.

The most important of channel-erosion effects result from ice jamming. A jam may divert flow to an ancillary channel, which may over years become the main channel. Partial jams may redirect both flow and the patterns of erosion and deposition, including scour. Ice-shove action causes gouging and redistribution of bank materials. Banks are commonly topped by ice-shove ridges.

**McPherson, H. J.,** 1971, Dissolved, suspended and bed load movement patterns in Two O'Clock Creek, Rocky Mountains, Canada, summer, 1969: Journal of Hydrology, v. 12, p. 221–233, 7 figs., 2 tables, 11 refs.

In the summer of 1969, 12,850 tons of suspended load, 440 tons of dissolved load, and 65 tons of bedload were yielded by Two O'Clock Creek—equivalent to a surface lowering of 0.0195 in. (0.5 mm)/yr, a figure in agreement with reported denudation rates. Most sediment (87 percent) was transported by the snowmelt flood.

**McRoberts, E. C., and Morgenstern, N. R.,** 1973, A study of landslides in the vicinity of the Mackenzie River, mile 205 to 660: Environmental-Social Committee Northern Pipelines (Canada), Task Force on Northern Oil Development Report no. 73-35, 96 p., 12 figs., 9 tables, 13 refs.

The many landslides between Fort Simpson and Fort Good Hope are classified by field analysis and aerial photographs into the broad categories of flow, slide, and fall. Flow landslides are divided into skin, bimodal, and multiple retrogressive flows. Landslides with coherent shear displacement are called slides and are divided into block, multiple retrogressive, and rotational types. A fall landslide is a specialized type of mass movement. With the addition of a subcategory of solifluction under flow landslides, the classification is applicable to periglacial mass wasting phenomena outside the study area. The distinction between solifluction and the flows of this area is one of movement.

Most slides of the area occur in frozen silts and clays of glacial lake basins which occur peripheral to large tributaries which are eroding the deposits. Associations with frozen-ground conditions are strong. The role of vegetation is certainly greater than it is in nonpermafrost conditions, and its primary role is via influence on the thermal regime of a frozen slope.

**Magakov, G. L.,**1975, Water problems of the Ob region: Water Resources (translation of Vodnye Resursy), v. 2, p. 225–231, 3 refs.

The water resources of the Ob region, the development of which has been hastened by oil and gas discoveries, are summarized. The Ob River floods huge areas each spring, because of earlier breakup (by about 1 to 1.5 months) in the southerly reaches, compared with the northerly downstream reaches. Dams constructed on the northern tributaries of the Ob River will reduce flooding as well as provide power for the development of the region. Also discussed are pollution, the fishing industry, reclamation measures, and other problems resulting from resource development.

**Melin, Ragnar,** 1970, Hydrological regions in Scandinavia and Finland: Nordic Hydrology, v. 1, p. 5–37, 12 figs., 7 tables, 21 refs.

Rivers of the area are categorized according to regime, regional distribution of yearly mean discharges, and long-term variations in discharge. Based on the results, the area is divided into hydrological regions. Large rivers in the nival regime of northern Scandinavia have a maximum discharge generally in June, yield a good water supply during the summer, and have low winter flows. Smaller streams, draining only the forested plateau, have peaks in May, a small secondary maximum in the autumn, and low flow in both winter and summer.

**Messick, Carl,** 1971, Pipeline construction in cold regions (the Russian literature), a bibliography: U.S. Department of the Interior, Office of Library Services, Bibliography Series, no. 21, 126 p., 602 refs.

This unannotated bibliography lists 602 citations on the Russian experience in pipeline construction, with English translation of titles. References are subdivided by subject, and an author index is included.

**Michel, B.,** 1972, Properties and processes of river and lake ice, *in* The role of snow and ice in hydrology: Proceedings of the Banff Symposia, September 1972, International Association of Scientific Hydrology Publication, v. 1, p. 454–481, 11 figs., 33 refs.

Topics include descriptions of the formation of both river and lake ice, the effect of roughness of ice cover on winter river stages, and the mechanisms of breakup as they influence hydrologic phenomena.

**Miles, M.,** 1976, An investigation of riverbank and coastal erosion, Banks Island, District of Franklin: Geological Survey of Canada Paper 76–1A, p. 195–200, 6 figs., 3 refs.

Study of the processes and timing of erosion at six river sites indicated that significant amounts of sediment are contributed to channels prior to breakup, that erosion is inhibited by several factors during breakup, and that active thermal undercutting in braided channels was associated with higher water temperatures several weeks after breakup.

**Mollard, J. D.,** 1973, Airphoto interpretation of fluvial features, *in* Fluvial processes and sedimentation: Proceedings of Hydrology Symposium no. 9, University of Alberta, Edmonton, May 1973, p. 339–380, 4 figs., 17 plates, 18 refs.

The report is a comprehensive discussion of channel patterns and other fluvial features visible on aerial photographs, and how they may be interpreted for geomorphic and engineering purposes. Several arctic streams are included in 34 case histories of aerial photograph interpretation. A provisional classification of alluvial channel patterns includes seven main types: straight, tortuous meandering, scroll meandering, truncated meandering, wandering, anastomosing, and braided. Other subsequent studies of arctic streams have recognized the wandering pattern, described as a pattern transitional between braided and meandering in which a meandering channel dominates at high flows and a faintly braided, point-bar-forming channel is characteristic of low flows.

**Moskvin, Y. P.**, 1974 Investigations of the thawing of the active soil layer in the permafrost zone: Soviet Hydrology: Selected Papers, no. 5, p. 323–328, 4 figs., 2 tables, 5 refs. (English edition published by the American Geophysical Union).

Thickness of the active layer in West Siberia is related to net solar radiation, air temperature, water conditions, drainage, vegetation cover, and soil composition. The thickness was higher in flooded areas, due to difference in albedo of plant cover (22 percent) and water (8–10 percent).

**Müller, G., and Förstner, U.**, 1968, General relationship between suspended sediment concentration and water discharge in the Alpensrhein and some other rivers: Nature, v. 217, p. 244–245, 3 figs., 1 table, 9 refs.

Suspended-sediment concentration is plotted versus discharge and velocity for the Rhine River above Lake Constance over a 30-year period. Values of the constant (intercept) and exponent (slope) in the relation are compared with those of other rivers. Bedload was not studied because it was believed to be insignificant in amount.

**Murakami, M.**, 1972, Method of forecasting date of breakup of river ice, *in* The role of snow and ice in hydrology: Proceedings of Banff Symposia, September 1972, International Association of Scientific Hydrology Publication, v. 2, p.1231–1237, 2 figs., 1 table, 7 refs.

Study of the Sungari River in China shows a useful relation between the number of days between the date air temperature rises above 0°C and the date of breakup, and the acceleration of rising stage before breakup. The critical air temperature date is estimated by the slope of average temperature variation, represented by a straight line connecting average monthly temperature in March and April.

**Nanson, G. C.**, 1974, Bedload and suspended-load transport in a small, steep, mountain stream: American Journal of Science, v. 274, p. 471–486, 5 figs., 3 plates, 2 tables, 15 refs.

In Bridge Creek, a tributary of the North Saskatchewan River in Alberta, bedload per unit water discharge was greater prior to spring peak flow than after, regardless of whether samples were taken on a rising or falling stage. Critical discharge required to entrain bedload increased substantially after the peak flow. Suspended-sediment concentration declined progressively as the season continued. These changes are ascribed to seasonal decreases in the intensity of processes controlling sediment supply to the stream channel, rather than to changes in hydraulic characteristics. The supply of sediment is restricted to less than capacity by the limited period of rapid, seasonal mass movement.

**Nebrasov, I. A.**, 1963, On the question of classification of taliks: Soviet Hydrology: Selected Papers, p. 192–200, 1 table, 34 refs. (English edition published by the American Geophysical Union).

Taliks are classified according to their genesis and subdivided on the basis of heat-transfer process, the characteristics of the heat-transfer medium, and other factors. Recognition of taliks; use of the term, talik: and previous classifications are reviewed.

**Newbury, R. W.**, 1974, River hydrology in permafrost areas, *in* Permafrost hydrology, proceedings of workshop seminar, 1974: Ottawa, Canadian National Committee, International Hydrological Decade, p. 31–37, 3 figs., 1 table, 14 refs.

The hydrology of permafrost and nonpermafrost areas is compared. Rainfall-runoff relationships are generally of the same order of magnitude and variability in permafrost, permeable, and relatively impermeable basins in Canada. However, the highest yields were observed in permafrost basins. The operation of index basins to investigate subsurface conditions, the development of river-behavior surveys, and the establishment of a Canadian agency to oversee hydrologic data from permafrost areas are proposed.

**Nezhikhovskiy, R. A., and Ardasheva, G. V.,** 1970, Computation of maximum ice-jam stages in the Neva River: Soviet Hydrology: Selected Papers, no. 1, p. 1–4, 2 figs., 1 table, 4 refs. (English edition published by the American Geophysical Union).

Maximum ice-jam river stages are required in the planning of flood-control structures on the Neva River. Probability curves of maximum ice-jam stages were plotted for several points on the river with long records of observations. Levels at other important points were reconstructed by plotting of longitudinal water-surface profiles and by a relationship of ice-jam stages with the average November level of Lake Ladoga or with stage at a reference station.

**Ning, Chien,** 1961, The braided stream of the lower Yellow River: Scientia Sinica, v. 10, p. 734–754, 13 figs., 5 tables, 1 ref.

The hydraulic behavior of braided reaches of the lower Yellow River is marked by extreme and variable changes in the channel in response to changes in discharge. Of the total length of 790 km, the 280 km section between Mengtsing and Kaotsun in Honan Province is braided and is confined to a width of 5 to 23 km between dikes. The main stream shifts an average of 10–300 m per day during floods. Downstream from Kaotson, the river gradually assumes a meandering pattern in response to the increased erosional resistance of cohesive bank material. A "wandering index" is developed to identify the transverse stability of the stream.

The extreme values of sediment concentration are a result of severe erosion of the loamy textured soil. The basin is covered with a blanket of loess. The rate of aggradation is alarming, and the water levels are now much higher than the adjacent land surface.

Bars and deltas may move 90–120 m/d and 5–25 m/d, respectively. An increase in stage of 1 m may cause 3 m of scour.

This paper, written prior to construction of a large upstream dam, contains an extensive discussion of the braiding process which should be applicable to glacial streams.

**Norman, V. W.,** 1975, Scour at selected bridge sites in Alaska: U.S.Geological Survey Water Resources Investigations Report 32–75, 160 p., 78 figs., 23 tables, 32 refs.

General scour at bridge crossings and local scour at piers were measured at nine sites in south-central and interior Alaska. Periods of flood discharge had recurrence intervals of approximately 2 to 100 years. Established scour formulas were used to calculate scour depth at contracted openings within 10 percent of the observed mean depth. An existing pier-scour formula was modified to estimate maximum local equilibrium scour depth at round- or pointed-nose piers aligned with the flow. It was also observed that (1) the minimum streambed elevation tended to remain constant but its position moved laterally with varying discharges in uniform or contracting reaches with straight alinement, and (2) the minimum streambed elevation of the scour hole at the noses of piers fluctuated with a magnitude about half that of the height of the dunes, where present. Local equilibrium scour depth at piers during a mean annual flood was near the depth that might occur during a 50-year flood.

**Northern Engineering Services Company, Limited,** 1974, Reference book of water crossings, volume II—river crossing design: Calgary, Alberta, 127 p., 49 figs., 2 tables, 35 refs.

The report is a design manual for the proposed Canadian Arctic Gas Pipeline that, through the assessment of river regime, develops engineering criteria for protection of the pipeline from lateral erosion and channel degradation; and for pipeline anchoring, river-bank rebuilding, and bank protection.

**Northern Engineering Services Company, Limited,** 1975, Drainage and erosion control measures, description and proposed design principles: Calgary, Alberta, 35 p., 12 figs., 2 tables, 16 refs.

Drainage and erosion-control measures for the right-of-way, access roads, and ancillary facilities of the Arctic Gas Pipeline are discussed. Design curves are generated. Methods for selecting the most appropriate control measures for a given section of the proposed pipeline, as opposed to uneconomical design for maximum runoff, are developed. Because of high repair costs, the design storm in northern regions is of a very high return period. Because of the small drainages crossed by the pipeline, the design storm is generally a short, intense rainstorm.

**Osterkamp, T. E., Gilfilian, R. E., and Benson, C. S.,** 1975 , Observations of stage, discharge, pH, and electrical conductivity during periods of ice formation in a small subarctic stream: Water Resources Research, v. 11, p. 268–272, 6 figs., 16 refs.

Frazil ice crystals suspended in the flow reduced velocity profiles and increased stage in Goldstream Creek near Fairbanks. Anchor ice and border ice decreased discharge significantly during periods of ice growth because of storage in the form of ice and upstream storage caused by increased flow resistance. Increases in electrical conductivity during periods of ice growth were related to ice concentrations—calculated as 1.8, 0.9, and 4.7 percent by volume for the first 150 minutes of three different periods. The pH was not affected by ice production.

**Østrem, G.,** 1972, Sediment transport in glacial streams (abs.), *in* Program with abstracts: Arctic and Mountain Environments Symposium, April 22–23, 1972, Michigan State University.

Daily sediment loads were calculated for four representative glacier basins. The most productive glacier yielded several thousand metric tons of sediment, equivalent to annual erosion of 0.5 to 1.0 mm for the entire glacier surface. Bedload was measured with a net and constituted between one-third and one-half of the total sediment load.

**Østrem, G., Bridge, C. W., and Rannie, W. F.,** 1967, Glacio-hydrology, discharge, and sediment transport in the Decade Glacier area, Baffin Island, N.W.T.: Geografiska Annaler, Series A, Physical Geography, v. 49, p. 268–282, 9 figs., 2 tables, 25 refs.

Snow accumulation and ablation and stream runoff are studied from a 12.8-km$^2$ watershed—the Decade River basin, of which 68 percent is glacier-covered. Measurements of suspended-sediment concentration indicated great variations in a 24-hour period. Peak concentrations occurred 2 to 3 hours before the daily peak of water discharge. During one day, July 30, 60 percent of the entire suspended-sediment load for the summer observation period occurred.

**Outhet, D. N.,** 1974. Progress report on bank erosion studies in the Mackenzie River Delta, N.W.T., *in* Hydrologic aspects of northern pipeline development: Environmental-Social Committee Northern Pipelines (Canada), Task Force on Northern Oil Development Report no. 74–12, p. 197–345, 13 figs., 19 plates, 7 tables, 56 refs.

Shapes of eroding banks in the southern part of the Mackenzie Delta are categorized according to rates and manner of erosion. By mapping five distinguishable bank shapes, behavior and rate of erosion can be predicted, and rapidly eroding types (up to 30 m/yr) can be avoided in construction planning.

Physical factors likely to be important in bank recession (e.g., open-water fetch in direction of prevailing wind) were tested by correlation and regression analysis. High near-shore current velocities were associated with banks with the highest erosion rates, as on the cutbank side of meanders. Large-scale sloughing was somewhat greater than in more temperate delta environments due to thermo-erosional niching and structural weaknesses associated with ice wedges and ground ice. Wave action was significant.

**Parker, Gary,** 1975, Meandering of supraglacial melt streams: Water Resources Research, v. 11, p. 551–552, 2 figs., 4 refs.

Instability leading to meandering results from a combination of hydrodynamic and differential heating effects. The heat involved is apparently largely frictional. Instability occurs only for supercritical flow. The meander pattern does not migrate downstream. Meander wave length is determined by channel width, depth, and Froude number.

Differential melting and freezing is necessary for sinuous tendencies in flow of supraglacial melt streams—this is the "extra factor" needed for sinuosity in such streams and is analogous to sediment transport in alluvial streams and Coriolis force in the meandering of oceanic currents.

**Peake, E., Baker, B. L., and Hodgson, G. W.,** 1972, Hydrochemistry of the surface waters of the Mackenzie River drainage basin, Canada—II. The contribution of amino acids, hydrocarbons and chlorins to the Beaufort Sea by the Mackenzie River system: Geochimica et Cosmochimica Acta, v. 36, p. 876–883, 5 figs., 7 tables, 34 refs.

Some samples from the group of 101 surface-water samples analyzed by previous workers were analyzed for amino acids and clorins. Six samples of mud-flat sediment were analyzed for saturated hydrocarbons. The major portions of these compounds are carried on suspended matter and are probably derived from soils and eroded sedimentary rocks rather than produced by biological activity within the river system. No apparent degradation of the compounds takes place during movement through the drainage basin.

**Petukhova, G. A.,** 1974, Dependence on natural conditions of the particle-size characteristics of bottom deposits of rivers in the European USSR: Soviet Hydrology: Selected Papers, no. 3, p. 168–178, 4 figs., 5 tables, 26 refs. (English edition published by the American Geophysical Union).

Bed material is described from predominantly mountain rivers at 558 sampling stations over variable observation periods. $D_{50}$ is related by regression to discharge, drainage-basin elevation, and channel slope.

Bed material from the northernmost region had an average $D_{50}$ of 0.46 mm. $D_{90}$ "reaches" 17 mm. There is a general decrease in bed material sizes from north to south in the lowland part of the European U.S.S.R.

**Péwé, T. L., ed.,** 1969a, The periglacial environment: Montreal, McGill-Queen's University Press, 487 p.

Papers annotated from this volume are those by Péwé, T. L., p. 1–9; Popov, A. I., p. 55–64; and Rudberg, S., p. 129–159.

**Péwé, T. L.,** 1969b, The periglacial environment, *in* Péwé, T. L., ed., The periglacial environment: Montreal, McGill-Queen's University Press, p. 1–9, 1 fig., 52 refs.

The paper is an introduction to the history and problems of periglacial research.

The periglacial environment is characterized by frozen ground, intense frost action in fine-grained sediment, and sorting of coarse materials. Mechanical weathering is accelerated, and ice growth is abundant. Sorting and pattern ground are common. The periglacial environment has a characteristic sequence of soil development.

**Péwé, T. L.,** 1974, Geomorphic processes in polar deserts, *in* Smiley, T. L. and Zumberge, J. H., eds., Polar deserts and modern man: University of Arizona Press, Tucson, p. 33–52, 20 figs., 64 refs.

The article is a comprehensive summary of geomorphic processes in glacier-free polar areas with less than a mean 25 cm of annual precipitation and a mean temperature of less than 10°C for the warmest month.

Polar desert, as defined above, includes the north slope of the Alaskan Brooks Range, large parts of Canada and Siberia, and the northern fringe of Greenland. The areas grade from a "wetter" end—tundra—to a dry end—rocky desert. Tundra is generally treeless, covered with a mat of shrubs, grass, moss, lichens, and has many lakes which in summer create the paradox of a swampy desert. Dry, rocky, vegetation-free areas are found in the far northern islands of Canada, Peary Land of Greenland, and the dry valleys of Antarctica.

**Péwé, T. L., Church, R. E., and Anderson, M. J.,** 1969, Origin and paleoclimatic significance of large-scale patterned ground in the Donnelly Dome area, Alaska: Geological Society of America Special Paper 103, 87 p., 25 figs., 9 plates, 2 tables, 100 refs.

Large (25–46 m in diameter) polygons in the Donnelly Dome area of central Alaska are apparently fossil ice-wedge polygons that formed as a result of melting of the ice wedges and filling of the voids with sediment. Deformed bedding occurs adjacent to the sediment-filled wedges. Bimodal size-distribution curves indicate dual sources of material—from the overlying silt mantle and the outwash gravel on the sides of the wedges. The polygons were formed when the snow line was 450 m lower than today and the mean annual air temperature was at least −6°C, in contrast to the −2.8°C of today. Subsequent warming resulted in disappearance of ice wedges, but renewed cooling is presently causing frozen ground to reform.

The occurrence of fossil ice-wedge polygons in coarse-grained sediment where large ice wedges are still present in fine-grained deposits suggests that permafrost and ice wedges thaw more rapidly in coarse-grained sediment. Ground water is more likely to modify the thermal regime in such deposits.

**Péwé, T. L., and Paige, R. A.,** 1963, Frost heaving of piles with an example from Fairbanks, Alaska: U.S. Geological Survey Bulletin 1111–I, p. 333–407, 17 figs., 2 plates, 6 tables, 120 refs.

This comprehensive treatment of the mechanics of frost heaving is illustrated with the example of heaving of piles in wooden bridges of the Alaska Railroad near Fairbanks.

The subsurface configuration of seasonal frost and permafrost was determined at three bridge sites in Goldstream Valley. The distribution of permafrost in other river valleys of the area, including the Chena and Tanana Rivers, is also discussed. The depth to permafrost in undisturbed areas ranges from 2 or 3 ft (.61 or .91 m) in the older parts of the flood plain to more than 4 ft (1.2 m) on the inside of meanders. As meanders advance, permafrost forms in newly accreted desposits. Ice in the flood-plain alluvium consists of granules and cement between grains. Large ice masses, common beneath the well-sorted silt of colluvial slopes and creek-valley bottoms, are absent, probably due to the coarseness of the flood-plain alluvium.

**Piguzova, V. M.,** 1965, Estimating underground flow into the rivers of the permafrost zone: Soviet Hydrology: Selected Papers, p. 114–129, 3 figs., 2 tables, 24 refs. (English edition published by the American Geophysical Union).

Ground-water contributions to streams of eastern Siberia and the northern U.S.S.R. are determined by hydrograph analysis. In the zone of continuous permafrost, ground-water augmentation of flow constitutes less than 10 percent of the total and varies in rate from 0.5 to 2.0 L/s/km$^2$.

The effect of permafrost is to reduce the exchange of surface water with ground water, thereby increasing mineralization of the latter. Interchange occurs along "underchannel" taliks. Nevertheless, much fresh water occurs below thick (500 m and up) permafrost and is utilized "in many cases," including at Yakutsk since 1941.

The effects of icings in redistributing ground-water contributions from winter to summer are also assessed by hydrograph analysis. The discharges of springs forming icings are determined from icing area, which is linearly proportional to volume.

Rivers with drainage areas of 200,000 km$^2$ may freeze completely in the winter, while some with drainage areas of 500 km$^2$ do not. There is no relation with size.

**Pipeline Application Assessment Group,** 1974a, River crossings: Mackenzie Valley Pipeline Assessment, p. 206–214, 5 refs.

River crossings by a proposed pipeline in the Mackenzie Valley are discussed. Many of the rivers carry large suspended-sediment loads that are subject to great variations. These streams contrast with the relatively clear Great Bear River with its important fish population. Rivers on the Yukon Coastal Plain have unstable banks that are composed of relatively fine-grained flood-plain sediment and that are highly susceptible to slumping caused by thermal niching and removal of vegetation.

A potentially significant cause of lateral erosion at pipeline crossings is the deflection of spring flood discharges by icings initiated at pipeline crossings. Armoring of banks may be necessary. Aerial photographs showing progressive rates of bank erosion do not reflect the increased potential for lateral erosion created by the pipeline itself.

Problems include the above effect of icings, and slumping caused by removal of vegetation, followed by melting of ground ice.

**Pipeline Application Assessment Group,** 1974b, Slope stability and erosion susceptibility: Mackenzie Valley Pipeline Assessment, p. 191–196, 2 refs.

Slope-failure and erosion problems along the pipeline route are discussed. A critique of the applicant data and recommendations for improvements in planning are included.

**Pissart, A.,** 1967, Les modalités de l'écoulement de l 'eau sur l'île Prince Patrick (76° lat. N., 120° long. 0., Arctique Canadien) [Modes of runoff on Prince Patrick Island (76° N. latitude, 120° E. longitude, Canadian Arctic)] : Biuletyn Peryglacjalny, v. 16, p. 217–224, 1 fig., 2 plates, 4 refs.

The following features of arctic streamflow are discussed: snowmelt while the air temperature remains below 0°C, flow and erosion beneath snow layers, commencement of flow in streambeds still filled with snow, and the prevention of all stream erosion for a considerable time during maximum discharge by ice covering the streambed. In a downstream direction, valleys commonly show (1) an open cross section, found where mass movement dominates, (2) a V-profile as the stream is able to transport debris brought down the slopes, and (3) a wide channel which, after snowmelt floods have subsided, is characterized by braided flow.

**Pissart, A., Vincent, J. S., and Edlund, S. A.,** 1977, Dépôts et phénomènes éoliens sur l'île de Banks, Territoires du Nord-Ouest, Canada (Eolian deposits and phenomena on Banks Island, Northwest Territories, Canada): Canadian Journal of Earth Sciences, v. 14, p. 2462–2480, 12 figs., 3 tables, 28 refs.

Eolian processes are active on the outwash plains of Banks Island, especially along the lower Thomsen River, where they are described in detail. Ice wedges develop in the deposits during periods of deposition.

**Polyakova, K. N.,** 1974, Characteristics of the forecast of the dates of ice appearance in the Lena River, of their probability distribution, and of the freeze-up regime: Soviet Hydrology: Selected Papers, no. 6, p. 371–377, 3 figs., 3 tables, 5 refs. (English edition published by the American Geophysical Union).

The distribution of the times of freeze-up and the physical factors that control freeze-up are analyzed. Duration of the autumn ice run varies from 4 to 30 days, with ice formation propagating from the mouth to upstream reaches in an average of 13 days.

**Ponomarev, V. M.,** 1962, Principal features of ground water in the area of development of permafrost formations: Soviet Hydrology: Selected Papers, p. 558–569, 1 fig., 1 table, 21 refs. (English edition published by the American Geophysical Union).

Ground water in permafrost areas is classified and described on a very general basis.

**Popov, A. L.,** 1969, Underground ice in the Quarternary deposits of the Yana-Indigirka lowland as a genetic and stratigraphic indicator, *in* Péwé, T. L., ed., The periglacial environment: Montreal, McGill-Queen's University Press, p. 55–64, 2 figs., 10 refs.

Extensive regional development and thickness of permafrost are determined by the character of the flood-plain environment. Ice formation in alluvial plains is the most important lithogenetic factor determining original environmental conditions. Character and size of ice veins indicate the paleogeographic conditions during formation.

**Price, L. W.,** 1973, Rates of mass wasting in the Ruby Range, Yukon Territory, *in* Permafrost, second international conference, Yakutsk, U.S.S.R., 1973: National Academy of Science, p. 235–245, 9 figs., 3 tables, 17 refs.

Rates of mass wasting in the Ruby Range are generally less than those recorded for other solifluction areas and average 1–3 cm/yr. Rates elsewhere in the Arctic range between 3 and 6 cm/yr. The lower rates in the Ruby Range may be explained by the locations where the measurements were made—large solifluction terraces with a complete vegetational cover, versus measurements in other areas made on individual lobes.

**Rainwater, F.M., and Guy, H. P.,** 1961, Some observations on the hydrochemistry and sedimentation of the Chamberlin Glacier area, Alaska: U.S. Geological Survey Professional Paper 414–C, 14 p., 10 figs., 9 tables, 3 refs.

The paper summarizes a reconnaissance of hydrochemical and sediment-transport characteristics of streamflow from the Chamberlin Glacier in the eastern Brooks Range in 1958. The study documented the diurnal and day-to-day variation in suspended-sediment concentration, load, and particle size.

The area gaged was 1.46 $mi^2$, of which 0.93 $mi^2$ is covered by the glacier. Waters of the region, including those from the glacier, are highly corrosive, indicated by negative calcium carbonate saturation indexes. Nitrate is absent, but ammonia nitrogen is present in large amounts in most samples. The water is low in sodium, calcium, and deuterium. The ions contributing most to the differences in dissolved-solids content of the streamflow are those related to the rocks of the area—calcium and magnesium as well as bicarbonate and sulfate. The inverse relation of hardness to quality of flow is sufficiently well defined to subdivide flow into components of water from the ground and from glacial melting and precipitation.

For the summer months of July and August, 820 tons of suspended sediment per square mile of drainage area were discharged. A large part of the sediment was introduced from erosion of moraines at the snout of the glacier. Diurnal variations in sediment concentration showed peaks at about 4 p.m. and low points at 4 to 5 a.m. Differences were more than a factor of 20 for clay, silt, or sand. Day-to-day variations indicated a general reduction in sediment discharge throughout the summer period, with great differences between adjacent days.

**Rampton, V. N.,** 1973, The influence of ground ice and thermokarst upon the geomorphology of the Mackenzie-Beaufort region, *in* Fahey, B. D., and Thompson, R. D., eds., Research in polar and alpine geomorphology: Proceedings of Third Guelph Symposium on Geomorphology, 1973, p. 43–59, 8 figs., 30 refs.

Landscape features related to ground ice and thermokarst formation are comprehensively surveyed. Thermokarst modification of stream valleys may be extensive, causing "macrobeaded" drainage, large depressions, and other features.

**Rampton, V. N., and Dugal, J. B.,** 1974, Quaternary stratigraphy and geomorphic processes on the arctic coastal plain and adjacent areas, Demarcation Point, Yukon Territory, to Malloch Hill, District of Mackenzie: Geological Survey of

Canada Paper 74-1, pt. A, p. 283, 2 refs.

This note discusses the stratigraphy of surficial deposits and a resurvey of stakes and painted rocks on scree slopes and solifluctuation lobes.

**Rapp, A.,** 1966, Solifluction and avalanches in the Scandinavian Mountains, *in* Proceedings, permafrost international conference, Lafayette, Indiana, 1963: National Research Council Publication no. 1287, p. 150–154, 3 figs., 2 tables, 30 refs.

Slope processes involving solifluction and snow avalanches are common in the Kärkevagge Valley in northern Scandinavia. The rate of solifluction movement generally varies from 0 to 8 cm/yr, but in extreme cases is as much as 30 cm/yr on slopes that range from 10° to 30°. Movement is rapid at the surface and decreases toward zero at depths of 50 to 60 cm. Specific examples of several types of snow avalanches are described.

**Rapp, A. and Strömquist, L.,** 1976, Slope erosion due to extreme rainfall in the Scandinavian mountains: Geografiska Annaler, Series A, Physical Geography, v. 58, p. 193–200, 7 figs., 5 tables, 14 refs.

Landslides and debris flows are triggered by intensive local convective rains in summer and cyclonic rains in autumn. The events generally are of high recurrence interval, typified by the storms of October 1959 and July 1972. The scars and deposits are long-lasting due to the slow growth of vegetation in cold areas. The mass movements can be dated by vegetation growth rates, soil analysis, historical data, stratigraphic analysis, and rainfall records.

**Reckendork, Frank, and Hussey, K. M.,** 1962, An unusual case of stream piracy: Iowa Academy of Science Proceedings, v. 69, p. 322–326, 2 figs.

Piracy of Hawk Creek by the Sagavanirktok River occurred at the Franklin Bluffs in the recent past. A dividing gravel ridge was narrowed, vegetation was removed, and consequently thaw extended to a greater depth, resulting in loss of ice cementation of the gravels and consequent piracy.

**Reeder, S. W., Hitchon, B., and Levinson, A. A.,** 1972, Hydrochemistry of the surface waters of the Mackenzie River drainage basin, Canada—I. Factors controlling inorganic composition: Geochimica et Cosmochimica Acta, v. 36, p. 825–865, 5 figs., 9 tables, 44 refs.

A suite of 101 surface-water samples was collected during a 3-week interval in 1965 and analyzed for 22 major and minor inorganic chemical components. Factor analysis was used to document the main control on the composition by the bedrock encountered by the water during its residence in the various sub-basins. Results of the study indicate that the likelihood that some elements are removed from true solution by biological activity or complexed by organic matter of the muskeg or tundra areas is decreased.

**Reid, K. W., Block, H. O., and Korchinski, M.,** 1974, Report on 1973 water quality studies in the Mackenzie drainage basin: Environmental-Social Committee Northern Pipelines (Canada), Task Force on Northern Oil Development Report no. 74–19, 108 p., 1 fig., 10 tables, 17 refs.

The soils of stream banks in the Mackenzie basin contain relatively large amounts of nutrients and heavy metals that may pollute surface drainage during pipeline and road construction. Thus it is important to minimize erosion at stream crossings. Water quality in the basin is strongly influenced by surface geology. Calcium in the soil accounts for over 70 percent of the exchangeable ion capacity. The major acid-soluble ions in the soil are iron and manganese but significant amounts of copper, lead, mercury, and, especially, zinc are present.

**Rex, R. W.,** 1961, Hydrodynamic analysis of circulation and orientation of lakes in northern Alaska, *in* Raasch, G. O., ed., Geology of the Arctic, v. 2, p. 1021–1043, 16 figs., 4 tables, 30 refs.

Hydrodynamic principles indicate that the lakes on the Arctic Coastal Plain are oriented in a nearly north-south direction (N. 9° W. to N. 21° W.) by current action that results from winds parallel to their minor axes, in a nearly east-west direction.

**Rice, E. F., and Simoni, O. W.,** 1966, The Hess Creek Dam, *in* Proceedings, permafrost international conference, Lafayette, Indiana, 1963: National Research Council Publication no. 1287, p. 436–439, 7 figs., 2 tables, 12 refs.

The Hess Creek Dam, on a tributary of the Yukon River, is an earth dam constructed over permafrost. Such dams are acceptably stable, even when founded on frozen ground of poor quality and near-thawing condition. Artificial cooling of the structure was discontinued when found to be unnecessary. The chief problems were an inadequately designed spillway and the failure of the outlet works.

In the spring of 1962, overfilling of the reservoir caused flow in the spillway channel. Headward erosion quickly undermined the wooden apron and steel sheet-pile cutoff wall, thereby destroying the spillway control. Gullying continued upstream and resulted in discharge of much of the water in the reservoir.

At the reservoir head, problems were encountered with the tunnel designed to deliver water to placer workings near Livengood. At each end, thawing caused caving over the portals. Thawing extended rapidly outward from the tunnel from 1.5 to 2 m, and was especially troublesome in areas of organic-rich silt. Attempted refreezing of the tunnel during the winter by exposing it to air resulted in frost-heaving that damaged the timbering. Constant maintenance was necessary.

**Ritchie, W., and Walker, H. J.,** 1974, Riverbank forms of the Colville River delta, *in* Reed, J. C., and Sater, J. E., eds., The coast and shelf of the Beaufort Sea: Arctic Institute of North America, p. 545–562, 12 figs., 2 tables, 2 refs.

Distributary banks of the Colville delta are composed of peat, gravel, sand, and finer sediment, and contain several forms of ground ice, including ice wedges. Nine types of banks are classified. More right-hand banks represent erosional types (72 percent) than left-hand banks (46 percent), showing that the delta channels are, on the whole, shifting eastward.

**Roberts, David,** 1968, Occurrences of weathering pits from Sørøy, northern Norway: Geografiska Annaler, Series A, Physical Geography, v. 50A, p. 60–63, 3 figs., 7 refs.

Weathering pits in gneiss from lat 71° N. in Norway are believed to have developed by a combination of microgelivation and chemical weathering.

**Root, J. D.,** 1975, Ice-wedge polygons, Tuktoyaktuk area, N.W.T.: Geological Survey of Canada Paper 75-1, pt. B, p. 181.

Characteristics of ice wedges in the area are enumerated. Fortress polygons, formed as a result of drainage of meltwater from the tops of ice wedges, may be the result of local reduction of base level. In areas of local drainage, thermally eroded ice wedges may refill with water, producing ice with a distinctively different character. Control of coastal erosion around Tuktoyaktuk is ascribed to ice wedges.

**Rosenfeld, G. A., and Hussey, K. M.,** 1958, A consideration of the problem of oriented lakes: Iowa Academy of Science Proceedings, v. 65, p. 279–287, 5 figs., 9 refs.

Theories of origin for the oriented lakes of northern Alaska are reviewed and it is concluded that none are completely satisfactory—the wind hypotheses have "some merit" but "it is not at all unlikely" that structural control is a significant factor.

**Rouse, W. R., Mills, P. F., and Stewart, R. B.,** 1977, Evaporation in high latitudes: Water Resources Research, v. 13, p. 909–914, 5 figs., 3 tables, 9 refs.

A simplified form of the equilibrium model of evaporation applied to six Canadian subarctic and tundra surfaces predicts evaporation with an accuracy of 8 percent. The tundra sites are near the Hudson Bay coast at lat 57° 45′ N. Input data to the model are net radiation, screen air temperature, and an evaporability factor characteristic of the surface.

**Rudberg, Sten,** 1969, Distribution of small-scale periglacial and glacial geomorphic features on Axel Heiberg Island, Northwest Territories, Canada, *in* Péwé, T. L., ed., The periglacial environment: Montreal, McGill-Queen's University Press, p. 129–159, 11 figs., 32 refs.

Periglacial features are portrayed on a map of the island, and present-day processes are discussed. The most important process is running water, mainly the result of occasional heavy summer rains. Little effective flow was observed during the snowmelt period, but runoff from summer storms was sufficient to move large boulders.

**Scott, K. M.,** 1978, Effects of permafrost on stream channel behavior in arctic Alaska: U.S. Geological Survey Professional Paper 1068, 19 p., 11 figs., 2 tables, 35 refs.

Sites with drainage areas from 88 to 12,2000 $km^2$ were monitored on five streams in northern Alaska during breakup in 1976 to determine (1) the effects of frozen bed and bank material on channel behavior, and (2) the importance of the annual breakup flood in forming the channels of arctic streams.

Substantial differences in rates of thaw in both submersed and emersed bed and bank material were directly related to sediment size. Once this effect of sediment size was assessed, and after the comparison was limited to reaches with the same channel pattern and a similar climate, a broad range of channel response to breakup flooding was evident. This range varied from total permafrost control of channel processes, including both scour and bank erosion, to only brief restriction of channel behavior early in the rise of the flooding. The watershed characteristic that seemed to explain most of this variation was drainage area. It is possible that similar variation is responsible for many of the seeming contradictions in the results of previous studies of the two problems posed above.

The direct effect of permafrost was to retard channel erosion during breakup for periods varying mainly with drainage area. Although not quantitively assessed, an indirect effect of permafrost in cohesive bank material was to facilitate channel erosion after breakup by maintaining a high moisture content in the bank. Comparisons of absolute rates of bank erosion are not feasible, but it is likely that the net effect of permafrost is to create greater channel stability than is found in natural streams of similar size in nonpermafrost environments. Combinations of factors, particularly those that encourage high rates of thermo-erosional niching, can nevertheless cause high rates of erosion that dictate caution in engineering design.

**Seagel, G. C., and Parish, R. P.,** 1974, Permafrost-runoff: the consulting engineer's experience, *in* Permafrost hydrology, proceedings of workshop seminar, 1974: Ottawa, Canadian National Committee, International Hydrological Decade, p. 59–61, 1 ref.

The paper is a general discussion of hydrologic problems related to runoff measurement and bridge and culvert crossings in the Mackenzie River valley between Fort Simpson and Fort Good Hope, Northwest Territories. It was noted that peak-flow estimates should be on the conservative side because of the high runoff rates caused by permafrost, the full impact of which cannot be accurately assessed because of other hydrologic complications.

**Sellmann, P. V., Brown, J., Lewellen, R. I., McKim, H., and Merry, C.,** 1975, The classification and geomorphic implications of thaw lakes on the Arctic Coastal Plain, Alaska: U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory Research Report 344, 21 p. 11 figs., 1 table, 30 refs.

Satellite imagery is used to classify all lakes on the Arctic Coastal Plain into units according to size, shape, and orientation. Persistence of ice cover during the thaw season will allow estimation of lake depth into three classes: <1 m, 1–2 m, >2 m. Regional slope is a major control of lake development, with most occurring at regional relief angles of less than 1 degree. Another important control is the location of major drainage networks, which influences both lake development and distribution.

**Shaw, John,** 1977, Tills deposited in arid polar environments: Canadian Journal of Earth Sciences, v. 14, p. 1239–1245, 3 figs, 1 table, 24 refs.

Tills of arid polar environments are passively deposited by sublimation of ice and thereby retain more attributes of the ice-transport phase than do tills of humid polar environments, which are more likely affected by meltwater. Consequently, properties of tills such as fissility, foliation, and clast orientation are more likely to be preserved in the arid environment.

**Sherman, R. G.,** 1973, A groundwater supply for an oil camp near Prudhoe Bay, arctic Alaska, *in* Permafrost, second international conference, Yakutsk, U.S.S.R., 1973: National Academy of Science, p. 469–472, 2 figs.,12 refs.

A year-round supply of good-quality water was believed to have been developed in the alluvial aquifer beneath the Sagavanirktok River. Thaw lakes were unacceptable sources of supply because of winter freezing, impurities, and susceptibility to contamination. River water was not usable because of turbidity, uncertain winter flow, potential flood damage to an intake, and shifting channels that may migrate away from the intake. Winter test drilling showed that, during maximum freezedown, the unfrozen cross-sectional area of alluvium beneath the river was at least 167 $m^2$. The aquifer, which lies above a saltwater aquifer in this reach of the river, was developed by means of a gallery.

**Shilts, W. W., Dean W. E., and Klassen, R. A.,** 1976, Physical, chemical, and stratigraphic aspects of sedimentation in lake basins of the eastern arctic shield: Geological Survey of Canada Paper 76–1A, p. 245–254, 7 figs., 1 table, 3 refs.

Physical and chemical factors that control sedimentation in lakes on the northwest side of Hudson Bay are described. Preliminary results of the study indicate that modern sedimentation rates are extremely low. Biogenic sediment may be severely degraded by oxidation, so that only resistant components with a low affinity for trace elements remain.

**Shpolyanskaya, N. A.,** 1969, Characteristics of permafrost and of the active layer in West Siberia: Soviet Hydrology: Selected Papers, no. 2, p. 195–200, 2 figs., 2 tables, 8 refs. (English edition published by the American Geophysical Union).

Permafrost regions are mapped and consist of a region of continuous recent and old (relict) permafrost, a region of scattered permafrost, and a region with only old, deep permafrost.

Two factors control the present distribution of permafrost: (1) climate and heat exchange between the soil surface and the atmosphere and (2) the evolution of permafrost in the Quarternary. Regions are divided on the basis of the ratio between the amounts of recent and relict permafrost. West Siberia is peculiar in that permafrost partially thawed during the Holocene and subsequent refreezing occurred.

**Slatt, R. M.,** 1972, Geochemistry of meltwater streams from nine Alaskan glaciers: Geological Society of America Bulletin, v. 83, p. 1125–1132, 3 figs., 2 tables, 31 refs.

The nine meltwater streams were similar in that Ca was the most abundant ion and the waters had a basic pH. The total concentration of Na, K, Ca, Mg, and Si and the concentration of suspended material varied with different bedrock, different glaciers on similar bedrock, and from the same glaciers with time. Rock type was determined not to be the primary control.

More Ca was introduced by partial dissolution of suspended material than any other ion, indicating the need for immediate filtering of samples. The dominance and behavior of Ca suggested a relationship between ions and suspended load in glacial streams.

**Sloan, C. E., Zenone, Chester, and Mayo, L. R.,** 1975, Icings along the trans-Alaska pipeline route: U.S. Geological Survey Open-File Report 75–87, 39 p., 32 figs., 8 refs.

Icings observed from 1969 to 1974 along the pipeline route are mapped and effectively illustrated with aerial photographs. Large flood-plain icings occur in braided channels of the Sagavanirktok, Atigun, Dietrich, and Delta Rivers. Smaller icings occur along streams and on hillslopes. Construction of the pipeline and ancillary facilities will displace some existing icings and also will create new icings, with consequent flood and erosion problems.

The buried pipeline may cause two types of icing problems. First, the thawed cylinder along the pipeline may serve as a conduit for ground-water flow, with surface discharge at low points. Secondly, heat from the pipeline buried at stream crossings may eliminate or thin any icing at that point, thus possibly concentrating any flow and producing severe scour conditions.

**Smiley, T. L., and Zumberge, J. H.,** 1974, Polar deserts and modern man: Tucson, University of Arizona Press, 173 p.

Papers annotated from this volume are those by Benninghoff, W. S., p. 91–97; Davies, W. E., p. 53–61; Giovinetto, M. B., p. 3–22; Péwé, T. L., p. 33–52; Tedrow, J. C. F., p. 63–69; and Tussing, A. R., p. 105–113.

**Smith, D. G.,** 1976, Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river: Geological Society of America Bulletin, v. 87, p. 857–860, 6 figs., 1 table, 19 refs.

Roots of meadow grass and scrub willow reinforce the banks and act as riprap along anastomosed channels in flood-plain silt of the Alexandria Valley, Banff Park, Alberta. The results suggest that, in cool climates with valley fill dominated by fine-grained overbank deposits, roots decay slowly and resist erosion even in deeper parts of the channel. Large relative differences in erosion rates caused by vegetation were shown by experiment and apparently account for the channel stability noted in the study area.

**Smith, D. I.,** 1972, The solution of limestone in an arctic environment, *in* Polar geomorphology: Institute of British Geographers Special Publication no. 4, p. 187–200, 3 figs., 2 tables, 33 refs.

Both the concentration of solutes (Ca and Mg) in runoff and the weathering rate are considerably less on Somerset Island (Canada) at 74° N. than those found in limestone terrains at lower latitudes. The lack of a soil cover is thought to be the significant factor, in that carbon dioxide is only available from the free atmosphere. There is evidence suggesting that the limestone solution is concentrated at the snow-rock interface.

**Smith, M. W.,** 1975, Microclimatic influences on ground temperatures and permafrost distribution, Mackenzie Delta, Northwest Territories: Canadian Journal of Earth Sciences, v. 12, p. 1421–1438, 12 figs., 12 tables, 31 refs.

Variations in the ground thermal regime are related to successional vegetation sequences caused by river migration, and there is a complex interaction between vegetation, topography, and microclimate. The vegetation succession on a slip-off slope is bare ground, to willow, to willow and alder, to spruce.

**Smith, M. W.,** 1976, Permafrost in the Mackenzie Delta, Northwest Territories, Geological Survey of Canada Paper 75–28, 34 p., 18 figs., 13 tables, 66 refs.

A consistent explanation of permafrost distribution is developed in terms of local environmental factors using heat conduction theory. Borehole data provide observed ground-temperature values that are compared with model values. Calculated thermal disturbances due to shifting of channels of the Mackenzie River north of Inuvik are in general agreement with the observations. A rate of channel shifting estimated from borehole temperature data compared closely with that determined from field evidence.

**Smith M. W., and Hwang, C. T.,** 1973, Thermal disturbance due to channel shifting, Mackenzie delta, N.W. T., Canada, *in* Permafrost, second international conference, Yakutsk. U.S.S.R., 1973: National Academy of Science, p. 51–60, 6 figs., 2 tables, 16 refs.

Variations in permafrost distribution in the Mackenzie delta that were calculated by mathematical modeling agree well with field measurements of thermal disturbance caused by channel shifting. The finite element formulation of the heat conduction equation provides good temperature predictions for such a problem and demonstrates the consistency of the ground temperature field in the framework of heat conduction theory. Simulation of river migration by use of a temperature wave yields satisfactory results.

**Smith, N. D.,** 1978, Sedimentation processes and patterns in a glacier-fed lake with low sediment input: Canadian Journal of Earth Sciences, v. 15, p. 741–756, 15 figs., 2 tables, 41 refs.

Sediment distribution in Hector Lake, in the Rocky Mountains northwest of Banff, Alberta, is strongly influenced by wind-generated currents during the summer when the lake is thermally stratified. Coriolis deflection of currents results in crosslake trends, in addition to the following downlake proximal-distal trends: reduction in grain size, sedimentation rates, total carbonate, dolomite/(dolomite + calcite), and varve thickness.

Five orders of inflow variation were recognized: diurnal, subseasonal (short-term weather changes), seasonal (nival melting versus glacial melting), annual, and exceptional events. Corresponding types of laminae were observed in the bottom sediment.

**Sofer, M. G.,** 1970, Some hydrologic characteristics of ice jam formation on the Lovat' River: Soviet Hydrology: Selected Papers, no. 2, p. 193–198, 3 figs., 1 table, 6 refs. (English edition published by the American Geophysical Union).

The Lovat' is a typical ice-jam river—competence is variable, slope and channel changes are pronounced. The times, frequency, and causes of ice jams along various sections of the river are discussed.

**Swett, Keene,** 1974, Calcrete crusts in an arctic permafrost environment: American Journal of Science, v. 274, p. 1059–1063, 1 fig., 2 plates, 14 refs.

Calcrete (caliche) crusts are common in central East Greenland and extend as much as 2 cm from host clasts of variable lithology in glacial detritus overlying carbonate bedrock. Inhibited percolation and a sharp temperature/solubility gradient in the upper 1 m are possible factors aiding the calcrete formation.

**Tedrow, J. C. F.,** 1969, Thaw lakes, thaw sinks and soils in northern Alaska: Biuletyn Peryglacjalny, v. 20, p. 337–344, 4 figs., 6 plates. 10 refs.

Lakes and sinks are developed by headward erosion, thawing, and filling in aeolian silt south of Umiat. Lake floors are steplike, caused by downcutting of drainage channels and collapse of underlying ground with erosion and filling along lake margins. Enrichment of lake sediment with organic matter is reflected in soil morphology.

**Tedrow, J. C. F.,** 1974, Soils of the High Arctic landscapes, *in* Smiley, T. L., and Zumberge, J. H., eds., Polar deserts and modern man: Tucson, University of Arizona Press, p. 63–69, 11 figs., 36 refs.

Soils in the area north of the July isotherm of 5°C are described.

**Thakur, T., and Lindeijer, A. G. F.,** 1974, A study of geomorphic and hydrologic characteristics of Mackenzie River tributary basins, *in* Hydrologic aspects of northern pipeline development, 1974: Environmental-Social Committee Northern Pipelines (Canada), Task Force on Northern Oil Development Report no. 74–12, p. 347–369, 5 figs., 5 tables, 3 refs.

Design floods for ungaged basins are determined by multiple regression and factor analysis using hydrologic, land use, and geomorphic variables and the known flow charateristics of 11 gaged basins.

**Tollan, Arne,** 1972, Variability of seasonal and annual runoff in Norway: Nordic Hydrology, v. 3, p. 72–79, 5 figs., 1 table, 4 refs.

A preliminary map of variability of annual runoff is based on estimates of the coefficient of variation for 56 unregulated stations with 35 years of record. The regional variation indicates low variability for higher parts of the country and possibly for areas with precipitation from polar-front lows.

**Tolstikhin, O. N., and Sokovov, B. L.,** 1972, Icing mounds as a factor of formation of river and underground runoff in eastern Siberia, *in* The role of snow and ice in hydrology: Proceedings of Banff Symposia, September 1972, International Association of Scientific Hydrology Publication, v. 1, p. 557–563.

The formation, distribution, and effects on runoff of icings in mountain rivers of eastern Siberia are described. The effects of icings on the water balance of the area are comparable to those of glaciers. Total winter volume of icings is estimated at over 30 $km^3$.

**Tsang, Gee, and Szucs, Leslie,** 1972, Field experiments of winter flow in natural rivers, *in* The role of snow and ice in hydrology: Proceedings of Banff Symposia, September 1972, International Association of Scientific Hydrology Publication, v. 1, p. 772–796, 10 figs., 1 table, 12 refs.

The paper summarizes a two-winter study of factors affecting winter flow: the formation, growth, and breakup of ice cover; the behavior of frazil ice under ice cover; and sediment activity in natural channels, mainly of the Nottawasaga River in Ontario and the Peace River in Alberta.

Sediment transport was studied because it was thought that the additional boundary (ice) would encourage transport. During later phases of freezeup, with ice cover, sediment transport was very active (in response to scour and fill, not bank erosion), due to velocity redistribution. The active sediment transport occurred at constant discharges and was solely the effect of the ice cover. Similar activity was observed during breakup. During the winter, gradual progressive erosion occurred, resulting in a 15 percent increase in depth. The greatest erosion occurred during breakup flooding, however.

**Tushinskiy, G. K., and Fleyshman, S. M.,** 1976, Geographic investigations of snow avalanches and mudflows: Soviet Hydrology: Selected Papers, v. 15, p. 163–166, 2 figs.

Large mountainous areas of the U.S.S.R. have a high potential for damaging snow avalanches and mudflows. This paper reviews the history, purposes, and recommendations of the Laboratory of Snow Avalanche and Mudflow Problems established in 1964 at Moscow State University.

Maps of mudflow and avalanche hazards are presented. The largest hazard areas occur in eastern Siberia and the Soviet Far East, regions which are poorly studied and which are the sites of rapid economic development.

**Tussing, A. R.,** 1974, Processes and costs imposed by environmental stress, *in* Smiley, T. L. and Zumberge, J. H., eds., Polar deserts and modern man: Tucson, University of Arizona Press, p. 105–113, 6 tables, 47 refs.

Little is known about the direct, internal costs of economic activity in polar areas, except that they tend to be high. Much of the differential in costs relative to temperate zones may reflect climate only in an indirect sense, through low population densities, for example. There is much discussion of internal costs, little on external costs. The author is not optimistic about ever finding the appropriate principles for evaluating the latter. Two attempts to apply benefit-cost analysis in the Arctic are mentioned; both assume arbitrary environmental costs.

**Tywoniuk, N., and Fowler, J. L.,** 1972, Winter measurements of suspended sediment, *in* The role of snow and ice in hydrology: Proceedings of Banff Symposia, September 1972, International Association of Scientific Hydrology Publication, v. 1, p. 814–827, 5 figs., 1 table, 5 refs.

The effects of ice thickness, slush ice, and equipment and measurement problems on the winter measurement of streamflow and suspended-sediment discharge in Canadian prairie streams are discussed. Winter data from the streams show small variations in flow and suspended-sediment discharge. About 10 percent of annual suspended-sediment discharge and about 20 percent of the flow in the larger streams occurs during severe ice conditions. On small streams the proportions are considerably less.

**Uzuner, M. S.,** 1975, The composite roughness of ice covered streams: Journal of Hydraulic Research, v. 13, p. 79–102, 8 figs., 2 tables, 7 refs.

Techniques for calculating the composite roughness of ice-laden streams and the shear stress exerted on the ice cover by the flow are compared and evaluated.

It is concluded that the methods of Hancu and Larsen are the most complete and rigorous. Hancu's method yields a Darcy-Weisbach type of composite friction factor, allowing use of that more generally applicable formula. Larsen's method yields the composite Manning's roughness, in a graphical form, which is limited to flows in the fully turbulent regime. To be more generally applicable, therefore, $n_1$ and $n_2$ (values of n associated with area of flow dominated by bed and ice cover, respectively) should be calculated on the basis of values of f determined from the Moody diagram. Also, in application, Hancu's analysis should be modified to incorporate a more reasonable value of von Karman's constant.

**Van Everdingen, R. O.,** 1974, Ground water in permafrost regions of Canada, *in* Permafrost hydrology, proceedings of workshop seminar, 1974: Ottawa, Canadian National Committee, International Hydrological Decade, p. 83–93, 1 fig., 4 tables, 13 refs.

The types, occurrences, and quality of ground water in Canadian permafrost areas are surveyed.

Winter discharges from springs maintain open-water reaches in a number of northern regions. Unless ground-water discharge enters a perennially unfrozen body of water, it will freeze at some distance downstream to form icings. The distance is a function of discharge, water temperature, dissolved-solids and gas contents, as well as meteorologic conditions. Some icings are so large that part may remain unmelted during a cool summer.

In many northern rivers, the inverse relation between discharge and dissolved-solids concentration does not apply. Discharge from the active layer and from shallow aquifers is seasonal, and different rating curves for discharge versus dissolved-solids concentration may have to be used for differing times.

**Viereck, L. A.**, 1973, Ecological effects of river flooding and forest fires on permafrost in the taiga of Alaska, *in* Permafrost, second international conference, Yakutsk, U.S.S.R., 1973: National Academy of Science, p. 60–67, 7 figs., 1 table, 26 refs.

Flooding on forested flood plains affects the close relationship between vegetation and permafrost in the following ways: (1) Flooding and rise of the water table may thaw permafrost or cause higher soil tempeatures in at least the upper 1.5 m of the substrate. (2) Siltation may compact and kill moss layers, thereby reducing insulation and increasing soil temperature and the thickness of the active layer. (3) Thawing of ground ice may cause subsidence, tipping of trees, and thaw ponds. (4) Flooding over permafrost can result in a separation of the organic layer at the permafrost boundary and a compression and rolling of the organic layer into peat mounds.

Fire causes temporary thickening of the active layer. Thawing by the end of the second summer after the burn may be 160 percent of that in unburned stands. Return to preburn levels takes about 50 years.

**Vita, S. H.**, 1971, Pipeline construction in cold regions (excluding Russian literature), a bibliography: U.S. Department of the Interior, Office of Library Services, Bibliography Series, no. 21, 92 p., 531 refs.

This unannotated bibliography of 531 citations relevant to pipeline construction in the Arctic and sub-Arctic includes subject and author indexes. The category "river crossings" has 25 references.

**Voskresenskiy, K. P., and Bochkov, A. P.**, 1972, Water resources and hydrologic budget of Siberia: Soviet Hydrology: Selected Papers, no. 6, p. 566–573, 4 tables (English edition published by the American Geophysical Union).

The runoff of the Ob and Yenisey Rivers accounts for 22.6 percent of the total U.S.S.R. runoff and 59 percent of that for Siberia. Average discharges of the two streams are 12,680 and 19,800 $m^3/s$, respectively.

The humid zone of Siberia covers 88.5 percent of the region. The average annual precipitation in Siberia is 562 mm, 6 percent higher than the U.S.S.R. average.

Duration of low-flow cycles (15–20 percent decrease) is 2 to 8 years, more rarely 15 to 20 years. High-flow cycles (10–15 percent increase) usually last 2 to 4 years, sometimes up to 20 years. Flow in only the smaller rivers decreases to 0 in winter. Present reservoirs decrease runoff in rivers like the Ob and Yenisey only 0.3 to 0.5 percent.

**Walker, H. J.**, 1972, Salinity changes in the Colville River delta, Alaska, during breakup, *in* The role of snow and ice in hydrology: Proceedings of Banff Symposia, September 1972, International Association of Scientific Hydrology Publication, v. 1, p. 514–527, 8 figs., 3 tables, 7 refs.

Movement of saline water in response to breakup flooding was monitored in the Colville River delta and under offshore sea ice. During winter, the oceanic influence reaches 60 km upstream beneath the river ice, as shown by salinity measurements.

In the discussion (p. 527), L. R. Mayo notes observations that suggest there is discharge in the Colville River in March and April. Walker has previously stated that there was zero discharge.

**Walker, H. J.**, 1973a, Morphology of the North Slope, *in* Britton, M. E., ed., Alaskan arctic tundra: Arctic Institute of North America Technical Paper 25, p. 49–92, 29 figs., 2 tables, 93 refs.

The geomorphic processes and physiographic divisions of the North Slope are surveyed. The discussion of stream processes includes thermo-erosional niching, formation of beaded streams, arctic hydrology, drainage patterns, and stream deposition.

**Walker, H. J.**, 1973b, The nature of the seawater-freshwater interface during breakup in the Colville River delta, Alaska, *in* Permafrost, second international conference, Yakutsk, U.S.S.R., 1973: National Academy of Science, p. 473–476, 3 figs., 1 table, 12 refs.

During freezeup, seawater replaces freshwater in the lower reaches of many arctic streams. During spring flooding, seawater is replaced by flood water that progresses seaward as a wedge beneath the sea ice. The position and nature of the sharp interface was established in 1971 in the Colville delta by use of a salinometer. Seawater penetrated as far as 58 km upriver.

Even though most rivers draining the zone of continuous permafrost cease to flow (except when fed by springs, as in the case of the Kolyma in Siberia, or by deep lakes, as in the case of the Sadlerochit in Alaska), deep rivers have unfrozen zones beneath their beds that are potential contributors to winter flow. In the Colville, no late-winter flow has been detected. Rivers such as the Ob, Yenisey, and Mackenzie originate outside the continuous-permafrost zone and flow across it to the Arctic Ocean throughout the year.

**Walker, H. J.**, 1974, The Colville River and the Beaufort Sea: some interactions, *in* Reed, J. C., and Sater, J. E., eds., The coast and shelf of the Beaufort Sea: Arctic Institute of North America, p. 513–540, 23 figs., 20 refs.

Interactions between the Colville River and the Beaufort Sea are described. Little mixing occurred when fresh flood waters advanced under the sea ice. Early flow was over the ice and deposited much sediment on the sea ice before draining through cracks in the ice. Flooding generally lasted less than two weeks, after which warm fresh water mixed with cold marine water to form the brackish system of summer.

**Walker, H. J., and Arnborg, L.**, 1966, Permafrost and ice-wedge effects on riverbank erosion, *in* Proceedings, permafrost international conference, Lafayette, Indiana, 1963: National Research Council Publication no. 1287, p. 164–171, 20 figs., 1 table, 14 refs.

Permafrost and ice wedges influence the morphology and dynamics of riverbanks in the Colville delta. Ice wedges provide planes of weakness for bank collapse and themselves are rapidly eroded, especially in banks of peat. Permafrost results in formation of a thermo-erosional niche and the developement of a cornice, leading to increased bank erosion by sloughing and collapse of cornices.

Bank sloughing in the Colville delta apparently does not account for more than a meter's recession per year, compared to 2 m calculated by Eardley (1938) for the frozen sand banks of the Yukon. More important is the collapse of the cornices, resulting in a local average of 10 m of bank recession. Most bank erosion occurs during or shortly after breakup flooding.

**Walker, H. J., and McCloy, J. M.,** 1969, Morphologic change in two arctic deltas: Arctic Institute of North America Research Paper 49, 91 p., 81 figs., 4 tables, 90 refs.

Processes and landforms are described from the deltas of the Colville River, the largest drainage in northern Alaska, and the Blow River, a smaller river in Yukon Territory, Canada. Both rivers drain to the Arctic Ocean.

**Walker, H. J., and Morgan, H. M.,** 1964, Usual weather and river bank erosion in the delta of the Colville River, Alaska: Arctic, v. 17, p. 41–47, 4 figs., 5 tables, 3 refs.

Extensive bank erosion was associated with the unusually wet, high-rainfall summer of 1961. Erosion and undercutting were caused by waves generated by westerly winds and were therefore concentrated on the right (east) banks of the river.

**Walsh, J. E.,** 1977, Measurements of the temperature, wind, and moisture distribution across the northern coast of Alaska: Arctic and Alpine Research, v. 9, p. 175–182, 2 figs., 1 table, 10 refs.

Data collected from flights conducted by the National Center for Atmospheric Research show that the arctic tundra near the northern Alaskan coast is characterized by large surface temperature variations over relatively small spatial scales (100 m and less) and that air temperature changes abruptly near the coastline.

**Washburn, A. L.,** 1956, Classification of patterned ground and review of suggested origins: Geological Society of America Bulletin, v. 67, p. 823–865.

Patterned ground is described, and a detailed discussion of its origin in terms of hypotheses involving 19 distinct processes is presented. Most patterned ground is polygenetic, and climatic and terrain interpretation of patterned ground is limited by the lack of data about the formative processes.

The paper is noteworthy for a comprehensively documented set of definitions for types of patterned ground. Classification is based on (1) pattern and (2) the presence or absence of obvious sorting, with features listed as follows in order of gradient of slope on which they occur: (a) circles, sorted (including debris islands) and nonsorted (including peat rings, tussock rings); (b) nets, sorted and nonsorted (including earth hummocks); (c) polygons, sorted and nonsorted (including frost-crack polygons, ice-wedge polygons, tussock-birch-heath polygons, desiccated polygons); (d) steps, sorted and nonsorted; and (e) stripes, sorted and nonsorted.

**Wilkinson, T. J., and Bunting, B. T.,** 1975, Overland transport of sediment by rill water in a periglacial environment in the Canadian High Arctic: Geografiska Annaler, Series A, Physical Geography, v. 57, p. 105–116. 12 figs., 1 table, 20 refs.

The highest discharges and sediment loads in two areas of the Queen Elizabeth Islands are related to flow from rills developed from melting snow cover. Snow patches may act as sediment traps and yield later summer flow and small fine-textured sediment loads. The production of fine-grained sediment by weathering in the High Arctic results in meter-deep accumulations of niveo-alluvial sediment on valley floors where it is homogenized by physical and biological processes.

**Williams, J. E.,** 1949, Chemical weathering at low temperatures: Geographical Review, v. 39, p. 129–135, 5 figs., 2 tables, refs. footnoted.

Observations in the Snoqualmie Pass region in Washington indicate active chemical weathering under snow cover, ascribed to high carbon dioxide concentrations in snowbanks. Daily freezing and thawing of snow surfaces releases carbon dioxide that remains in the snow banks, and meltwater and rain infiltrating the snowbanks then become saturated with carbon dioxide. It is believed that the phenomenon contributes to the asymmetry of mountain ridges where snow drifts are preferentially concentrated on lee slopes.

**Williams, J. R.,** 1952, Effect of wind-generated waves on migration of the Yukon River in the Yukon Flats, Alaska: Science, v. 115–520, 7 refs.

Wind-generated waves erode the frozen north banks of the complexly braided river in the Yukon Flats, an alluvial basin 20–75 mi (32.1–120.6 km) wide and 200 mi (321.8 km) long. The net result is northward migration, caused by strong summer winds from the southwest which produce waves with a height of up to 3 ft (.9 m). Banks 20–30 ft (6.1–9.1 m) high are undercut and collapse. Residents of the town of Beaver reported 200 ft (60.9 m) of erosion during the 1950 summer, with as much as 35 ft (10.6 m) in 2 days.

**Williams, J. R.,** 1965, Ground water in permafrost regions—an annotated bibliography: U.S. Geological Survey Water-Supply Paper 1792, 294 p., 1 plate.

This annotated bibliography on ground water in permafrost regions covers North American, Scandinavian, and Russian papers published through 1960. A glossary of ground-water terminology is included. Plate 1 illustrates the distribution of permafrost in the northern hemisphere.

**Williams, J. R.,** 1970, Ground water in permafrost regions of Alaska: U.S. Geological Survey Professional Paper 696, 83 p., 25 figs., 4 tables, 270 refs.

The paper is a comprehensive, areally specific survey of ground water in permafrost areas of Alaska. Although ground water occurs according to the same geologic and hydrologic principles as elsewhere, profound modifications of ground-water systems occur with permafrost. Permafrost creates impermeable barriers to the recharge, movement, mixing, and discharge of ground water, and acts as a confining layer. It also limits the volume of unconsolidated deposits and bedrock in which liquid water can be stored.

The Colville River has formed a thawed zone several hundred feet deep beneath its bed. The zone may perforate the permafrost. Drilling beneath smaller streams in the continuous-permafrost zone, such as the shallow Shaviovik River, showed that permafrost is present at shallow depths but is surficially warmer than that beneath adjacent tundra. Shallow streams connecting lakes on the arctic coastal plain overlie shallow, linear unfrozen zones and linear indentations in the base of the permafrost.

In the discontinuous-permafrost zone, unfrozen zones that perforate permafrost occur beneath most large and medium-sized rivers. Shifts in channel position cause corresponding shifts in the unfrozen zone. The speed of channel migration influences the time available for thermal effects to alter the permafrost. Soviet studies have shown that permafrost on the cutbank side is commonly colder than that on the slip-off side.

**Williams, P. F., and Rust, B. R.,** 1972, The sedimentology of a braided river, *in* Bushnell, V. C., and Ragle, R. H., eds., Icefield Ranges Research Project scientific results: American Geographic Society and Arctic Institute of North America, v. 3. p. 183–210, 28 figs., 5 tables, 22 refs.

Morphologic and sedimentologic parameters are compiled for a straight, 4-mile (6.4-kilometer) reach of the Donjek River, southern Yukon Territory. Seven sedimentary facies are distinguished on the bases of texture, flora, and sedimentary structures. Trends of hierarchical orders of sedimentary structures, mainly ripples, are compared with the river trend.

**Wilson, Lee,** 1973, Variations in mean annual precipitation: American Journal of Science, v. 273, p. 335–349, 2 figs., 20 refs.

The paper is a critique of the well-known relationship between sediment yields and mean annual precipitation described by Langbein and Schumm. A similar relationship is developed, based on 1500 basins, which shows 2 peaks, one at 30 in. (76.2 cm), of precipitation, and another, higher peak at 70 in. (177.8 cm), contrasting with the peak sediment yield at a value of 12 in (30.48 cm) for the data of Langbein and Schumm. It is concluded that no such curve is suitable for quantitative application, and that the most important factor in sediment-yield magnitude is land use, not mean annual precipitation. In general, factors that control the supply of sediment are more important than those that control transport.

Information on sediment yields in areas with a "pure glacial climate" is virtually non-existent, and what does exist serves only to indicate that meltwater floods are capable of considerable sediment transport. However, because of the rarity of meltwater floods (under glacial conditions), sediment yield is probably not great. A parallel with an arid climate is implied, based on the presence of significant but infrequent events. If so, the basins of glacial regions show a similar relationship of sediment yield to mean annual precipitation—a positively sloped line to the left of a peak similar in configuration to that of Langbein and Schumm and in a position between that of Langbein and Schumm and those of Wilson.

**Wolman, M. G.,** 1959, Factors influencing erosion of a cohesive river bank: American Journal of Science, v. 257, p. 204–216, 7 figs., 3 tables.

Most of the bank erosion along Watts Branch (Maryland) occurs during the winter months. Erosion was pronounced in the hours during which a bankfull flow attacked banks that had been thoroughly wetted, and was most severe at the water surface. Second in effectiveness were cold periods marked by wet banks, frost action, and low rises in stage. Significant erosion occurred during times of moist banks and low rises in stage. Last in erosion severity were times of freezing and thawing without change in stage, and rare flashy summer floods on hard, dry banks. Thus, the cumulative effect of moderate flows exceeds that of the rarer events of greater magnitude. The analysis suggests a crude correlation between precipitation and erosion in selected time intervals. Precipitation increases bank moisture as well as stream discharge. Frost action acts both to hold moisture in the soil and to comminute surface material.

**Woo, M., and Slaymaker, H. O.,** 1975, Alpine streamflow response to variable snowpack thickness and extent: Georgrafiska Annaler, Series A, Physical Geography, v. 57, p. 210–212, 13 figs., 2 tables, 13 refs.

Snowmelt and meltwater discharges from the Central Creek drainage, a small alpine basin in British Columbia, were investigated in the spring of 1973. Thickness of the ripened snowpack affected movement and storage of meltwater to the extent that lag times and recession flows changed noticeably. Snow cover was variable in the basin, and spacial variations in flow consistently indicated the differing snowmelt source areas.

**Zalesskiy, F. V.**, 1976, Flash flood formation in permafrost regions: Soviet Hydrology: Selected Papers, v. 15, p. 95–97, 1 table. (English edition published by the American Geophysical Union).

Floods in the area of continuous permafrost in the Soviet Northeast are described. Surface runoff in the area is only rarely observed during flash floods. Instead, seepage within the active layer is the main mechanism of storm runoff, because of the permeable tundra surface and generally low-intensity rainfall. Catastrophic floods of high recurrence interval apparently result from a many-day rainfall in which a precipitation total of at least 200 mm saturates a shallow active layer.

**Zenone, Chester, Helmers, A. E., and Miller, M. M.**, 1972, Glacio-hydrology and the jökulhlaup phenomena in Alaskan glaciers (abstract), *in* Program with abstracts: Arctic and Mountain Environments Symposium, April 22–23, 1972, Michigan State University.

Examples of major jökulhlaups from ice-dammed lakes on the Juneau Icefield are described and are regarded as important environmental hazards. Climatic trends are considered in terms of shifting positions of the Arctic Front. Present conditions reveal a detectable increase in annual runoff caused by inland shift of storm tracts and phasing in of more maritime conditions on the Juneau Icefield, in spite of regional cooling which in adjoining continental areas may produce less precipitation through remaining decades of the century.

**Zinov'yeva, L. Y.**, 1970, Computation of rain flood runoff in the Lena basin: Soviet Hydrology: Selected Papers, no. 4, p. 401–402 (English edition published by the American Geophysical Union).

Summer and autumn rain floods compose an average of 80 percent of the annual flow in the Lena basin. Water depth available for runoff, calculated from precipitation with corrections for vegetation, soil characteristics and permeability, and a geomorphic factor, varied from 20 to 400 mm throughout the basin.

# INDEX

Water temperature: Colby, B. R., and Scott, C. H., 1965; Hubbell, D. W., and Al-Shaikh Ali, K., 1961; Lane, E.W., and others, 1949

Weathering features—See also listing for Chemical Weathering
  Norway: Roberts, D., 1968