

Articles



River Studies in Northern Canada: Reading the Record from River Morphology

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Summary

Proposals for resource developments in northern Canada have generated a demand for rapid improvement in knowledge of northern hydrology and river processes. The regimen of northern rivers and aspects of northern river behaviour are discussed, emphasis being given to description of reconnaissance techniques used to develop rapidly information on these subjects. Some special techniques evolved in the course of recent studies in northern Canada are reviewed.

Introduction

Proposals for resource development projects, and for associated transportation corridors, in northern Canada have generated a need for extensive information about environmental conditions over large

geographic areas for which knowledge has heretofore remained scant (see Fig. 1). Within many of the earth and biological sciences refinements of reconnaissance traverse methods, with intensive use of air photographs and extensive airborne surveys have been employed to meet the need. For hydrology, particularly for surface water studies, similar techniques have had to be developed rapidly.

Rivers constitute an important focus of attention in surface water studies because of their dynamic nature. They are linear transport systems for the

removal of water from the land. In fulfilling this function they may entrain sediment; hence, they can modify their own bed and banks and the adjacent terrain. Rivers represent an important biotic environment, particularly in the arctic where large tracts of land are comparatively barren. Consequently they represent a focus of life for the local people, both as a source of food resources and as arteries for travel. For the new resource developers, rivers and river valleys may still be routeways. In addition, they are a source of engineering materials - particularly

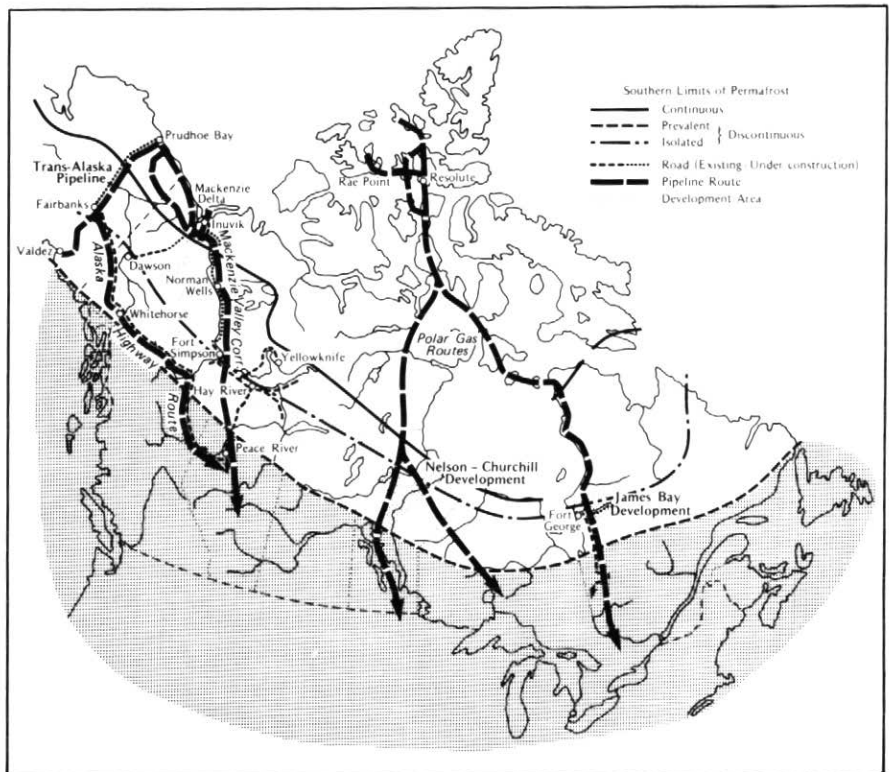


Figure 1
 Routeways and locations of recently proposed pipelines, highways and hydroelectric power developments in northern Canada. The relevant geographical area extends over the entire Canadian mainland beyond the limits of reasonably

close settlement, and parts of the Arctic islands: it is largely coincident with that half of the country that is underlain by permafrost. Boldface type indicates a major project; those in italics are proposed only. Not all roads are shown: Alaska Highway and Mackenzie Highway are included for information.

gravel and water – and they may present special engineering problems on floodplains and at crossing points.

This paper will discuss river processes in northern Canada and describe some of the methods employed to develop that knowledge.

The Regimen of Northern Rivers

Northern rivers behave in much the same way as rivers anywhere else, but the severe thermal climate introduces some novel effects associated with the extreme hydrological regimen and the seasonal occurrence of ice. For much of the year precipitation remains on the ground as snow. The effect of spring melting, so far as runoff is concerned, is to redistribute six to 10 months' precipitation as if it had all occurred during the period of snowmelt. This is the most important feature of the hydrological cycle in the north.

Permanently frozen ground restricts exchanges between surface water and subpermafrost groundwater. A perched water table commonly occurs above frozen ground, with standing surface water a frequent result. The chief contributions to runoff come from seasonal rainfall and snowmelt by direct surface flow, or by flow through the active layer above the frost table. However, a continuous ground cover of moss or grasses, sometimes abetted by frozen ground, limits erosion and rill development. Overflow of puddles and ponds or seepage through the sodmat are frequent means of water movement (see illustration in Fig. 3–3D)

Types of annual river hydrographs were classified by Church (1974). Arctic rivers are winter dry and permafrost occurs at shallow depth beneath the channel. The spring snowmelt flood is apt to be most severe, except in very small watersheds or rare circumstances (see, for example, Cogley and McCann, 1976). Subarctic rivers experience generally low summer flows punctuated by periodic rainstorm floods which may exceed the spring freshet, especially those on rivers with mountainous headwaters (see Mackay, *et al.*, 1973). Large rivers continue to flow through the winter, baseflow being derived from unfrozen gravels along the channel, from deep springs or from lakes. Progressively larger rivers become winter dry farther to the north. Because of the large water-retaining capacity of muskeg and heathy tundra vegetation,

floodflows are greatly attenuated in watersheds dominated by these surface-cover types: the effect is like that of a relatively large lake. Lowland tundra with many standing water bodies may exhibit a similar regime.

Ice action is important in northern rivers. When ice forms in autumn it develops as a continuous cover of skim ice in quiet water (velocity less than about 0.3 m/s) and then thickens into sheet ice. In rougher flow, frazil ice platelets form in the flow when the water is slightly supercooled and anchor ice spicules form on the bed. These agglomerate to form frazil slush which jams at obstructions. It may be drawn under stable ice cover to form "hanging ice dams" below which bed scour may occur as the result of the constriction. In spring, stable ice cover is usually broken first by rising water with snowmelt. If the water rises quickly, massive ice movement may occur until a constriction of the channel is reached, where a large jam occurs. Major jams recur at the same places along a river from year to year. Such events may produce spring floods that precede the peak runoff and may be associated with the most severe erosion along the river. By contrast, where the river freezes to the bed in winter, spring runoff may begin over the bottomfast ice, which thereby protects the channel bed.

Icing (*aufeis*) is an additional feature found in northern rivers. Icing occurs in winter where water is forced to the surface by frost closure of an unfrozen zone in the streambed, or where spring seepage occurs. Massive accumulations of ice may develop in this way, particularly downstream from Lake outlets. They may have two major effects on river channel stability. Sometimes, water may be trapped and freeze *below* the bed, which may heave the entire channel bottom. When the icing mound melts in the following summer, bed material is moved away; in this way superficially stable lag cobble beds may be deranged (Fig. 2a). Where icing occurs on top of the bed and does not disturb it, spring runoff may be rerouted out of the streamcourse and hence produce relocation of the channel (Fig. 2b).

Records of the rivers. Conventional stream gauging is carried on at 37 sites in Yukon Territory (1 site per 15,000 km²), and at 67 sites in the Northwest

Territories (1 per 50,000 km²). Fifty-one of the NWT sites are in the District of Mackenzie (1 per 27,000 km²). Twenty-five of the Yukon sites have 10 years or more of record, but only 21 NWT sites (16 in Mackenzie) have been established so long. No sediment transport observations were made before 1970, and such observations are still restricted to some 20 sites in all the north.

As the basis for development planning the data remains inadequate, particularly when it is realized that most long-term records and sediment transport observations are restricted to Yukon River and Mackenzie River.

An alternative way to gain information about river activity – at least, about "channel forming" discharges that involve significant erosion and deposition and concern project planners – is to study the evidence of river morphology directly. The river channel and floodplain preserve a record of the significant events that have affected them, which through air photography is accessible for any river site in Canada (within the limits of photo scales).

In order that the evidence of river morphology can be properly understood and verified, it is necessary to develop consistent methods for interpretation of data derived from air photographs and field reconnaissance. A basic unit for interpretation must first be defined, which may be termed a *homogeneous reach*. This is a length of channel, of any appropriate length, within which hydrological and geological conditions remain sufficiently uniform so that a substantially uniform river morphology results. The characteristics of a river change wherever a change occurs in one of the conditions that govern fluvial morphology. The most important such conditions may be summarized as follows: 1) geomorphological setting and geological history of the reach (initial condition); 2) nature of the materials through which the river flows (boundary condition); 3) supply of water and sediment from upstream (forcing condition). In the north, seasonal ice regime is an important additional condition. Only the second of these may be satisfactorily observed on the ground during a short visit. Nevertheless, the correspondence between river morphology and the governing conditions may be used to deduce information about them from the



Figure 2

River icing: A. River bed heaved by icing growth beneath the surface, upper Babbage River, Yukon Territory. B. Icing accumulation on the delta fan of Firth River, Yukon Territory. Such icings contribute to the periodic relocation of the river channel that occurs

here (photo taken 17 July, 1972 by C. P. Lewis, GSC). C. Landsat view of icings developed on delta fans of Yukon north coast rivers: MSS Band 5 image of 15 August, 1975. The icings visible are probably perennial, as this view is from relatively late in a warm season.

appearance of the channel. For this purpose, a summary river classification was presented by Mollard (1973). Morphologically and hydraulically homogeneous reaches also constitute uniform habitat for aquatic organisms so that such classification, with additional attention paid to water quality, may serve as a framework for biological studies as well.

A more complete, and inevitably more complex scheme of river typing has evolved out of studies of Alberta rivers by Kellerhals *et al.* (1972) and northern river studies by the writer and by McDonald and Lewis (1973). The resulting classification of river features is presented in a paper by Kellerhals *et al.* (1976) and Figure 4 includes a data sheet for channel features according to this scheme. The main reach types identified by the writer for northern rivers are shown in Figure 3 along with a summary of typical conditions along them. These types vary regionally with geology and glacial history and are systematically (but not uniquely) associated with hydrological regimen types.

Quantitative data of river condition and river processes may be deduced in one of two ways from air photo and reconnaissance studies: 1) by direct measurement of channel changes obtained from repeated photography or from other historical records, from evidences of vegetation development on floodplain features, or from datable stratigraphic features; and 2) by estimates of river hydraulic parameters computed by "regime theory" formulae, following measurements of river morphology on photos or in the field. These methods will be described at more length.

Experience in Northern River Investigations. Starting in about 1970, reconnaissance studies of northern rivers have been carried out by both government and business groups in connection with the resource projects mapped in Figure 1. Such investigations normally include several well-defined phases: identification of river reaches of interest, preliminary classification from air photographs and selection of major targets of attention; assembly of relevant gauging records and other pertinent historical information; field visits to examine river morphology, usually timed to coincide with high and low flow

periods; derivation of preliminary project data from the assembled information; continued observations of annual regime and special problems for as long as the project allows or interest continues. Neill and Galay (1967) have presented a detailed discussion of river evaluation procedures. Figure 4 portrays several stages of this procedure. The expansion of the conventional gauging network represents a vital aspect of the latter phase of study. Where important biological resources must be protected, documentation of the undisturbed annual hydrological regimen is particularly important.

Single-visit ground reconnaissance may supplement air photo interpretation in the following respects: survey of channel slope, an important hydraulic parameter not accurately obtainable from maps or photos; channel sounding to determine channel depth, particularly scour depths near natural obstructions; sub-bottom profiling by seismic or sonar methods to detect bedrock; characterization of bed materials and configuration, including collection of materials to establish grain size; observation of bank materials and stability, particularly ice content in perennially frozen ground; survey of cross sections to establish sectional geometry; observation of flood and ice damage limits; sampling of floodplain materials and vegetation, particularly as they bear on channel stability and flood limits; observations of transient effects - icing, unusual sedimentation, signs of persistent aggradation or degradation. Discharge, sediment transport and water quality measurements may be taken if the results of isolated measurements can be used (cf. a biological application in Craig and McCart, 1975).

Some special methods have been developed which are applicable in field investigations of this type to yield information on river lateral stability. Hickin and Nanson (1975) have shown that tree-ring dating of floodplain vegetation (cf. Fig. 3 (2B)) may be used to absolutely date rates of river channel shifting over time periods of up to several hundred years. On a shorter time scale, the writer has used ages of willows to estimate minimum time periods of river bar stability. Similarly, adventitious roots may be used to study rates of sediment accretion of floodplains (see Fig. 5 and Strang, 1973). Damage to floodplain

vegetation and the age of its occurrence (determined dendrochronologically) have also been used to determine the time and frequency of severe floods and ice damage events along northern rivers (see, for example, Parker and Jozsa, 1973).

Smith and Hwang (1973; see also Smith, 1976) have shown that, in northern environments where river water temperatures remain substantially higher than mean annual ground temperatures, the transient effects of channel shifting may be traced for many decades in the ground thermal regime adjacent to the channel.

Riverbank stability presents some special features on northern rivers in association with frozen ground. In particular, high ice-content ground produces distinctive erosional mechanisms (a classification is given in Fig. 5). The rapid erosion which may be associated with exposure of ground ice may indeed prove to be the most difficult engineering problem on northern rivers. The extent and configuration of ground ice is often evident from surface morphology, but it is sometimes necessary to use geophysical methods (cf. Collett and Brown, 1974) or borings to detect buried ice, particularly in more southern regions.

Location and behaviour of recurrent ice jams and icing may be studied by serial air photography. Landsat photography has been used in recent years to gain information on the annual regime of large icings (see Fig. 2C).

Hydraulic computations based on reconnaissance information depend heavily on appropriate classification of the river reach. "Regime" formulae must be utilized if only air photo data or scanty field data are available. Regime "theory" (which is not) consists of sets of empirically derived equations which describe the relationships of hydraulic parameters for river channels in equilibrium (see Simons and Albertson, 1960, and Blench, 1969, for two approaches to regime studies). Originally derived for design of unlined canals in alluvium, the technique has been modestly successful in predicting river behaviour for "channel forming" or "dominant" discharge - usually taken to be bankfull discharge. However, the constants of the formulae change for rivers of different type.

The most successful "regime" relationship is that relating channel

width (w) to discharge (Q) as $w = aQ^{0.5}$; this appears to represent a general scaling relation for open channels, but the constant, a , varies for different channel types. Values utilized by the writer for large northern channels are given on Figure 3. Data of bankfull width may be measured from air photographs or field surveys.

In some cases the assignment of appropriate equations is difficult. Tributary streams commonly become anomalously wide near their confluence with a major river as the consequence of frequent backwater conditions. This situation was dealt with by the writer for certain tributaries of Mackenzie River by using equations developed for tidal estuaries.

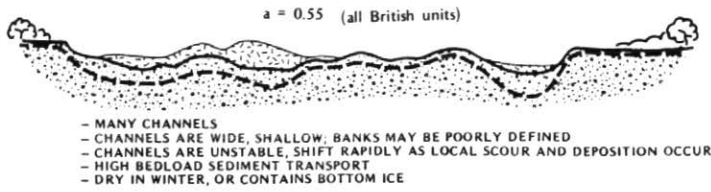
Related formulae incorporate data of depth, velocity, slope and possibly, planform geometry. When sufficient field data of bed material granulometry and bedforms are available, along with a reasonable estimate of river slope, the scaling relation can be used in association with a resistance formula. McDonald and Lewis (1973) used such a technique following their field reconnaissance of northern Yukon rivers.

All such calculations remain at best gross approximations. They must be checked against other estimates for river discharge, such as hydrological estimates of peak watershed runoff or appropriate comparisons with gauged basins. Unfortunately, though the character of sediment transport may be deduced from river channel appearance, there are no techniques for reliably assessing the magnitude of sediment transport or of scour - for many purposes the most important variables - in absence of field observations. Before proceeding to major projects, every effort must be made to obtain as many direct observations of river behaviour as possible. The present paucity of such records about every aspect of the environment is a major reason to proceed cautiously with northern resource development.

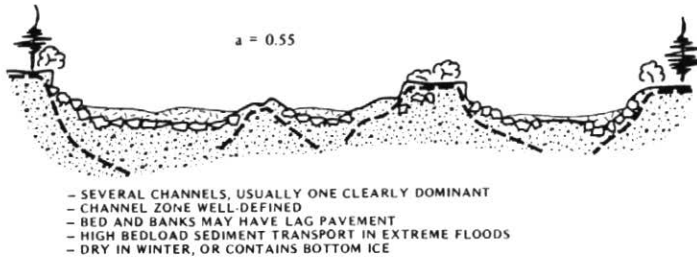
Prospects for Long Term Study. The construction and maintenance of major projects in the north will require far more extensive information than we presently have for northern rivers. Methods for gathering the information must be particularly efficient in view of the severe

1. LARGE GRAVEL CHANNELS

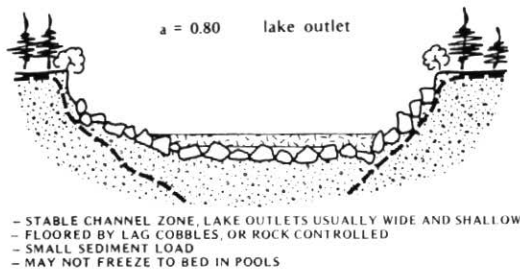
A. BRAIDED, AGGRADING



B. BRAIDED / ANASTOMOSING, STABLE

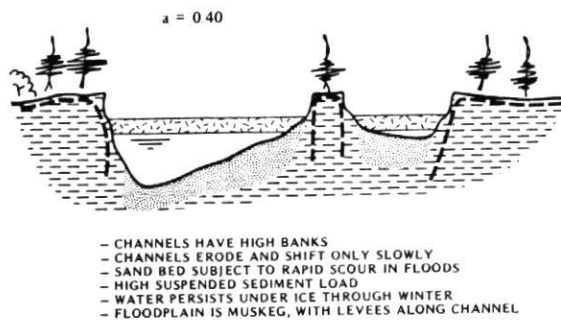


C. SINGLE THREAD, STABLE OR DEGRADING; LAKE OUTLETS

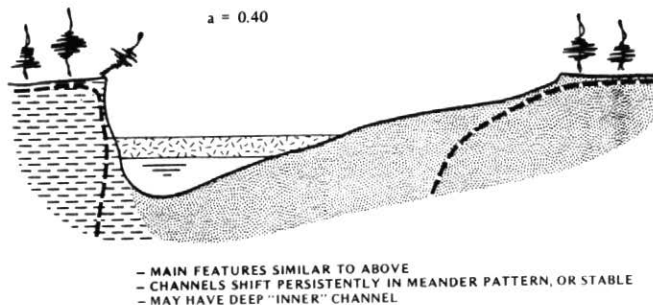


2. LARGE SAND BED / SILT BANK CHANNELS

A. ANASTOMOSING, AGGRADING OR STABLE



B. SINGLE THREAD, MEANDERING, AGGRADING, STABLE OR DEGRADING
DELTAIC DISTRIBUTARIES (cf. MACKENZIE DELTA)



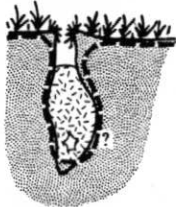
3. SOME SMALL CHANNEL TYPES

A. UPLAND GRAVEL CHANNEL



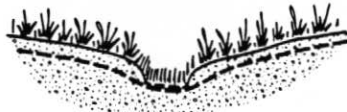
- MAY BE COBBLE-LINED
- MAY HAVE COHESIVE TILL BANKS
- VEGETATION RIP-RAP MAY BE IMPORTANT, OR TURF BANKED
- OFTEN NON-ALLUVIAL (ROCK CONTROLLED)
- MAY BE STABLE: MAY CARRY HIGH BEDLOAD IN EXTREME FLOODS

B. BEADED (THERMOKARST) CHANNEL



- VERY NARROW AND DEEP, OFTEN WIDEST BELOW SURFACE
- TURF BANKED
- COMMON IN HIGH ICE-CONTENT GROUND, SHIFTS AND GROWS BY THERMAL EROSION

C. TUNDRA SEEPAGE



- NO WELL-DEFINED CHANNEL; WATER MOVES LARGELY BY SEEPAGE THROUGH PEAT
- SOLIFLUCTION ACTIVITY INFLUENCES CHANNEL FORM AND POSITION

D. MUSKEG CHANNEL



- NARROW AND DEEP
- BANKS VEGETATION PROTECTED
- BED MAY BE SILT, SAND OR GRAVEL
- STABLE: FREQUENTLY OVERFLOWS (SOMETIMES THERMAL EROSION OCCURS)



Figure 3.

River channel types in northern Canada. See the text for explanation of the data. Reach illustrations are as follows (from the top); Mountain River, NWT, near Gayna River

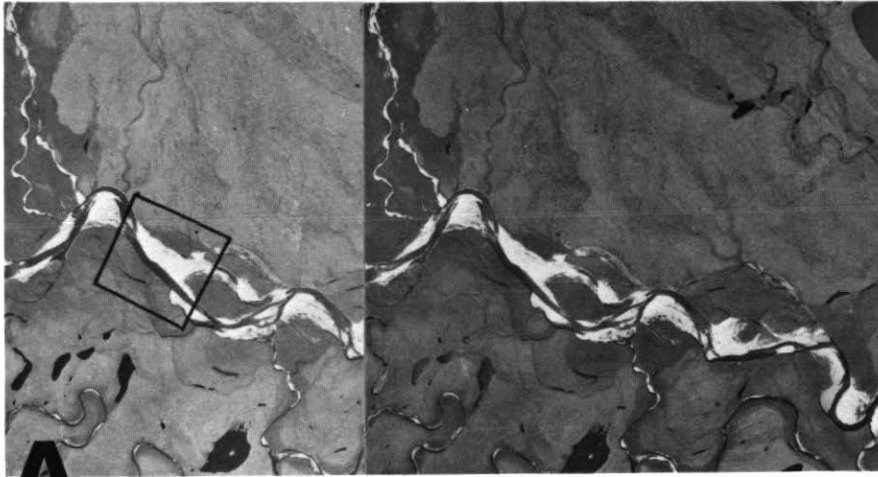
confluence (photo by Alberta Research); Arctic Red River, NWT, near Martin House; Porcupine river, Alaska, near Yukon border (note the vegetation succession of the slipoff

slope of the foreground meander); Strangle Woman River, Yukon-Alaska border; small stream near Yukon north coast (photo by R. Kellerhals); tributary of Coleen River.

environment and sparse settlement. Whilst conventional gauging will continue to be expanded, it should be done within a deliberate framework of hydrological regionalization in order to maximize information returned. There are two aspects to such a rationalization of effort: 1) choice of sites with respect to geographic variability of runoff characteristics; 2) choice of sites with respect to position in the drainage network of a river basin. The second aspect has received less attention than the first.

Beyond this, effort should be devoted to collecting information on river channel changes over a period of years. This could be done by regular survey of designated study reaches in a variety of rivers. Such reaches should be chosen from amongst gauge reaches, project sites, and additional reaches of special interest - such as ones with perennial springs, ones with important fish passages or spawning areas, or ones with special stability problems. Already, initial surveys of this type have been made on reaches of some Yukon rivers

for the territorial Water Management Section (DIAND, 1975). In this way, experience will be gained for enhanced interpretation of the "morphological record" of ungauged rivers.



Photos A13383-148/149; 1952
scale approximately 1:60 000

A

CLASSIFICATION OF VALLEY FLAT AND CHANNEL FEATURES

Reach Name: BABBAGE RIVER; YUKON TERR. Reach No: 8-1: 69°09'N., 138°20'W.

Description of Valley Flat

- Presence: ① none
1 indefinite
2 fragmentary
3 continuous
- Extent: ① none
1 narrow (< 1 Ws)
2 moderate (1-5 Ws)
3 wide (> 5 Ws)

- Average width _____ mi.
Maximum width _____ mi.
Channel length with valley
flat on left _____ %
on right _____ %

- Vegetation:
0 0 not applicable
1 1 almost none or bare
2 ② grass
3 ③ shrubs
- 4 4 sparsely forested
5 5 moderately forested
6 6 heavily forested
7 7 swamp or muskeg

- Forest type:
① 0 not applicable
1 1 deciduous
2 2 coniferous
- Land use:
① 0 not cultivated,
not built-up
1 1 partly cultivated

- 2 2 mainly cultivated
3 3 partly built-up
4 4 mainly built-up

Comments: WILLOW SHRUB
TUNDRA ON OUTWASH
PLAIN

Channel Description (near long-term mean)

- Channel pattern:
1 straight
2 sinuous
3 irregular
4 regular meanders
5 irregular meanders
6 tortuous meanders

- Islands:
① none
1 occasional
2 frequent
3 split
4 braided

- Type of flow:
1 uniform water surface
2 uniform with rapid
in reach
3 irregular

- 4 pool and riffle
sequence
5 tumbling flow

- Bar type:
0 0 0 none
1 1 ① channel side bars
2 2 2 point bars
3 3 3 channel junction bars
4 4 4 mid-channel bars
5 5 5 diamond bars
6 ⑥ 6 diagonal bars
7 7 7 sand waves or large dunes

- Meander dimensions:
belt width 0.5 mi.
wave length 1.0 mi.
sinuosity 1.5

- Natural obstructions:
① 0 none
1 1 logs
2 2 beaver dams
3 3 boulders
4 4 vegetation

- Degree of obstruction:
① 0 none
1 1 occ. minor
2 2 occ. major
3 3 frequent minor
4 4 frequent major

Comments: CLEAN GRAVEL CHANNEL;
SOME VEG. OBSTRUCTION AT FLOOD
LEVEL

Lateral Channel Activity

- Lateral activity:
0 not detectable
1 downstream progression
2 progression and cut-offs

- 3 mainly cut-offs
4 entrenched loop development
5 irregular lateral activity
6 avulsion

- Lateral stability:
0 stable
① slightly unstable

- 2 moderately unstable
3 highly unstable

Comments: PERIODIC
'CHUTE CUT-OFF'
ACROSS POINT BARS

Channel Banks and Bed

- Alluvial bank material:
0 0 0 no alluvial banks
1 1 1 clay and silt (cohesive)
2 2 2 silt and sand (non-cohesive)
3 3 3 sand and gravel (< 64 mm)

- 4 4 4 sand to cobbles
5 5 5 sand overlain by silt
6 ⑥ 6 gravel overlain by silt
7 ⑦ 7 cobbles overlain by silt

- Non-alluvial bank material:
① 0 0 alluvial bank
material
1 1 1 lacustrine deposits
2 2 2 till

- 3 3 3 easily erodible rock
4 4 4 moderately erodible rock
5 5 5 resistant rock
6 6 6 boulders

Percentage of left bank in alluvium 100 %
Percentage of right bank in alluvium 100 %

PEAT

- Bank vegetation:
0 none
1 weak
2 good
3 very strong

- Predominant bed material:
1 sand
2 sand with local gravel
3 gravel
4 gravel with local sand
5 sand and gravel

- Depth of alluvium:
0 no alluvium
1 shallow
2 moderate
3 deep

Estimated depth of alluvium > 50 ft.

Reference or comments: DEEP GLACIAL
OUTWASH

Bed Rock Below Channel

- Presence of rock outcrops in channel bed:
① none
1 one occurrence
2 two occurrences
3 several occurrences

- Rock type at channel base:
① 0 0 not applicable
(none for great depth)
1 1 1 compact clay
2 2 2 shale
3 3 3 limestone

- 4 4 4 sandstone
5 5 5 conglomerate
6 6 6 granite
7 7 7 _____

- Erodibility:
① 0 0 not applicable
1 1 1 soft cohesive
2 2 2 easily erodible
3 3 3 moderately erodible
4 4 4 resistant

Comments: INTERPRETED
REACH DOWNSTREAM
FROM CROW RIVER
CONFLUENCE

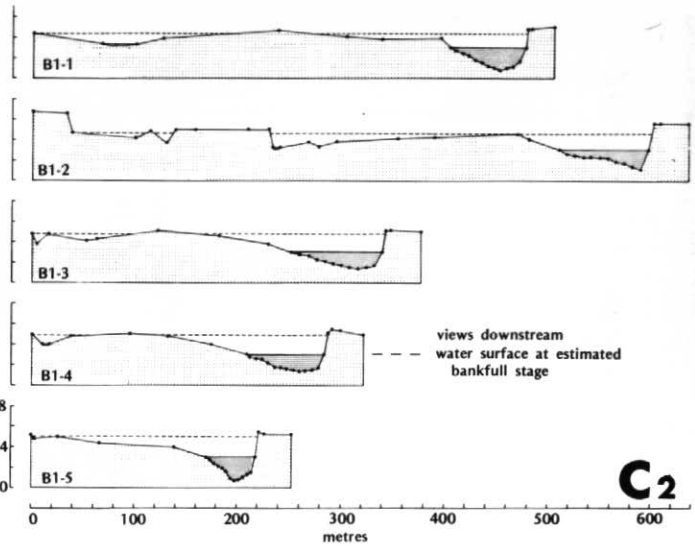
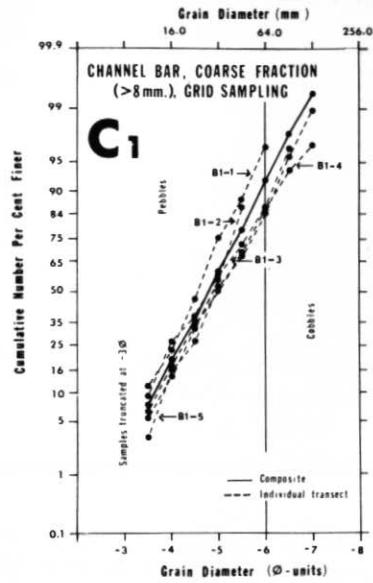
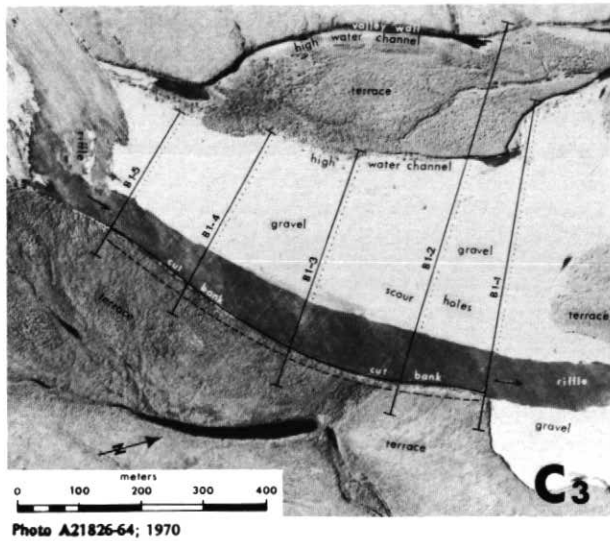
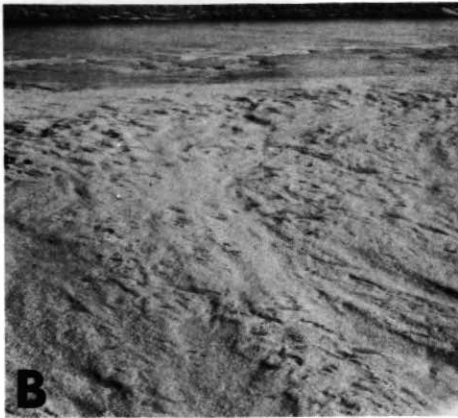
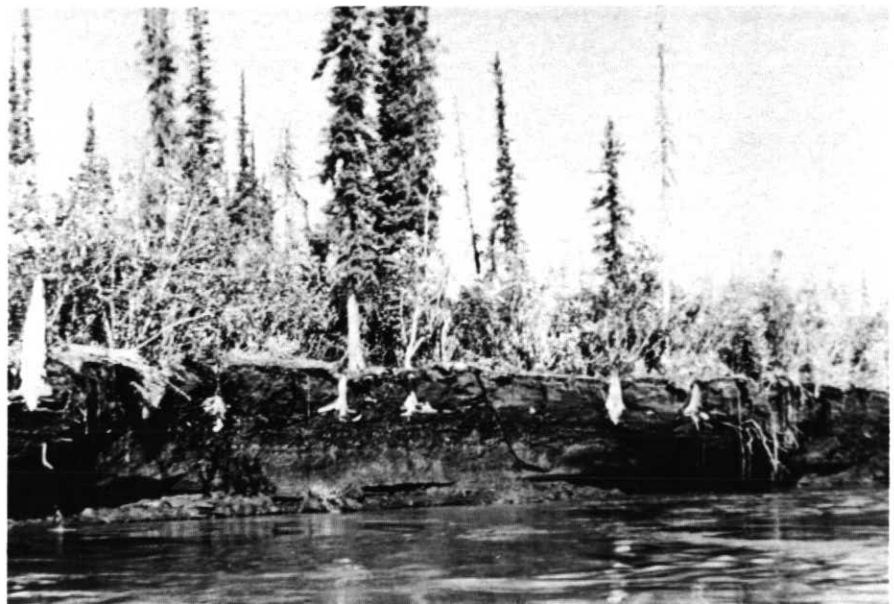


Figure 4

Air photo and field reconnaissance of a reach on Babbage River, Yukon Territory. A - Classification of river morphology from air photographs. B - Field reconnaissance: ice scour holes on gravel bar surface. C - Display of field results and computations (partly after McDonald and Lewis, 1973).

Figure 5

Cutbank in Mackenzie Delta. The exposed root bole indicates the amount of sedimentation that has occurred since the tree commenced growth. The bank is being undercut by a thermal niche: the warm river water is melting ground ice. Photo courtesy of Helen Kerfoot, GSC.



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