Contents

Author Index

Channel changes along the lower reaches of major Mackenzie River tributaries

G.R. Brooks[1]

Brooks, G.R., 2000: Channel changes along the lower reaches of major Mackenzie River tributaries; in *The Physical Environment of the Mackenzie River Valley, Northwest Territories: a Base Line for the Assessment of Environmental Change, (ed.) L.D. Dyke and G.R. Brooks; Geological Survey of Canada, Bulletin 547, p. 159–166.*

Abstract: Alluvial rivers undergo lateral channel change through progressive lateral migration at bends or through channel avulsions. The floodplains of rivers experiencing lateral channel change contain geomorphic features indicative of past migration. Based on aerial photography spanning from the late 1940s–early 1950s to the 1970s–1980s, insignificant lateral channel change occurred along the lowest reaches of the Root, Willowlake, Blackwater, Great Bear, Hume, Ramparts, Hare Indian, Ontaratue, and Arctic Red rivers; all of which have a meandering or meandering-straight planform. In contrast, the lowest reaches of the North Nahanni, Dahadinni, Redstone, Keele, Mountain and Carcajou rivers have all experienced significant lateral channel change, ranging from up to 3 m/year to 11 m/year. An increase in the magnitude and frequency of extreme flows arising from climate warming may cause an overall increase in the rate of bank erosion and net widening of the channel along those river reaches presently experiencing active lateral migration.

Résumé : Les cours d'eau de plaine alluviale voient leur chenal se déplacer latéralement à cause de la migration latérale progressive des méandres ou du détournement du chenal par avulsion. Les plaines d'inondation des cours d'eau se déplaçant latéralement contiennent des éléments géomorphologiques qui témoignent d'une migration antérieure. L'analyse de photographies aériennes prises durant la période allant de la fin des années 1940 et du début des années 1950 aux années 1970 et 1980 révèle qu'il y a eu un déplacement latéral non significatif du lit dans les tronçons inférieurs des rivières Root, Willowlake, Blackwater, Great Bear, Hume, Ramparts, Hare Indian, Ontaratue et Arctic Red; toutes ont une forme en plan méandrique ou méandrique-rectiligne. Par contre, les tronçons inférieurs des rivières Nahanni Nord, Dahadinni, Redstone, Keele, Mountain et Carcajou ont subi un changement latéral important de leur lit qui s'est produit à un rythme d'environ 3 à 11 m/a. L'augmentation de l'intensité et de la fréquence des crues extrêmes causées par le réchauffement climatique pourrait causer une accélération globale de l'érosion des berges et un élargissement net des chenaux qui subissent actuellement une migration latérale.

[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8

INTRODUCTION

Alluvial rivers flowing within a valley bottom containing a floodplain inherently undergo channel change. Over time this can result in lateral migration of the river within the valley bottom, and the widening and narrowing of the river channel. The specific type and relative magnitude of these processes are controlled by local factors and thus can vary considerably from river to river and between different reaches of the same river. Large sections of the major tributaries to the Mackenzie River are alluvial rivers. The purpose of this paper is to briefly review lateral channel change and channel widening processes, summarize channel migration and channel widening occurring along the lower reaches of major Mackenzie River tributaries, and generally discuss the possible implications of climate change on channel change processes.

LATERAL CHANNEL CHANGE

Alluvial rivers undergo lateral channel change through progressive lateral migration and/or avulsions. Progressive lateral migration occurs at river bends through concomitant erosion along the concave (outer) banks and deposition along the convex (inner) banks. This process occurs along both meandering and braided planforms, but is most often associated with the meandering rivers. Along a meandering river, progressive lateral migration over time results in the outward expansion and downvalley procession of the river meanders (Fig. 1). The rate of lateral migration along a river reach is dependent upon a number of local factors, specifically: stream power, planform geometry, sediment transport, bank height, and erosional resistance of the concave banks (Hickin and Nanson, 1984).

An avulsion occurs when a river creates a new channel or abandons an old one. There are several types of avulsions: 1) the meander cutoff process which results in a new section of channel being formed across the neck of the meander being cutoff (Fig. 2a); 2) the creation or abandonment of a channel across the floodplain or vegetated island along a braided channel network (Fig. 2b); and 3) the total abandonment and relocation of the existing channel (Fig. 2c). Avulsions are most likely to occur during periods of high discharge when a river overtops its banks and begins to flow within abandoned channels, depressions, or irregularities on the floodplain. A new or reactivated channel may then be eroded into the floodplain which eventually captures all or part of the river flow.

The floodplains of rivers experiencing lateral channel change contain geomorphic features indicative of past lateral instability. These features are readily apparent on aerial photographs and include abandoned channels, channel scars,

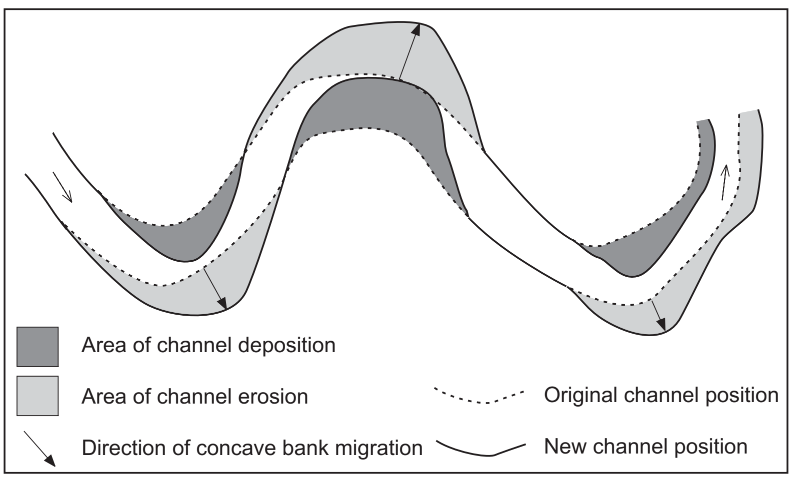


Figure 1.

The process of progressive lateral channel migration along a meandering river through the concomitant erosion of the concave bank and deposition along the convex bank.

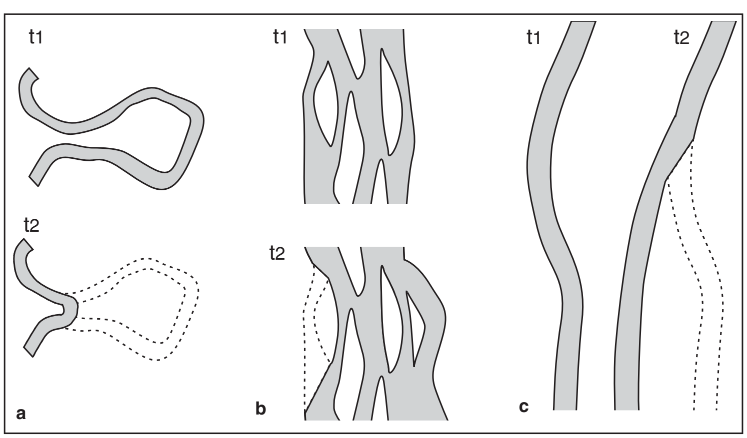


Figure 2.

The three basic types of avulsions: ***a)*** *the meander cutoff process;* ***b)*** *the creation and/or abandonment of channels within a braided channel network; and* ***c)*** *the total abandonment and relocation of an existing channel. The channel positions before and after the avulsions are indicated by the times t_1 and t_2, respectively.*

ox-bow lakes, lateral successions of vegetation communities which are progressively older beginning from the convex banks, and curvilinear tracts of different types and age of vegetation communities (Fig. 3a, 3b).

DYNAMIC CHARACTER OF CHANNEL WIDTH

Channel change processes operate most intensely during periods of high flow (spring runoff or storm events), after a threshold discharge has been exceeded which allows a river to erode the sediments along the base of the concave bank. In some instances, this erosion may be removing sediments that have wasted from the bank face during periods of low flow and which have accumulated along the edge of the channel, rather than actually eroding the intact bank face.

Along a given river reach, concave bank erosion varies considerably from year to year because of variation in the magnitude of the annual high flow. Research on mid-latitude meandering rivers indicates that major concave bank erosion can occur during infrequent, very high-magnitude discharge events (e.g. Pizzuto, 1994) causing significant lateral displacement of the channel. This can also result in major widening of the channel when the relative amount of concave bank erosion greatly exceeds the deposition along the convex bank. Such infrequent, high-magnitude events commonly are followed by a period of successive years having lower, more frequent, high discharges during which the relative amount of aggradation along the convex bank exceeds the erosion occurring along the concave bank, thus causing the channel width to slowly narrow. After a period of time (years or decades), the recurrence of a very high-discharge event may again cause major erosion of the concave bank and substantially widen the channel. The episodic occurrence of major concave bank erosion followed by periods of net aggradation allow the channel cross-section to respond dynamically to discharge conditions over time through widening or narrowing of the channel. Overall, at any give time, channel morphology of a river will reflect the recent discharge history.

Braided rivers generally are also sensitive to the occurrence of infrequent, very high-discharge events. Such events may cause significant progressive erosion of the concave banks of channels both within and along the margin of the braided network resulting in erosion of floodplain, vegetated islands, and stabilized bars. This may be accompanied by avulsions that increase the number of channels. The net result of these processes is the lateral migration of channel(s) and the net increase in channel width. The occurrence of infrequent, very high-magnitude discharges have been documented to cause dramatic widening of some braided river reaches. Again, the infrequent, high-magnitude events commonly are followed by a period of successive years having

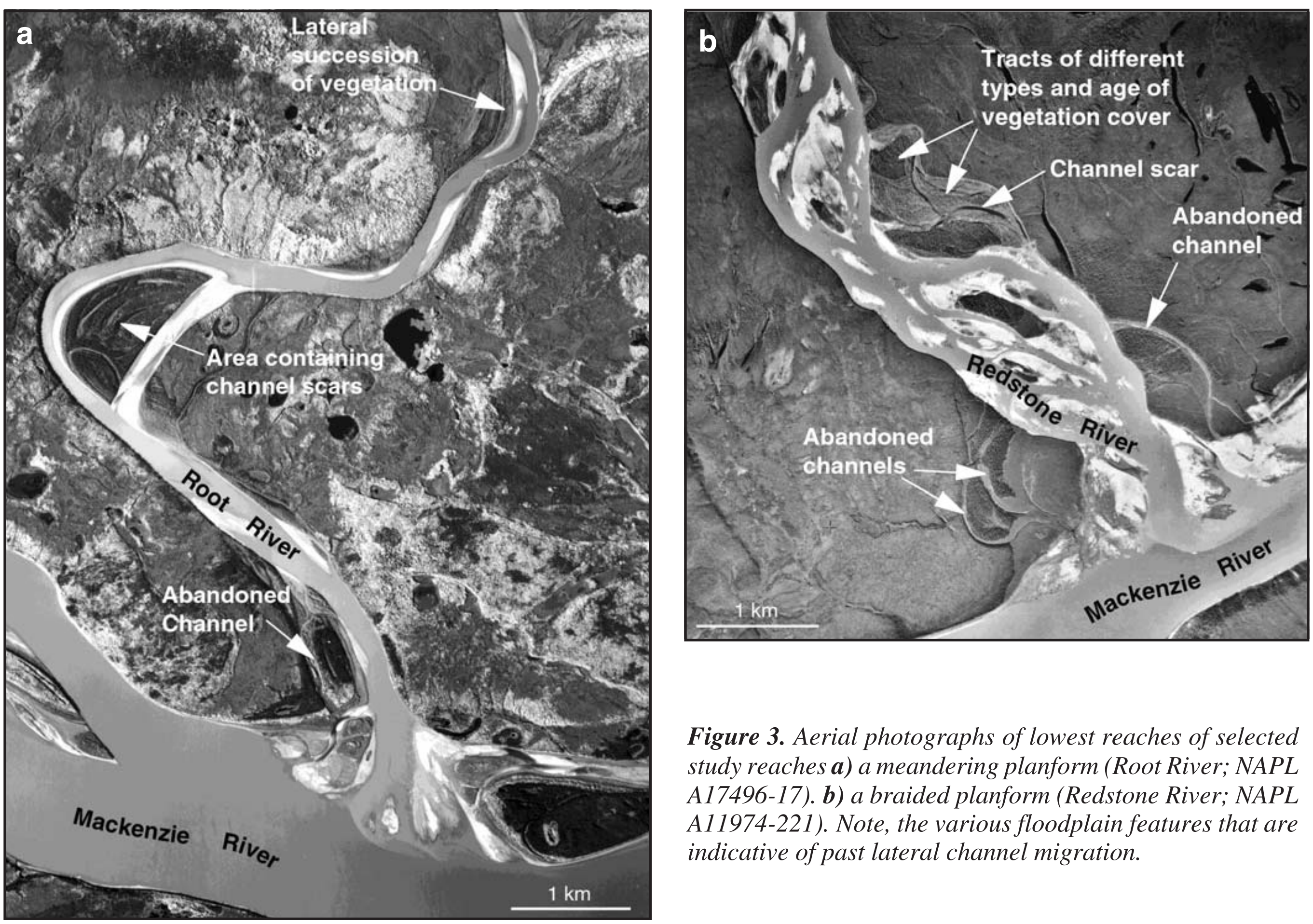


Figure 3. *Aerial photographs of lowest reaches of selected study reaches **a)** a meandering planform (Root River; NAPL A17496-17). **b)** a braided planform (Redstone River; NAPL A11974-221). Note, the various floodplain features that are indicative of past lateral channel migration.*

lower, more frequent high discharges, in which net aggradation occurs in the channel(s) causing the river width to gradually narrow. This occurs because of reduced concave bank erosion in combination with bar accretion, channel abandonment, and revegetation of the inactive bar surfaces. After a sufficient period of channel 'recovery', the recurrence of another infrequent, high-magnitude discharge will repeat the widening-narrowing cycle.

Recognition of the cyclic nature of channel migration and widening is important in determining rates of lateral channel migration (Nanson and Hickin, 1983). It is critical that channel change be assessed over a sufficient period of years so that a very wide range of peak flows and storm events have occurred within the intervening period to gain a proper understanding of local channel change characteristics and to allow a representative average of channel migration to be determined. Representative average rates of channel change can be determined from historic aerial photographs or from dendrochronology of the forest on the floodplain behind the convex bank (*see* Hickin, 1988).

CHANNEL CHANGE ALONG THE MACKENZIE VALLEY

Overall, few channel change studies have been conducted on the Mackenzie valley river systems. G. Brooks (unpub. data, 1994; Brooks, 1996) mapped lateral channel migration along the lowest 4–10.5 km of 15 major tributaries entering Mackenzie River between Fort Simpson and the Mackenzie Delta (Fig. 4) using aerial photography beginning in the late 1940s or early 1950s and extending into the 1970s or the 1980s, depending upon availability. Rates of lateral channel change were based upon the amount of erosion occurring along the steep concave banks which on aerial photographs

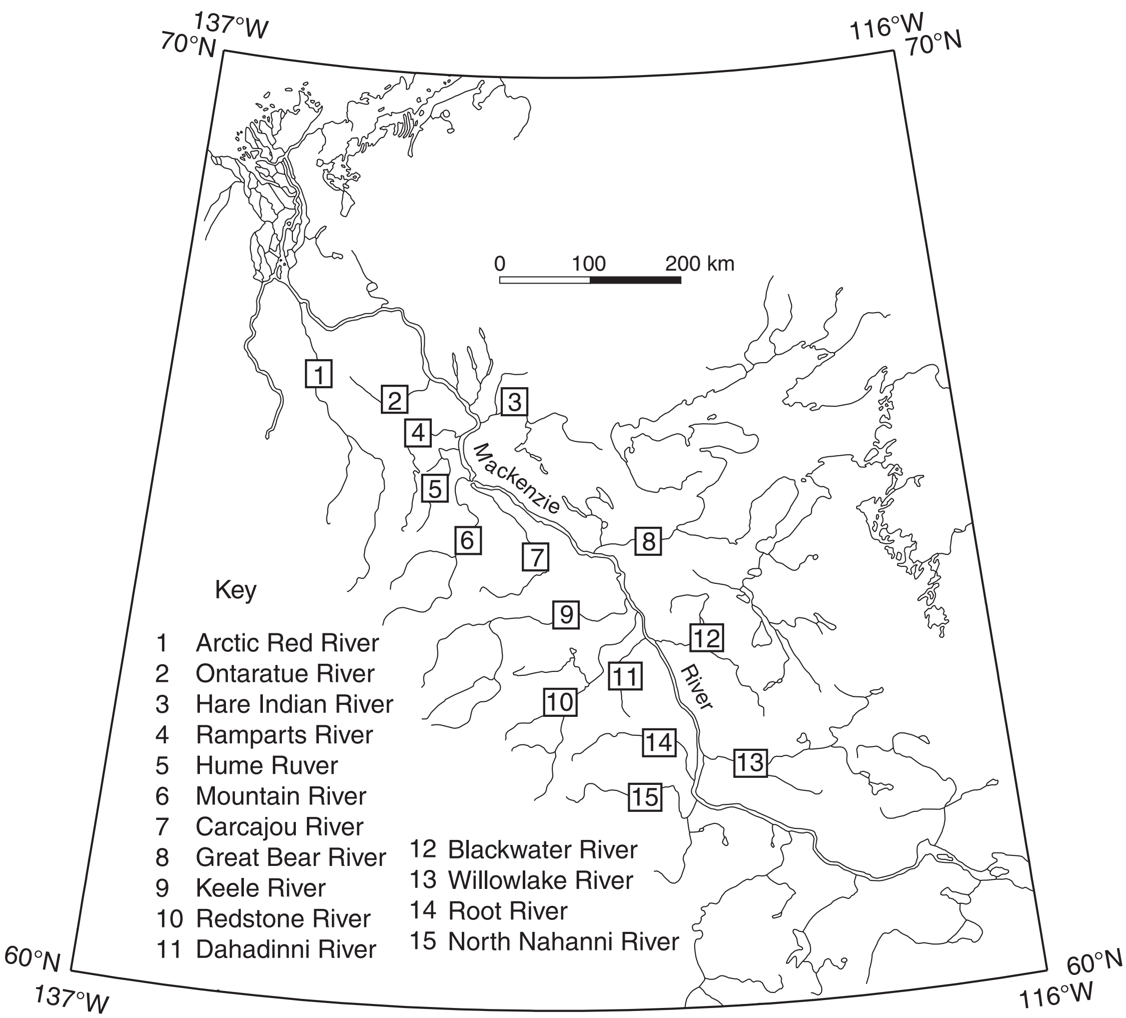


Figure 4. *Map showing the location of 15 major tributaries of the Mackenzie River. Channel change data of the lowest 4–10.5 km of each tributary is summarized in Table 1.*

are well defined by a sharp break in the vegetation cover at the edge of the river. Rates of lateral accretion were not determined because the margin of the water surface on the river bars is affected considerably by stage differences between sets of aerial photographs and thus is subject to considerable error. Examples of the net historic channel change occurring over the lower reach of a selected meandering and braided study reach are depicted in Figure 5. From Figure 5b, it is obvious that channel change within a braided river can be very complex resulting in modification to both the outer margins of and the islands and bars within the braided network.

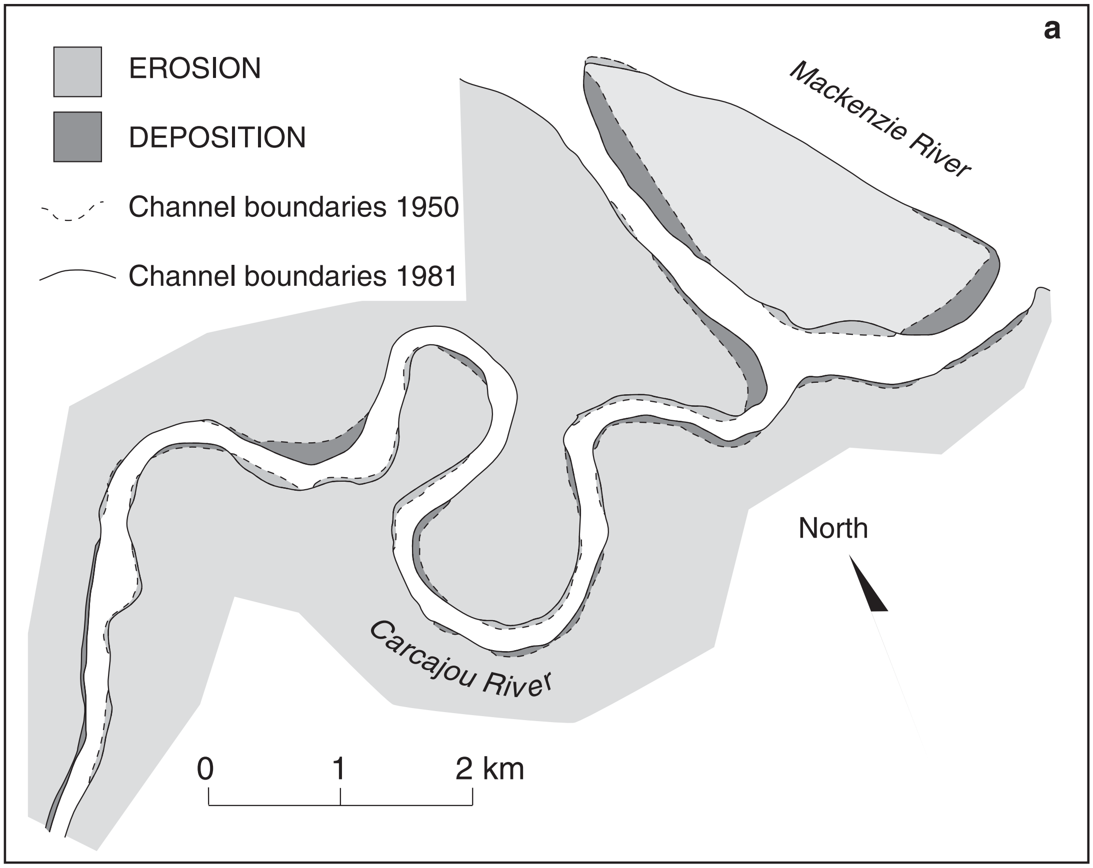
Table 1 lists the maximum average rate of lateral channel change occurring along the lowest 4–10.5 km of the 15 tributaries. Bank erosion of 50 m is considered to be the detection level of the methodology used to determine the amount of channel change, thus erosion of less than 50 m is reported as insignificant in Table 1. In Table 1, the rate of maximum erosion along the braided rivers relates to the outer margin of the river and corresponds generally to the concave bank of a major channel meandering back and forth from one side of the braided network to the other. The results in Table 1 represent the average of the maximum rate of erosion occurring within the study reaches over the time span of the aerial photography.

As summarized in Table 1, insignificant lateral channel change has occurred along the lowest reaches of 9 of the 15 tributaries (Root, Willowlake, Blackwater, Great Bear, Hume, Ramparts, Hare Indian, Ontaratue, and Arctic Red rivers). All of these nine rivers have a meandering or meandering-straight planform. Backwater conditions from Mackenzie River exist along seven of these rivers (Root, Willowlake, Hume, Ramparts, Hare Indian, Ontaratue, and Arctic Red rivers) even during relatively moderate discharge levels and this is the major factor limiting lateral channel change. The lower reaches of these rivers are in a sense ‘drowned’ by the Mackenzie River whereby flow velocity is severely limited causing low stream power. An additional factor limiting lateral channel migration is that some sections of Root, Willowlake, Hume, Hare Indian, and Arctic Red rivers are confined against the relatively high valley sides. Along the remaining two of the nine rivers (Great Bear and Blackwater rivers), the lower reaches are both relatively

Table 1. Summary of channel change processes along lower reaches of selected major Mackenzie River tributaries.

River	Channel planform	Channel change processes	Length of study reach above tributary mouth[a] (km)	Time of airphoto coverage	Maximum lateral channel migration[b] (m)	Maximum rate of lateral channel migration (m/year)
North Nahanni	Braided	Progressive lateral migrations Avulsions Cyclic channel widening	7	1948–1977	200	6.9
Root	Meandering	Progressive lateral migrations Avulsions	8	1947–1977	Insignificant	na
Willowlake	Meandering	Progressive lateral migration	4.5	1947–1972	Insignificant	na
Blackwater	Straight	Progressive lateral migration Avulsions	4	1945–1987	Insignificant	na
Dahadinni	Braided	Progressive lateral migrations Avulsions Cyclic channel widening	6	1945–1981	338	9.4
Redstone	Braided	Progressive lateral migrations Avulsions Cyclic channel widening	6.5	1949–1981	340	10.6
Keele	Braided	Progressive lateral migrations Avulsions Cyclic channel widening	7.5	1949–1981	203	6.3
Great Bear	Meandering	Progressive lateral migration	5.5	1944/45–1983	Insignificant	na
Carcajou	Meandering	Progressive lateral migration Cyclic channel widening (?)	10.5	1950–1981	100	3.2
Mountain	Braided	Progressive lateral migrations Avulsions Cyclic channel widening	8	1950–1981	233	7.5
Hume	Meandering	Progressive lateral migration	5.5	1950–1971	Insignificant	na
Ramparts	Meandering straight	Progressive lateral migration	7	1950–1971	Insignificant	na
Hare Indian	Meandering	Progressive lateral migration	6	1950–1971	Insignificant	na
Ontaratue	Meandering straight	Progressive lateral migration	5.5	1950–1970	Insignificant	na
Arctic Red	Meandering	Progressive lateral migration	7	1950–1980	Insignificant	na

[a] Distance measured along valley axis
[b] The amount of lateral channel migration is averaged over the time interval between sets of air photos. Lateral channel migration of less than 50 m is not considered significant.
na = not applicable



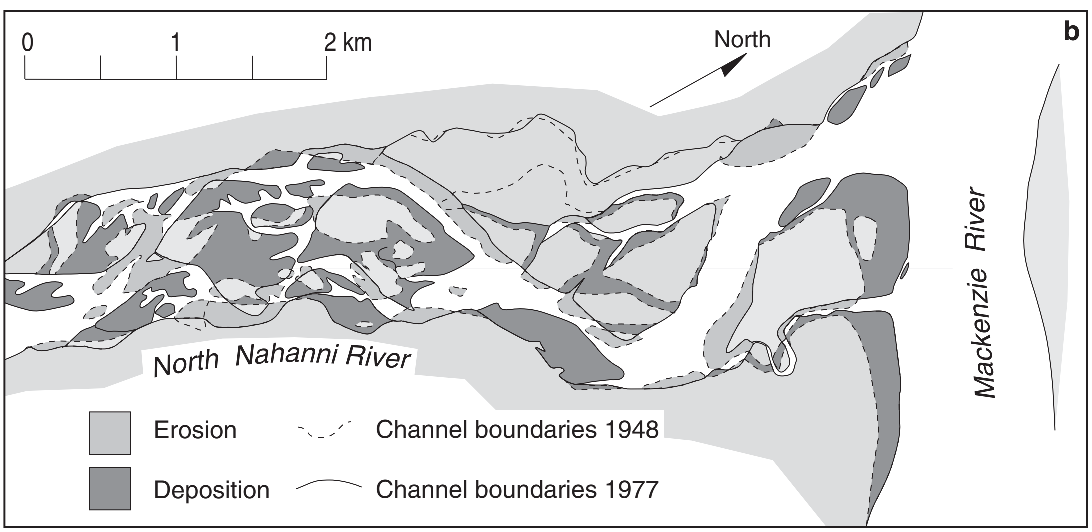


Figure 5. *Net channel migration as determined from historical aerial photographs along:* ***a)*** *the meandering Carcajou River between 1950 and 1981 and* ***b)*** *the braided North Nahanni River between 1948 and 1977. Note that the mouth of Carcajou River is split by an island situated along the edge of the Mackenzie River channel.*

fast-flowing streams. Channel change along Great Bear River is limited by a very regular discharge regime, low sediment load and confinement within a Tertiary bedrock valley. Along the study reach of Blackwater River the channel margins are formed by coarse boulder lag which seems to be resistant to erosion by the river.

The lowest reaches of the five braided rivers (North Nahanni, Dahadinni, Redstone, Keele and Mountain rivers) and the meandering Carcajou River have all experienced significant lateral channel change ranging from about 3–11 m/year. Along these reaches, all five braided rivers are swift flowing, thus, stream power is relatively high, particularly during extreme discharges. Stream power along Carcajou River is lower than the five braided rivers because the flow is slower, but still is sufficiently high to significantly erode the river banks. Significantly, along all six rivers a major proportion of the concave bank erosion is occurring directly into the contemporary floodplains which are relatively low in height and consist of silt, sand, and gravel alluvium that is susceptible to cutbank erosion.

CYCLICAL CHANNEL WIDENING

There has been no study monitoring channel width along any reach of a Mackenzie valley river system. The general effects of high-magnitude flows that have been documented, observed on sequences of aerial photographs and in the field, suggest that cyclic channel widening and narrowing does occur along at least several of the major Mackenzie River tributaries. In 1970, a severe storm centred upon the Mackenzie Mountains caused flooding and major channel changes (including channel widening) along the Redstone, Keele, Mountain, and Arctic Red rivers (MacKay et al., 1973). Early 1970s aerial photography of the Keele, Redstone, and Dahadinni study reaches depict a significantly wider braided channel than that appearing in 1940s aerial photography. Although this widening has occurred sometime in the interval between the 1940 and 1970 aerial photography, it may well have resulted from this flood which preceded the 1970s photography by only a few years. Severe rainstorms in early July 1988 produced major flooding along the upper Mackenzie valley which caused net channel widening along the Keele, Redstone, Dahadinni, and North Nahanni through bank erosion, channel avulsions, and reorganization of the braided channel networks. The geomorphic effects of this storm were still apparent along these rivers in 1992 in the form of wide areas of inactive channels and bar surfaces that were in the very early stages of revegetation and which probably represent the initial period of channel narrowing.

EFFECTS OF CLIMATE CHANGE

As described in Brooks (2000), hydrological modelling of the effects of global climatic change in the Mackenzie basin area indicates that precipitation would increase resulting in greater stream runoff. Some modelling scenarios, however, suggest that this increased precipitation would be more than offset by greater evapotranspiration, thus making the landscape drier causing a decrease in river runoff. These contradictory results perhaps suggest that the net effect upon average streamflow in the Mackenzie basin may be minimal.

The effects of global climatic change upon the rates of channel change along the lowest reaches of the major Mackenzie River tributaries are not known with certainty. A minor change to mean annual discharge probably will have an insignificant effect upon channel change. In some regions of North America, it is believed that an increase in the frequency of very high-magnitude discharges will be associated with climate change (Knox, 1993). As discussed above, major bank erosion and channel widening can occur along some river reaches during infrequent, very high-magnitude flows. If the frequency of these flows increased, then there could be an overall increase in concave bank erosion and thus an increase in the rate of lateral channel migration. There might also be a net widening of the river channel or braided network because the period between the high-magnitude events would be less thus preventing the same degree of narrowing. Finally, on a smaller scale along the braided rivers, a greater amount of channel shifting within the braided channel networks could occur because of increased erosion and deposition of the river bars.

Increased rates of migration and channel widening could occur along the study reaches of North Nahanni, Dahadinni, Redstone, Keele, Mountain, and Carcajou rivers, all of which currently are experiencing significant amounts of lateral channel change. Of those lower reaches which experienced insignificant channel migration, perhaps only the Blackwater River study reach might be affected if the high-magnitude events have sufficient competence to erode the coarse channel bed. Negligible impacts might be expected along the remaining study reaches. The Great Bear River study reach would continue to experience a very low range of discharge because of the regulating effects of Great Bear Lake whereas backwater conditions from Mackenzie River, which inhibit stream power, would still be present along the lower reaches of Root, Willowlake, Hume, Ramparts, Hare Indian, Ontaratue, and Arctic Red rivers.

ACKNOWLEDGMENTS

This research was funded by the Green Plan and Northern Oil and Gas Action Plan. Thanks to J. Jasper for critically reading the manuscript.

REFERENCES

Brooks, G.R.

1996: The fluvial geomorphic character of the lower reaches of major Mackenzie River tributaries, Fort Simpson to Norman Wells, Northwest Territories; Geological Survey of Canada, Bulletin 493, 89 p.

2000: Streamflow in the Mackenzie valley; *in* The Physical Environment of the Mackenzie Valley, Northwest Territories: a Base Line for the Assessment of Environmental Change, (ed.) L.D. Dyke and G.R. Brooks; Geological Survey of Canada, Bulletin 547.

Author Index

Hickin, E.J.
1988: Lateral migration rates of river bends; *in* Civil Engineering Practice, Volume 2 (Hydraulics/Mechanics); (ed.) P.N. Cheremisinoff, N.P. Cheremisinoff, and S.L. Cheng; Technomic Publishing Company, Lancaster, Pennsylvania, p. 419–444.

Hickin, E.J. and Nanson, G.C.
1984: Lateral migration rates of river bends; American Society of Civil Engineers, Journal of the Hydraulic Division, v. 110, p. 1557–1567.

Knox, J.C.
1993: Large increases in flood magnitude in response to modest changes in climate; Nature, v. 361, p. 430–432.

MacKay, D.K., Fogarasi, S., and Spitzer, M.
1973: Documentation of an extreme summer storm in the Mackenzie Mountains, N.W.T; *in* Hydrologic Aspects of Northern Pipeline Development; Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development, Report 73-3, p. 191–221.

Nanson, G.C. and Hickin, E.J.
1983: Channel migration and incision on the Beaton River; American Society of Civil Engineers, Journal of the Hydraulic Division, v. 109, p. 327–337.

Pizzuto, J.E.
1994: Channel adjustments to changing discharges, Powder River, Montana; Geological Society of America Bulletin, v. 106, p. 1494–1501.