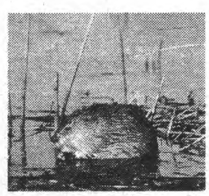
Canada Alberta Northwest Territories

Northern River Basins Study





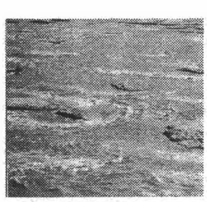





NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 102

CHANGES IN MORPHOLOGY AND RIPARIAN VEGETATION FOLLOWING FLOW REGULATION,

PEACE RIVER, 1968 AND1993



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by

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PREFACE:

The Northern River Basins Study was initiated through the "Canada-Alberta-Northwest Territories Agreement Respecting the Peace-Athabasca-Slave River Basin Study, Phase II - Technical Studies" which was signed September 27, 1991. The purpose of the Study is to understand and characterize the cumulative effects of development on the water and aquatic environment of the Study Area by coordinating with existing programs and undertaking appropriate new technical studies.

This publication reports the method and findings of particular work conducted as part of the Northern River Basins Study. As such, the work was governed by a specific terms of reference and is expected to contribute information about the Study Area within the context of the overall study as described by the Study Final Report. This report has been reviewed by the Study Science Advisory Committee in regards to scientific content and has been approved by the Study Board of Directors for public release.

It is explicit in the objectives of the Study to report the results of technical work regularly to the public. This objective is served by distributing project reports to an extensive network of libraries, agencies, organizations and interested individuals and by granting universal permission to reproduce the material.

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Whereas the above publication is the result of a project conducted under the Northern River Basins Study and the terms of reference for that project are deemed to be fulfilled,
IT IS THEREFORE REQUESTED BY THE STUDY OFFICE THAT;
this publication be subjected to proper and responsible review and be considered for release to the public.

(Dr. Fred J. Wrona, Science Director) — (Date) 22 Apr 96

Whereas it is an explicit term of reference of the Science Advisory Committee "to review, for scientific content, material for publication by the Board",
IT IS HERE ADVISED BY THE SCIENCE ADVISORY COMMITTEE THAT;
this publication has been reviewed for scientific content and that the scientific practices represented in the report are acceptable given the specific purposes of the project and subject to the field conditions encountered.
SUPPLEMENTAL COMMENTARY HAS BEEN ADDED TO THIS PUBLICATION: [ ] Yes [ ] No

(Dr. P. A. Larkin, Ph.D., Chair) — (Date) April 23/96

Whereas the Study Board is satisfied that this publication has been reviewed for scientific content and for immediate health implications,
IT IS HERE APPROVED BY THE BOARD OF DIRECTORS THAT;
this publication be released to the public, and that this publication be designated for: **[ ] STANDARD AVAILABILITY [ ] EXPANDED AVAILABILITY**

(Lucille Partington, Co-chair) — (Date) April 23/96

(Robert McLeod, Co-chair) — (Date) 30/04/96

CHANGES IN RIVER MORPHOLOGY AND RIPARIAN VEGETATION FOLLOWING FLOW REGULATION, PEACE RIVER, 1968 AND 1993

STUDY PERSPECTIVE

The filling and operation of Williston Reservoir created by the W.A.C. Bennett Dam in British Columbia in 1967, altered the natural flow patterns of the Peace River. The effects of this change are discernable most immediately downstream of the dam, but are also apparent in the Peace - Athabasca Delta, almost 2000 km downstream, and in the Slave River Delta, a further 500 km downstream. People associated with these riverine environments had previously raised concerns about the effect of flow regulation on the aquatic ecosystem. The Northern River Basins Study Board identified under its science program flow regulation as an area requiring further investigation. A program of studies was initiated within the Hydrology component to investigate the effects of flow regulation. The studies included a number of impact related investigations into the effects of flow regulation on river morphology, flows, ice jamming and aquatic habitat of the Peace and Slave rivers and their associated deltas. Considerable attention has previously been directed at the Peace-Athabasca Delta with minimal examination of possible effects on the main channel of the Peace River.

Related Study Questions

10. How does and how could river flow regulation impact the aquatic ecosystem?

13. a) What predictive tools are required to determine the cumulative effects of man made discharges on the water and aquatic habitat?

b) What are the cumulative effects of man made discharges on the water and aquatic environments?

14. What long term monitoring programs and predictive models are required to provide an ongoing assessment of the state of the aquatic ecosystems. These programs must ensure that all stakeholders have the opportunity for input.

The report describes the result of an investigation into the impacts of regulation on the Alberta portion of the Peace River channel and its associated vegetative cover downstream of the W.A.C. Bennett Dam. Four representative reaches of the Peace River totalling 500 km of the total 1100 km channel were selected for investigation. Examination of changes between 1968 and 1993 have revealed a significant narrowing of the river channel in the Alberta border to Dunvegan, and upstream-Tompkins Landing to downstream Fort Vermilion reaches, as the river abandoned side channels and vegetation became established on sand / gravel bars. Channel processes in the lowest most section, Garden Creek to Jackfish River, will continue as before but narrower channels are likely. The extensive bar development common to the Alberta border to Tompkins Landing are also the areas where the greatest change is occurring. It is anticipated that these areas will continue to be the least stable zones. Although the Peace River downstream of its juncture with the Smoky River is carrying the same quantity of sediment as prior to flow regulation, the present streamflow regime is incapable of moving incoming sediment as was the case historically. Consequently, there is now more deposition taking place downstream of Tompkins Landing. The loss of side channels combined with the expansion and stabilization of bars with vegetation common to drier sites has influenced the structure of the aquatic and terrestrial communities associated with the Peace River. The effects of these changes on the aquatic / terrestrial fauna remain largely unknown and without additional investigation there can be only speculative assessment.

A compilation of information from this project and others examining the effects of flow regulation on the Peace River will form the foundation for a synthesis report. There is an ongoing analyses of additional information for five time periods, including the effects of a flood of record that occurred in 1990. The National Hydrology Research Institute of Environment Canada will publish the report when it is completed. A CD Rom of the maps prepared for this project will be released with this latter report.

REPORT SUMMARY

This project was to determine the changes in morphology and riparian vegetation that have occurred in the Alberta reaches of Peace River by constructing maps of river morphology and principal riparian vegetation communities from air photographs taken at various dates. The intention is to complete maps at 5 dates, including 1950, so that pre-regulation changes can be measured. Mapping was completed in 4 major reaches, totalling some 612 km of the 1050 km course of the river in Alberta. The maps were constructed in an analytical stereoplotter and the files exported to a GIS for manipulation and map production. In addition field work was undertaken in 1994 to provide ground truth for interpreting the vegetation communities.

At this writing, the maps have been completed for 1968 and 1993, so changes that have occurred over the 25 years of regulation can be summarised (the 1968 coverage is actually constructed from available photography taken in several years near the nominal date). Each complete set of maps comprises 40 sheets at 1:20 000 that approximately correspond with the Alberta digital topographic mapping. In addition, extended vegetation mapping was provided on the 1993 maps to show the valleyside vegetation beyond the riparian zone. Morphological changes have been summarised in 31 subreaches of 10 to 25 km length, which reasonably samples the riffle/pool scale along the river. River morphology has been summarised in six major elements, water surface, unvegetated bar surface, vegetated bar surface, island surface, floodplain surface, and tributary alluvial fans within the floodplain. Changes amongst all combinations of these features are available between each date of mapping.

Changes during the 25 years since regulation have included substantial narrowing of the river in major reaches 1 and 3 (the proximal gravel-bed reach and the proximal sand-bed reach), but much less narrowing in the remaining two reaches. Most of Reach 2 was formerly confined and this probably limits the adjustment that will occur. Reach 4, in the Slave Lowland, has different morphology which preconditions less rapid adjustment. Where adjustments have occurred they have dominantly been achieved by riparian vegetation succession onto abandoned bartops and into abandoned side channels. Hence the adjustment process thus far has largely been passive and has depended in a significant way upon riparian succession.

The dominant pattern of riparian succession has been the establishment of scattered shrubs and grasses on the upstream gravel bar surfaces but, once sand becomes trapped on the bartop a continuous shrub cover develops. Downstream, banded galleries of shrubs have established on bar surfaces surrounding old island cores. The changes are most extensive in areas with substantial island development where the river always has been least stable. These are places where bed material is transiently stored on its way down the river. They will remain the sites of main instability and will ensure some renewal of the early, allogenic plant succession.

ACKNOWLEDGMENTS

This project was established because of the foresight of Dr. Terry Prowse, of the National Hydrological Research Institute, and Dr. Gordon Walder, advising NRBS. Ms. Margaret North was co-principal investigator in the project, responsible for the vegetation mapping. Her work and ideas have been instrumental in the success of the project. A critical contribution was made by Dr. Bruce Maclock, of Alberta Environmental Protection, who recovered geodetic control data which we had been unable to obtain.

In the nature of this project, which was essentially a mapmaking exercise, we had relatively little interaction with the people of the Peace River valley. We wish to acknowledge, however, the proprietors of the LaCrete Motel, who gave us some exceptional help during a 1994 reconnaissance trip. We hope that, in years ahead, our maps may help the people of the valley to understand the changes that are occurring along their river as the result of flow regulation and resource development.

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1.0 INTRODUCTION

1.1 OBJECTIVES AND APPROACH

Since 1968, the flow in Peace River has been regulated at W.A.C.Bennett Dam, near Hudson's Hope, British Columbia. The usual effect of flow regulation in rivers is to change the flow and sediment transport regimes of the river and, consequently, to modify the morphology of the channel. It is the purpose of this report to describe the changes that have occurred in the morphology of Peace River in Alberta between 1968 and 1993 and the associated changes in riparian vegetation. In addition, predictions will be made of the probable final form of the channel, and of the time scales to achieve full adjustment following regulation.

The main approach to the work was the preparation of planimetric maps of four reaches of Peace River totalling some 600 km of the total 1050 km course of the river between the Alberta border and the Peace-Athabasca delta. The reaches were chosen to represent four distinctive reaches of the river, varying from an upstream cobble-gravel reach to the downstream sand-bed meandered reach just upstream from the delta. Major elements of the river morphology and major riparian vegetation formations were mapped using a computer-linked stereophotogrammetric plotter and entered into a GIS for manipulation. The project entails the completion of mapping at five dates between 1950 and 1993. At present mapping is completed for three dates and analysis is complete for 1968 and 1993. The GIS is used to estimate areas occupied by each morphological element at each date, thence the changes in the intervening period. The changes can be displayed on maps to permit study of the mechanisms by which change is proceeding.

In June, 1994, a reconnaissance of the river was conducted in order to provide ground truth information to guide the mapping and, in June through September, 1995, a traverse was made of the river from the British Columbia-Alberta border to Fort Vermilion, Alberta, covering all of three study reaches and the intervening channel. Study reach 4, below Vermilion Chutes, has not been visited on the ground.

This program is immediately relevant to the purposes of the Northern River Basins Study because changes in river morphology and the associated changes in riparian vegetation influence the quantity and quality of both aquatic and riparian habitat along the river, and may thereby influence the occurrence and abundance of the fauna. The river fishery and certain birds and mammals remain significant elements in the economy of people along the river, and the conservation of all of these elements is of national significance along a major waterway such as Peace River. It is, furthermore, important to establish a basis to distinguish the effects on these elements of flow regulation, other land use effects (such as forest harvest), and regional environmental change, and to separate these from the normal effects of flow, sediment transport and ice effects along the river.

1.2 CURRENT STATE OF KNOWLEDGE

Regulation of river flows, and the consequent adjustment to the pattern of sediment transfer downstream alter alluvial river regime (cf. Petts, 1984). In the most common case, sediment is intercepted in the reservoir where flow regulation occurs. The geomorphological effects of these primary changes in flow and sediment regimes have been analysed by Galay (1983) and by Williams and Wolman (1984). Provided the post-regulation flows remain competent to move bed material, the initial effect is degradation downstream from the point of regulation because the entrained sediment is no longer replaced by material arriving from upstream. According to the relative erodibility of stream bed and banks the degradation may be accompanied by either narrowing or widening of the channel. A result of degradation is coarsening in the texture of material left in the streambed; in many cases, a change from sand to gravel is observed and in some, scour proceeds to bedrock. On most rivers these effects are constrained to the first few kilometres or tens of kilometres below the point of regulation. Typically, 1 to 3 metres of degradation occurs within a decade or two of regulation. Farther downstream, aggradation may occur because material mobilised below a dam and material recruited from tributaries cannot so quickly be moved through the channel system by the regulated flows. Channel widening is a frequent concomitant of aggradation.

Because of the reduction in sediment transport, the channel pattern near the point of regulation may ultimately be changed from braided to split or single-thread, and from less toward more sinuous (see examples in Galay, 1983, and in Williams and Wolman, 1984). The progradation of riparian vegetation down the banks of the regulated channel may be an important element of long term width and pattern adjustment which ultimately leads to a substantially narrower channel because a smaller conveyance area is required. The time scale of these adjutments is influenced by the severity of the regulation and by the time for development of seral vegetation communities. Because of the time required to redistribute substantial volumes of sediment, the ultimate adjustment of large rivers requires a very long period, but no system has yet been studied for more than a few decades.

A circumstance of virtually all prior studies is that sediment transfer downstream has been significantly interrupted at the point of regulation. Consequently, the direct effects of the interruption of sediment delivery, and those associated with the changed ability of the river to move and redistribute sediment downstream are confounded. In Peace River, virtually the entire sediment load is added downstream from the point of regulation, so the only primary regulated factor is the water flow. The authors are unaware of a significant precedent for this case which has been studied.

The character of the alluvial sediments influences the nature of morphological response to regulation. Sand-bed channels have been well-studied, and the response to regulation commonly is described in terms of such channels. Peace River flows over a cobble-gravel bed in its upstream reaches but transition to a sand bed occurs near Carcajou. Hence, the river is influenced along its course by a wide range of bed materials with substantially different mobility. Seasonal ice significantly influences the morphology of this river as well. A major study has not been made of the morphoogical effects of regulation in an ice-affected river.

Aside from its regional significance, then, this river presents opportunities for unprecedented scientific studies. A preliminary report on the river was presented in Church (1995).

2.0 STUDY AREA AND HYDROLOGICAL CONTEXT

Peace River (Figure 1) drains parts of two large-scale landscape units, the Rocky Mountains and the Interior Plains. Along most of its course east of the Rocky Mountains, the river flows in a valley incised several hundred metres below the adjacent prairie level. The river is partly confined and the floodplain is narrow and discontinuous. The bedrock is composed of poorly lithified sediments of mainly Cretaceous age (Holland, 1964). Consequently, basal erosion by the river has induced frequent, major landslides. The incidence of failures is perhaps one every few decades at some place along the river. The pre-regulation river was of low sinuosity with frequent channel islands, often overlapping in the proximal gravel-bed reach. Farther downstream, bed materials are much finer and confined sinuosity (i.e., sinuosity constrained by the valley width) increases. Beyond Carcajou, the river is essentially a sand-bed river, but there remains a significant gravel component in the channel sediments all the way to Vermilion Chutes, a severe, bedrock-controlled rapid below Fort Vermilion.

Precipitation in the upper part of the montane portion of the Peace River basin is much higher than in the plains to the east, and the geology of the two regions is also quite different. Controlled by different geographical and geological circumstances, the major contributing areas of water are different than those of sediment. The water arises preponderantly from the upper part of the basin above Bennett Dam, and the sediment from the area below it.

Above the dam, the headwaters of Peace River are located in the Rocky Mountains, and above Peace River town all the major tributaries originate from the Rocky Mountains and foothill region. The trunk stream below Hudson Hope and the tributaries below Peace River town are all located in the Alberta Plateau region and Peace River Lowland (Figure1). The drainage area above the dam accounts for only 24% of the total basin area, but the mean annual water discharge from this part of the basin (based on the gauge at Hudson's Hope, WSC 07EF001) accounts for 51% of the total at Peace Point (the most distal gauge, WSC 07KC001). In the pre-dam period, the mean annual flood reached its peak value of 10 580 m^3s^{-1} at Peace River town (WSC gauge 07HA001), and the mean annual flood at Hudson's Hope was 6 310 m^3s^{-1} accounting for 60% of the former value. Thus the drainage area above the dam can be regarded as a major contributing area of runoff.

On the other hand, the source of sediment is mainly located in the part of the basin east of the mountains. Because data are very limited (only at Peace River town is there available a relatively complete record of suspended sediment load in the river), this can not at present be demonstrated by direct measurements. However, this conclusion can be reached by considering the geology and geomorphology. The Rocky Mountains consist mainly of resistant lithologies with good resistance to erosion by flowing water. The surface material to the east is quite different. In the Pleistocene Epoch, this area was located between the Cordilleran Ice Sheet to the west and the Laurentide Ice Sheet to the east, and the material carried by ice came together from opposite directions and was deposited here. After about 14 000 years ago, Glacial Lake Peace formed along the valley where the present Peace River flows. So in this area thick unconsolidated drift and lake deposits, composed of clay, silt and sand with boulders, are widely distributed. The resistance of these materials to erosion is

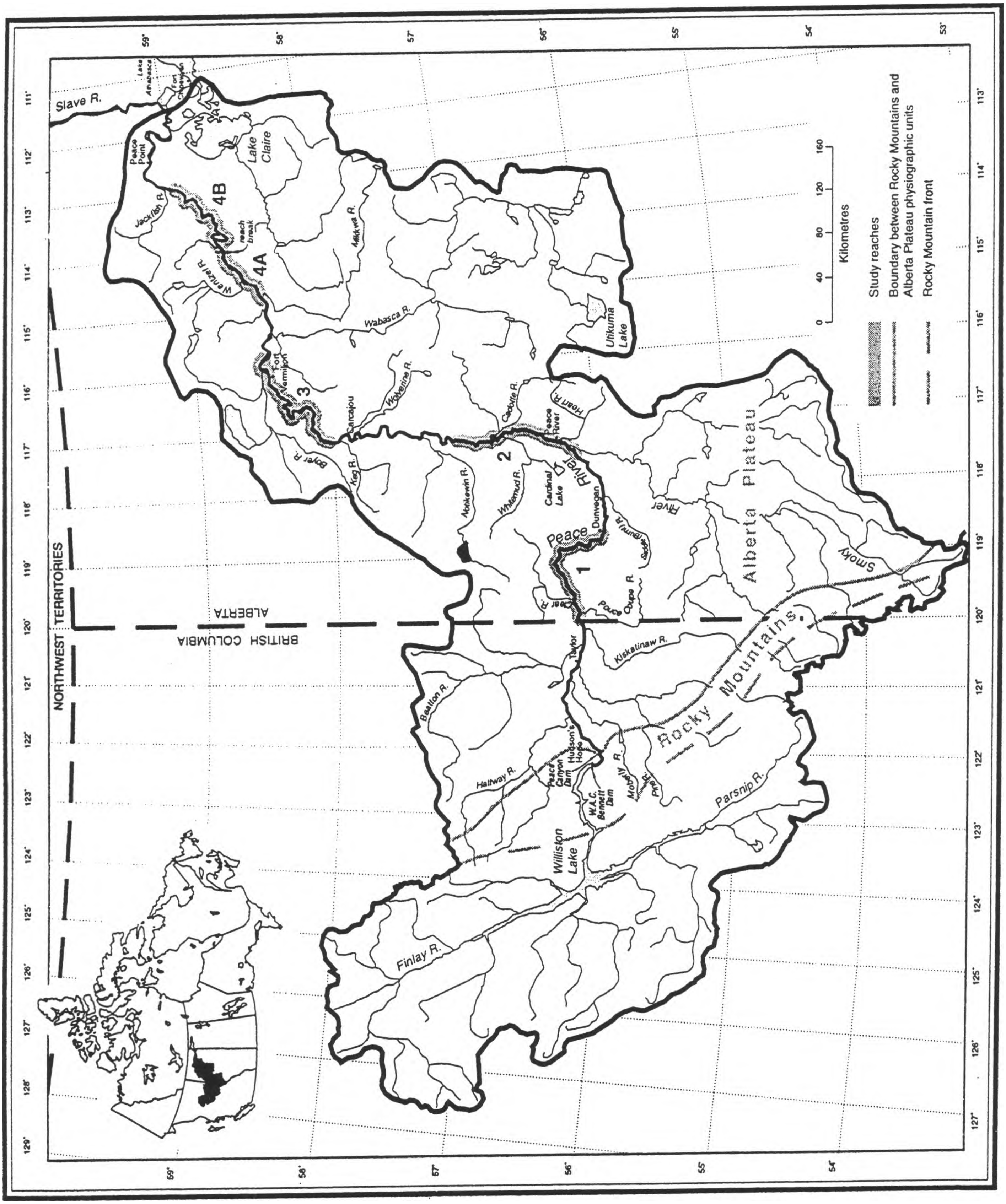


Figure 1. The drainage basin of Peace River, showing the principal physiographic divisions and the four study reaches.

relatively low. Additionally, some of the rock units underlying the Alberta Plateau are poorly lithified and therefore highly erodible. There are major, deep-seated landslides along most of Peace River east ofthe mountains. The trunk stream and tributaries are incised below the plains surface, so mass-movement on the valley slopes is very active.

The adjustment of the fluvial system in western Canada in the postglacial period can be divided into two stages (cf. Church and Slaymaker, 1989). At first, glacially derived material stored in headwater basins was eroded and evacuated by flowing water. As most of the mobilisable material has been removed, erosion intensity and sediment yield are relatively low there at present. In the second stage, the huge quantities of material stored in the major valleys is eroded and transported downstream. This process is still far from completion. Controlled by this mechanism, the relation of sediment yield to basin area in this region is quite different than those observed in other areas of the world, since sediment yield per unit area (specific sediment yield) increases with drainage area rather than decreasing with it (Figure 2). Although the data from the Peace River are very limited, the trend is clear, and indicates that the major sediment source is not the headwater basins, but the large tributaries and trunk streams where thick unsolidated deposits and poorly lithified valleysides are easily eroded and thereby large quantities of sediment are supplied to the river.

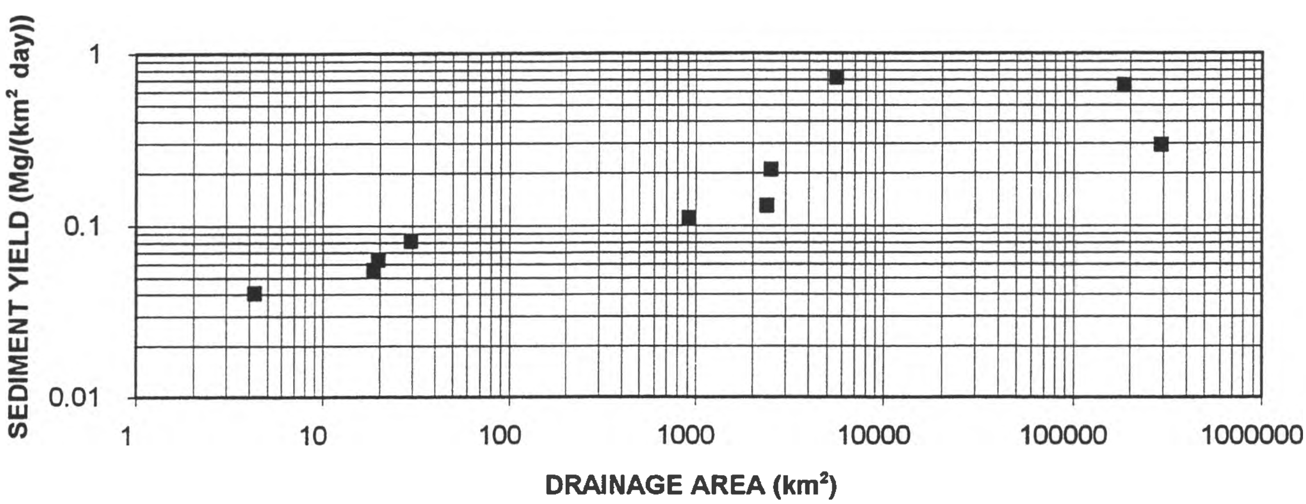


Figure 2. The variation of specific sediment yield (sediment yield per unit area) with drainage area in the Peace River drainage basin. The data are based mainly on tributary streams and include no stations within the mountains.

2.1 HYDROLOGY

Peace River has a mean annual flow ranging from 1080 m^3s^{-1} at Hudson's Hope to 2110 m^3s^{-1} at Peace Point and has not basically changed between the pre- and post-regulation periods, although interannual variability is high (Figure 3). For most water resources purposes, mean flows and minimum flows are the focus of concern. However, in considering morphological changes along the

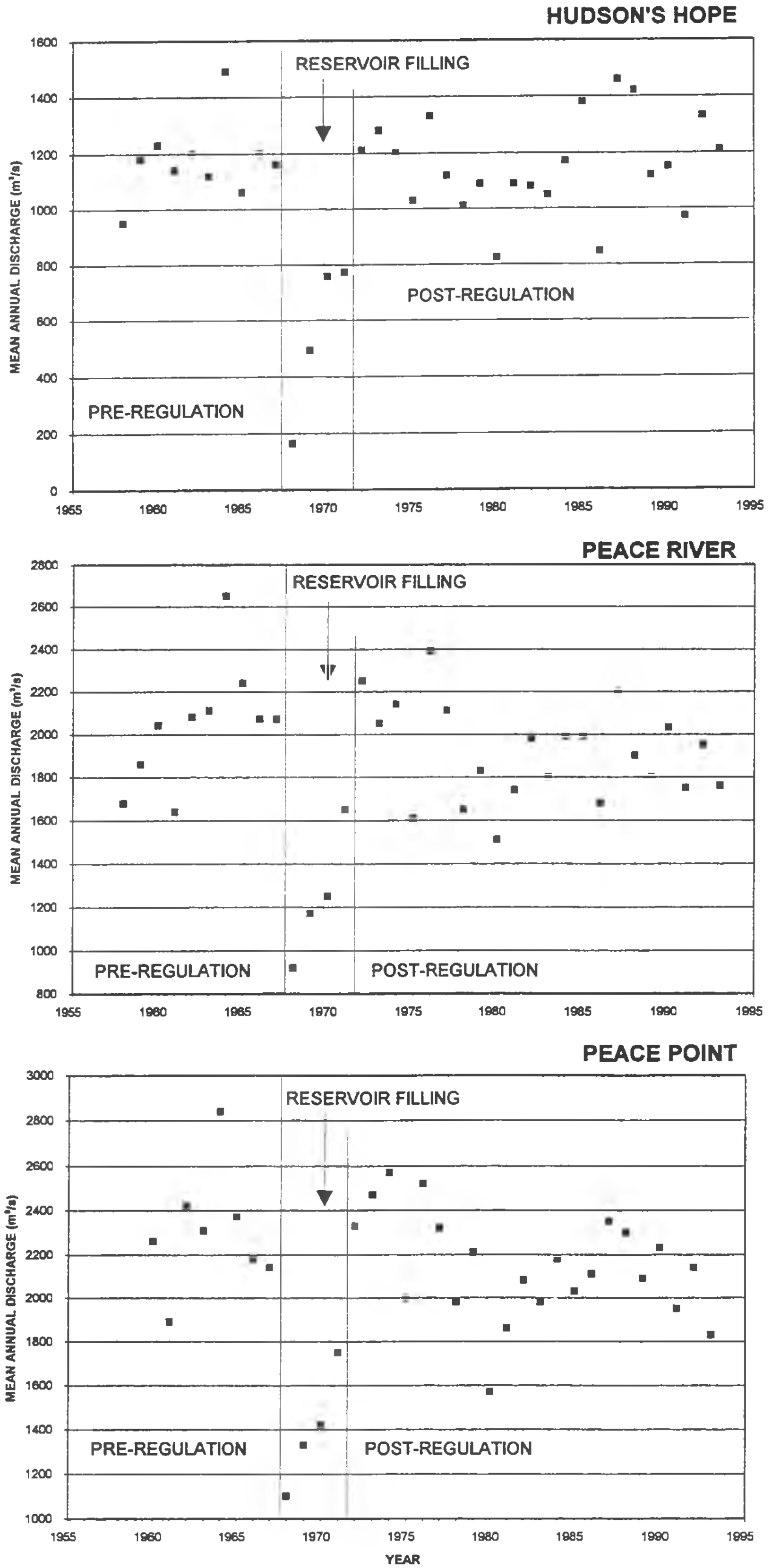


Figure 3. Time sequences of annual mean discharge at principal gauging stations along Peace River (complete duration of records).

river, interest is centered upon the incidence of relatively high flows that are competent to move the sediments which make up the bed and lower banks of the river. Accordingly, the flood regime of the river is analysed here. Gauge records along Peace River restrict pre-regulation flow analysis to the ten year period 1958-1967. Following the period of reservoir filling (1968-1971), there are 22 subsequent years of records available. The comparison periods are short and serve only to demonstrate the overall magnitude of the flow regulation.

The variation in annual flood (annual maximum daily discharge) is given in Figure 4, revealng a striking difference between the pre- and post-regulation periods. If the flood of 1972 is omitted because of a spillway test, the year-to-year fluctuation in annual flood at Hudson's Hope after reservoir commissioning is very low. In the pre-regulation period, the mean annual flood on average was 6310 m^3s^{-1}, but in the post- regulation period it decreases to 1920 m^3s^{-1}. At stations downstream, the situation is similar but the difference between the pre- and post-regulation periods tends to decrease. To further describe the flood characteristics along the river, an index of annual water discharge range is adopted, defined as the annual maximum daily discharge Q_{max} divided by mean annual discharge $\langle Q \rangle$. The year to year variation in this index is plotted in Figure 5. At Hudson's Hope, the mean value of the index declined from 5.42 before regulation to 1.88 afterward. It can also be seen that the spatial variation in runoff regulation varies significantly along the river. Below the Smoky River confluence (just upstream of Peace River town), the index declines from about 4.5 or 5 only to about 3.0. In the downstream records, the remarkable flood of 1990, generated downstream from the dam, also stands out dramatically in this analysis.

Figure 6a illustrates the magnitude of the mean annual flood (MAF) measured at gauging stations along the river during the pre-regulation period and a post-regulation period of the same length selected to represent a period of hydrologic stability following reservoir filling and adjustments in the operation of the power station which occurred in the 1970s. At Hudson's Hope the post-regulation MAF is only 32 per cent of the pre-regulation figure. At Peace Point, just above the river delta at Lake Athabasca, it is 58 per cent of the pre-regulation value. An interesting feature of the downstream variation in flood magnitude is the sharp increase as far as Peace River town, and the slight decline in average flood magnitude after that. This results from two factors. The tributaries with mountain headwaters enter the river as far down as Peace River town (the last being Smoky River). Farther down, the tributaries rise on the Alberta Plateau and generate much smaller unit runoffs. Secondly, the river turns north at Peace River, so tributaries downstream contribute out-of-phase flood flows because of the progressively later spring thaw. Figure 6b displays flood frequency graphs for the principal hydrometric stations based on the same 10-year periods. Again it is clear that the magnitude and variability of flood flows are much more severely reduced in the cobble-gravel reach upstream of the Smoky River confluence than below it. Nonetheless, at Peace River town, the flow that represented MAF before regulation is expected to occur only once in 20 years, on average, and the flow that formerly occurred once in 10 years on average is now expected to be a 90-year flood.

From the perspective of riparian vegetation, high stage is more significant than high flow. The relation between high stage and high flow is not simple on Peace River. As a northward flowing, boreal river, ice jams are prone to create high water during the early spring ice-drive when flow is not particularly high. A comparison between open-water flood levels and breakup levels during the pre-

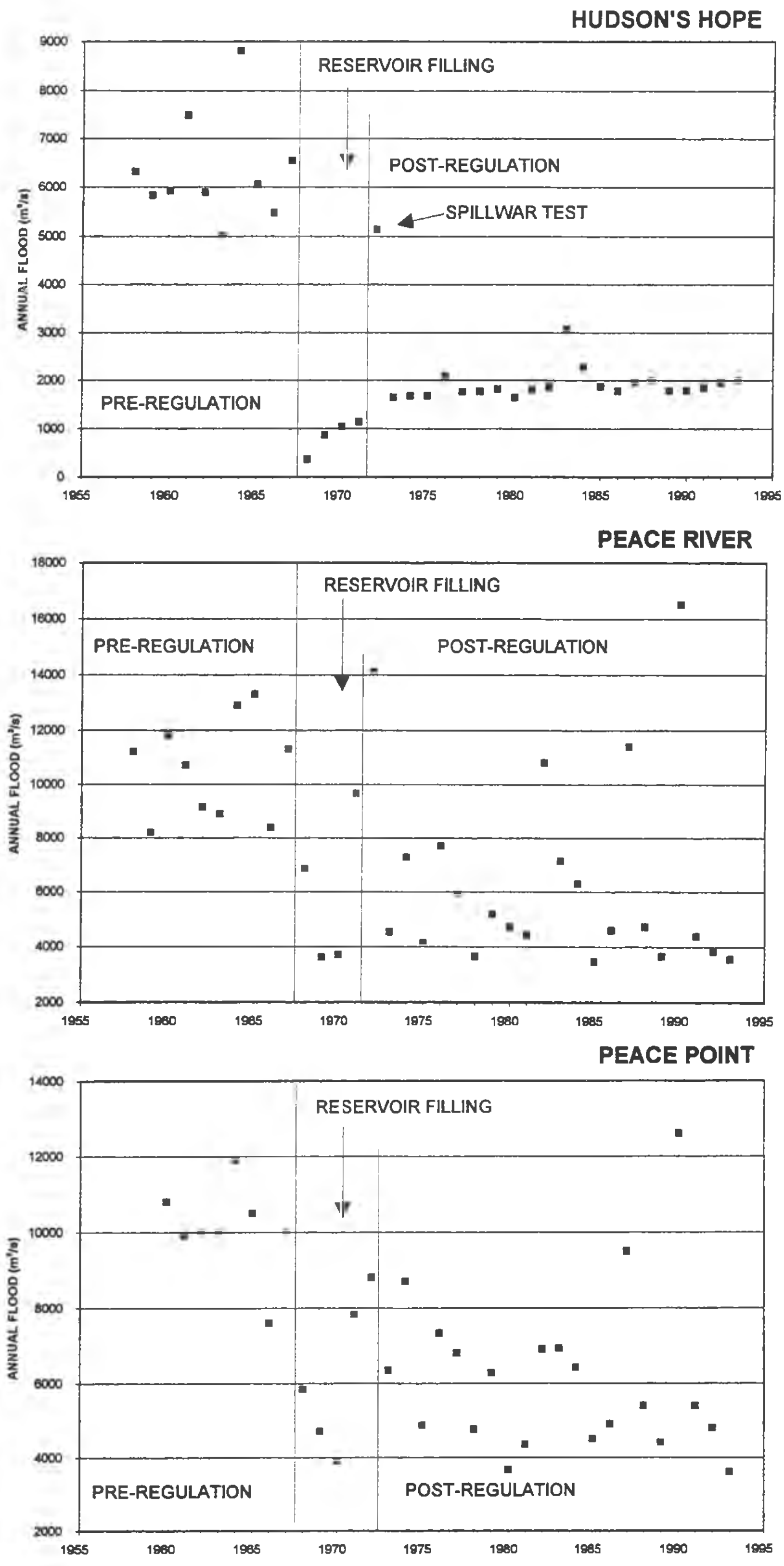


Figure 4. Time sequences of annual maximum flow (daily at principal gauging stations along Peace River (complete duration of records).

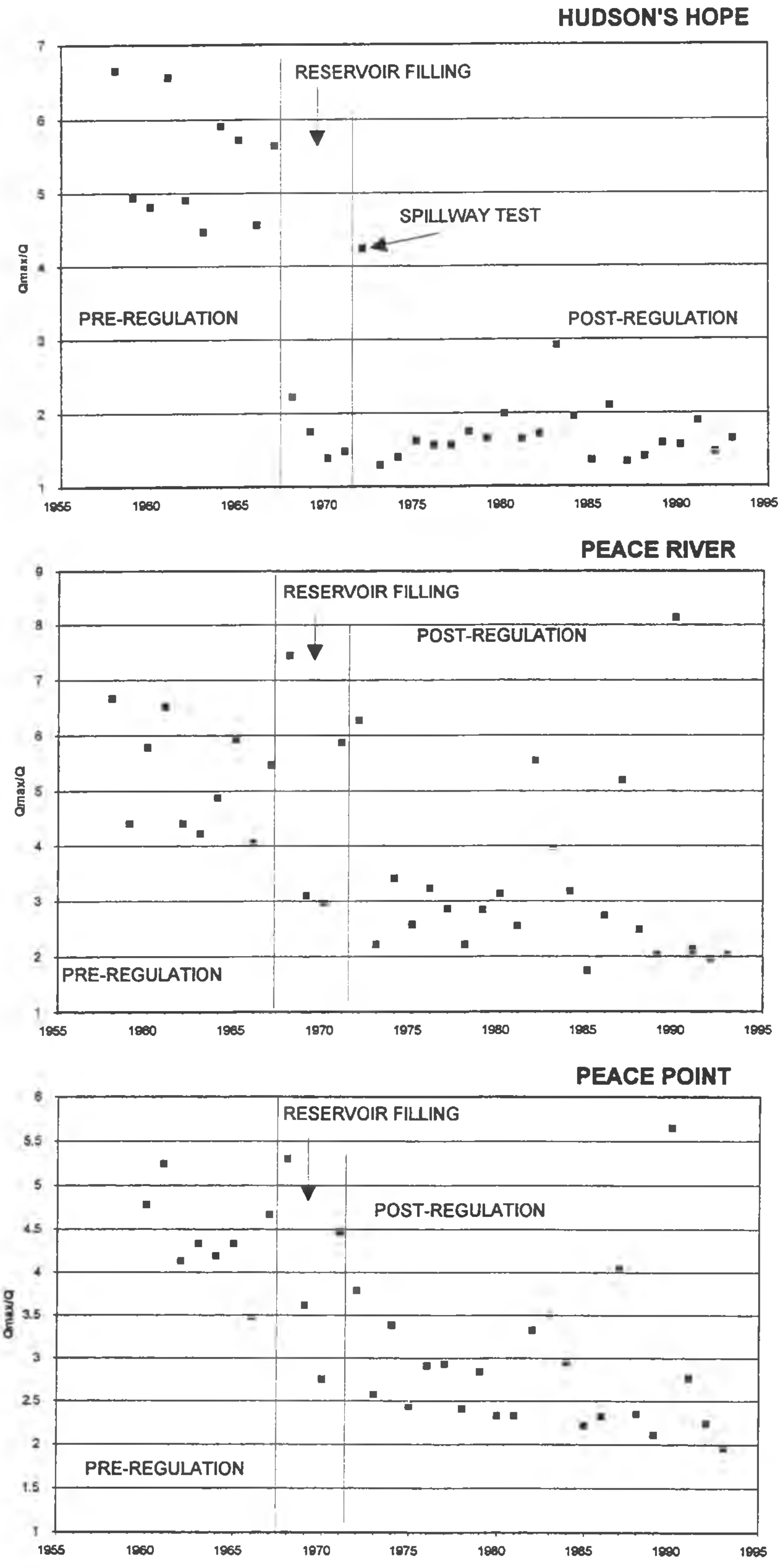


Figure 5. Time sequences of the ratio $Q_{max}/\langle Q \rangle$ (annual maximum daily flow/annual mean flow) at principal gauging stations along Peace River (complete duration of records).

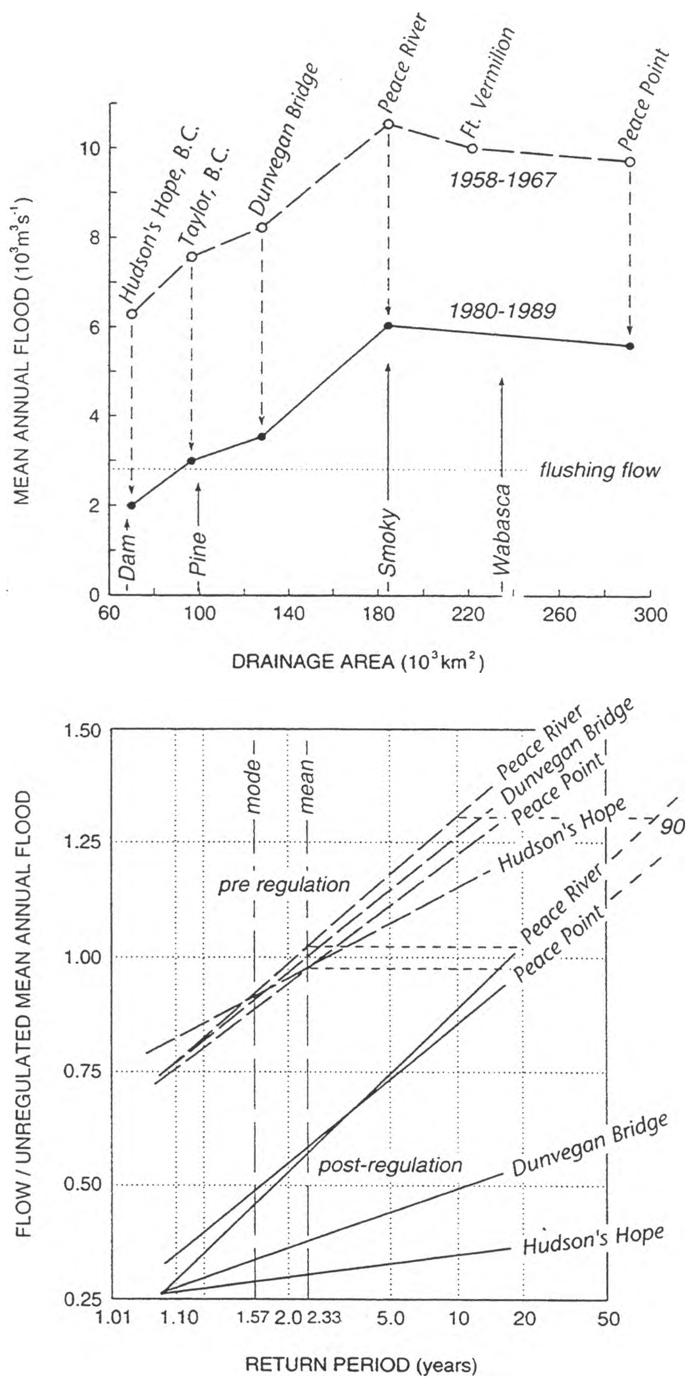


Figure 6. (a) Variation of mean annual flood at all gauging stations in Peace River downstream of W.A.C.Bennett Dam for periods before and after regulation. The principal tributaries are noted. In the pre-regulation period there are only 6 years of record at Fort Vermilion and 9 years at Peace Point. The truncated records appear not to have systematically biased the results. (b) Flood frequencies at gauges on Peace River for which both pre- and post-regulation flows are available for at least 10 years. A common period of record has been chosen to facilitate comparisons. The horizontal dashed lines between pre-regulation graphs and post-regulation graphs for the same station indicate the shift in expected average return period. For example, at Peace River town, the former 10-year flood becomes a 90-year flow.

regulation period for Peace River at Fort Vermilion (Gerard and Karpuk, 1979) revealed that the highest water levels are associated with breakup. In the post-regulation period there has been a notable absence of major flooding induced by ice jamming between 1974 and 1996 (see Prowse and Lalonde, 1996; major flooding occurred in 1996). This circumstance appears to be the consequence of reduced flow rises at the time of breakup, possibly allowing thermal weakening of the ice to become more important before the ice moves.

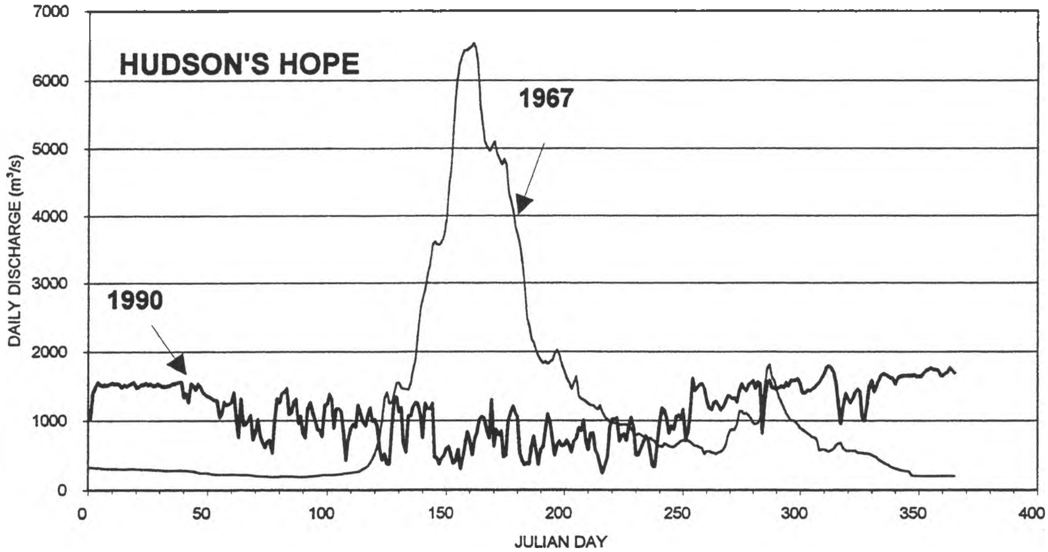
Daily discharge hydrographs for the years 1967 and 1990 are plotted in Figure 7 for Hudson's Hope and Peace River stations to illustrate the change in seasonal distribution of runoff. After reservoir construction, the seasonal water discharge variation has been greatly reduced, with both an increase in discharge in the low flow season and a decrease in the high flow season. This effect is an important aspect of the reduced severity of spring ice drives and ice jams. At Hudson's Hope, the winter flows actually become dominant. Free from the influence from tributaries, hydrograph peaks at Hudson's Hope are few and low but, at Peace River, the spring runoff peak is still evident. The 1990 hydrograph includes the highest flood of record on the river. This is caused by large floods from the tributaries below the reservoir, particularly from the Smoky River.

2.2 SEDIMENT TRANSPORT

As pointed out earlier, the construction of Bennett Dam has not appreciably decreased the downstream sediment yield to Peace River because the major sediment sources are located below the dam. But the runoff regime is greatly changed and, with it, the channel geometry and channel hydraulic characteristics. These changes may have an important influence on sediment transport. The lack of sediment load data greatly limits the possibilities to study this question. However, some analysis has been based on data from the hydrometric station at Peace River town. Because only two years (1966-1967) of data are available for the pre-regulation period, it is impossible to make a comparison on the basis of long term averages. Instead, comparisons are made for typical years before and after reservoir commissioning.

We selected 1982 as a representative year in the post-regulation period. The mean annual discharges of 1967 and 1982 were 2070 and 1980 m^3s^{-1} respectively, the floods of the two years were 113 000 and 10 800 m^3s^{-1}, and the total suspended sediment loads of the two years were 34.6 and 40.3 million tonnes. However, because of the regulation by reservoir, the hydrographs and sediment graphs of the two years show a marked difference (Figure 8). In Figure 9, the daily suspended sediment load is plotted against the daily water discharge for the two years. Data of 1982 plot above data of 1967 for equivalent flows, indicating that suspended sediment concentration in 1982 was higher than that in 1967.

To understand effects on channel morphology, it would be more reasonable to plot the relation based on bed material load rather than that for the total suspended load but, because of the lack of suspended sediment grain size data, this can not be done. One possible explanation for the shift in sediment rating evident in Figure 9 is that fine sediment supply to the river is essentially supply controlled (rather than being controlled Peace River flows). After regulation, sediment delivered from tributaries during spring and early summer high flows experiences much less dilution in the



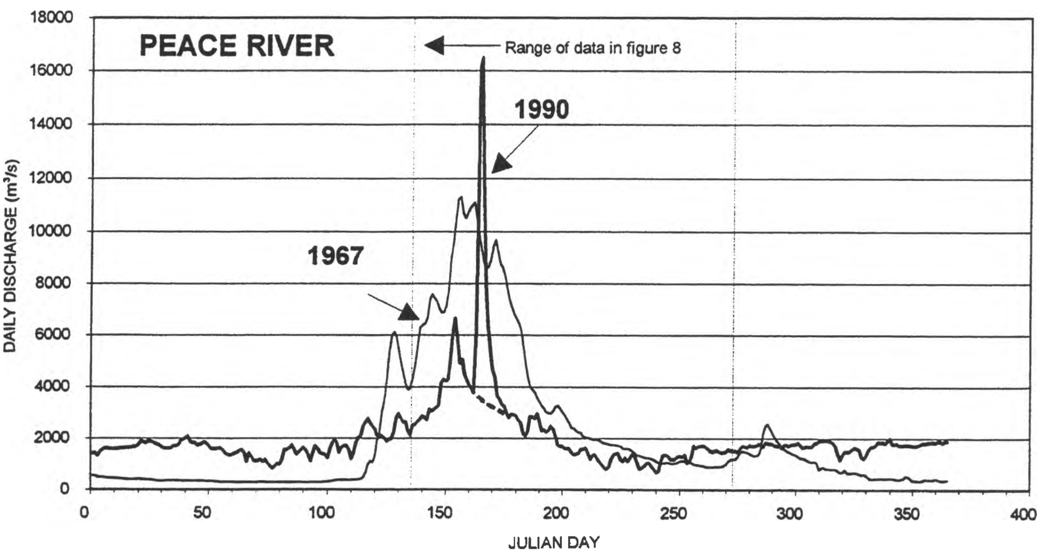
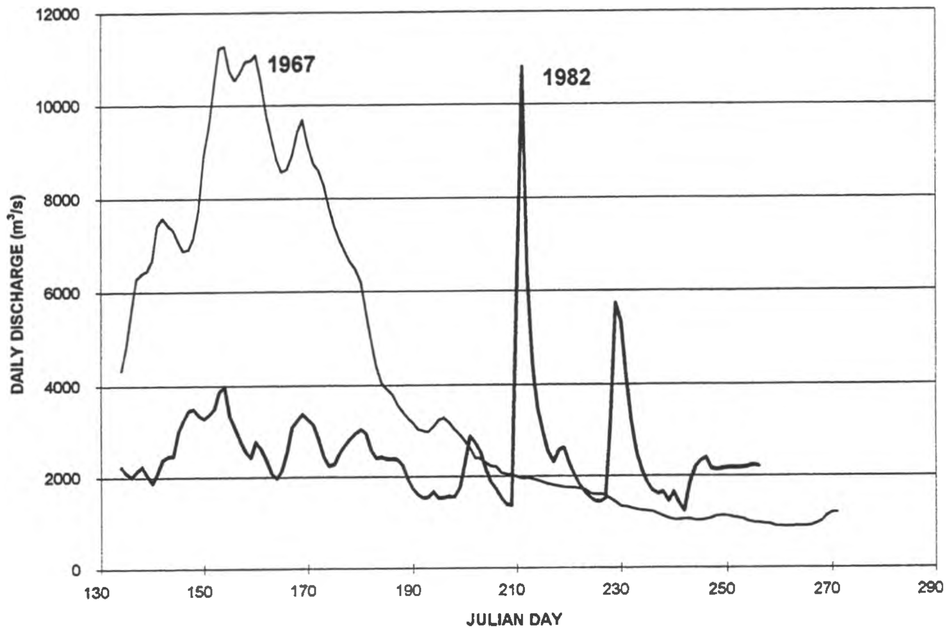


Figure 7. Annual hydrographs at Hudson's Hope, British Columbia (immediately downstream from W.A.C.Bennett Dam) and Peace River town for 1967 (pre-regulation) and 1990. The 1990 hydrograph at Peace River includes the flood of record. The pecked line under the flood peak indicates the more usual post-regulation hydrograph.



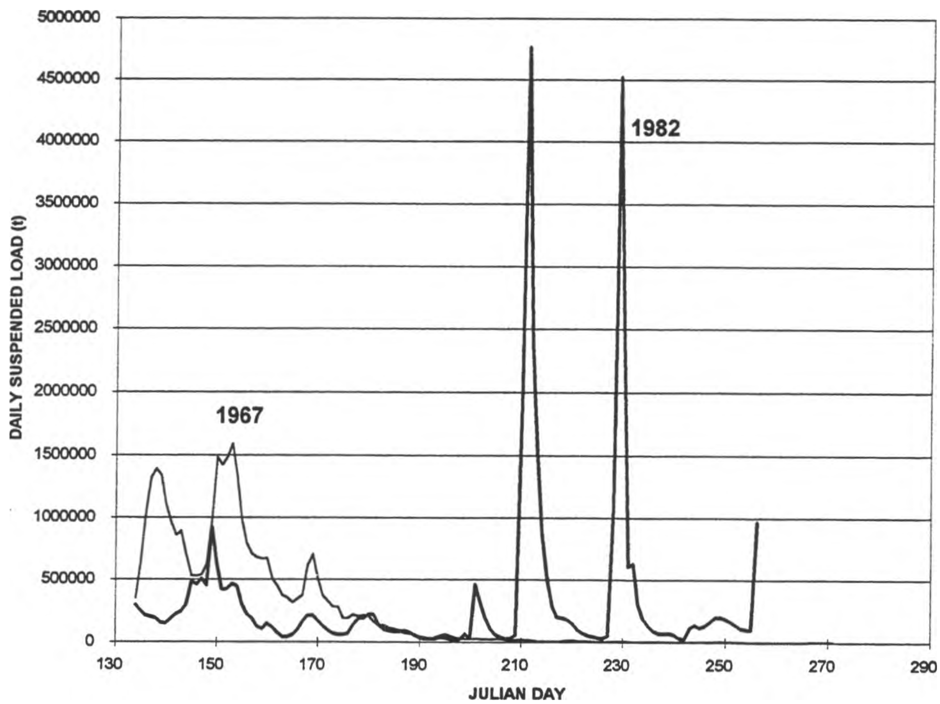


Figure 8. Summer period daily flow and suspended sediment load of Peace River at Peace River in 1967 (pre-regulation) and 1982.

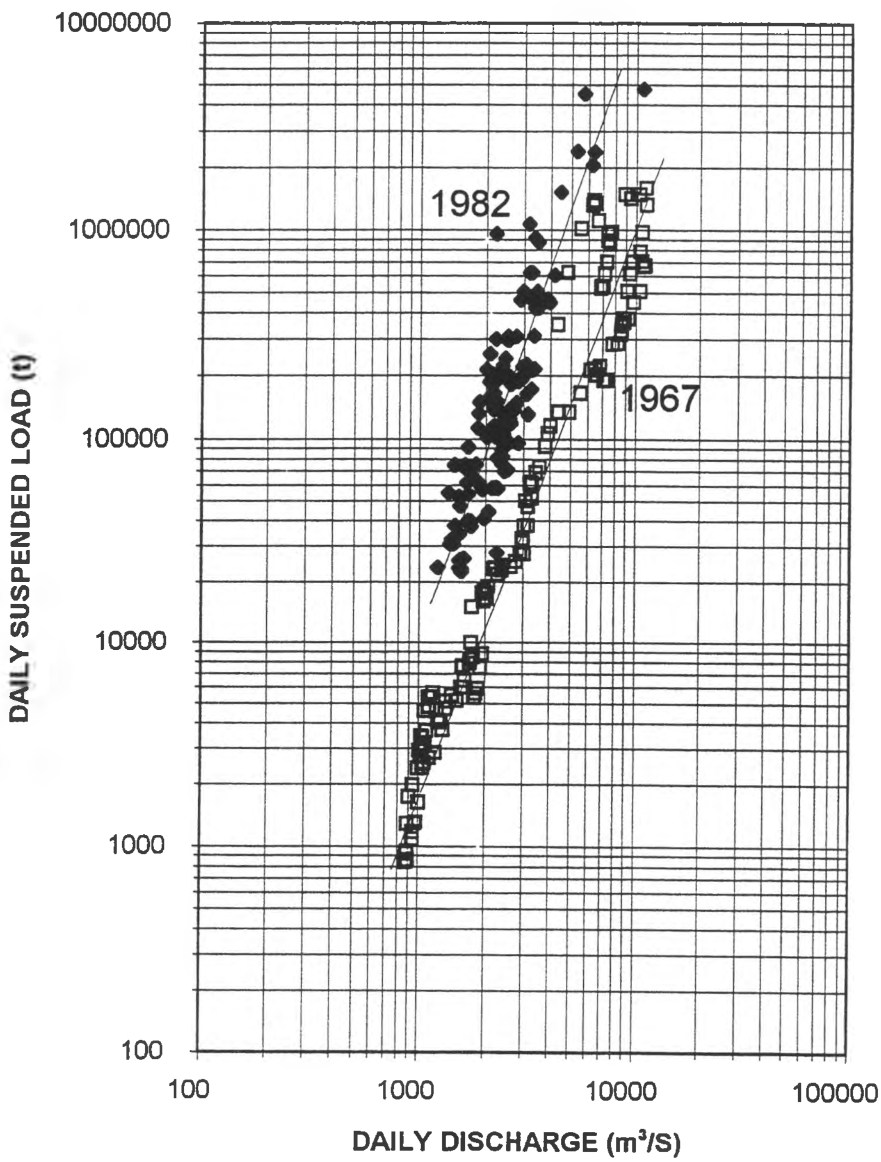


Figure 9. Daily suspended sediment load rating plots for Peace River at Peace River, 1967 (pre-regulation) and 1982.

main channel, where flows now remain lower. This circumstance yields typically higher concentrations in Peace River.

Another way to approach the question of supply versus hydraulic control of suspended sediment transport is to examine the modest number of size analyses for suspended sediment available from Peace River and Peace Point. The proportions of sand and silt (on average about two-thirds of the load is silt and clay size) are similar at the two stations and vary systematically with the flow. After regulation, similar flows appear to carry roughly similar proportions of sands and finer sediments but, since the duration of high flows has been dramatically reduced, the overall effect is for a higher proportion of the annual suspended load to consist of the finer materials. The most straightforward explanation for the differences -- both within-season and between regimes -- is that they are due to the loss of intermittently suspended sand to the bed. Before regulation, about 10% of the suspended load was coarser than 180 μm; that is, composed of sizes normally found resident on the bed in the zone of the main flow. After regulation, this proportion declined to less than 5%. This is evidence, at least, for hydraulic influence upon the size distribution of the suspended load, but it does not tell us anything definitive about the total sediment transporting capacity of the river since the bedload remains unmeasured. (The reader is cautioned that the observations in this paragraph are only approximate, and are presented in an essentially qualitative way, because of the small number of size analyses available, particularly in the period after regulation.)

Sediment ratings exhibit somewhat different features between "small flood" years and "large flood" years. Figure 10 illustrates ratings for two small floods (1985 and 1989) -- years when peak flow did not exceed 4000 m^3s^{-1} -- and for two large flood (1987 and 1990), when the flow exceeded 10 000 m^3s^{-1}. In the latter years, the rating relations appear to flatten at the highest flows. This suggests that, at the highest flows, sediment inputs increase more slowly than at lower flows. This might, in turn, suggest that the river possesses additional erosive capacity downstream. At present, it is difficult to confirm this conjecture.

The relation of annual suspended load to mean annual discharge is plotted in Figure 11. The points of the pre- and post-regulation periods are located near the same straight line, indicating that the annual water volume - sediment volume relation is unchanged. This result confirms that regulation has had little effect on the total annual load of the river, again indicating the importance of supply. In comparison with Figure 9, which implied higher typical suspended sediment concentrations after regulation, this result implies that the increased winter flows in the post-regulation period must carry relatively little sediment. Again, off-river supply control would lead to this result. However, it remains conjectural since very few sediment samples are available from the winter period.

The four points from the period of reservoir filling plot to the left of the main correlation. It seems that, at a given discharge, the suspended sediment concentration in this period was larger than that in the period of normal river flows. Although the discharge was decreased greatly during reservoir filling, it appears not to have exerted a major negative influence on the transport of sediment from the drainage area below the dam. In other words, the river can carry the delivered fine sediment by a smaller discharge, once again implicating supply control.

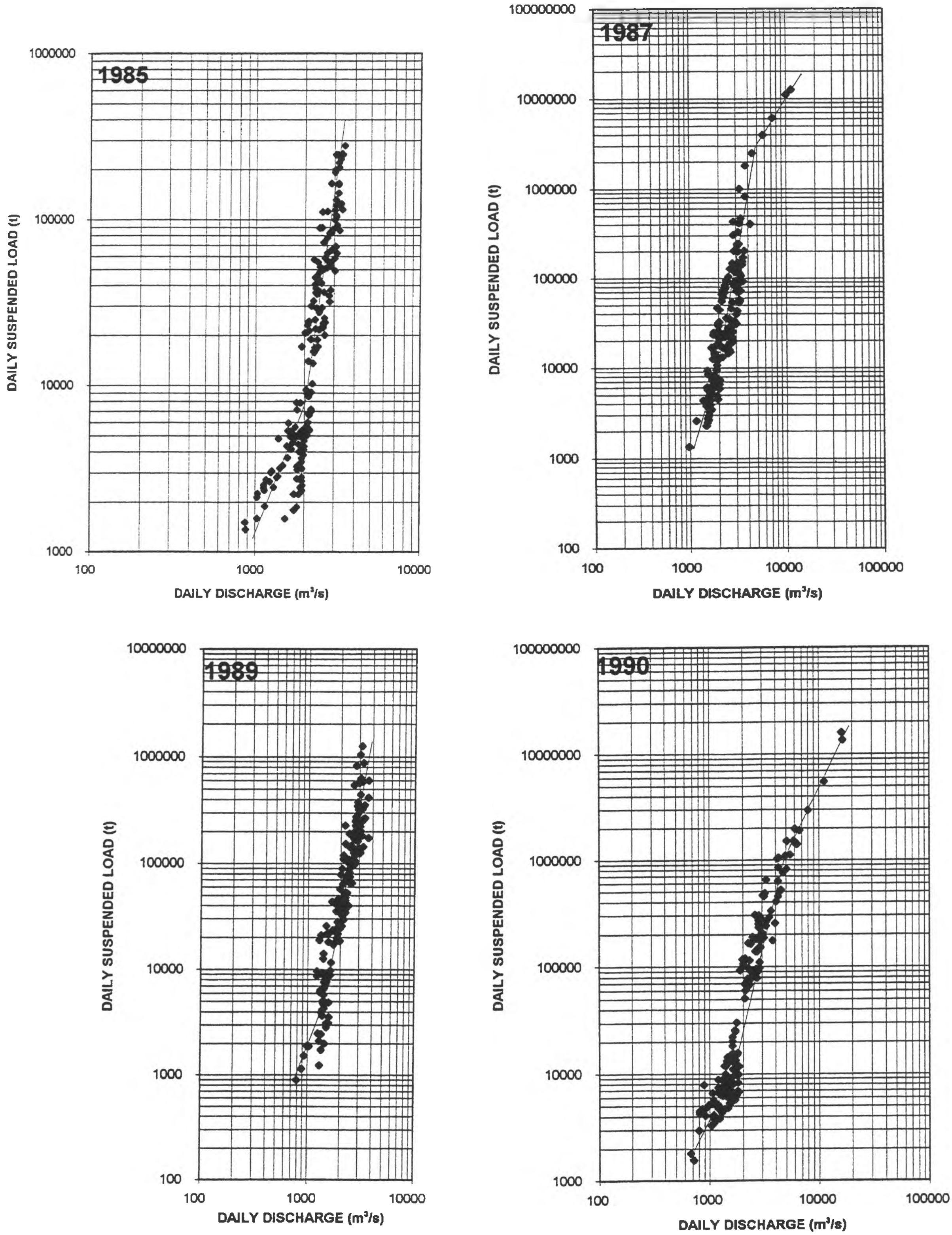


Figure 10. Daily suspended load rating curves for various years post-regulation years, Peace River at Peace River. 1985 and 1989 were low flow years (Q_{max} < 4000 m^3s^{-1}), whereas 1987 and 1990 were high flow years (Q_{max} > 10 000 m^3s^{-1}).

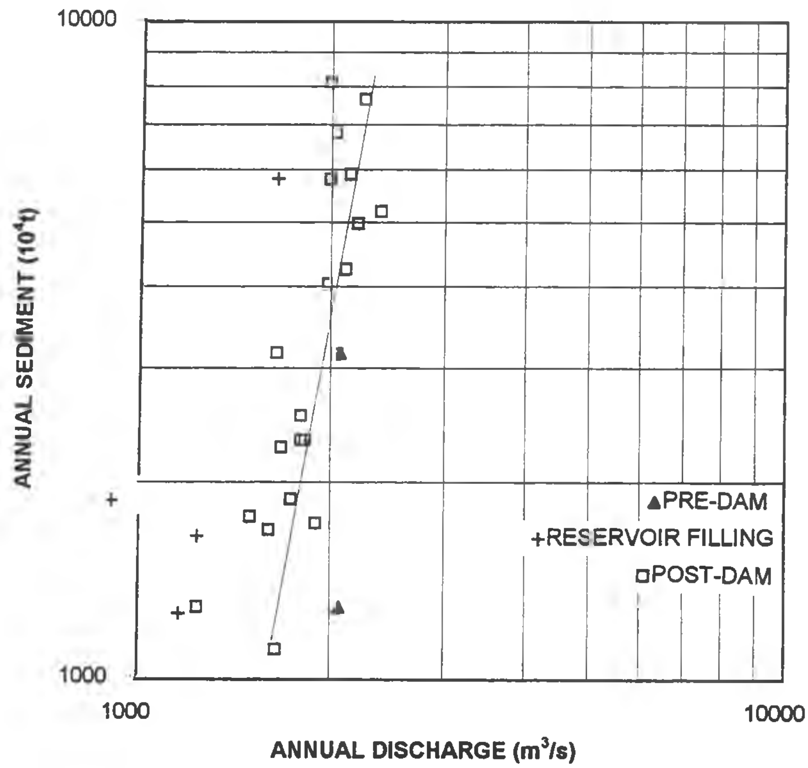


Figure 11. Annual suspended sediment load rating for Peace River at Peace River.

Figures 3 and 4 contain some hint of longer term fluctuations in flow within the post-regulation period, especially at the downstream stations (where the effect of the regulation is less severe). In Figure 12, this possibility is examined by the use of a 5-year running average applied to the data of mean flow, annual flood, and annual suspended sediment load at the town of Peace River. The mean flow and the sediment load give some hint of an irregular oscillation with an approximately 10 to 15 year period. Flood flows give less hint of structure. The suggestion that sediment load follows flow (volume) is consistent with the evidence presented above. The trend of declining flows occurred in the 1970s, the first years after the reservoir was commissioned. This will have reinforced the tendency for channel margin and bar surface areas formerly inundated for many weeks a year to remain exposed most of the time -- perhaps being submerged only during ice jam floods. In turn, this may have expedited riparian vegetation succession in some of these newly exposed areas. Conversely, flows and sediment transport increased during the early 1980s. If, by then, channel conveyance was substantially reduced, downstream sedimentation might have been more pronounced than otherwise. It remains to investigate what has actually happened, which is the main purpose of this report. The indication of this paragraph is that short-term climatic trends may have acted, over the 25-year period of regulated flows, to reinforce the primary effects of flow regulation.

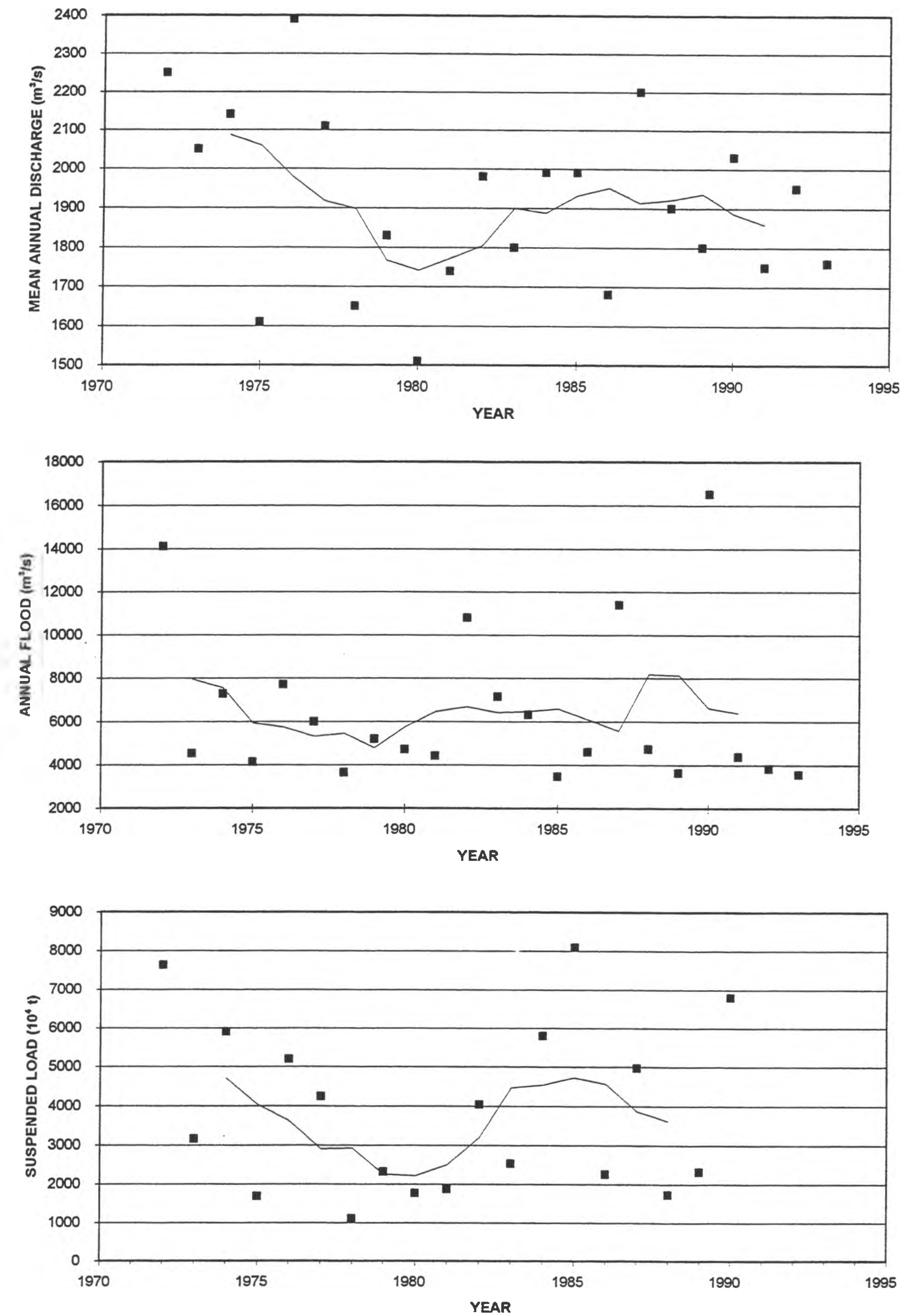


Figure 12. Pattern of annual mean flow, annual maximum daily flow and annual suspended sediment load in Peace River at Peace River since 1972. Solid lines are five-year running means

3.0 STUDY METHODS

3.1 PRINCIPAL ACTIVITY

The major work in this project was the preparation of planimetric maps of selected reaches of Peace River at five dates between 1950 and 1993. The reaches were chosen to represent each major morphological type along the river and, in addition, a reach including the junction with Smoky River was selected for study. Smoky River is the largest tributary of Peace River and delivers a large sediment load, so that changes around the junction of these rivers may be substantial. The selected reaches are summarised in Table 1 and located in Figure 1.

The dates selected for analysis were largely dictated by the availability of air photography. An important reference date is 1968, when the filling of Williston Reservoir commenced. In fact, there is no photography covering the entire river at that date. The river condition at the time of dam closure is mapped from photographs taken during the period 1966-1969 except in reach 4, where photography from 1964 and 1970 had to be used (and coverage remains incomplete). Photos from 1961 and 1970 were also used for short lengths of reaches 1 and 2. The earliest date selected, 1950, was to provide a period before regulation so that natural changes along the river immediately before regulation could be studied. The period is not long, but is consistent with the available hydrometric records. The final date, 1993, was determined by the time of flight of special photographs commissioned by NRBS. Additional dates chosen for attention are 1976 and 1988. The former allows study of the period immediately after regulation when the most dramatic primary changes in the river channel are expected to have occurred and primary vegetation succession began onto surfaces abandoned by the river. The 1988 date provides for study of an additional decade of change and isolates the major 1990 flood, the effects of which may be studied by comparison of the last two sets of maps.

Reach maps were constructed using an analytical stereoplotter. An analytical stereoplotter is a device which mathematically relates two-dimensional coordinates located on air photographic images to the three-dimensional coordinates of the imaged ground surface. The instrument used was a Carto AP190, a PC-based analytical stereoplotter located in the Department of Geography, The University of British Columbia. The stereoplotter allows the user to read precise 3-D location data from a parallax-free stereo image. The coordinates obtained in the plotter are corrected to true earth space using standard photogrammetric equations for interior, relative and absolute orientation. Interior orientation is a procedure that registers the location of fiducial marks on the photos and relates them to the photo carriers of the stereoplotter. The location of the photo fiducials is obtained from camera file reports produced by the organization responsible for taking the photographs (usually the federal or provincial governments). Relative orientation is a procedure in which corresponding points on the left and right images are related using a number of well-spaced, parallax-free points selected on the photographs. Software performs a mathematical best fit to these points, allowing the operator to obtain parallax-free images everywhere in the field.

Table 1

Study reaches for morphological changes of Peace River

Reach	Location[1]	Length[2]	Morphological character	Remarks
1	BC-Alberta border (km 1074) to Dunvegan (km 941)	133.83 km	cobble-gravel; largely confined	River similar to u/s end reach 2; WSC gauge at Dunvegan
2	u/s Shaftesbury Ferry (km 867) to u/s Notikewin Prov. Park (km 724)	143.26 km	sandy gravel; partly bedrock controlled; largely confined	Similar d/s to Carcajou WSC gauge at Peace River town
3	d/s Tompkins Landing (km 546) to d/s Fort Vermilion (km 392)	153.80 km	mainly sand-bed (gravel locally); partly confined	Similar u/s to Carcajou and d/s to Vermilion Chutes; WSC gauge at Vermilion Chutes (inactive)
4A	Below Vermilion Falls (km 332) to Fifth Meridian (km 270)	61.63 km	sand bed; frequent channel islands; unconfined	
4B	Fifth Meridian (km 270) to Jackfish River (km 149)	120.90 km	sand bed, meandered; not confined	Similar d/s to Delta; WSC gauge d/s at Peace Point

[1] Reach maps are in Appendix C.

[2] Channel distances measured along the channel centre line from the head of Slave River using a combination of GIS tools and 1:50 000 maps. Measurements generally correspond with values determined by Alberta Research Council and Alberta Environmental Protection Branch, River Engineering Division.

Absolute orientation is a procedure to relate actual ground coordinates (analogous to the UTM grid) to the same set of points on the stereo image. Points for orientation (control points) may be obtained from digital or analogue maps, or from a set of photographs on which surveyed ground points and points determined through aerial triangulation have been accurately marked. Once a set of marked photos has been properly oriented, control points are "bridged" to other sets of photography (of any date) such that all distortion and displacement errors are systematically minimised. Bridging is a process by which the coordinates of a point on the oriented stereopair are transferred to the corresponding points on other photographs. In this way, all orientation parameters and scales are systematically preserved so that direct overlays are correctly positioned with respect to each other (relative accuracy) and to the base map (absolute accuracy).

Air photo scales varied from 1:20 000 to 1:60 000 (Reach 4B; 1988), but were mostly in the range 1:30 000 to 1:50 000 (see Appendix Table C1 for a complete list of specifications). The AP190 is designed to measure objects to within ±80 cm from 1:40 000 scale photos (and the error varies linearly with scale). In practice, errors of 2 to 4 metres are more reasonable at this scale when attempting to locate natural boundaries, chiefly in view of the indistinctness of most such boundaries. Therefore, interpretive resolution limits the precision in most cases.

Lengths, heights, areas and feature locations which are digitised directly from the photographs are stored in the computer as a series of lines and polygons which are associated with unique feature codes. These codes allow digitised data to be organised for transfer to a GIS program. Data were manipulated using ARC/INFO, a vector-based GIS operating under an X-Windows graphic environment on a Sun Sparcstation. The choice of GIS and workstation were predicated upon the size of the files generated in this project. Maps were generated directly from ARC/INFO.

Mapped features of the river landscape were divided into six classes (water surface, unvegetated bars, vegetated bar surfaces, vegetated islands, floodplain, and alluvial fans) and each was imported into the GIS and manipulated as a separate "coverage". In addition, riparian vegetation communities were mapped and, for the 1993 mapping only, the valleyside vegetation to the level of the prairie surface. It is necessary to compare various coverages in temporary files to ensure that adjacent units share common boundaries. Attribute information is then attached to the units of each coverage to ensure that they are given the right associations and identification. At this stage, different coverages for the same date can be analysed to determine areas occupied, and can be combined to produce maps of the river. Coverages of similar features at different dates were compared (overlaid) to determine changes from one mapping to another.

Terrestrial units are typically of order 200 m in diameter. Considering an outside error of boundary placement of 4 m, the worst error in the assignment of area to such a unit would be ±8%, and the worst probable error (pooled error) of change in area for such a unit could be ±11.5%. These numbers would change for larger or smaller units. However, in summarising subreach characteristics, many such units are summed, so the subreach errors for area or change of area for each morphological class are of order 1% or less.

The water area may, of course, vary from one mapping to another because of differences in stage at the times of photography. Adjustments for this effect require independent knowledge of channel topography which is not available. For nearly all photographs, flows varied in a relatively narrow range about approximately 1000 m^3s^{-1} at Taylor, British Columbia, and 2000m^3s^{-1} at Peace River town (see Appendix table C1 for complete specifications). Some notable excursions had to be accepted, however, for mapping in Reach 4, where there was far less photography from which to choose. Most notably, "1968" photography for Reach 4A was flown in late June, 1964, when the discharge at Peace River was near 8000 m^3s^{-1}. However, Reach 4 is unlike the upstream reaches in exhibiting cohesive, near vertical banks along much of the reach. The effect of unadjusted stage variations generally introduces the least bias in this case. No adjustments have been made for stage variations. It must be recognised that the data of the primary reference date for Reach 4 is, as the result, biased to an unknown degree. Results in Reach 4 are, altogether, the least reliable of the survey. Indeed, there is no photography and no data at all for the 1960s for most of Reach 4B. It is supposed that bias introduced by flow variations elsewhere is, in general, comparable with the practical resolution of the map boundaries (although the water edge is the easiest natural boundary of all to establish and customarily very precisely located).

Vegetation mapping presents a special problem at the map scales selected. In general, it is not possible to identify all significant individual plant species and, in any case, practical map polygons are too large to be, in general, monospecific. On the other hand, the general morphology and structure of vegetation communities are easily interpreted, even on black and white photography. Such communities are, furthermore, suitable units for habitat characterisation. The vegetation mapping scheme used in this project, then, is based upon a morphological classification of vegetation communities. Legends are given in Appendix D. Vegetation was first mapped from 1993 colour photography. Comparison with black and white prints served to train the interpretors to recognise the more subtle signals of community types on the black and white images of earlier dates.

Morphology and vegetation polygons have been recorded on digital files in UTM coordinates using the North American Datum - 1927 (NAD27). Hence our mapped features can be combined with the digital topographic files produced by Alberta Environmental Protection to produce topographic maps with interpreted features along the river. Maps have been produced at a scale of 1:20 000 using map quadrangles similar to those of the Province of Alberta digital topographic mapping. However, in order to display mapped areas effectively and to reduce costs, some of our maps incorporate small parts of adjacent quadrangles (reach maps are located in Appendix C). A complete mapping of the study reaches covers 40 sheets. A sample fragment of a map and a complete map at reduced scale are presented in Appendix C. Complete sequences of the maps will be deposited at the Alberta Department of Environment (Edmonton), at the National Hydrological Research Institute of Environment Canada (Saskatoon), and at the Department of Geography, University of British Columbia. The ARC/INFO files will be preserved on CD-ROM.

To study morphological changes along the river we have summarised areal changes between different mappings for all possible transitions from one identified morphological unit to another. These summaries have been produced for subreaches which are typically of 10 to 25 km length. Given average river widths of 400 to 700 m, these subreaches are of order 15 to 50 river widths in length, which is sufficient to encompass between 2 and 6 characteristic units of the river pool and riffle sequence. We have created "change" maps for certain subreaches in which significant or typical patterns of change have been identified. We have not created change maps along the entire river, since they are complex (potentially containing up to 36 different units) and expensive to produce.

3.2 PRODUCTION SCHEDULE

The project was originally scheduled to commence in October, 1993, and to be complete by August, 1995. In fact, it commenced in April, 1994. In addition, substantial, unexpected delays attended the acquisition of control data for absolute orientation of the air photographs. Final control data (reaches 3 and 4) were not finally obtained until July, 1995, due to previous unavailability of the control photo set. The time absorbed searching for control data and resolving hardware mismatches have extended the production schedule well beyond the original time lines. At present (June, 1996) mapping is complete for 1950, "1968" and 1993, comprising 120 of a projected 200 sheets, including extended mapping of valleyside vegetation on the 1993 maps. These maps permit the summary effect after 25 years of regulated flows to be measured; results are summarised in this report. Currently, 1988 mapping is underway. It is expected that mapping of all dates will be completed in August, 1996; the real slippage in the schedule being 6 months. Table C1 (Appendix C) shows the current status of the project by map sheet.

3.3 SUPPORTING ACTIVITIES

In June, 1994, a reconnaissance trip was conducted by M. Church and M. North, accompanied by three assistants, to obtain ground truth information to support map interpretation. The principal focus of activity was to obtain information on riparian vegetation communities, which were expected to change along the river. For that reason, activities were concentrated around the town of Peace River (reach 2) and in the LaCrete - Fort Vermilion district (reach 3), near the two limits of the major northerly oriented reach of the river. Reach 1 was not visited in 1994 because morphology and vegetation were expected to be similar to the adjacent reach in British Columbia, which have been studied in detail by the contractors. Reach 4 was not visited because of its relative inaccessability. A short report of the field work is included as Appendix B. In addition, photographs were taken of the river for reference during mapping, and to support the subsequent analyses of morphological change, and boat access was reconnoitred along the river. During this trip all of reach 3 was traversed by boat and substantial shoaling in that reach was recognised.

In June to August, 1995 Lars Uunila, accompanied by two student assistants, traversed the river by boat from the British Columbia border to Fort Vermilion. The purposes of the trip were to study morphological changes along the river, with particular attention to ice-induced effects, and to record sediment sources along the river. Tributary junctions were accorded special attention. The photo atlas assembled during this trip has been consulted by other investigators of the NRBS study.

4.0 RESULTS

4.1 MORPHOLOGICAL CHANGES ALONG PEACE RIVER

We have available two means to document the changes that have occurred along Peace River since regulation. One is field evidence of erosional and sedimentary processes, and of vegetation succession along the river. The latter is particularly important because vegetation age in uniformly young communities provides an important indication of when succession began. The second means, which provides a systematic view of changes, is the comparative classification of morphological units along the river in 1968 and in 1993 obtained from the maps. The GIS permits overlay of maps of the same reach so that all changes may be identified and measured. In this section, we provide a summary of the results of this exercise and some comparisons with field evidence to demonstrate the consistency of the results.

Table 2 gives a summary by major study reach of areas occupied by each of the mapped morphological units along Peace River in "1968" and in 1993, and of the changes that occurred between the two dates. The same summary is given by subreaches in Appendix C, where reach maps are also given which show the location of the subreaches. Most of the subsequent analysis is based on the subreach data. In the tables, areal units are given in square metres, and distances in metres. In comparison with the practical resolution of the photogrammetic plotting, the nominal error of distance measurements is less than 4 m, and of areal measurements is less than 20 m^2. However, classification errors in mapping probably increase the areal error measure by some amount. Because of the large areas involved, the summary results nonetheless remain highly precise. The individual morphological units are sufficiently distinct that no systematic bias is expected in the results, except bias that may be associated with different water levels at the times of photography.

The following definitions should be understood in the table (see also Figure 13). "River" denotes area occupied by water at the time of the photography. "Bar" denotes emergent, seasonally water-covered river bed with an elevation distinctly lower than that of the adjacent floodplain. Normally bar surfaces are bare, or are occupied only by weedy annual vegetation. However, because of the recent regulation, substantial bartop areas along Peace River are now permanently emergent (except, possibly, during ice-jam floods) and terrestrial vegetation succession has begun on them. These surfaces eventually will define a new floodplain level, so they are separately mapped. The active channel zone is the area between the limits of perennial terrestrial vegetation, so it includes water and bare bar areas. For determining the extent of the river channel area, the active channel zone, not the water area, is the relevant quantity. This quantity is not affected by bias introduced by variable flow levels. Accordingly, river channel widths refer to the average distance between the lower limits of terrestrial vegetation on each bank. "Floodplain" denotes the wooded valley flat, deposited by flood sedimentation but only occasionally water covered, adjacent to the river. "Island" denotes an area of floodplain isolated from the main floodplain by river channels on both

Table 2

Areas occupied by major morphological units along Peace River, by main study reach

*1966-69 to 1993**	Total Area (square metres)				
	REACH 1	REACH 2	REACH 3	REACH 4A	REACH 4B
1966-69					
bar (bare)	6751340	5920460	38358661	383054	17870776
bar (vegetated)	3194661	11462459	7423049	7909329	11619051
island	4336416	6395427	31849748	13184188	50798167
river	52854469	69378036	84435195	79036678	77027431
floodplain	7081693	36333151	90215133		
fan	325734	266010	19222	0	0
1993					
bar (bare)	3693886	9598186	16033823	8167811	13525816
bar (vegetated)	9375718	13461641	25710943	5956080	19486827
island	4905965	7451638	32678292	17955251	55461114
river	49738416	62804218	87412653	65600542	69216685
floodplain	6839762	36644205	90303094		
fan	645927	265091	0	0	0
Absolute change					
bar (bare)	-3057454	3677726	-22324838	7784757	-4344960
bar (vegetated)	6181058	1999182	18287893	-1953248	7867776
island	569548	1056211	828544	4771063	4662947
river	-3116054	-6573818	2977458	-13436136	-7810747
floodplain	-241921	311054	87961		
fan	320192	-919	-19222	0	0
% change					
bar (bare)	-45.3	62.1	-58.2	2032.3	-24.3
bar (vegetated)	193.5	17.5	246.4	-24.7	67.7
island	13.1	16.5	2.6	36.2	9.2
river	-5.9	-9.5	3.5	-17.0	-10.1
floodplain	-3.4	0.9	0.1		
fan	98.3	-0.3	-100.0	0.0	0.0
Reach length (m):	132830	143260	153800	61630	120900
Average width, 1966-69 (m):	449	526	798	1289	785
Average width, 1993 (m):	402	505	673	1197	684
Absolute change in width (m):	-46	-20	-126	-92	-101
% change in width:	-10.4	-3.8	-15.8	-7.1	-12.8

CUMULATIVE AREA:

Morphology

Net erosion (sq. m):	2149105	2462640	14015938	2992852	24896872
Net deposition (sq. m):	4465423	8186894	10194157	16242780	30645437
Stability (sq. m):	62266603	83878290	139130116	81995076	116684383
Avulsion (sq. m):	0	0	0	0	59870
Accretion (sq. m):	0	437964	0	577000	3069463

Vegetation

Removal (sq. m):	2058543	3965000	2664537	2986401	22274483
Recovery (sq. m):	8013243	8197836	22942413	15187285	44194890
Stability (sq. m):	6186768	13414056	36239923	12751435	47971760

Note: Lateral extent of floodplain was not defined in reaches 4A and 4B.
* As photo coverage of reach 4B in 1966-69 is incomplete, 1950 data was used in place of 1966-69 data for reach 4B in this table.

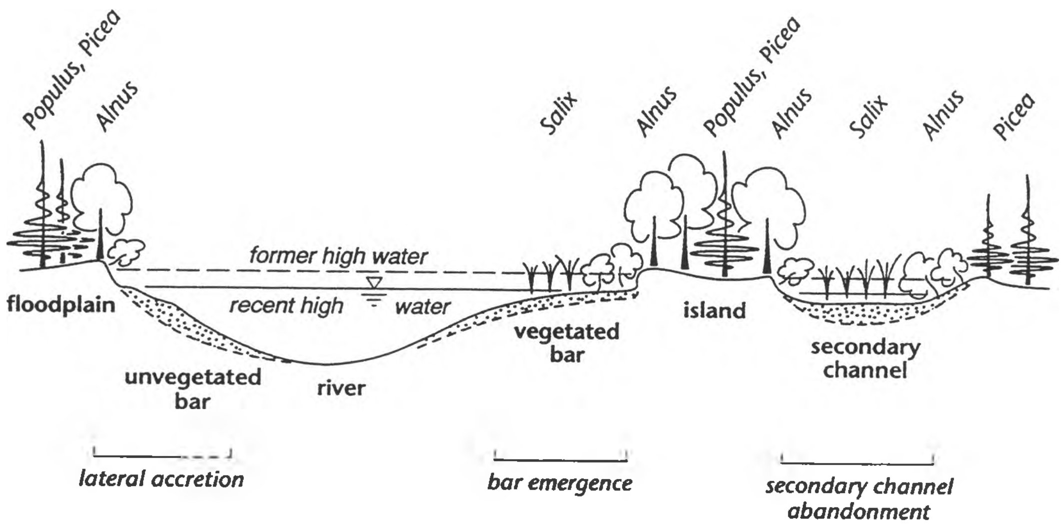


Figure 13. Typical cross-section of Peace River, showing the vegetation succession following regulation (the species are most typical of downstream sites), the mapped morphological units and the principal modes of channel adjustment (see text for further discussion).

sides. "Fan" denotes the area of sedimentary deposits at the mouth of a tributary stream. Active fans are devoid of vegetation.

In the table the nature of the observed changes amongst these morphological units is characterised as to the geomorphological processes (erosion, deposition, etc.) that created the changes. The areas subject to the individual processes are recorded in the Appendix tables. (They cannot be directly related to changes summarised in table 2 because several processes contribute to the change of each morphological unit.) All but two of the terms are familiar ones. The possibly unfamiliar terms are "accretion", which denotes the transfer of a former island unit to the adjacent floodplain as the result of abandonment of a former channel between the island and the adjacent edge of the river. Conversely "avulsion" denotes the creation of an island from a section of former floodplain by the establishment of a channel through a portion of the floodplain. Usually this represents reoccupation of a formerly abandoned channel. Erosion and deposition are characterised as "net" because compensating erosion and deposition occurring within the period cannot be detected. The nature of morphological changes on a river as large as Peace River (where individual sites remain subject to the same processes for many years) is such that compensating effects are small.

4.2 WITHIN-REACH CHANGES

The effect of river regulation has been to dramatically reduce the incidence of open water floods, especially upstream of the Smoky confluence (Figure 5). Furthermore, the higher winter flows and reduced magnitude of the spring rise induced by operation of the Williston Reservoir (see Figure

7) appear to have substantially reduced the severity of spring ice breakup along the river. (One says "apparently" because this effect is confounded with that of the generally lower spring floods and mean annual discharges since the mid-1970s.) There was no severe ice jam season between 1974 and 1996 (Prowse and Lalonde, 1996). Furthermore, ice-induced high water causes significant erosion only when ice is being driven downstream, and, possibly, in the vicinity of the ice jam. In the backwater of an ice jam, water velocities are low and morphological effects are mainly depositional. Ice-drives between 1974 and 1996 were of only modest severity.In summary, we expect that the overall effect of the river regulation has been a reduction in active channel area.

This expectation is borne out. In Reach 1, the average reduction in active channel width is 10.4%. In reaches 2 to 4A, it is 3.8%, 15.8% and 7.2% respectively. The relatively small change in reach 2 is related to the substantial confinement of the river here and to the establishment of a substantial backwater upstream of the Smoky River confluence.

The reduction in channel width has been accomplished by substantial reduction of bare bar area in reaches 1 and 3 (but in reaches 2 and 4 it increased), and by the increase of vegetated bar area (except in Reach 4), island and floodplain area. Proportional changes vary widely because the total area represented by some of these units (e.g., alluvial fans) was very small in "1968".

The means by which these adjustments are occurring are the following means (Figure 13), in order of relative significance (cf. Church, 1995):

- abandonment of formerly seasonally inundated channel bar surfaces (leading to the creation of vegetated bar surfaces);
- abandonment of secondary channels in split reaches (causing former islands to be accreted to the adjacent floodplain);
- accretion of sand and silt to channel edges (creating new bare bar, vegetated bar, island and floodplain).

Only the last, and least significant, process is an active "regime adjustment". On gravel bar surfaces in reaches 1 and 2, the beginning of floodplain development is marked by invasion of *Populus balsamifera* and various annuals. Once established, the plants trap and hold sand. On banks with finer soils (Figure 13) all along the river, *Alnus incana* forms a gallery forest near the new high water line, and *Salix* spp. invade at lower elevations. All of these species can spread rapidly by vegetative means and are adapted to survive repeated breakage by ice.

The river is no longer competent to move the cobble-gravel delivered by the major tributaries in reach 1 and the upstream portion of reach 2. This material is observed to be deposited into the channel of Peace River as "in-channel alluvial fans", which then push Peace River toward the opposite valley wall and also act as a low weir. At significant confluences Peace River is backwatered upstream for several kilometres whilst a steepened reach is developing on the downstream side of the tributary deposits (Figure 14). Over a period of many decades, Peace River will develop a "stepped profile" in the vicinity of these fans. This pattern has developed naturally in rivers in many mountain valleys of Alberta and British Columbia, where tributaries draining steep mountainsides have built alluvial fans across the main valley floor.

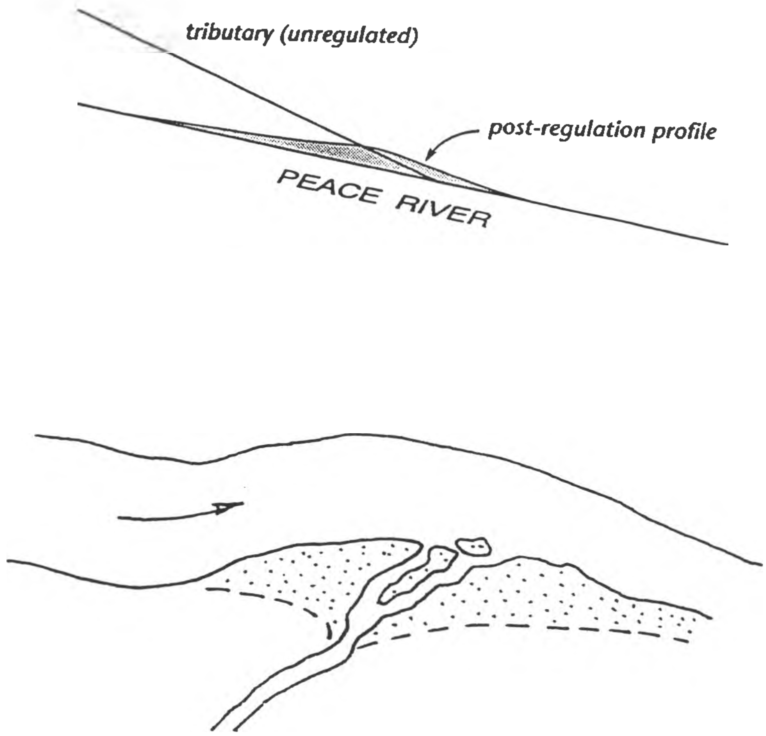


Figure 14. Typical situation of prograding fan blocking Peace River at principal tributary confluence.

The most notable such development is at the confluence of Smoky River (Figure 15). The "fan" of Smoky River has prograded into the main channel, creating a substantial additional bar area. This has established a more significant backwater than formerly, which now extends many kilometres upstream on Peace River. Deposition area totals 10.8% of the reach area, whilst erosion constitutes 5.1%, and the channel narrowed, on average, from 729 m to 706 m in the immediate subreach. Nearly all of the instability occurred at the Smoky junction and the net effect so far has been a transient reduction in forest area. Exposed surface was extended by 708 000 m^2 and riparian forest by 202 000 m^2, but there was also a loss of 253 000 m^2 of forest. Major changes at the junction include a downstream shift in the main channel of Smoky River so that it now flows straight into Peace River. Formerly, it entered Peace River via a sinuous channel at the upstream limit of the junction. In addition, the former secondary channel along the downstream edge of the confluence fan has been virtually abandoned. These changes are almost certainly the consequence of the substantially lower water levels in Peace River when the Smoky spring flood occurs, so the tributary stream (which is now the dominant channel at the time of spring flood) flows directly and on a relatively steep gradient into Peace River. There has also been substantial bar accretion around the islands downstream from the confluence. The bar tops now carry "meadow" vegetation and will eventually recruit forest species, beginning with poplar.

Elsewhere along reaches 1 and 2, there are no systematic changes in the channel cross-section because the cobble-gravel bed remains static. Active changes are still concentrated at sites of historic

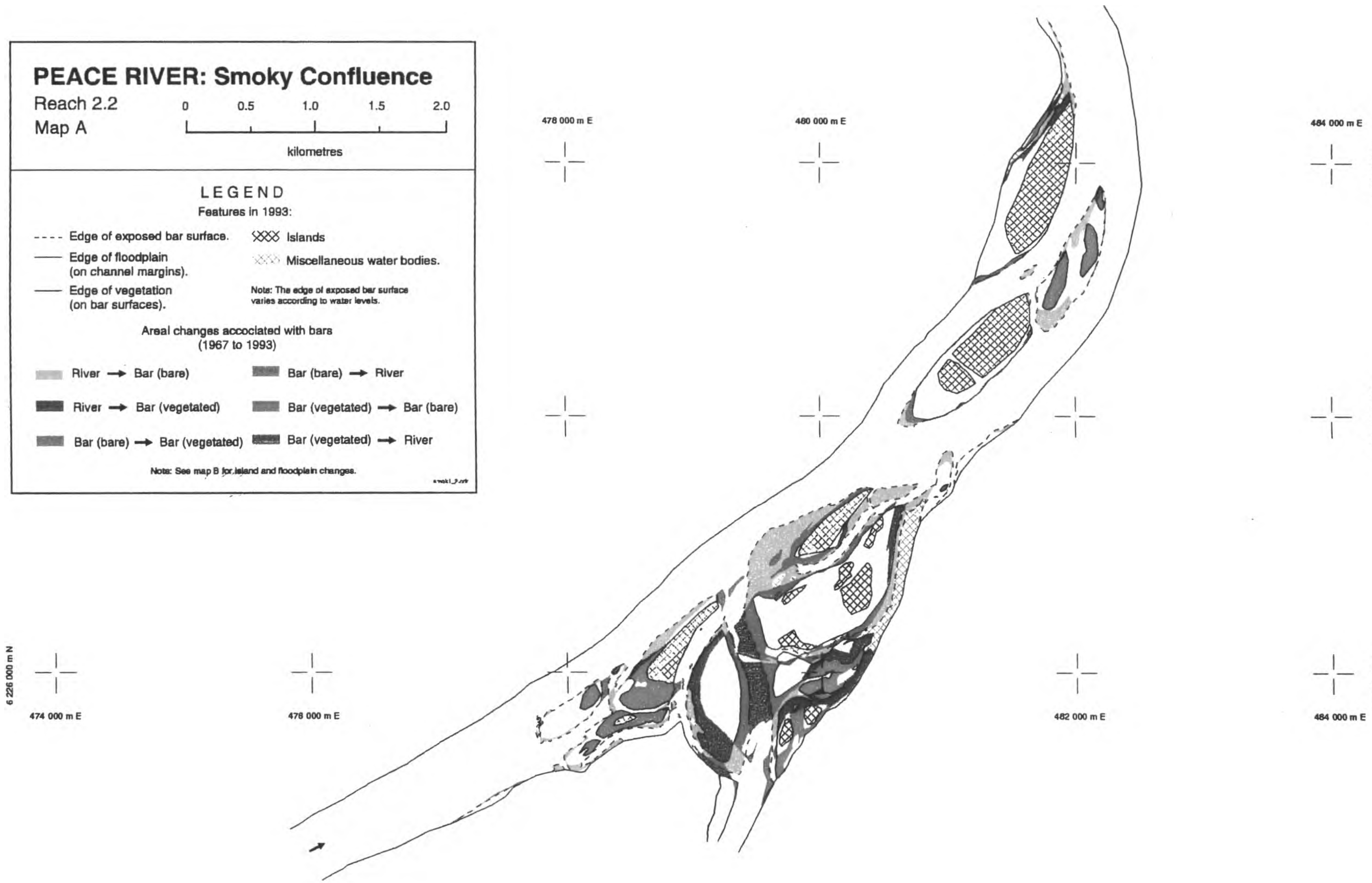
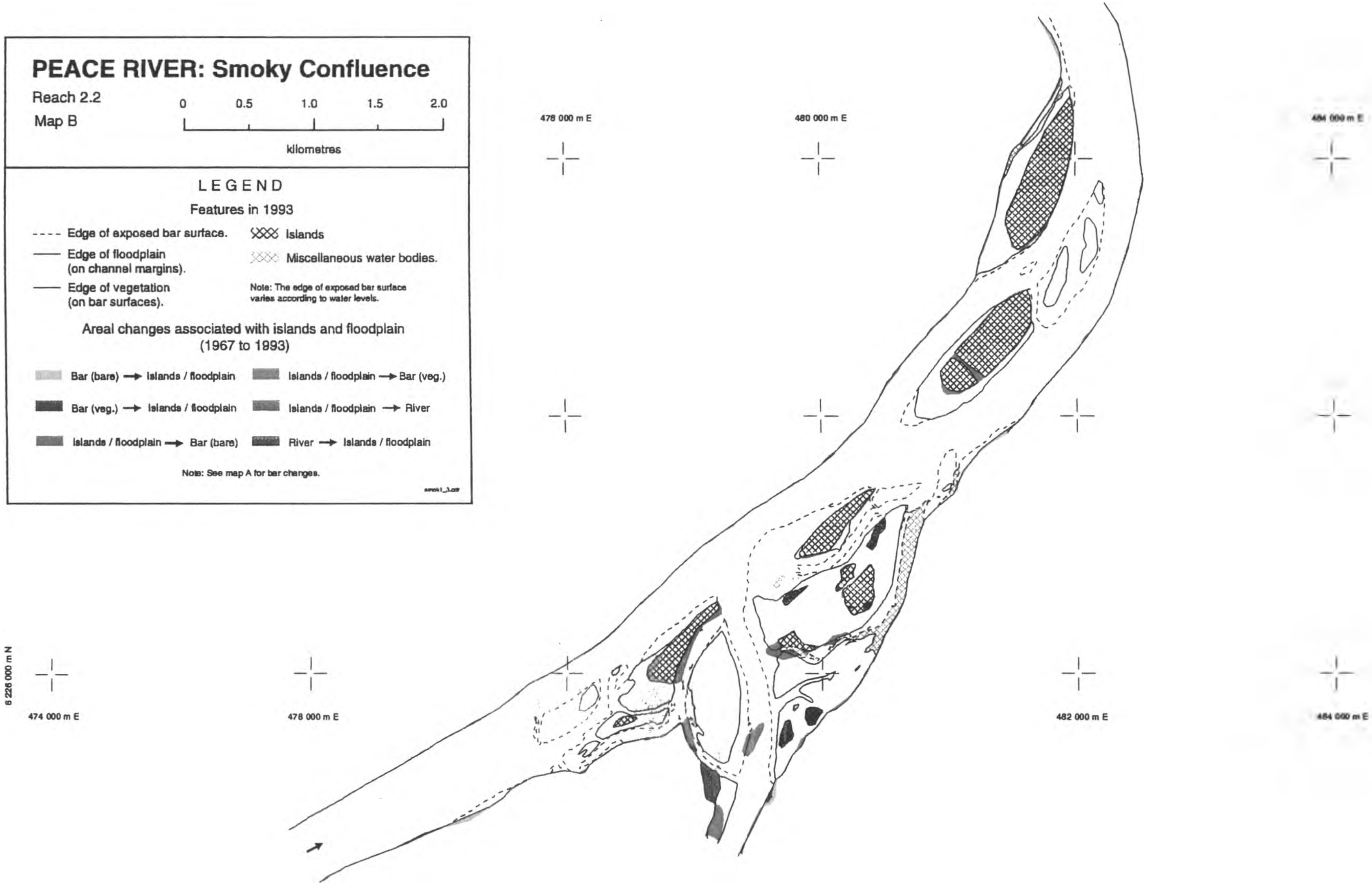


Figure 15. Morphological changes between 1968 and 1993 at the confluence of Smoky River with Peace River, near Peace River town (subreach 2.2) (2 sheets).


PEACE RIVER: Smoky Confluence
Reach 2.2
Map B
0 0.5 1.0 1.5 2.0
kilometres
LEGEND
Features in 1993
Edge of exposed bar surface.
Edge of floodplain (on channel margins).
Edge of vegetation (on bar surfaces).
Islands
Miscellaneous water bodies.
Note: The edge of exposed bar surface varies according to water levels.
Areal changes associated with islands and floodplain (1967 to 1993)
Bar (bare) → Islands / floodplain
Bar (veg.) → Islands / floodplain
Islands / floodplain → Bar (bare)
Islands / floodplain → Bar (veg.)
Islands / floodplain → River
River → Islands / floodplain
Note: See map A for bar changes.
478 000 m E
480 000 m E
484 000 m E
6 230 000 m N
6 228 000 m N
6 226 000 m N
474 000 m E
478 000 m E
482 000 m E
484 000 m E
6 226 000 m N

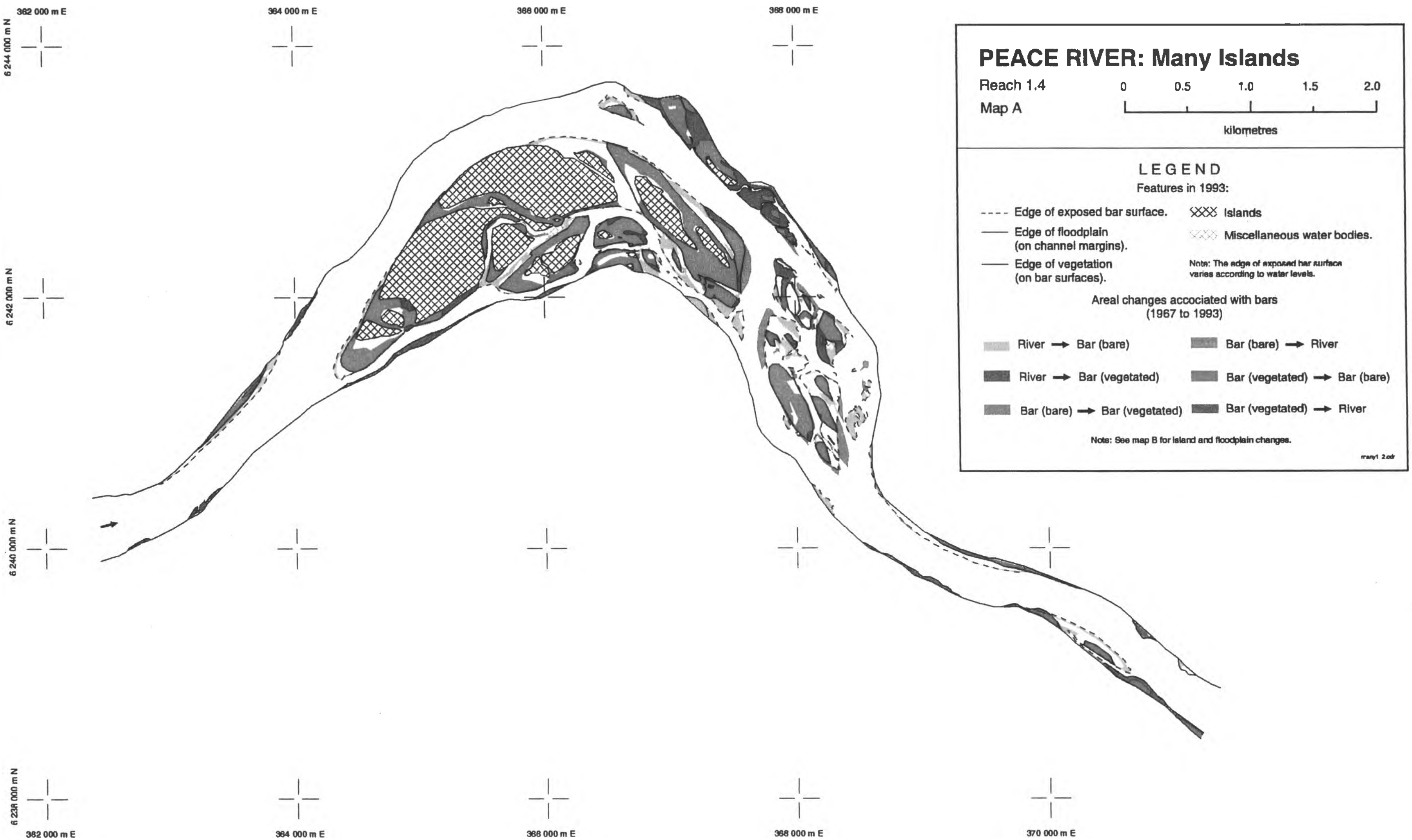
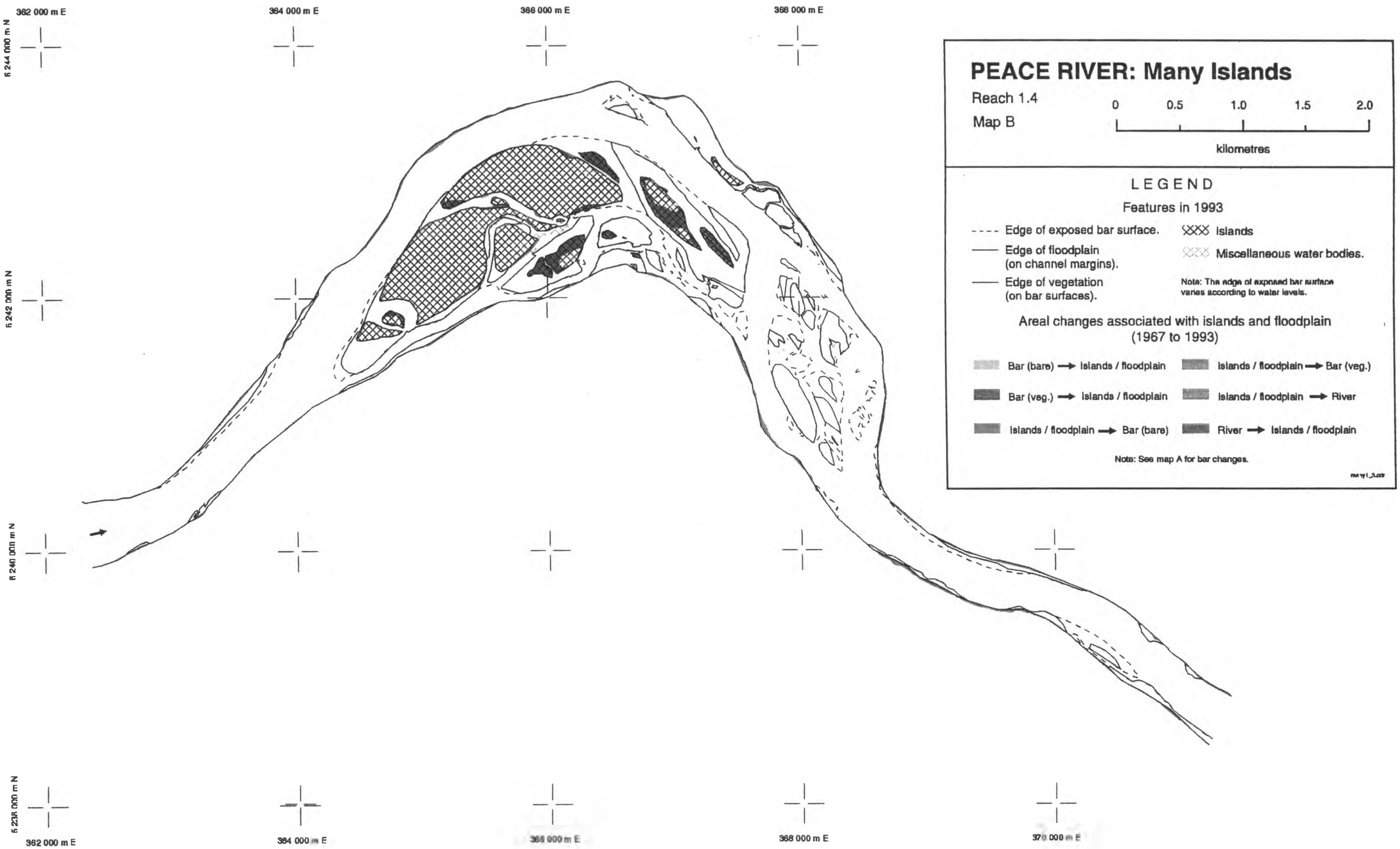


Figure 16. Morphological changes, 1968 to 1993, at Many Islands (subreach 1.4) (2 sheets).


PEACE RIVER: Many Islands
Reach 1.4
Map B
0
0.5
1.0
1.5
2.0
kilometres
LEGEND
Features in 1993
Edge of exposed bar surface.
Edge of floodplain (on channel margins).
Edge of vegetation (on bar surfaces).
Islands
Miscellaneous water bodies.
Note: The edge of exposed bar surface varies according to water levels.
Areal changes associated with islands and floodplain (1967 to 1993)
Bar (bare) → Islands / floodplain
Bar (veg.) → Islands / floodplain
Islands / floodplain → Bar (bare)
Islands / floodplain → Bar (veg.)
Islands / floodplain → River
River → Islands / floodplain
Note: See map A for bar changes.
362 000 m E
364 000 m E
366 000 m E
368 000 m E
370 000 m E
6 244 000 m N
6 242 000 m N
6 240 000 m N
6 238 000 m N

river instability, notably at Many Islands and Montagneuse Islands in Reach 1. Many Islands (Figure 16) represents a substantial accumulation of sediments deposited where the river currents are slowed down by the resistance to flow presented by a 90° bend in the valley. The morphology of the reach has not fundamentally changed here since regulation. Between 1967 (the actual date of the early photography here) and 1993, net deposition constituted about 8.8% of the total subreach area while erosion was 3.2%. There was a net gain of 370 000 m^2 of exposed surface, mostly as bar surface. There was also a gain of 297 000 m^2 of riparian forest on islands and floodplain, some of which was open water in 1967. This should be compared with a 113 000 m^2 loss to erosion. The net result was a narrowing of the river channel width from average 570 m to 458 m. Bar accretion was concentrated immediately downstream of the bend in the main (left bank) channel and along the right bank channel. It is likely that the right bank channel will eventually be abandoned unless ice-jam overflow maintains it. In the downstream group of islands, which were mainly active bars in 1967, there has been both accretion and erosion. Primary succession of sedge and grass meadows has occurred there. The left-bank channel around these islands has shoaled during the period and it is apparent that the eventual principal channel will cross to the right bank unless an avulsion occurs. Many bar surfaces have become vegetated since 1967 and will eventually become riparian forest.

The Montagneuse Islands (Figure 17) occupy a situation identical with that of Many Islands -- a sharp right bend of the valley. The former major islands have changed very little, but there has been a major extension of the downstream area where a major island group is developing which will eventually become attached to the right bank. Net deposition in the period 1966 (date of photography) to 1993 was 10.4% of the total subreach area, whilst net erosion was 3.9%. Over the same period, the river channel width narrowed from 516 m to 451 m. There was a gain of 750 000 m^2 of exposed surface and 240 000 $m^2$of riparian forest. There was also a 258 000 m^2 loss of forest, but whereas the gain was concentrated in the islands area, the loss was widely distributed along the reach as the result of bank erosion. Both bar and riparian forest extension are concentrated in the right bank island group downstream of the bend. Here the channel has more definitely established a single main course which crosses to the left bank (a development which duplicates that at Many Islands). Most of the erosion in this area is associated with this establishment of the main channel. Channels around the upstream islands all remain substantial, but it is likely that the left bank channel eventually will be dominant here.

The sandy gravel and sand-bed reaches downstream from the Smoky confluence are observed to still transport a substantial sand load. Adjustments occur as bars continue to build and erode. The same mechanisms, in the same order of significance, contribute to channel narrowing, but channel edge accretion is relatively more prominent downstream where the the load of sand and silt is much greater. Bar surfaces are rapidly covered by fine material, so early vegetative succession is dominated by *Salix* and grasses, with *Populus balsamifera* appearing later. Sediment accretion is more rapid than upstream, the consequence of the larger load of fine sediment carried by the river below the Smoky River confluence and the trapping efficiency of the abundant vegetative growth.

In reach 2, the river is confined, with only a fragmentary floodplain, mainly in the form of channel islands. It follows a mainly single thread channel with non-overlapping islands narrowly separated from the bank by minor secondary channels. The principal morphological changes since the regulation of the river have involved the abandonment of back channels, so that the islands are

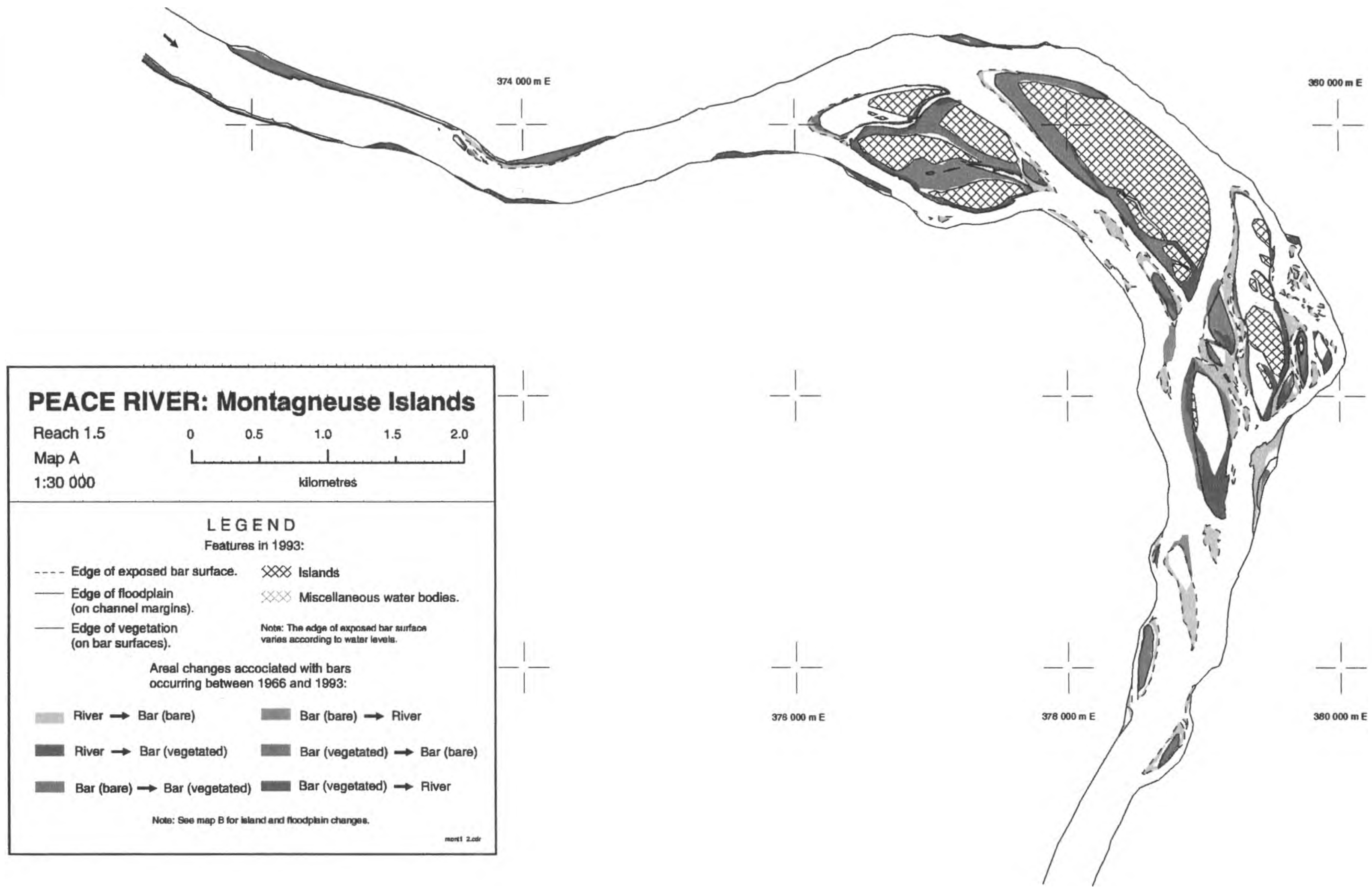
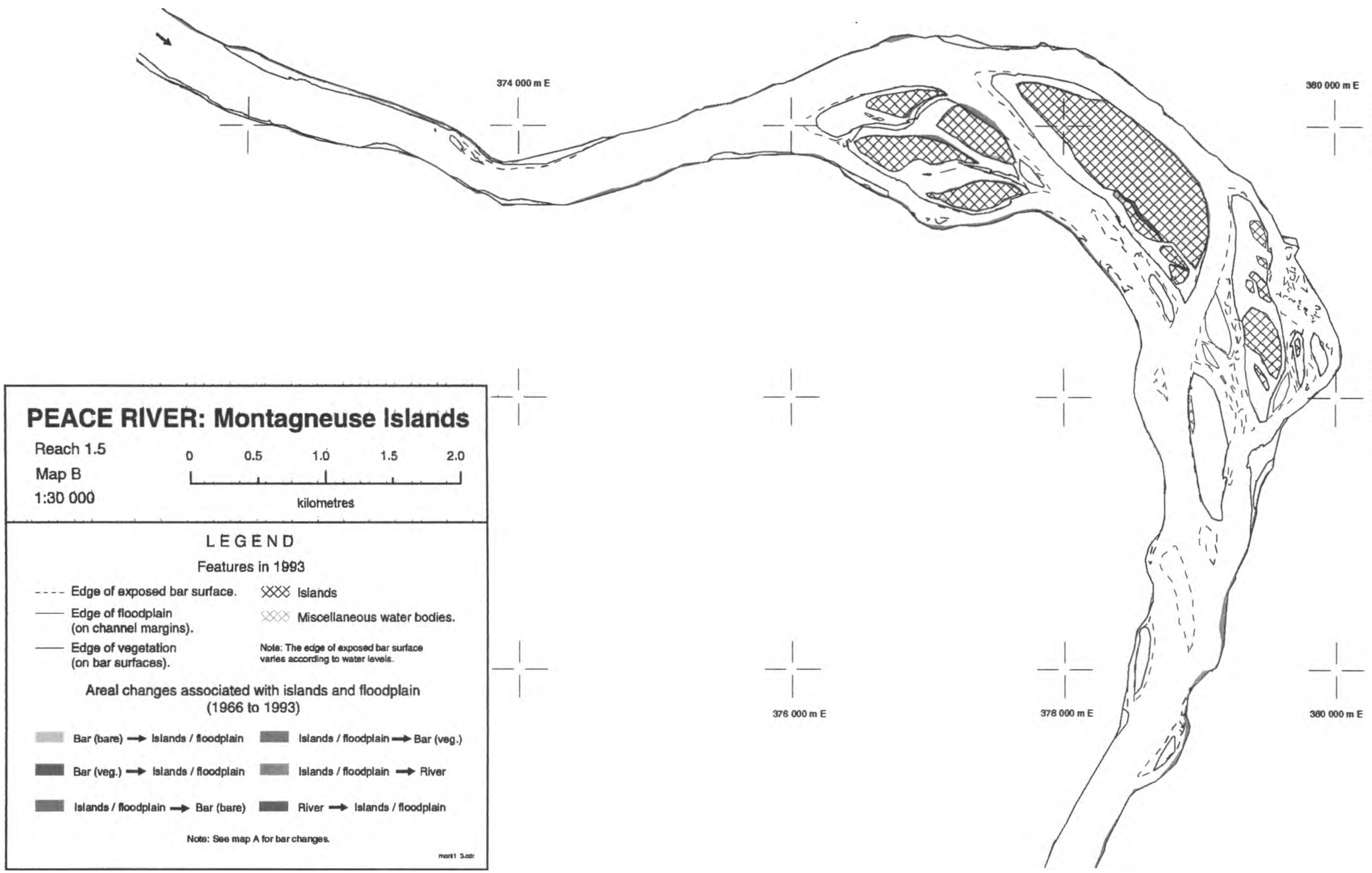


Figure 17. Morphological changes, 1968 to 1993, at Montagneuse Islands (subreach 1.5) (2 sheets).


374 000 m E
380 000 m E
6 238 000 m N
6 236 000 m N
6 234 000 m N
376 000 m E
378 000 m E
380 000 m E
PEACE RIVER: Montagneuse Islands
Reach 1.5
Map B
1:30 000
0
0.5
1.0
1.5
2.0
kilometres
LEGEND
Features in 1993
Edge of exposed bar surface.
Islands
Edge of floodplain (on channel margins).
Miscellaneous water bodies.
Edge of vegetation (on bar surfaces).
Note: The edge of exposed bar surface varies according to water levels.
Areal changes associated with islands and floodplain (1966 to 1993)
Bar (bare) → Islands / floodplain
Islands / floodplain → Bar (veg.)
Bar (veg.) → Islands / floodplain
Islands / floodplain → River
Islands / floodplain → Bar (bare)
River → Islands / floodplain
Note: See map A for bar changes.

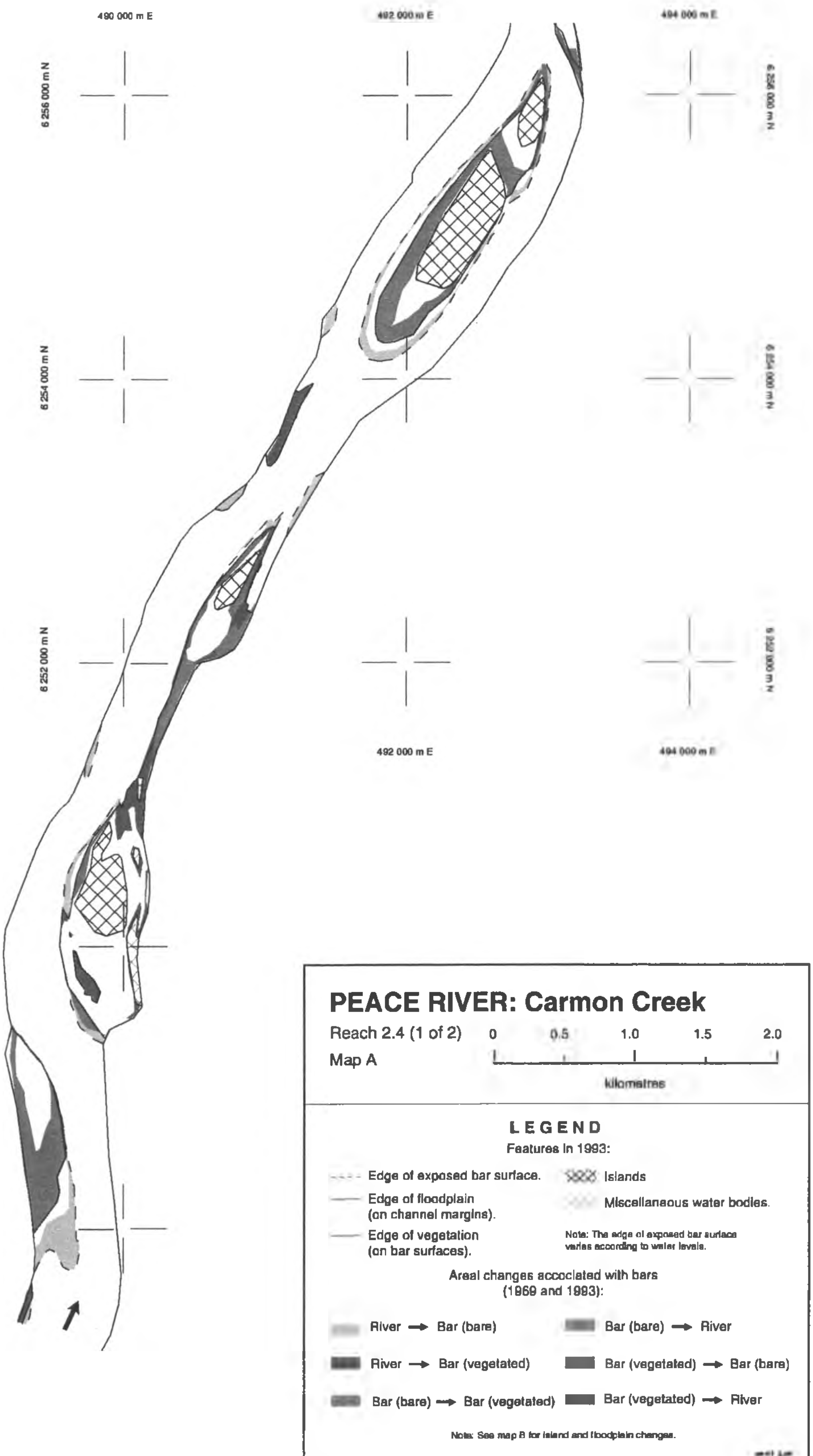
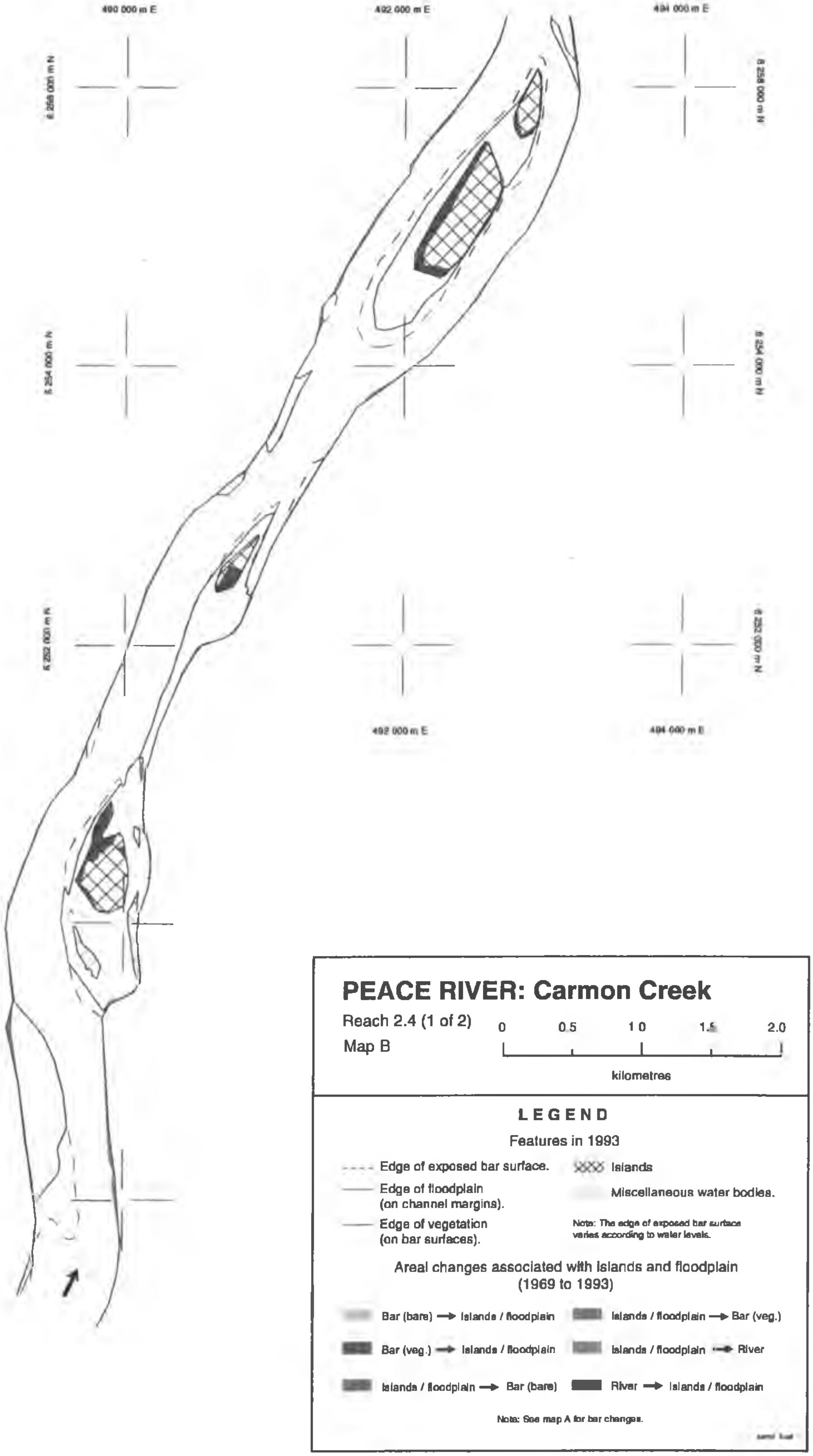


Figure 18. Morphological changes, 1968 to 1993, near Carmon Creek (subreach 2.4) (2 sheets).



490 000 m E
492 000 m E
494 000 m E
6 256 000 m N
6 254 000 m N
6 252 000 m N
PEACE RIVER: Carmon Creek
Reach 2.4 (1 of 2)
Map B
0 0.5 1.0 1.5 2.0
kilometres
LEGEND
Features in 1993
Edge of exposed bar surface.
Islands
Edge of floodplain (on channel margins).
Miscellaneous water bodies.
Edge of vegetation (on bar surfaces).
Note: The edge of exposed bar surface varies according to water levels.
Areal changes associated with islands and floodplain (1969 to 1993)
Bar (bare) → Islands / floodplain
Islands / floodplain → Bar (veg.)
Bar (veg.) → Islands / floodplain
Islands / floodplain → River
Islands / floodplain → Bar (bare)
River → Islands / floodplain
Note: See map A for bar changes.

becoming discontinuous units of ordinary floodplain. An example is the subreach at Carmon Creek where there are four islands the backchannels of which have essentially been abandoned, and two which still have regular through flow (three are illustrated in Figure 18). One of the latter is a true medial (channel-centre) island. Deposition in the reach is 8.6% of total area, and erosion is 2.4%. Average channel width has declined from 497 m to 472 m, which may not be significant. Forest extension is 390 000 m^2, whilst forest loss has been 270 000 m^2. Many backchannels have lost through circulation, except possibly during times of ice-jam induced stage rise, yet they retain pools with downstream connection to the main river. Some pools are replenished by bank seepage. These constitute valuable rearing habitats for fish, provided the water does not become too shallow and warm.

In Reach 3, the river morphology is superficially like that upstream in the distal part of Reach 2. However, the channel is less continuously confined and the bed is now largely sand, although gravels remain exposed on most bar edges and bar platforms. River gradient is substantially lower in Reach 3 than in Reach 2 and substantial deposition of sand is occurring. In some places, such as downstream from Tompkins Landing (Figure 19), the channel has become very wide and shallow. Here, width has changed since regulation from 711 m on average, to 658 m. Hence, the channel here remains wider than the pre-regulation channel in most upstream reaches. Deposition in the reach, nearly entirely in the form of bar extensions, is 11.5% of the total reach area, while erosion is 4.7%. Erosion is relatively large in this subreach, and represents the attempt by the river to maintain conveyance in shoaling sections of the channel by bank attack. Forest extension in the reach is 298 000 m^2, whilst erosional loss is 170 000 m^2.

There are three major island-bar complexes in the subreach, the first below Tompkins Landing. The first has developed large areas of new bar surface in the left bank channel, so that the river now passes to the right of the island, although there is still a through connection to the left. The bars are growing up in willow and will eventually form new floodplain, at a substantially lower level than the former floodplain (which is now a terrace). The second island occurs in a right bend of the river. Here the backchannel has become blocked to all but ice jam stage overflows and the main channel has shoaled dramatically. A new medial bar has emerged on the left hand side of the channel and the right bank bar (on the upstream part of the island) has been substantially eroded to maintain conveyance through the bend. At the next island, the left bank secondary channel is also largely sand-choked. The draping of sand sheets around the barhead here is very evident. Because of erosion on the island flank, net addition of bar surface here is not great. Eventually, all three of these islands may become attached to the adjacent floodplain, but the passages between the two units will remain substantially lower than the old floodplain surface and will remain subject to ice-induced high water for many decades.

Near Moose Island, the river flows through a series of relatively gentle bends with a major island-bar area in each bend (Figure 20). Net deposition in this subreach is 4.1% of the total riverine area, whilst erosion covers 5.8% of the area. In this subreach, there has been more erosion than deposition since the regulation of the river. Although the proportion of erosion is similar to that found elsewhere, deposition lags behind that found in most other reaches. As the result, forest establishment has been 304 000 m^2, but loss to erosion has been 383 000 m^2. Secondary channels behind the islands have mostly silted in, so that the islands are becoming attached, and the river is

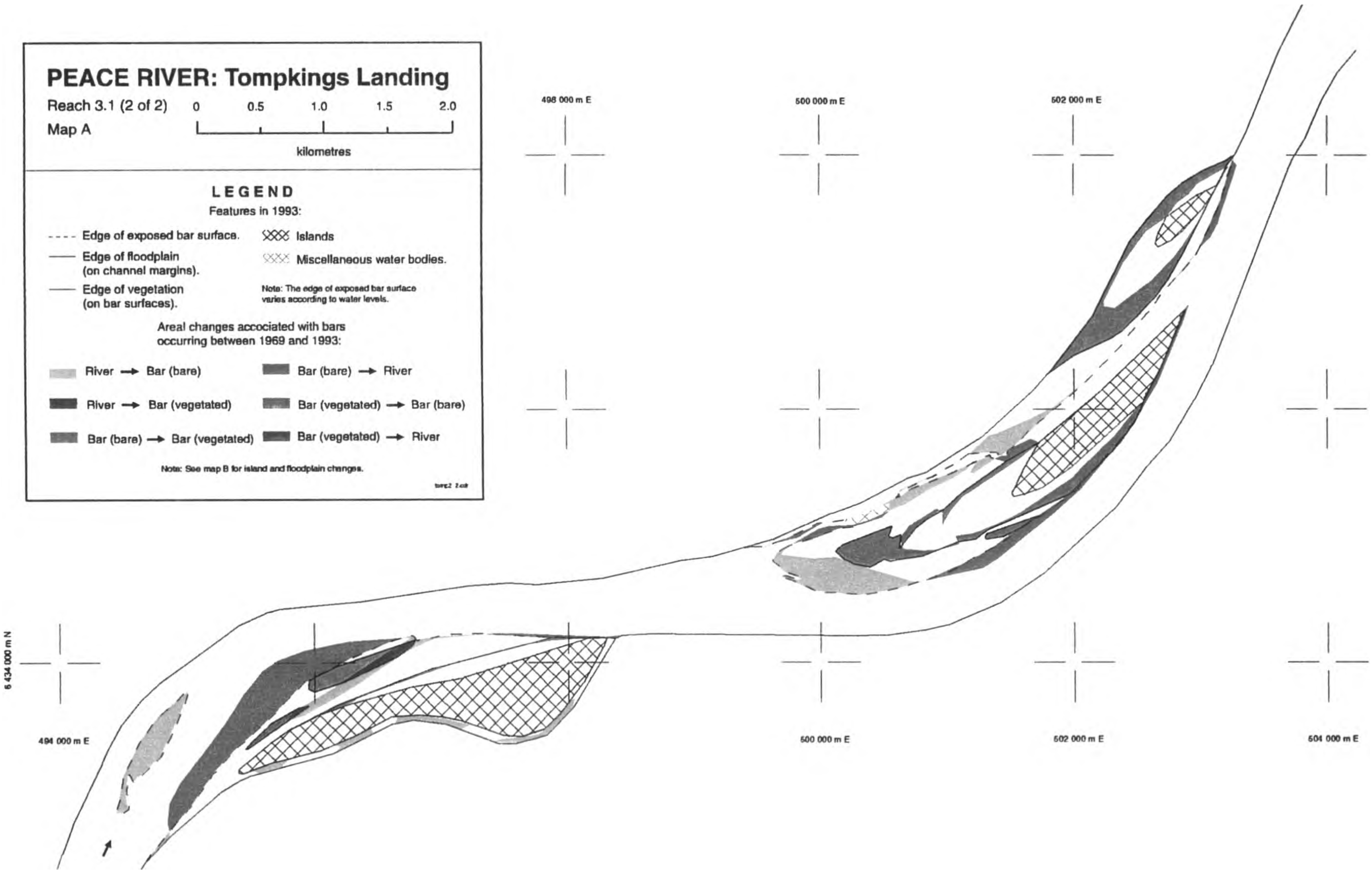
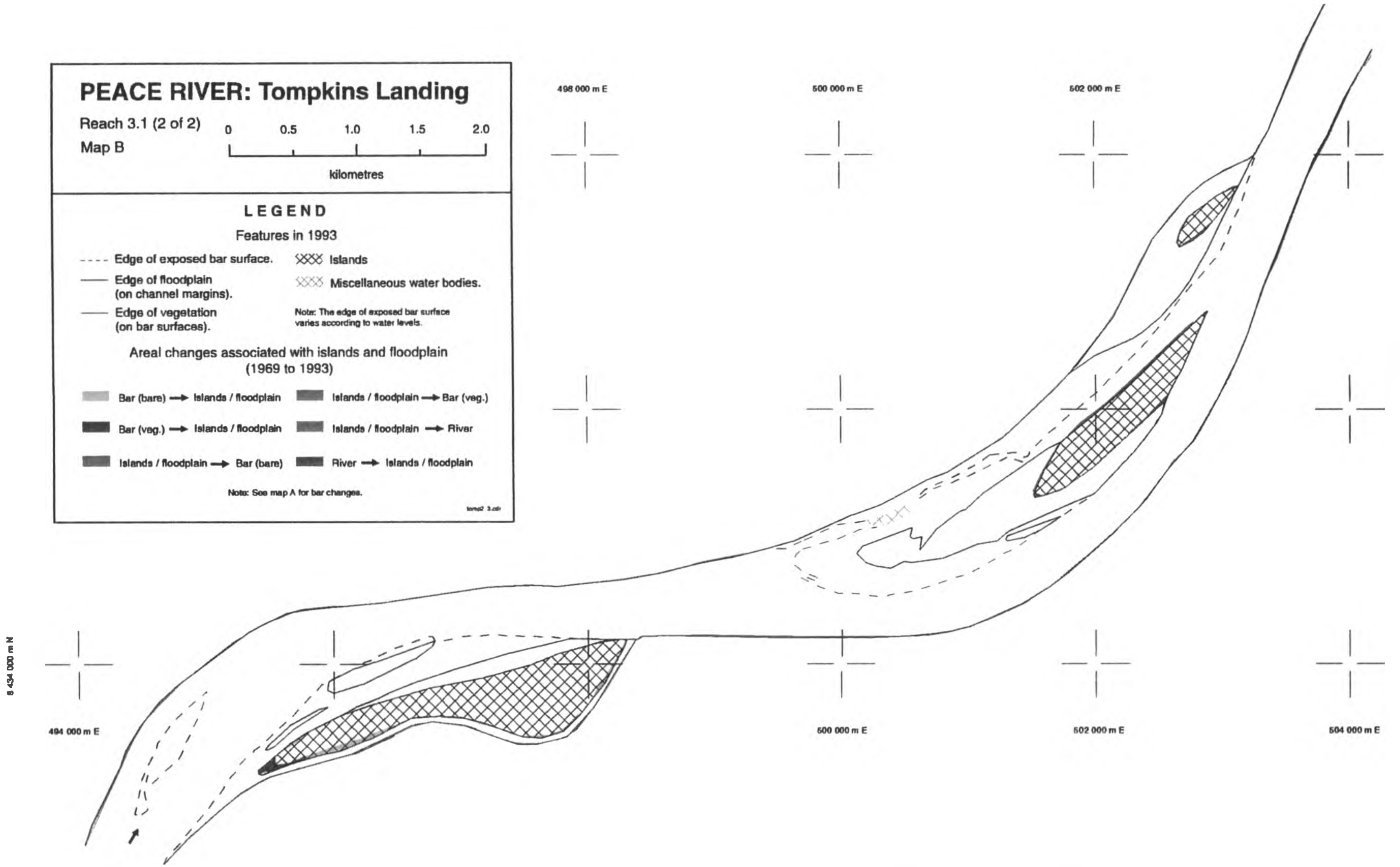


Figure 19. Morphological changes, 1968 to 1993, downstream from Tompkins Landing (subreach 3.1) (2 sheets).


PEACE RIVER: Tompkins Landing
Reach 3.1 (2 of 2)
Map B
0
0.5
1.0
1.5
2.0
kilometres
LEGEND
Features in 1993
Edge of exposed bar surface.
Edge of floodplain (on channel margins).
Edge of vegetation (on bar surfaces).
Islands
Miscellaneous water bodies.
Note: The edge of exposed bar surface varies according to water levels.
Areal changes associated with islands and floodplain (1969 to 1993)
Bar (bare) → Islands / floodplain
Bar (veg.) → Islands / floodplain
Islands / floodplain → Bar (bare)
Islands / floodplain → Bar (veg.)
Islands / floodplain → River
River → Islands / floodplain
Note: See map A for bar changes.
tomp2 3.cdr
498 000 m E
500 000 m E
502 000 m E
494 000 m E
504 000 m E
6 438 000 m N
6 436 000 m N
6 434 000 m N

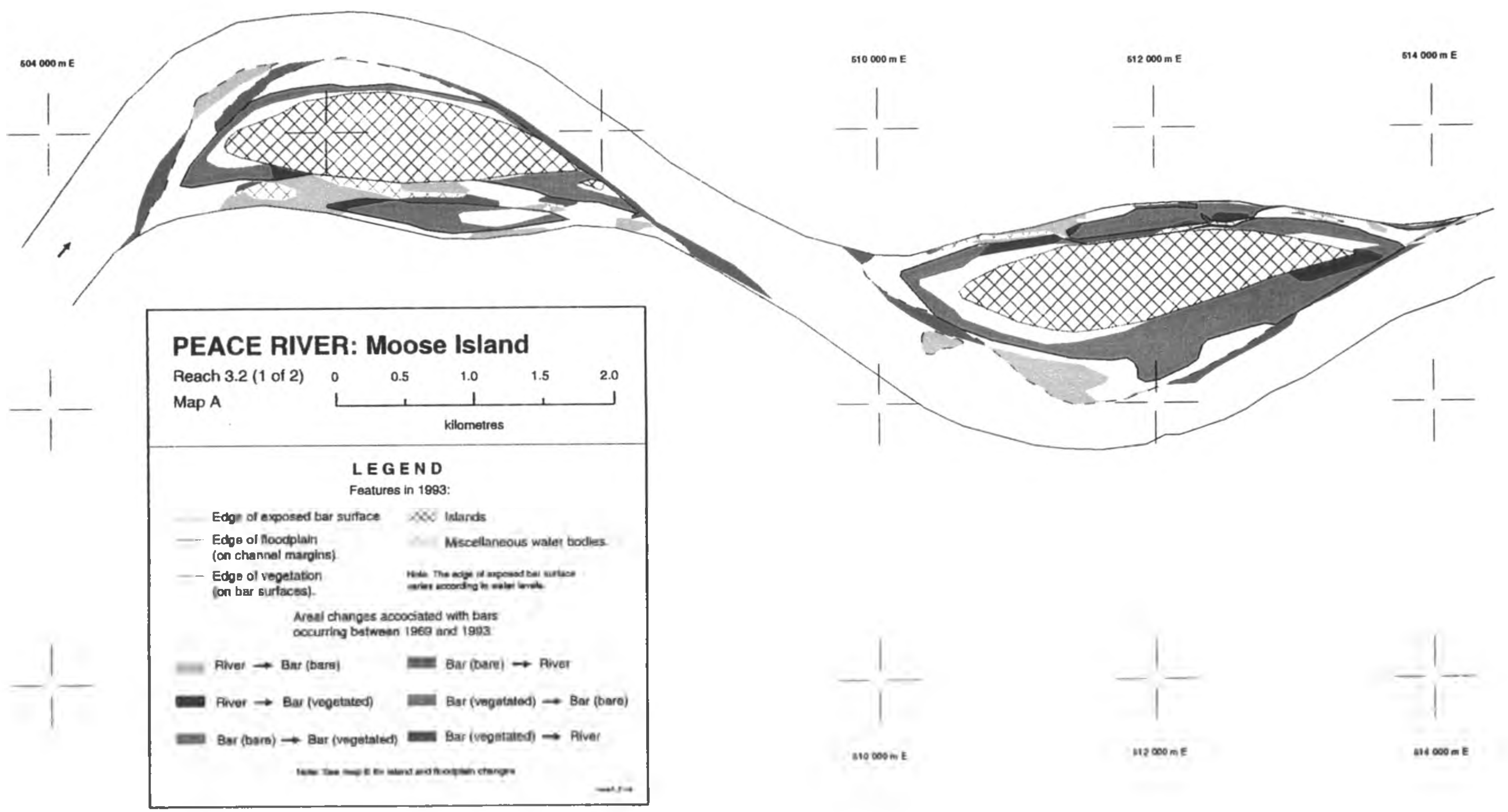
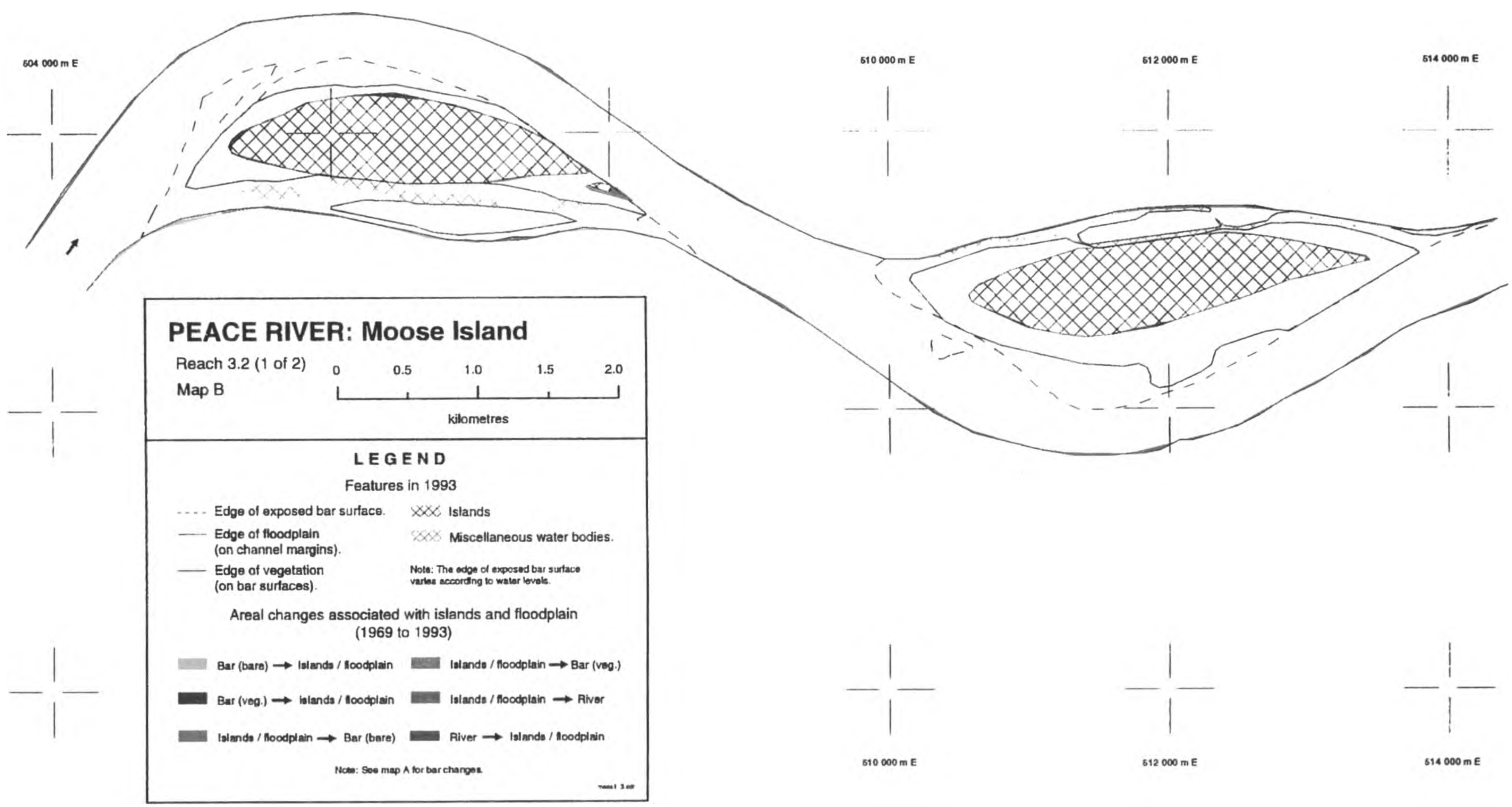


Figure 20. Morphological changes, 1968 to 1993, at Moose Island (subreach 3.2) (2 sheets).


PEACE RIVER: Moose Island
Reach 3.2 (1 of 2)
Map B
0 0.5 1.0 1.5 2.0
kilometres
LEGEND
Features in 1993
Edge of exposed bar surface.
Edge of floodplain (on channel margins).
Edge of vegetation (on bar surfaces).
Islands
Miscellaneous water bodies.
Note: The edge of exposed bar surface varies according to water levels.
Areal changes associated with islands and floodplain (1969 to 1993)
Bar (bare) → Islands / floodplain
Bar (veg.) → Islands / floodplain
Islands / floodplain → Bar (bare)
Islands / floodplain → Bar (veg.)
Islands / floodplain → River
River → Islands / floodplain
Note: See map A for bar changes.
504 000 m E
510 000 m E
512 000 m E
514 000 m E
6 440 000 m N
6 438 000 m N
6 436 000 m N

assuming a single thread habit. However, ice-jam high water still passes through the backchannels. Erosion has mostly been bankline erosion of modest magnitude but extending over considerable distances as the main channel adjusts its conveyance to adapt to the loss of backchannels and shoaling, which takes the form of sand deposition. Overall, the average width of the channel was reduced by more than 100 m, the measured averages being 727 m and 623 m. Backchannel losses were nearly exactly compensated by widening of the main channel. At the downstream illustrated island, a nearly attached sand bar has developed offshore in a moderately abrupt bend. The opposite bank is confined by high bluffs, so this bar will not further develop laterally.

In Reach 4, river instability is historically of lower intensity than upstream, and has continued to be so. The dominant changes have been the exposure of bar surfaces formerly part of the channel bed and for islands to become part of the floodplain by backchannel abandonment. These trends are the consequence of lower water levels. Incremental bank erosion to continues at a relatively low rate.

What is happening to the gradient and planform pattern of the river is a complex question, the answer to which can only be inferred at present. These two characteristics are intimately related because the easiest way for a gradient adjustment to occur -- in the sense that the least sediment transporting work need be completed -- is for the river to become more or less sinuous. The necessity for adjustment is mediated by changes in form resistance to flow along the channel, and by the concentration of mobile sediment in the river -- the greater the sediment load, the higher must be the gradient to maintain the ability of the flow to move it downstream. Whilst the concentration of sand has increased (as the result of the reduction in flow; figure 9), the relatively high gradient of the river in the gravel-bed reach ($> 10^{-4}$) is sufficient to pass most of the sand downstream, so there are only minor accumulations at channel-side and on bar surfaces.

In reaches 3 and 4, however, where the gradient is lower ($< 10^{-4}$), the increased summertime sediment concentrations may promote increased deposition of sand along the channel. Observed shoaling suggests that this is occurring. River morphology before regulation also influences the changes that may occur:

- Along much of its course between the British Columbia-Alberta border and Carcajou, the river is confined and flows over a gravel bed on a relatively high gradient, so the adjustment may be restricted to bartop and channel edge sedimentation.
- The effect of secondary channel abandonment in some reaches due to the decreased flows has been to increase the sinuosity of the river locally, so the average channel gradient has decreased; this may induce aggradation locally.
- One may speculate that secondary channel abandonment may also have reduced channel form resistance to flow by concentrating the flow in a single relatively deep channel, to at least partly compensate the reduced energy of the smaller flows.

In the long run, aggradation in the distal, sand-bed reaches will cause increased shoaling and, where the river is not confined, irregular lateral instability and renewed island formation may occur. The full expected reduction in overall channel width may in fact not be observed if, instead, channel division increases again so that the total channel width conveys water less efficiently. Such effects are already beginning to be evident downstream from Carcajou where channel shoaling has made small boat navigation locally and seasonally difficult.

Everywhere along the river, the old floodplain has become a low terrace. Former bar surfaces have become the sites of new floodplain development. Sand and silt accretion along the channel edges and in former backchannels is providing sites for progradation of semiaquatic and shoreline vegetation. In the proximal gravel reach, where the reduction in flood flows is most severe, the newly active floodplain level appears to be more than 2 metres lower than the former floodplain surface. Farther downstream, it appears to be 1 to 2 metres, but the long term effect of ice jam water levels may eventually reduce the difference to a small value.

4.3 DOWNSTREAM PATTERN OF CHANGES

Patterns of adjustment downstream reveal both variations in the way the river is adapting to regulation and some systematic aspects of change. The following discussion is based on observed average conditions in each of the 26 subreaches (out of 31) for which comparative information is available between "1968" and 1993.

Figure 21 illustrates 1993 channel width as a fraction of "1968" width. In Reach 1, the variability in adjustment is quite dramatic, with subreaches near Pouce Coupe River, Many Islands and Montagneuse Islands showing the greatest effect (ratio <0.9). These are reaches in which substantial sediment deposition occurs, where adjustments may be expected to occur relatively rapidly. In Reach 2, there has been relatively little narrowing. This effect probably is compounded of the backwater effect upstream of the Smoky confluence and river confinement downstream. Downstream of the Smoky confluence, the river is not entirely alluvial and overall changes are relatively small. In Reach 3, the reduction in channel width becomes systematically greater farther downstream, except in the divided subreaches around Fort Vermilion. This pattern may be linked with the sand transport and deposition in this reach, with relatively extensive deposition in the upstream subreaches maintaining a relatively wide channel zone. Reach 4 has experienced moderate reduction in width, in keeping with the relatively deep narrow channel that has developed in the distal portion of the river, the consequence of silty, cohesive banks.

Through reaches 1 to 3, river channel width is correlated with channel bar development (Figure 22). For channel width in the range 350 to 400 m, bar area varies from 8 to 25% of the active channel zone. The largest proportion of bar area is 40 to 50%, and occurs when channel width is greater than 600 m. In both cases, the actual water conveyance width is in the order of 300 m. It appears that if bar area exceeds 50% of the active channel zone, the resulting channel morphology presents sufficiently great resistance to flow to induce a compensating increase in the channel zone. Alternatively, a regime shift may occur to create a braided channel. Some parts of Reach 3 appear to be on the threshold of such a shift. In Reach 4, an inverse correlation appears. This probably is related to systematic changes in channel hydraulics and morphology on the approach to the Peace-Athabasca Delta within the Lesser Slave Lowland.

Ratios of various channel deposits to channel area have changed over time. Figure 23 illustrates "1968" and 1993 ratios downstream for bars and islands. Through reaches 1 to 3, proportional bar and island areas have increased systematically. In Reach 4, islands have increased, but bar areas exhibit a trend from increase near the head of the reach to decrease downstream. Alluvial

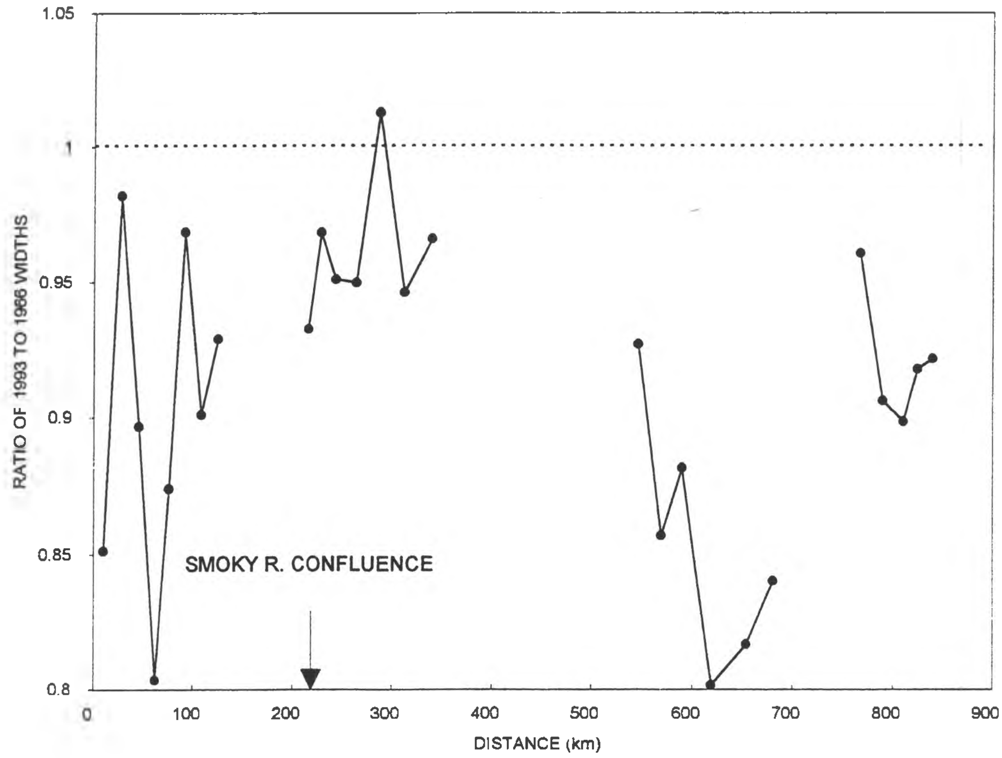


Figure 21. Proportional change in width of Peace River between 1968 and 1993, by subreach.

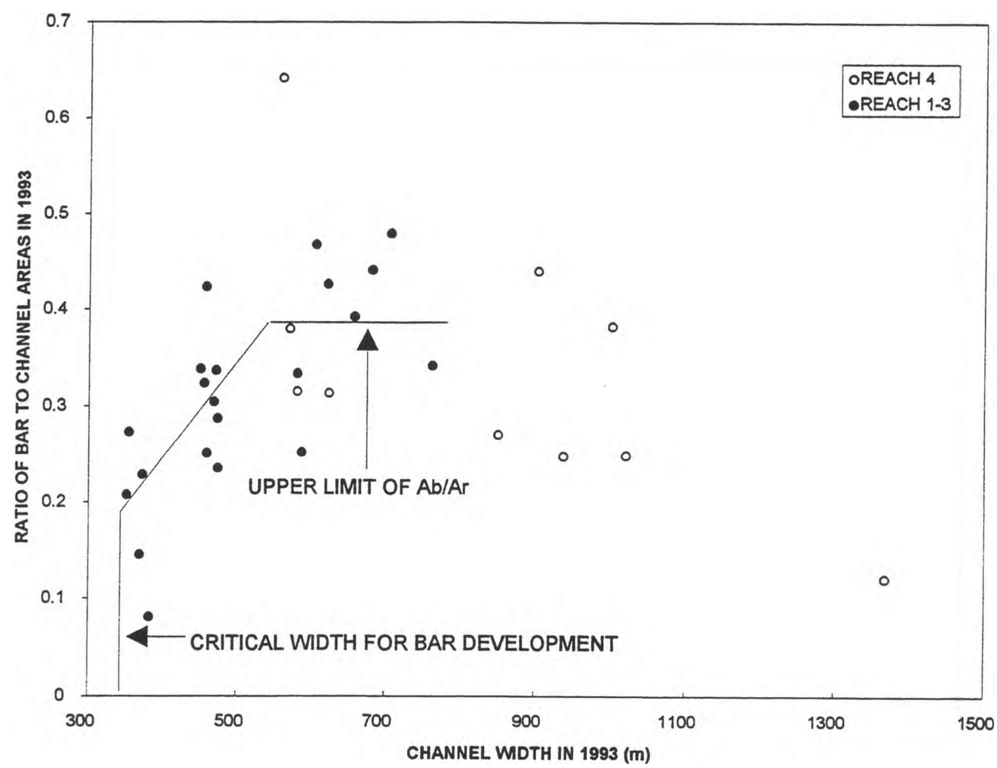


Figure 22. Ratio of total bar area (bare + vegetated) to channel zone area as a function of channel width in 1993: includes only the upstream portion of reach 4.

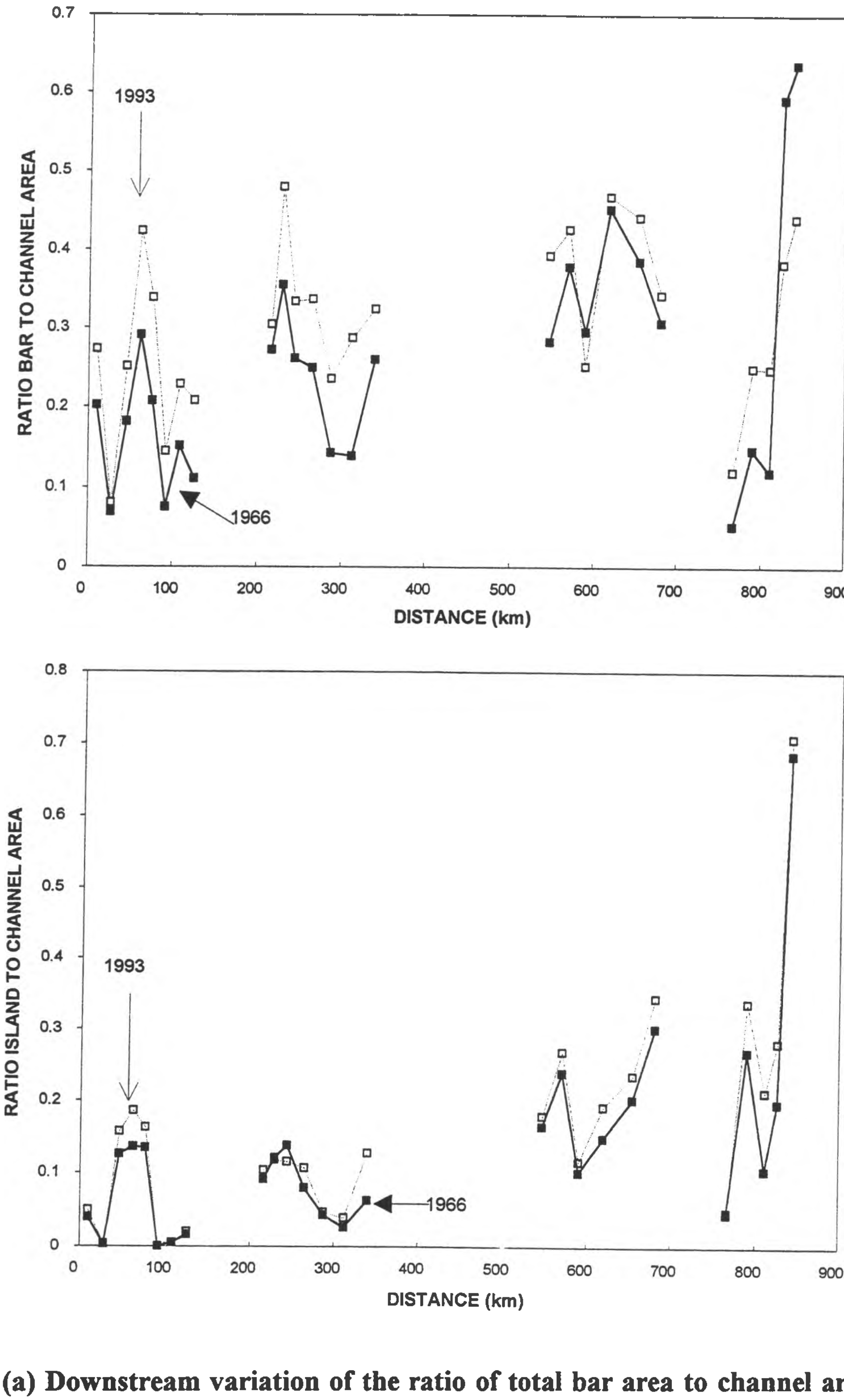


Figure 23. (a) Downstream variation of the ratio of total bar area to channel area in Peace River for 1968 and 1993, by subreach. Distances are measured downstream from the British Columbia - Alberta border; (b) Downstream variation of the ratio of island area to chanel area in Peace River for 1968 and 1993, by subreach; distances downstream from the British Columbia - Alberta border.

fan area per unit length of channel (Figure 24) has increased in reach 1 and at the Smoky confluence. Farther downstream fans become a very minor component of the riverine landscape altogether. The reason for this distribution is that notable alluvial fans consist of cobble-gravel delivered by the steeper tributaries in the upper part of the Peace River system.

The development of riparian vegetation, closely associated with the appearance of emergent sedimentary deposits, can be indexed along the river by the ratio (total vegetated area/total area of the channel zone). This index is shown in figure 25 for the dates of analysis. Each reach exhibits a distinct downstream pattern. In Reach 1, there is a dramatic increase in the vegetation index in the vicinity of the depositional subreaches at Many Islands and Montagneuse Islands, but elsewhere the changes are modest. Ice scour is a significant factor influencing channel morphology and vegetation development in the narrower, more confined subreaches of Reach 1. Reach 2 shows little change, the consequence already discussed of the developments around the Smoky confluence and of river confinement downstream.

In Reach 3, increase of the vegetation index is greatest in the downstream portion where channel narrowing has been greatest, but it is relatively great everywhere. In Reach 4, in contrast, there is a modest increase in vegetation index in the proximal subreaches where channel narrowing has also occurred. Overall, there are reasonable correlations through reaches 1 to 3 between the vegetation index and both channel narrowing and island/bar ratio (Figure 26), giving some indication of the close association between morphological development of the river and riparian vegetation development.

The observed transitions between morphological units given in tables can, when normalised by the total area comprising the transformed unit at the earlier date, be interpreted as probabilities for a transition to occur. For example, Figure 27 plots the fraction (bare bar area in 1966 transformed to river in 1993)/(total area of bare bar in 1966), which is interpreted as the probability for bar erosion to have occurred. Similarly, vegetated bar and island fractions are also plotted. Bare bar is generally less stable than the other two depositional categories. This is scarcely surprising, since it comprises the sedimentary unit which usually is most immediately adjacent to the water. However, some care must be exercised in interpreting the results since this is the category most likely to be biased by differences in water surface level between years. There is a reasonable correlation between the probability for bar erosion and channel width (Figure 28), implying that erosion is more likely in those parts of the channel with a high incidence of bar area. This appearance is entirely consistent with the notion that the greatest instability occurs in those parts of the channel which are characteristically depositional reaches.

It is likely that the probability for transformation amongst morphological units has varied with time since regulation. This conjecture will become testable as additional map series are completed, providing additional temporal resolution. If the probabilities are evolving systematically in time -- as seems possible -- then a basis will exist for modest extrapolation to predict further change. However, it is also likely that individual major events have a large effect on the pattern of change; they may accentuate, arrest, or even reverse secular trends for years after their occurrence. This hypothesis can be tested by study of the 1990 flood.

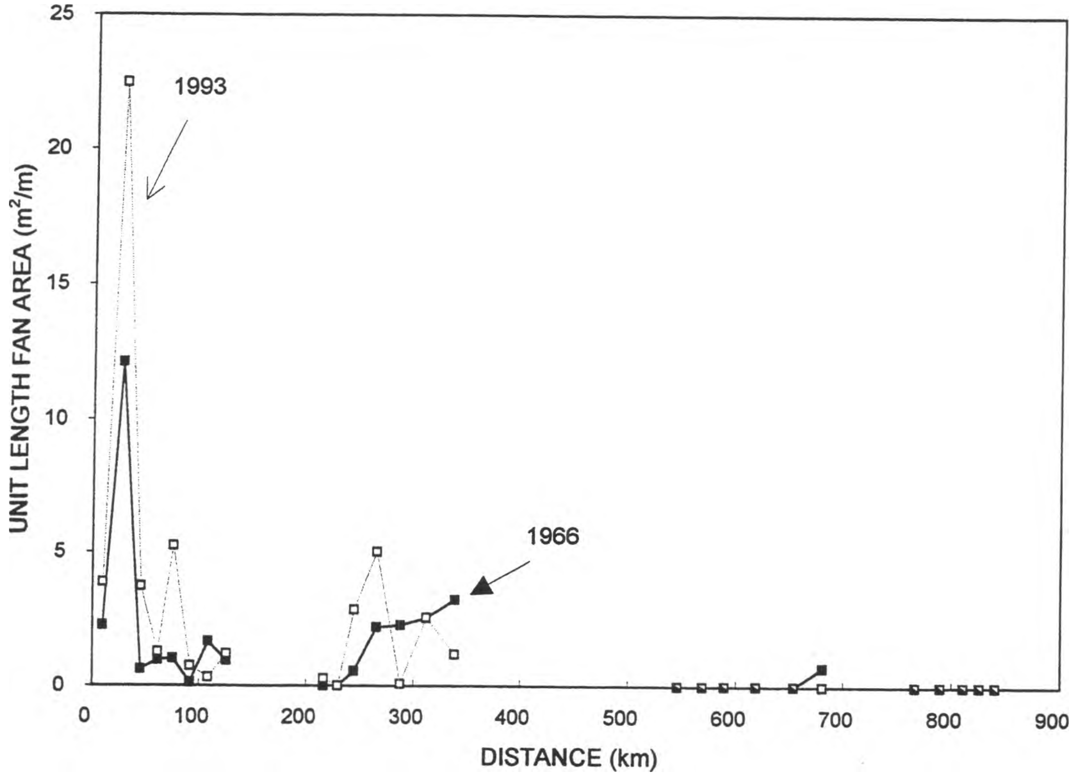


Figure 24. Area of alluvial fans within the Peace River valley flat per unit length of channel, by subreach; distances downstream from the British Columbia - Alberta border.

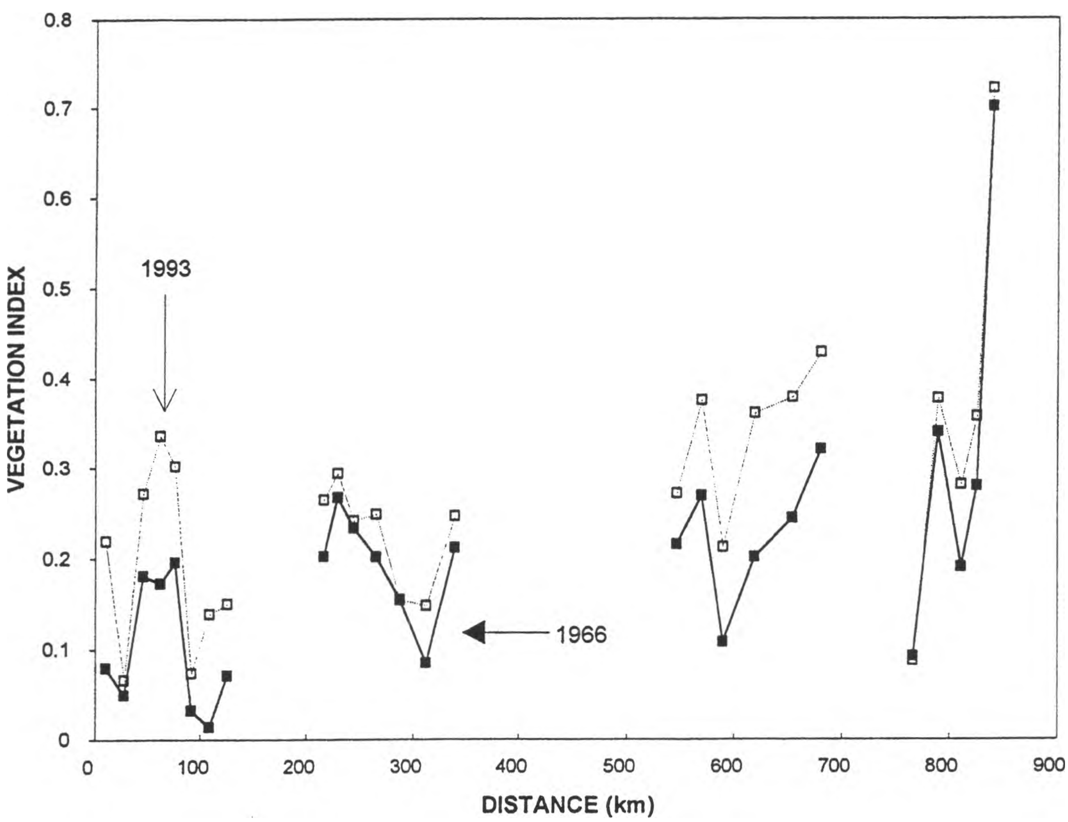


Figure 25. Variation of the vegetation index along Peace River, by subreach, downstream from the British Columbia - Alberta border (see text for definition of the vegetation index).

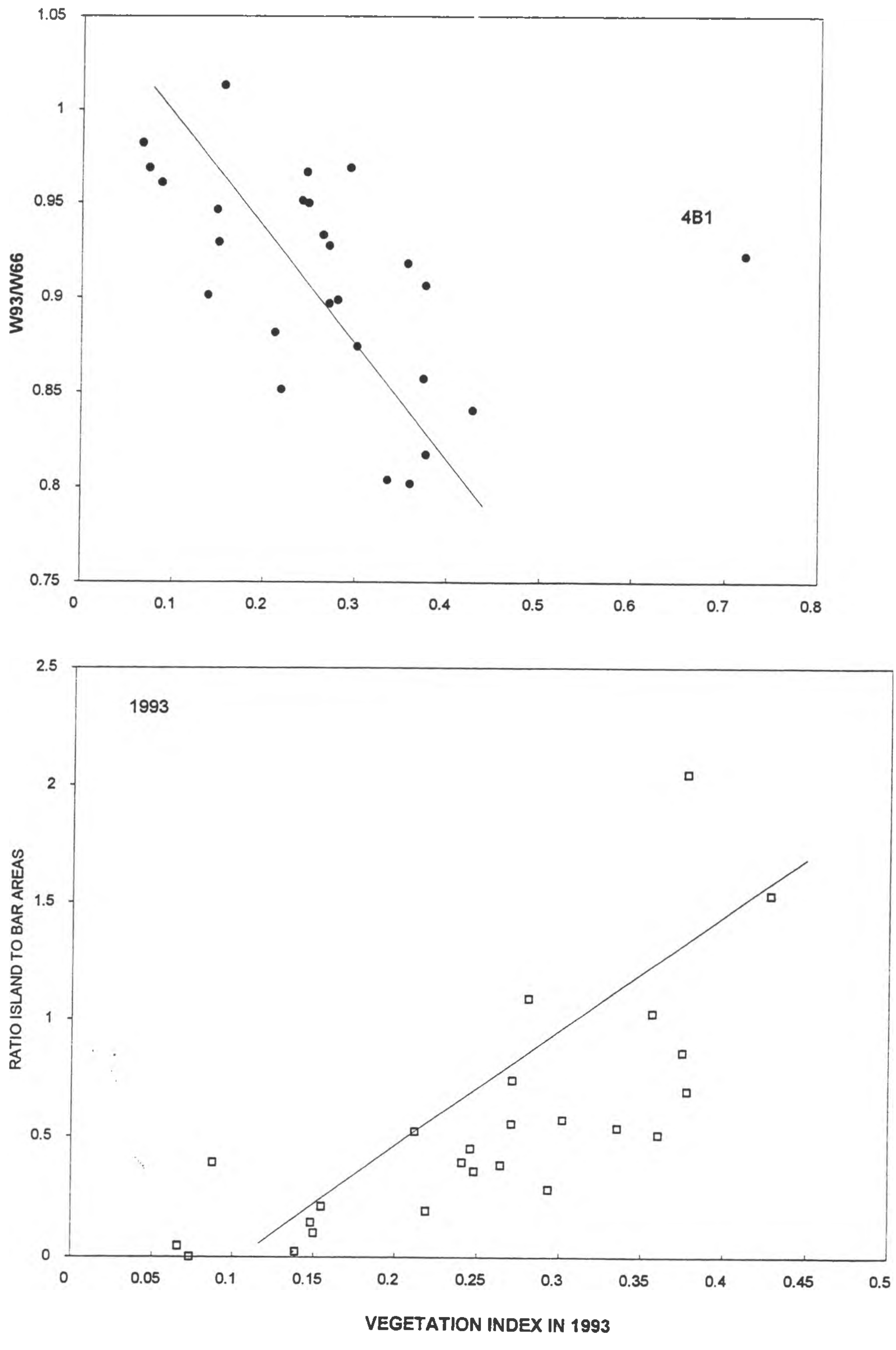


Figure 26. Correlation between the 1993 vegetation index and (a) relative narrowing of Peace River; (b) ratio of island to total bar area, by subreach means.

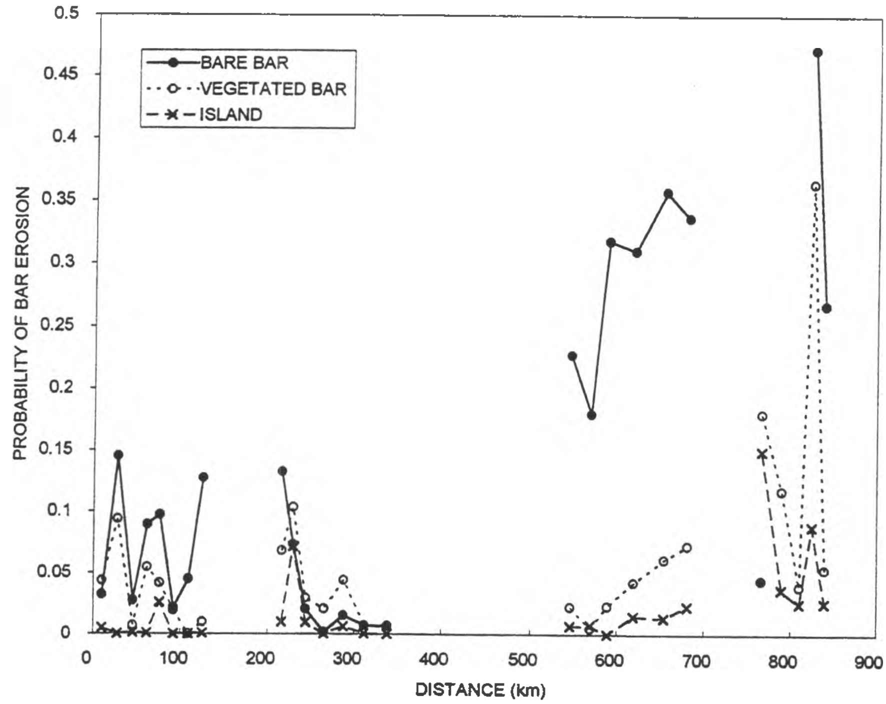


Figure 27. Probability of erosion for bare bars, vegetated bars and islands between 1968 and 1993, by subreach means, along Peace River downstream from the British Columbia - Alberta border.

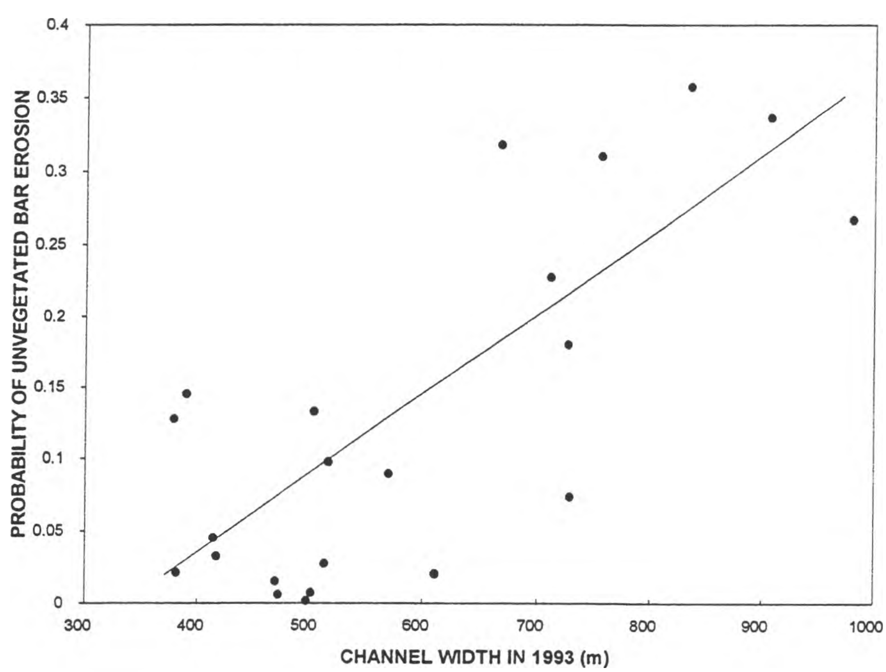


Figure 28. Correlation of the probability of erosion of unvegetated bars between 1968 and 1993with channel width in 1993 (subreach means).

5.0 DISCUSSION

It is desirable to be able to predict what the ultimate geometry and morphology of the regulated Peace River will be. The maps and field observations do not directly lead to this result because it is not clear that change is yet completed. On the contrary, it appears rather likely that it is by no means finished. We must have recourse to some more general predictive method. In this section, the questions of the equilibrium dimensions of the channel and the time scale to achieve those dimensions will be taken up. Predictions will be compared with the observations to 1993 as a means to obtain a judgement about how reasonable they may be. The basis for the predictive approach has previously been published by Church (1995).

5.1 THE EQUILIBRIUM DIMENSIONS OF THE REGULATED CHANNEL

Alluvial river channels conform to "alluvial regime" relations first developed early this century for the design of unlined irrigation canals. Relevant equations, which have also been called -- in application to river channels -- equations of "hydraulic geometry" (Leopold and Maddock, 1953), are as follows:

$$w_s = aQ^b \qquad (1)$$

$$d_* = cQ^f \qquad (2)$$

$$\langle v \rangle = kQ^m \qquad (3)$$

wherein w_s is river surface width; $d_* = A/w_s$ is hydraulic mean depth; $\langle v \rangle = Q/A$ is mean flow velocity, and A is cross-sectional area of flow; Q is a "channel-forming flow", and the other notations indicate coefficients. The coefficients, a, c and k take values that vary according to the nature of the bed and bank materials of the river. However, the exponents b, f and m appear to be well-constrained (Ferguson, 1986). A scale equation also is available to describe the relation between flow and meander or riffle spacing (Dury, 1976):

$$L = jQ^t \qquad (4)$$

in which L is meander wavelength, or riffle spacing.

Bray (1982) and Neill (1973) have developed systems of regime equations for Alberta rivers, Bray for gravel-bed channels and Neill for sand-bed ones. These provide us with values for a, c, k and j in equations (1) to (4). However, expected morphological adjustments to a change in channel-forming flow can be calculated by forming the ratio of regulated (r) to unregulated (u) values; e.g., for width

$$w_{sr}/w_{su} = (Q_r/Q_u)^b \qquad (1a)$$

The coefficients cancel provided that the regime type (i.e., bed and bank material, and channel pattern) does not change.

In canals, the channel-forming flow is well-defined (it is the full design flow), but in rivers it is clear only that, to predict a morphologically meaningful result, we require a flow that closely approximates the "bankfull" flow of the river: that is, the flow when the wetted cross-section occupies the entire channel between the trimlines of terrestrial riparian vegetation. Some analysts have claimed that this is equivalent to the mean annual flood (MAF), but it is clear that this is not true everywhere (cf. Williams, 1978). For present purposes, the exponents of the equations are set by adopting results from the analyses by Bray and Neill of Albertan rivers (i.e., of rivers in the same hydroclimatic zone as Peace River). For predicting changes, MAF values are used. Predicted changes are based upon the ratios of regulated to unregulated flows, and the ratios will be reasonably approximated by the MAF values even if the actual flows appropriate for initiating channel changes along Peace River should have a somewhat different frequency.

Results are presented in Table 3. In the gravel-bed reach above the town of Peace River and the Smoky confluence, widths are predicted eventually to be about 60 per cent of present widths, and depths about 75 per cent. Downstream of the Smoky confluence, width and depth are expected to be about 75 per cent and 83 per cent of preregulation values respectively. There is one gauging station in each principal reach, and these show that results do not vary over substantial distances. The change in velocity will be of order 10 per cent or less everywhere along the river. How these adjustments may be achieved will depend upon the competence of the regulated river to move sediment supplied by the tributaries and sediment resident along the main river.

Table 3

Regime Predictions for Regulated Peace River

Reach	Gauge (place)	Drainage area (km^2)	Mean annual flood Q_u (m^3s^{-1})	Q_r	Q_r/Q_u	w_{sr}/w_{su}	d_{*r}/d_{*u}	v_r/v_u
1	07FD003 (Dunvegan)	130 000	8275[1]	3549	0.43	0.63	0.75	0.90
2	07AA001 (Peace River)	186 000	10 580	6125	0.58	0.74	0.83	0.93
3	07HF001 (Fort Vermilion)	223 000	10 096[2]	5926[3]	0.59	0.75	0.84	0.94
4	07KC001 (Peace Point)	293 000	9817[4]	6563	0.58	0.75	0.83	0.93

[1] 8 years' record; [2] 6 years' record; [3] 8 years' record; [4] 9 years' record

A special circumstance may be developing in Reach 3 where a portion of the sand load introduced by Smoky River appears to be depositing, leading to channel shoaling. New medial sand bars are forming in the channel and this may indicate a regime change such that a single set of alluvial regime equations, upon which are based the proportions given above, would no longer hold. In this circumstance it is necessary to adopt an equation which reflects the new morphology of the bed. It appears as if the chnnel may eventually take up a low-order braided habit (i.e., there would be two principal channels about medial sand bars). There is no well-established equation for this circumstance. An equation has been given by Ashmore on the basis of model observations:

$$w_s = 12.8Q^{0.45} \qquad (5)$$

This equation predicts an ultimate regime channel width of 658 m, in comparison with the current reach-wide width of 673 m. Neill's sand-bed equation predicts only 365 m for a stable channel, but he notes that channels with frequent bars and islands may be wider. An estimate of 625 m is fair to make from his data plot. It appears then that the regime channel width may be not too far off the current width.

5.2 TIME SCALES FOR ADJUSTMENT

The time scale for adjustment of alluvial river morphology following a regime change can be estimated most directly by considering the transfer of sediments which effects the adjustment. Alternately, one may acknowledge the significant role played by riparian vegetation in stabilising river banks and flood surfaces, and consider riparian succession.

Recognition that the mechanism of adjustment entails transfer of sediments leads to a hydraulics-based approach which must include a sediment transport function. Unfortunately, the transport of bed material in alluvial rivers is not a well-resolved problem. However, for a process of adjustment that must require at least a period of decades to accomplish, approximate formulations may be informative. Such an approach was outlined by de Vries (1975), who arrived at the criterion

$$T_{50} = L^2/Y \qquad (6)$$

$$Y = b<Q_b>/3w_sS \qquad (6a)$$

in which T_{50} is the time for the river bed adjustment to be 50% complete at a distance $L > 3d_*S$ from the origin of the disturbance; d_* is hydraulic mean depth of the channel; S is channel gradient; b is the exponent of the bed sediment transport relation; $<Q_b>$ is the mean annual bulk volume of bed material transported; and w_s is river channel width (channel scale). b signifies the dependence of the time scale upon the sensitivity of the transport process. de Vries specified the process for an up-channel propagating disturbance. However, the approximation is sufficiently robust to be indicative for downstream propagating disturbances such as we are considering here.

Table 4

Data for estimating the time scale of channel adjustments

Parameter	upstream	downstream
Bed material	cobbles	sand
b	1.5	1.5
S	6.0×10^{-4}	9.0×10^{-5}
w_s (m)[1]	445	776
d_*[1]	6.0	6.5
$\langle Q_b \rangle$ (m3)	$O(10^5)$	1.0×10^6
$3d_*/S$ (km)	30	217
L (km)	100	200
Y	$O(10^4)$	8×10^6
T_{50} (yr)	>>104	5000

Notes:
Symbols are defined in the text.
[1] Pre-regulation values.
Data for Peace River downstream are drawn from McLean (1980) and refer to the reach near Fort Vermilion. Data for Peace River upstream are based on the writers' observations. Post-regulation flows are assumed.

Table 4 gives relevant data for proximal and distal reaches of Peace River. All the estimates of adjustment time are comparable with the entire span of Holocene time. They result from the small magnitude of bed material transport in northern rivers, which is a documented observation (e.g., McLean and Church, 1986). The only direct measurement of sediment transport available for Peace River is at the town of Peace River (Environment Canada, 1986). The value is 34×10^6 tonnes yr^{-1}, on average, of which only 5% -- roughly 1.7 million tonnes -- is bed material (sand > 0.18 mm diameter and gravel). Even if de Vries' formulae are incorrect by an order of magnitude, the indication is that hydraulic adjustment time on this river will be very long. The main part of this adjustment is related to slope adjustment along the river. The primary sectional adjustments undoubtedly are completed during perhaps 1 per cent of this time scale. One is forced to two significant conclusions:

(i) the gradient and channel pattern changes will not be detected as different than the normal pattern of instability of these alluvial channels;

(ii) cross-section changes will partly be effected by freezing the channels in something like their present configuration, with progradation of bank vegetation ultimately defining the new channel edge on a lower floodplain level.

Riparian succession is, therefore, apt to play a dominant role in the development of the new riverscape.

Riparian (and possibly aquatic) plant communities may influence sediment transfer by mediating the erodibility of material from stream banks and bed. This is not considered in hydraulics. Petts (1987) presented a formal model for the adjustment of lotic and riparian ecosystems to changed flow regime. He indicated that the adjustment time for aquatic ecosystems may be comparable with the time for channel stabilisation, which he estimated may be a century or more.

Along northern rivers like Peace River, initial riparian adjustment to reductions in flood frequency is allogenic succession on former bar surfaces and on newly deposited sediments along the channel edges (Kellerhals and Gill, 1973). (Allogenic succession refers to replacement of one plant association with another as the result of sedimentation changing substrate conditions.) A history of interaction between plant establishment and sedimentation occurs, since the plants affect sediment trapping and site aggradation during floods. After the new flood surface stabilises, seral succession commences toward the establishment of a boreal coniferous forest. (Seral succession refers to autogenous succession in the plant community.) These processes will be limited by sedimentation rates, by seed availability, possibly by plant/animal interactions, and by hydroclimatological events. It would require more than a century to proceed to completion, probably more at most sites. Observations over 25 years in the study reaches emphasise this point.

On Peace River, the initial width adjustments associated with channel abandonment and bar exposure were accomplished largely within the first decade of regulation. This is consistent with most reported experience, for reductions in flow, although the largely passive nature of the adjustment has not been emphasised in previous studies. Hydraulic adjustments do not constrain the rate at which floodplain succession occurs, but sedimentation and ice scour constrain developments on bar surfaces and along the banks. Shrub to young mature stage *Populus balsamifera* are well-established on many gravel bars in the upstream reach, and *Salix/Alnus* gallery stands are well established on finer substrates all along the river. These are allogenic developments. Undisturbed seral succession has not commenced on the lower, post-regulation flood surfaces.

The fraction of the total expected width adjustment to have occurred by 1993 can be calculated (Table 5). In reaches 1 and 3 more than half of the expected adjustment has occurred (or possibly much more in Reach 3 if a regime shift is occurring). These reaches have extensive island groups and backchannels, the abandonment of which would permit relatively rapid adjustment. In comparison, only a small portion of the expected adjustment has occurred in reaches 2 and 4. Reach 2 is largely confined and may, indeed, be fundamentally not an alluvial channel below the Smoky confluence. Bar surfaces have been abandoned within the reach, but such areas are less extensive than in reaches 1 and 3. If the width of the river was constrained by bedrock banks before regulation (as certainly is the case at Peace River town, for example, the unregulated width may be too narrow and the river may never take up the predicted adjustment. Bray's regime equation predicts an unconstrained pre-regulation regime width for this reach of 645 m. This estimate would yield a regulated equilibrium width of 477 m, and the river has currently achieved 0.46 of this adjustment.

Reach 4 has silty banks and few exposed bars. In this reach there is only limited opportunity for the river to adjust by bar abandonment. Most of the adjustment will eventually be achieved by siltation along the channel edge. Accordingly, the process is proceeding much more slowly and only about one-third of the ultimate predicted adjustment has occurred so far.

Table 5

Fractional adjustment of channel width by 1993

Reach	w_{su}	w_{sr}	w_{sp} [1]	fractional adjustment	Remarks
1	445 m	280 m	339 m	0.64	
2	520	384	500	0.15	River confined. See text.
3	776	582	673	0.53	Adjustment may be complete if a regime shift has occurred
4	1211	908	1123	0.29	

[1] w_{sp} denotes the present width (reach-averaged value)

The differences in behaviour amongst the reaches emphasise the relative importance of riparian succession on abandoned flood surfaces for creating rapid early adjustment to regulation. It must also be recognised that ice jam effects remain significant along Peace River, quite clearly maintaining scoured banks and setting back bar surface succession, especially in Reach 1. This, then, is a factor which we cannot quantify which may influence the results predicted in Table 5.

6.0 CONCLUSIONS

The main objective of this project was to determine the morphological changes that have occurred in the Alberta reaches of Peace River since regulation in 1968, primarily by mapping the river at the time of the regulation and at three dates since. For comparison, the river is also being mapped ca. 1950 to yield comparative data on the rates of morphological changes that occurred before regulation. In addition, riparian vegetation has been mapped, both as an aid to interpreting the riparain habitat and to reveal the role of riparian succession in affecting the morphological changes along the river.

Over the first quarter-century of regulated flows, the river has narrowed its course relatively dramatically in reaches 1 and 3, the proximal gravel-bed reach and the proximal sand-bed reach. Most of the change has been achieved by abandonment of side-channels behind and between channel islands, and by riparian vegetation succession onto abandoned bar tops. Both of these are essentially passive adjustments. With competent flows on the order of 40 to 60% as large as those which occurred before regulation, the river does not fill its former channel. There is, however, a significant interaction between the riparian succession and sedimentation processes. As vegetation progrades onto bar tops and down channel edges, it traps sediment which is advected into these areas during high water. High water today is created mainly by ice jams. In Reach 1 there is field evidence that even gravels may be trapped on bar tops during ice jam episodes.

Below the Smoky confluence, it is still possible for high floods to occur. Although the mean annual flood is substantially reduced, the flood of record actually occurred in 1990. This raises an interesting question how far single exceptional events can influence developments along a river in which the dominant regime has changed. We are not yet in a position to comment on this question, but have mapping underway to address it.

In Reach 2, narrowing has been much less marked. This reach has two distinct subreaches. Upstream of the Smoky confluence it flows in a relatively wide valley and has a substantial floodplain. Bar-top abandonment has occurred here, but the reach is in backwater to the Smoky River, which is depositing coarse sediment into the Peace River channel, so narrowing remains limited. Downstream, the river is confined, with only a fragmentary floodplain and sometimes rock banks. It appears probably that the river was not formerly at regime width in this reach. Hence, there have been relatively few changes and relatively little narrowing of the channel. Floodplain extensions may occur here in future, primarily by the attachment of islands, which occur in some of the bends, to the bank.

Reach 4 of the river is in the Slave Lowland. In this sedimentary basin, the river has a lower gradient than upstream and silty banks. Islands become steadily less numerous as one continues downstream, and the number of exposed bartops is much less than upstream. Here the main means by which the river can adjust its width are by side-channel abandonment in Reach 4A and by sediment accretion along channel edges. The pattern of floodplain vegetation shows that silt accretion along channel edges has been the normal mode of natural channel instability in this reach. The process will continue, but it will produce narrower channels than it has in the past.

Those riparian vegetation communities which have most greatly extended their area since regulation are the shrub units, including our classes mixed discontinuous shrubs and herbs, mixed medium shrubs (less than 2 m) and mixed tall shrubs. The former occurs on gravel bars in Reach 1, and on certain sandy surfaces farther downstream where there may be rapid sedimentation. The continuous shrub classes occur in concentric bands of varying height, width and spatial contiguity that surround the forested centres of islands. The banded appearance is possibly due to episodic extension of the riparian vegetation. These shrub communities are mainly 5 to 20 years of age, suggesting that they are a major response to flow regulation. However, in places, the plants have been flattened by recent ice and/or water damage, so the height of the shrubs cannot be interpreted as an unequivocal indicator of time since first substrate colonisation.

It is apparent that areas with extensive bar development along the channel are coincident with areas where the greatest changes are occurring today. In particular, riverbank erosion affects mainly unvegetated bar surfaces in the wider parts of the river. These areas are "sedimentation zones", areas where substantial transient accumulations have always occurred along the river. They will continue to be the least stable zones in the future. Downstream from the Smoky confluence, the river is carrying essentially the same load as before (less a small gravel contribution, perhaps). The river appears competent to move the sand load through the balance of Reach 2, but substantial deposition is occurring in Reach 3. Areas with substantial sand accumulations, which are mainly areas in bends, will continue to receive transient deposits of sediment and may continue to be unstable for many years. Ultimately, the river may stabilise in this reach only when sufficient aggradation has occurred to move the sand load farther on. However, the processes involved in staging sand through this reach in the meantime will appear like normal "regime instability" along the river; that is, the tendencies for sediment deposition here will not produce dramatic changes in river morphology. It will, however, create zones of frequently renewed bartop shrub communities.

Much more detail of the response to regulation outlined in this report will become accessible when mapping is completed for the two dates intermediate between 1968 and 1993. We will then be able to examine rates of adjustment over time and to isolate the effect of the 1990 flood. Clearly, these results will be interesting.

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APPENDIX A: TERMS OF REFERENCE

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NORTHERN RIVER BASINS STUDY

Project 1321-C2 **Temporal Evolution of Channel Morphology and Riparian Vegetation - Peace River**

SCHEDULE A - TERMS OF REFERENCE

I. Description

The purpose of this project is to conduct a historical review of variability, changes, and trends in river morphology and riparian vegetation at representative morphological reaches of the Peace River in Alberta. These changes or trends will be related to major controlling variables including: prevailing flow (and water levels where possible) conditions and suspended sediment loads, particularly those supplied by major tributaries. This analysis will provide an understanding hydrological conditions and begin to develop an ability to predict the types of changes likely to occur under future hydrological and sediment loading regimes. An improved understanding of how the river responds to changing hydrology (eg., high flow events; series of exceptional wet or dry years) and how it has adapted to flow regulation due to the operation of the W.A.C Bennett Dam is necessary for addressing Study Board Question # 10: "How does and how could river flow regulation impact on the aquatic ecosystem?"

Limited amounts of historical series of transect data, including vegetation community analysis, are available in the Peace-Athabasca Delta and in the reach of the Peace River between the Bennett Dam and the Alberta-B.C. border. However, no similar data exists for any part of the Peace River between these points. A historical review for the entire length of the Peace River within Alberta can therefore only be undertaken by interpretation of existing aerial photography in selected reaches of the Peace River.

II. Objectives

1. To quantify changes in the river morphology and riparian vegetation of representative reaches of the Peace River over the past 50 years.

2. Report on changes that have occurred at selected representative reaches (to be selected in consultation with the scientific authority for the project).

III. Study Location

The study location includes the Peace River from the B.C. border to Slave River. Several reaches will be selected for comparison. The reaches will be representative of the cobble-gravel-sand continuim of the river.

IV. Study Requirements

1. Examine the changes in morphology in representative reaches of the Peace River for the period 1949 - 1993 from aerial photography.

2. Examine the changes in riparian vegetation in representative reaches of the Peace River for the period 1949 - 1993 from aerial photography.

3. Determine if there have been significant changes in the morphology or riparian vegetation over the period and if any changes can be tied to river regulation.

4. Confirm the aerial photography interpretation with field checks.

5. All sampling locations presented in the report and in electronic format should be geo-referenced. This is to include decimal latitudes and longitudes (to six decimal places) and UTM coordinates. The first field for decimal latitudes/longitudes should be latitudes (10 spaces wide). The second field should be longitude (11 spaces wide).

6. Write a report which:

   (a) documents changes in river morphology over the period 1949 - 1993;

   (b) documents changes in riparian vegetation over the period 1949 - 1993;

   (c) documents variation in bar and island growth/formation;

   (d) documents changes in the widths of side channel segments;

   (e) documents vegetation succession, encroachment and colonization;

   (f) documents changes in bank stability;

   (g) presents an interpretive analysis of the observed changes in relation to the historic hydrometric record and sediment data;

   (h) offers an opinion on what role river regulation may have played in any changes, including the special role of ice;

(i) offers an opinion on how the ecosystem has been affected as a consequence of these changes;

(j) offers suggestions for continued long term monitoring of the river for unnatural morphological changes;

(k) documents the methods used to determine the conclusions reached; and

(l) follows the enclosed report format.

V. Reporting Requirements

1) The Contractor is to provide draft and final reports of the form and quantity outlined in Schedule B. The reports are to outline the tasks carried out by the Contractor in II, above.

2) The final report is to include the following: an acknowledgement section that indicates any local or native involvement in the project, table of contents, list of tables, list of figures and an appendix with the Terms of Reference for this project. Text for the report should be in Times Roman 12 point font. If photographs are to be included in the report they should be high contrast black and white. All tables and figures in the report should be clearly reproducible by a black and white photocopier.

Along with copies of the final report, the Contractor is to supply an electronic version of the report in Word Perfect 5.1 format. Electronic copies of tables, figures and data appendices in the report are also to be submitted to the Component Coordinator along with the final report. These should be submitted in a spreadsheet (Quattro Pro preferred, but also Excel or Lotus) or database (dBase IV) format. Where appropriate, data in tables, figures and appendices should be geo-referenced.

Any GIS files should be in ArcExport uncompressed format. Also suitable are DLG, DXF, SIF, Atlas and SPANS format. Any point files should contain two fields idnetifying latitude and longuitude in decimal degrees to six decimal places.

APPENDIX B: 1994 FIELD REPORT

Report on fieldwork undertaken on Peace River reaches 2 and 3, June 1994 by Margaret E.A.North, Julie Beer and Nick Williams

Objectives:

1. To establish ground truth for air photo interpretation of the vegetation in riparian habitats, both islands and adjacent floodplains, from the October 1993 photography.

2. To establish the species composition of the mappable cover types.

3. To observe the effects of recent flooding and ice-damage on the vegetation.

4. To establish a potential model of plant succession.

Methods:

1. The 1993 photographs were examined for the entire length of reach 2 and 3. Each island group was assigned a six digit alpha-numeric code number that identified the reach as P2 or P3, its position in that reach, numbered from the upstream end, and its individual number within the group. (See the attached copies of the NTS maps of each reach.)

2. The air photos of each group of islands were then laser printed at double the photo scale. The apparent vegetation cover types were drawn onto one set of these prints using the stereo-pairs to assist in establishing the colour tone and texture and height differences that suggest a variation in the plant cover.

3. These photo-maps were taken into the field and checked for the accuracy of the boundary lines. The checking was done from the river and from adjacent banks by direct observation and with the aid of binoculars, and from within the communities. Ground level and more distant views were photographed to supplement field notes and sketches.

4. A number of islands in each reach were pre-selected for detailed field study. The basis for selection was the presence of all or most of the recognisable cover types. The final number studied was further reduced because of problems of accessibility.

5. Detailed field study involved reconnaissance of each cover type to establish the species variation. Quadrat sizes were selected based on the complexity of the plant cover; 20x20 metres in woodland or forest types, 10x10 or 5x5 metres in shrub areas, in some cases the cover type was too narrow for a 10x10 quadrat. For each quadrat standard information was collected on species by strata, this included counts of live and standing dead trees, height and circumference at breast

height of the main canopy species; estimated cover of each of the high, medium and low shrub layers as well as the herbaceous layer; presence of moss, lichen and fungi; depth and type of litter; texture of the surface soil. (For plot details see Appendix I.) Plant collections were made at each plot and later pressed and identified for further reference.

6. The species composition of the various cover types was established for a number of islands in each reach. As there is a constant repetition of the cover types on all the islands except those that have been subject to unusual disturbance, such as logging, it was soon apparent that setting out more plots was not necessary.

7. Ability to predict the cover types from the photos and to predict detailed species composition of these types was tested during the last two days of field work. Success rate was good for cover type identification but was weakest in the prediction of the deciduous species in the mixed coniferous-deciduous forests in the interior of the older islands in reach 3. These islands usually have a cottonwood fringe to the mixed forest that may be made up of spruce, cottonwood, birch and the occasional aspen. In some of these forests birch is as common as cottonwood.

8. To assist the air photo mapping the field observations, sketches and ground level photographs and corrected field photos have been assembled into a series of island "identi-kits".

Results:

The islands and adjacent floodplains of Peace River reach 2 and 3 have very similar cover types. These are related to the age of the surface and the nature and frequency of disturbance. The youngest surfaces that we saw in June 1994 were just emerging from the spring high-water. These surfaces were either bare of vegetation, or the vegetation was buried under 2.5 to 3 cms of damp silt. In places the silt layer was pierced by emerging thin-leaf willow and a variety of herbaceous plants. On these sites wherever farmland provided a seed source, alfalfa was common.

The next older surfaces are found higher above the river. They are covered with willow dominated shrub communities, usually at least three species of willow occur of which the narrow leaf species is the commonest. In reach 2 the dominant willow appears to be the silver-leaf species although the narrow leaf is also present. Ice-damage of the reach 2 willow stands was common, though not universal. The willow shrub communities are of varying heights and densities. One could assume that both height and density may increase with age. (It may be possible to use the snow cover on the 1993 photographs to indicate density of cover.) As the shrub communities increase in height they also are increasingly made up of other than willow species, alder and cottonwood are the usual invaders. Cottonwood emerges fron the high shrub communities when they reach an approximate height of 6 metres, though there are willow communities at lower heights where this emergence has already occurred.

Bands of alder, rarely exceeding 10 metres in height but varying in the width from a single, discontinuous line to bands 10 metres wide, to belts several times that width, lie between the willows and the forest. On many islands these bands are composed of old, multi-stemmed alders, about 10 metres high, with a dense shrub layer beneath. However on other islands fresh silt carpets the ground beneath the alders and here the alders are of mixed age with many single stems, forming thickets that lack any dense shrub layer. In June there were only occasional shrubs and herbaceous plants emerging from the silt in these alder stands and it is impossible to tell whether these more disturbed sites would have a denser shrub layer later in the season. The density of the canopy and greater stem count of these disturbed sites would suggest that there may be inadequate light for a dense shrub layer. (Note that a major omission in the fieldwork was the failure to lay out a plot in this type of community, easily accessed from the Vermillion Bridge, see notebook.)

The forest cover that occupies the centres of the larger, older islands is either cottonwood dominated, a mixed spruce-deciduous cover, or a spruce dominated forest. In reach 3 birch becomes a more significant component of the mixed forest, replacing cottonwood in the interior of the islands, though cottonwood always occurs around the edge of the forest. In the floodplains adjacent to the river aspen is the common deciduous tree in both the deciduous and mixed forest types. Here the riparian vegetation is continuous with the adjacent valley slopes and uplands that are dominated by aspen or by spruce-aspen mixed forests. The aspen and cottonwood are severely affected by caterpillars in reach 2. We were told that this is the third consecutive year of the infestation and that it is endemic to the area and recurs on a 15 to 17 year cycle. The first leaves are completely consumed leaving the trees without the capability of photosynthesising, however the trees put out a second set of leaves by mid July that are not consumed as the caterpillars are then in the cocoon stage. Presumably this reduces the growth rate of the mature trees for the duration of the caterpillar infestation. It also raises questions as to how this recurrent infestation affects the competetive ability of these species and how it may affect the survival rates of younger trees.

APPENDIX C: SUBREACH DATA AND MAPS

Table C1: Dates of photography, by period of photography and main study reach (4 pages)

	Location of photos in downstream order*		Dates of photography	Scale of photography	Daily mean flows on date of photography (m3/s) **		
					Hudson Hope	Taylor	No other stations were in operation along Peace River
	from km:	to km:	(month/day/yr)	(1:)	07EF001	07FD002	
1950							
Reach 1	1074.3	982.5	October 2/50	40 000	589		
	982.5	968.0	September 7/50	40 000	776	915	
	968.0	956.0	September 5/50	40 000	799	929	
	956.0	941.5	September 4/50	40 000	804	934	
Reach 2	867.4	857.0	September 7/50	40 000	776	915	
	857.0	818.0	October 2/50	40 000	589		
	818.0	815.0	June 9/50	40 000	4620	5240	
	815.0	806.5	October 2/50	40 000	589		
	806.5	787.5	June 7/50	40 000	4130	4620	
	787.5	760.0	June 8/50	40 000	4360	4790	
	760.0	752.5	August 30/50	40 000	847	1020	
	752.5	734.0	June 28/50	40 000	2890	3370	
	734.0	728.0	June 23/50	40 000	5040	5830	
	728.0	724.1	August 30/50	40 000	847	1020	
Reach 3	545.7	538.0	June 29/50	40 000	2790	3230	
	538.0	525.0	August 19/50	40 000	920	1160	
	525.0	495.0	August 14/51	40 000	881		
	495.0	488.0	August 21/50	40 000	895	1100	
	488.0	471.0	June 26/50	40 000	3260	3740	
	471.0	438.5	August 18/50	40 000	934	1200	
	438.5	427.5	August 14/51	40 000	881		
	427.5	421.0	August 14/50	40 000	985	1230	
	421.0	391.9	September 10/50	40 000	711	878	
Reach 4A	331.9	293.0	September 10/50	40 000	711	878	
	293.0	285.0	October 12/50	40 000	609		
	285.0	270.2	September 12/50	40 000	674	847	
Reach 4B	270.2	205.0	July 24/50	40 000	1140	1610	
	205.0	189.0	July 10/50	40 000	1510	2000	
	189.0	180.0	July 24/50	40 000	1140	1610	
	180.0	163.0	September 12/50	40 000	674	847	
	163.0	149.3	September 3/50	40 000	816	946	

*** Channel distances (km) measured along centerline from head of Slave River.**

Reach 1 = km 1074.3 - km 941.5
Reach 2 = km 867.4 - km 724.1
Reach 3 = km 545.7 - km 391.9
Reach 4A = km 331.9 - km 270.2
Reach 4B = km 270.2 - km 149.3

km 1213.6 = Hudson Hope
km 1120.6 = Taylor
km 1074.3 = BC/Alberta border
km 942.7 = Dunvegan bridge
km 865.7 = Shaftesbury ferry
km 839.8 = Hwy 2 bridge @ Peace River town
km 822.8 = Daishowa bridge
km 546.5 = Tompkins Landing
km 419.9 = Fort Vermilion bridge
km 331.9 = bottom of Vermilion falls
km 270.2 = Fifth Meridian
km 149.3 = Jackfish River
km 108.75 = Peace Point

**** Daily mean flows as reported by Water Survey of Canada.**

A manual gauging
E estimated
(hatched) no record

Table C1 cont'd.

	Location of photos in downstream order*		Dates of photography	Scale of photography	Daily mean flows on date of photography (m3/s) **				
					Taylor	Dunvegan	Peace River	Ft Vermilion	Peace Pt
	from km:	to km:	(month/day/yr)	(1:)	07FD002	07FD003	07HA001	07FD003	07KC001
1966-69									
Reach 1	1074.3	1035.0	September 12/66	31 680	1540	1600	1970	2010	2350
	1035.0	1022.0	September 15/66	31 680	1380	1480	1900	1880	2250
	1022.0	1002.5	September 15/67	31 680	736	742	968	1040	1130
	1002.5	992.0	September 15/66	31 680	1380	1480	1900	1880	2250
	992.0	982.5	September 12/66	31 680	1540	1600	1970	2010	2350
	982.5	956.0	August 2/70	31 680	742		1360	1420	1320
	956.0	954.0	May 18/61	31 680	2920	2640	2860	2050	3710
	954.0	941.5	May 10/61	31 680	1190	1530E	1840	1930	3620
Reach 2	867.4	850.0	August 2/70	31 680	742		1360	1420	1320
	850.0	842.0	September 12/66	31 680	1540	1600	1970	2010	2350
	842.0	832.0	Sepember 15/66	31 680	1380	1480	1900	1880	2250
	832.0	823.5	August ??/67	31 680	1090	1120	1530	1620	1870
	823.5	814.0	September 12/66	31 680	1540	1600	1970	2010	2350
	814.0	808.0	May 10/69	31 680	1190	1400	1900		4450
	808.0	804.0	June 7/69	31 680	1460	1640	2730	2410	2270
	804.0	795.5	May 10/69	31 680	1190	1400	1900		4450
	795.5	748.0	June 7/69	31 680	1460	1640	2730	2410	2270
	748.0	724.1	May 10/69	31 680	1190	1400	1900		4450
Reach 3	545.7	538.0	August 21/66	31 680	1610	1720	2400	2220	2410
	538.0	492.5	June 24/69	31 680	855	736E	1100	1330	1530
	492.5	402.5	July 29/69	31 680	731	558	878	988E	1380
	402.5	396.0	August 20/69	31 680	816	742	1090	1130	1190
	396.0	391.9	July 29/69	31 680	731	558	878	988E	1380
Reach 4A	331.9	293.0	June 29/64	31 680	6460	6310	7650	7160	8920
	293.0	280.0	June 26/64	31 680	6060	6480	8130	8810	10300
	280.0	270.2	June 29/64	31 680	6460	6310	7650	7160	8920
Reach 4B	270.2	242.0	August 28/70	32 000	515		804	767	988
	242.0	149.3	No photos available						

Table C1 cont'd.

	Location of photos in downstream order*		Dates of photography	Scale of photography	Daily mean flows on date of photography (m3/s) **				
					Taylor	Dunvegan	Peace River	Ft Vermilion	Peace Pt
	from km:	to km:	(month/day/yr)	(1:)	07FD002	07FD003	07HA001	07FD003	07KC001
1974-78									
Reach 1	1074.3	1042.5	August 3/74	50 000	1340		2060	2390	2970
	1042.5	990.0	August 14/74	50 000	1760		2080	2120	2360
	990.0	982.5	August 3/74	50 000	1340		2060	2390	2970
	982.5	941.5	August 4/74	50 000	1530		1870	2390	2890
Reach 2	867.4	857.0	August 4/74	50 000	1530		1870	2390	2890
	857.0	842.0	August 3/74	50 000	1340		2060	2390	2970
	842.0	814.0	August 14/74	50 000	1760		2080	2120	2360
	814.0	795.5	August 20/74	50 000	1660		1670	1930	2370
	795.5	783.5	August 22/74	50 000	1630		1910	1800	2270
	783.5	770.0	August 28/74	50 000	1580		1870	1950	2350
	770.0	743.0	September 22/74	50 000	1340		1610	1700	2010
	743.0	732.5	August 31/74	50 000	1410		1730	1940	2350
	732.5	724.1	September 24/74	50 000	1430		1480	1690	2060
Reach 3	545.7	391.9	May 9/76	50 000	1700	1950	3140	3540	3540E
Reach 4A	331.9	320.0	September 14/78	50 000	614	657	1140	1280	1700
	320.0	280.0	September 13/78	50 000	603	668	1140	1240	1590
	280.0	270.2	September 14/78	50 000	614	657	1140	1280	1700
Reach 4B	270.2	255.0	July 1/75	53 000	1740	2410	4130	2580	3110
	255.0	250.0	July 9/75	53 000	1150	1310	2240	2670A	3990
	250.0	180.0	July 1/75	53 000	1740	2410	4130	2580	3110
	180.0	163.0	July 9/75	53 000	1150	1310	2240	2670A	3990
	163.0	149.3	June 28/75	56 500	1640	1590	2430	2220	3370

Table C1 cont'd.

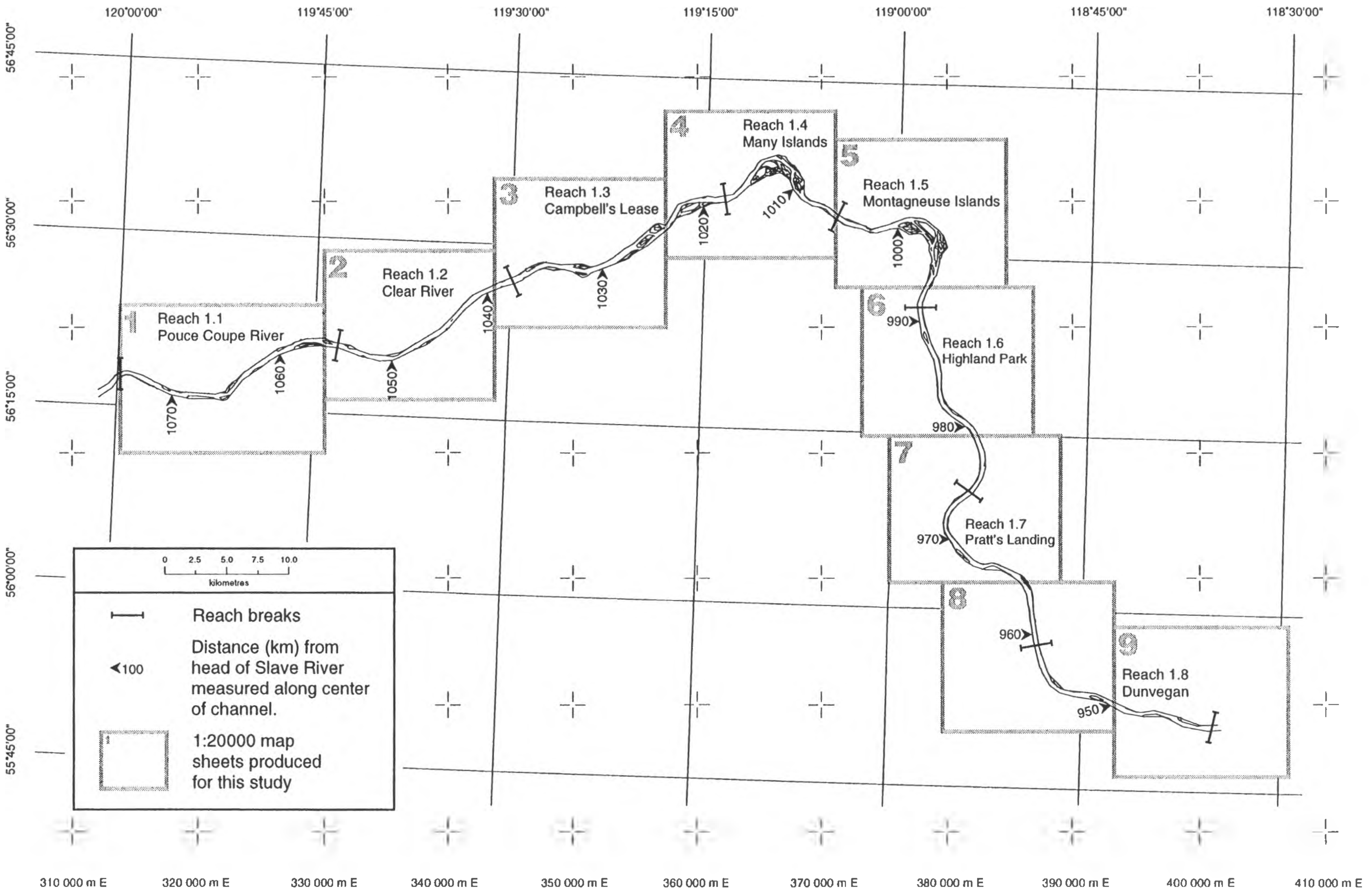
	Location of photos in downstream order*		Dates of photography	Scale of photography	Daily mean flows on date of photography (m3/s) **				
					Taylor	Dunvegan	Peace River	Ft Vermilion	Peace Pt
	from km:	to km:	(month/day/yr)	(1:)	07FD002	07FD003	07HA001	07FD003	07KC001
1987-88									
Reach 1	1074.3	961.0	August 2/88	40 000	1260	1160	1390		2720
	961.0	941.5	August 12/88	40 000	1350	1270	1400		2140
Reach 2	867.4	847.0	August 2/88	40 000	1260	1160	1390		2720
	847.0	815.5	July 28/88	40 000	1900	1780	2010		3300
	815.5	760.0	June 13/90	10 000	5190	7600A	16100		4800
	760.0	730.0	June 20/88	20 000	2310	2230	2990		4840
	730.0	724.1	August 7/88	20 000	1700	1570	1790		2120
Reach 3	545.7	445.0	August 23/87	40 000	1240	1490	2210		2210
	445.0	391.9	August 25/87	40 000	1270	1400	1940		2130
Reach 4A	331.9	285.0	August 27/88	40 000	1370	1430	1450		1740
	285.0	270.2	August 28/88	40 000	1210	1320	1500		1690
Reach 4B	270.2	149.3	October 4/88	60 000	1500	1330	1340		1640
1993									
Reach 1	1074.3	941.5	October 10/93	30 000	1060	1160	1360		1340
Reach 2	867.4	724.1	October 10/93	30 000	1060	1160	1360		1340
Reach 3	545.7	528.0	October 10/93	30 000	1060	1160	1360		1340
	528.0	391.9	October 9/93	30 000	1130	1130	1370		1380
Reach 4A	331.9	270.2	October 9/93	30 000	1130	1130	1370		1380
Reach 4B	270.2	149.3	October 9/93	30 000	1130	1130	1370		1380

Table C2: Peace River Project Progress Chart

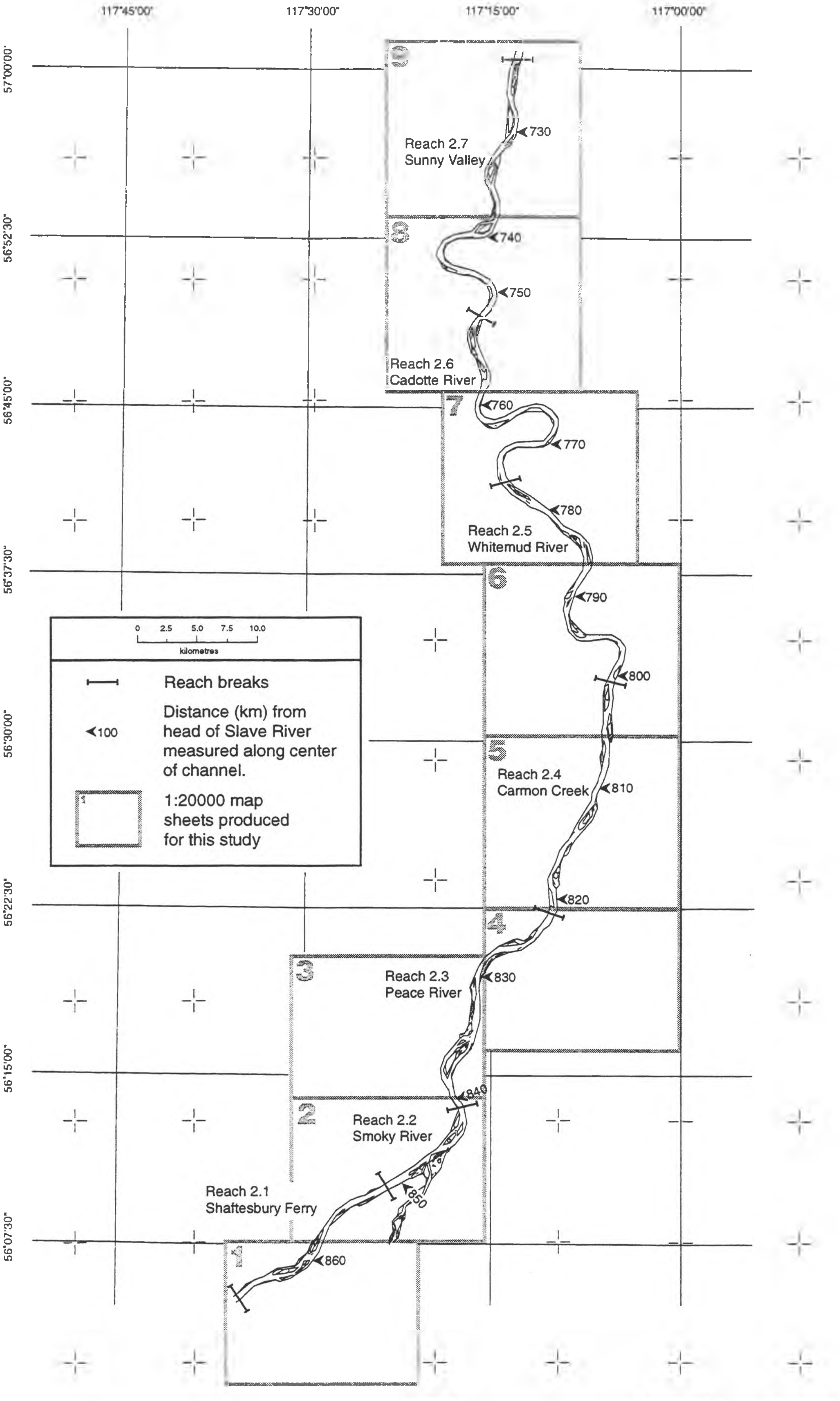
1:20 000 Map Sheet	DATES OF PHOTOGRAPHY 1950	1966-69	1974-78	1987-88	1993
Reach 1					
1	R A M V E B	R A M V E B P	R A M V E B P	R A M V E B P	R A M V E B P
2	R A M V E B	R A M V E B P	R	R	R A M V E B P
3	R A M V E B	R A M V E B P	R	R	R A M V E B P
4	R A M V E B	R A M V E B P	R	R	R A M V E B P
5	R A M V E B	R A M V E B P	R	R	R A M V E B P
6	R A M V E B	R A M V E B P	R	R	R A M V E B P
7	R A M V E B	R A M V E B P	R	R	R A M V E B P
8	R A M V E B	R A M V E B P	R	R	R A M V E B P
9	R A M V E B	R A M V E B P	R	R	R A M V E B P
Reach 2					
1	R A M V E B	R A M V E B P	R	R	R A M V E B P
2	R A M V E B	R A M V E B P	R	R	R A M V E B P
3	R A M V E B	R A M V E B P	R	R	R A M V E B P
4	R A M V E B	R A M V E B P	R	R	R A M V E B P
5	R A M V E B	R A M V E B P	R	R	R A M V E B P
6	R A M V E B	R A M V E B P	R	R	R A M V E B P
7	R A M V E B	R A M V E B P	R	R	R A M V E B P
8	R A M V E B	R A M V E B P	R	R	R A M V E B P
9	R A M V E B	R A M V E B P	R	R	R A M V E B P
Reach 3					
1	R A M V E B	R A M V E B P	R	R	R A M V E B P
2	R A M V E B	R A M V E B P	R	R	R A M V E B P
3	R A M V E B	R A M V E B P	R	R	R A M V E B P
4	R A M V E B	R A M V E B P	R	R	R A M V E B P
5	R A M V E B	R A M V E B P	R	R	R A M V E B P
6	R A M V E B	R A M V E B P	R	R	R A M V E B P
7	R A M V E B	R A M V E B P	R	R	R A M V E B P
8	R A M V E B	R A M V E B P	R	R	R A M V E B P
9	R A M V E B	R A M V E B P	R	R	R A M V E B P
Reach 4A					
1	R A M V E B	R A M V E B P	R	R	R A M V E B P
2	R A M V E B	R A M V E B P	R	R	R A M V E B P
3	R A M V E B	R A M V E B P	R	R	R A M V E B P
4	R A M V E B	R A M V E B P	R	R	R A M V E B P
5	R A M V E B	R A M V E B P	R	R	R A M V E B P
Reach 4B					
1	R A M V E B	R A M V E B P	R A	R A M	R A M V E B P
2	R A M V E B	R A M V E B P	R A	R A M	R A M V E B P
3	R A M V E B	No Photos	R A	R A M	R A M V E B P
4	R A M V E B	No Photos	R A	R A	R A M V E B P
5	R A M V E B	No Photos	R A	R A	R A M V E B P
6	R A M V E B	No Photos	R A	R A	R A M V E B P
7	R A M V E B	No Photos	R A	R A	R A M V E B P
8	R A M V E B	No Photos	R A	R A	R A M V E B P

R = Relative Orientation complete
A = Absolute Orientation complete
M = Channel morphology digitized
V = Vegetation digitized
E = Coverages edited in Arc/Info
B = Map sheets built in Arc/Info
P = Map sheets printed

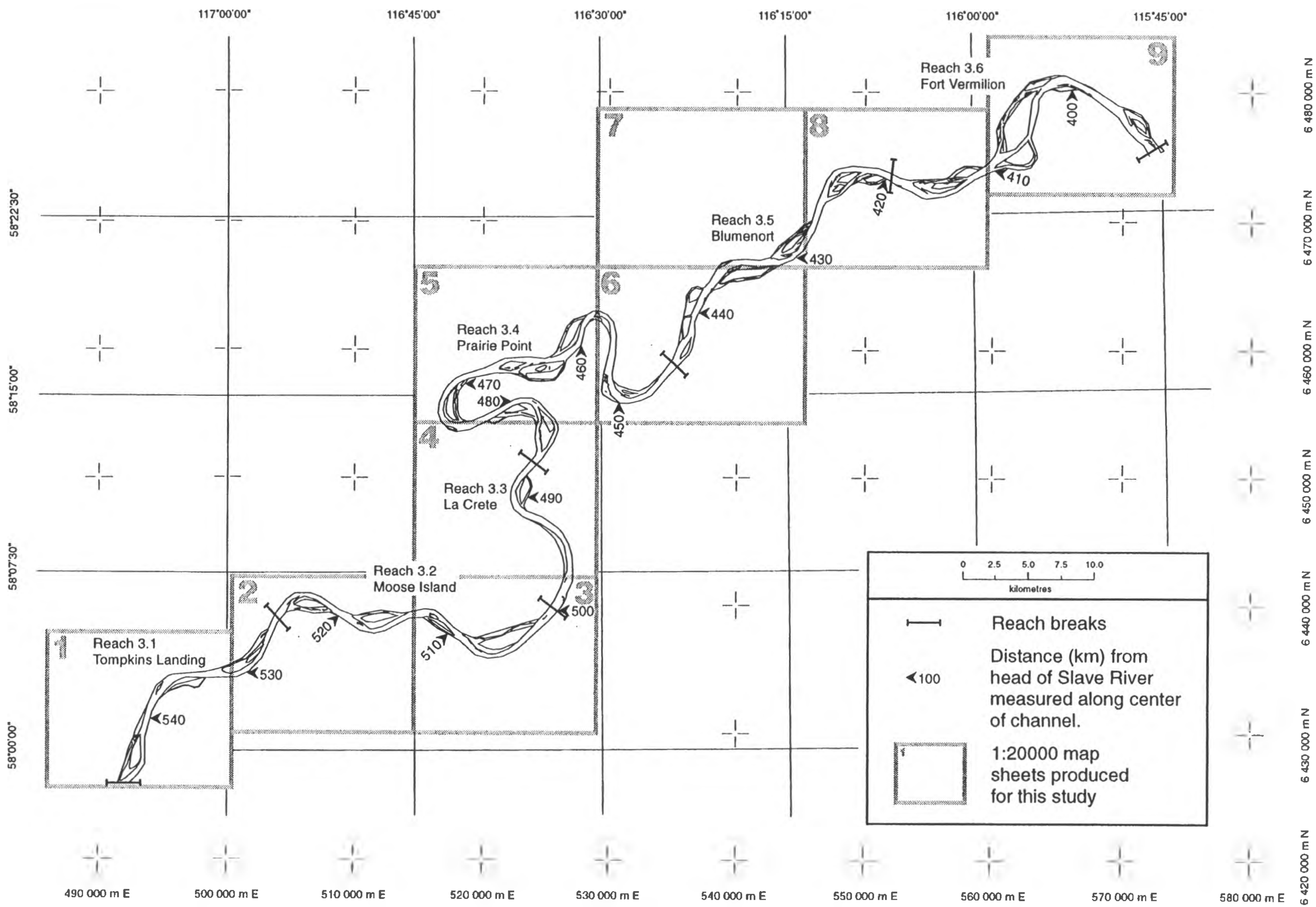
PEACE RIVER: Reach 1



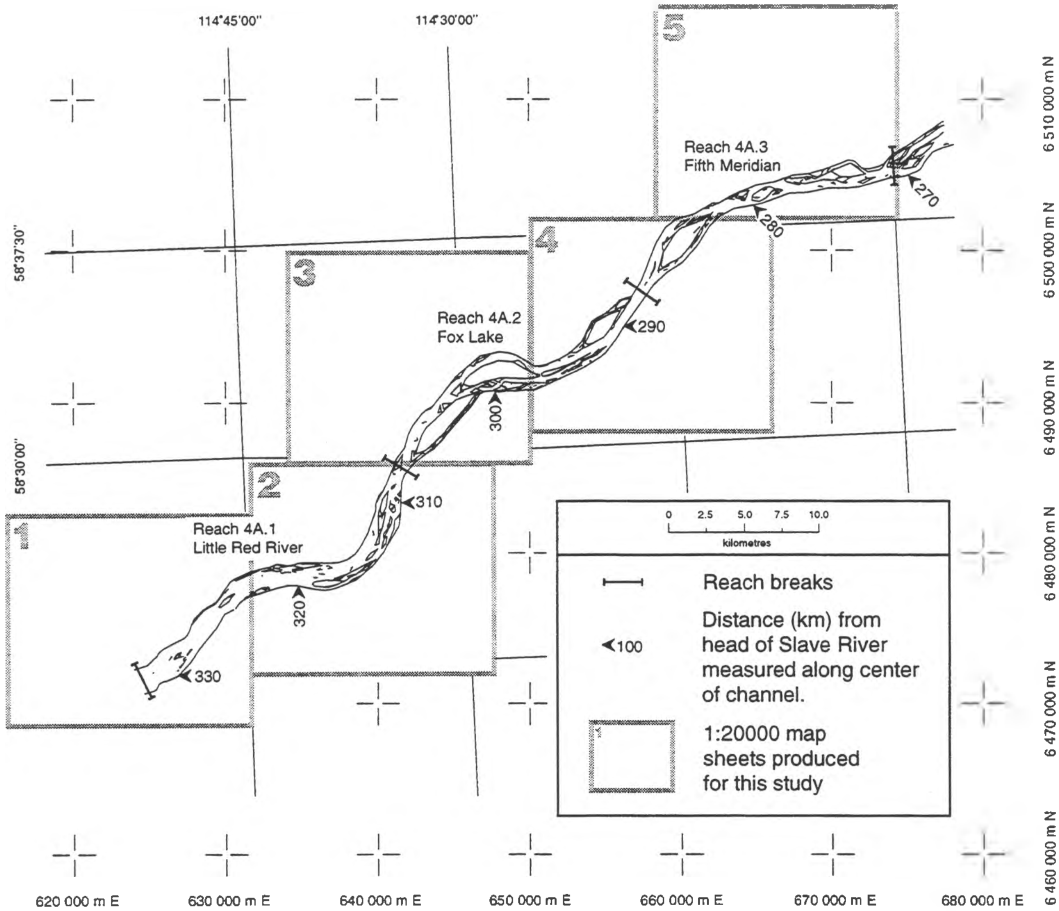
PEACE RIVER: Reach 2



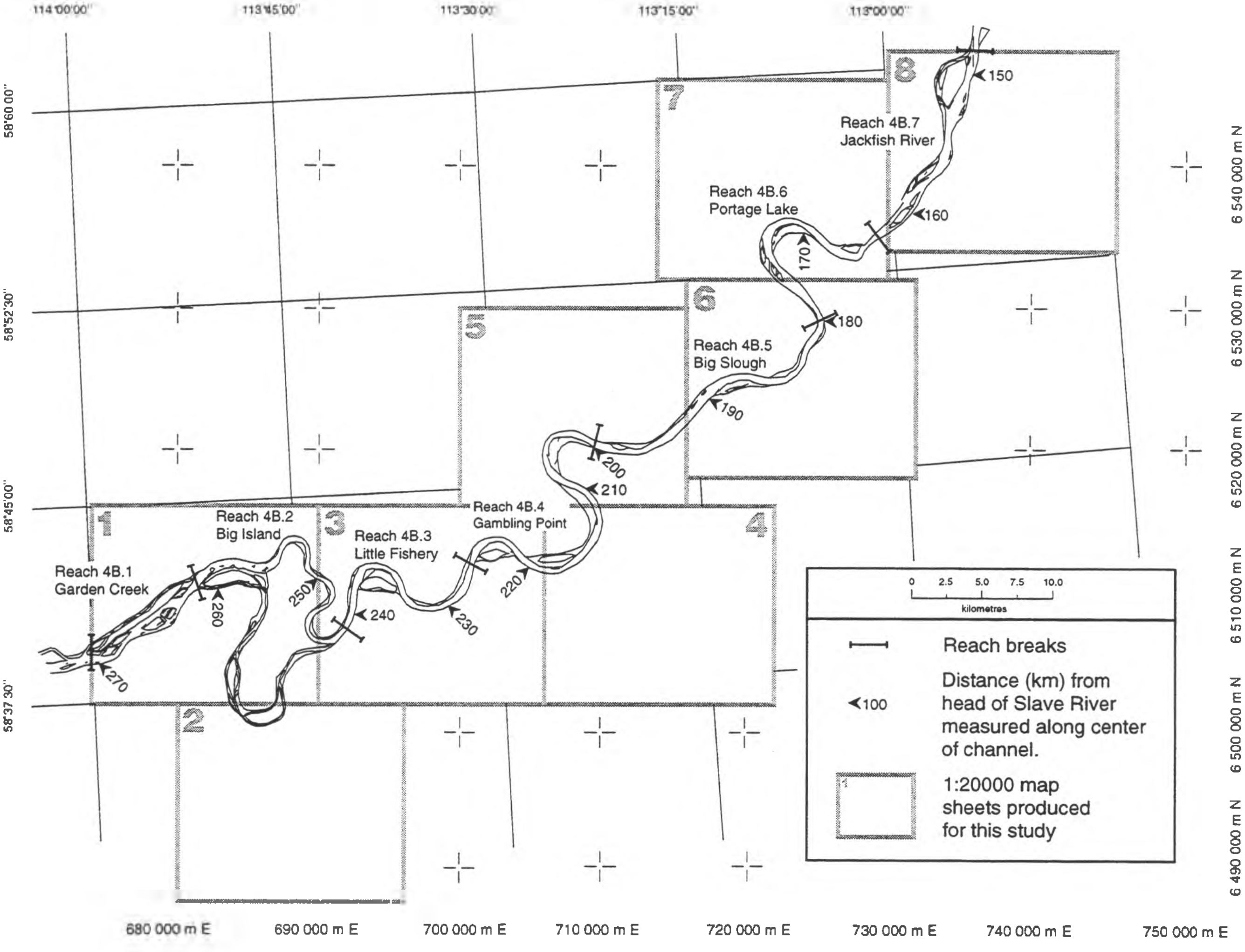
PEACE RIVER: Reach 3



PEACE RIVER: Reach 4A



PEACE RIVER: Reach 4B



PEACE RIVER: Summary of morphology and vegetation changes - Reach 1

"At-a-point changes"

1966-69 to 1993

1966-69	1993	Process: *Morphology*	Process: *Vegetation*	Area (sq. m): Reach 1.1 Pouce Coupe River	Reach 1.2 Clear River	Reach 1.3 Campbell's Lease	Reach 1.4 Many Islands	Reach 1.5 Montagneuse Islands	Reach 1.6 Highland Park	Reach 1.7 Pratt's Landing	Reach 1.8 Dunvegan	REACH 1 TOTAL
bar (bare)	bar (bare)	stable		195643	34705	253884	492806	117031	44653	265470	37711	1441903
bar (bare)	bar (vegetated)	stable	recovery	1007525	73319	745092	1085147	669881	206476	687006	245525	4719972
bar (bare)	island	stable	recovery	14556	1786	18666	27081	45874	0	1755	2	109720
bar (bare)	river	erosion		41090	18621	28667	158238	90062	5550	44894	41723	428846
bar (bare)	floodplain	stable	recovery	18947	0	3792	10985	2769	6099	2086	2299	46977
bar (bare)	fan	stable		3772	150	0	0	0	0	0	0	3922
bar (vegetated)	bar (bare)	stable	removal	39131	40484	27521	28314	46319	118927	25821	18324	344840
bar (vegetated)	bar (vegetated)	stable	stable	283914	231439	506877	142657	459477	83579	33493	328126	2069562
bar (vegetated)	island	stable	recovery	31921	4186	252385	191340	147707	0	2610	27118	657268
bar (vegetated)	river	erosion	removal	16195	28894	5289	20924	28385	4021	0	3711	107420
bar (vegetated)	floodplain	stable	recovery	1051	301	446	0	0	4157	744	2778	9476
bar (vegetated)	fan	stable	stable	0	2912	0	0	3182	0	0	0	6093
island	bar (bare)	erosion	removal	5117	0	7583	13050	3276	0	0	3725	32750
island	bar (vegetated)	erosion	removal	17216	7291	34839	19314	53092	0	10837	14786	157374
island	island	stable	stable	312633	13448	1415792	1133930	1120059	0	26964	88286	4111113
island	river	erosion	removal	1558	0	1652	874	31025	0	0	70	35180
island	floodplain	accretion	stable	0	0	0	0	0	0	0	0	0
river	bar (bare)	deposion		54712	6076	285262	332296	501416	202312	115612	226364	1724051
river	bar (vegetated)	deposition	recovery	215668	50948	371703	376735	408009	155260	155438	243438	1977200
river	island	deposition	recovery	1309	2720	9735	5305	3222	0	0	5574	27864
river	river	stable		6531160	5939910	8368489	4852750	5840881	5637195	5736720	5481942	48389046
river	floodplain	deposition	recovery	73352	41671	39756	61694	38466	33677	19297	98423	406337
river	fan	deposition		35393	149447	56802	10400	55935	8197	4239	9559	329972
floodplain	bar (bare)	erosion	removal	10391	2239	16295	5251	12857	33843	45487	18257	144619
floodplain	bar (vegetated)	erosion	removal	65108	53113	35507	18508	26855	38933	81242	94816	414081
floodplain	island	avulsion	stable	0	0	0	0	0	0	0	0	0
floodplain	river	erosion	removal	75291	129178	132259	53421	125709	62394	95356	97761	771369
floodplain	fan	erosion	removal	6212	24698	8401	2794	5470	2112	604	621	50912
fan	bar (bare)	stable		0	158	1029	0	3	0	4535	0	5724
fan	bar (vegetated)	stable	recovery	6746	0	1320	8809	0	0	20655	0	37530
fan	river	erosion		312	3981	0	64	0	89	0	2109	6555
fan	floodplain	stable	recovery	6726	5295	1412	559	640	110	2348	3807	20897
fan	fan	stable		30309	186869	8132	2985	14650	1799	533	9752	255028

CUMULATIVE AREA

Morphology

	Reach 1.1	Reach 1.2	Reach 1.3	Reach 1.4	Reach 1.5	Reach 1.6	Reach 1.7	Reach 1.8	REACH 1 TOTAL
Net erosion (sq. m):	238490	268015	270492	292438	376733	146941	278419	277577	2149105
Net deposition (sq. m):	380433	250863	763258	786430	1007048	399446	294586	583359	4465423
Stability (sq. m):	8490781	6534962	11606158	7986172	8468470	6102994	6831395	6245670	62266603
Avulsion (sq. m):	0	0	0	0	0	0	0	0	0
Accretion (sq. m):	0	0	0	0	0	0	0	0	0

Vegetation

	Reach 1.1	Reach 1.2	Reach 1.3	Reach 1.4	Reach 1.5	Reach 1.6	Reach 1.7	Reach 1.8	REACH 1 TOTAL
Removal (sq. m):	236219	285896	269346	162449	332989	260228	259346	252069	2058543
Recovery (sq. m):	1377802	180227	1444307	1767656	1316567	405780	891939	628965	8013243
Stability (sq. m):	596547	247799	1922670	1276587	1582718	83579	60457	416412	6186768

Note: The change from floodplain to floodplain was omitted as no outer limit of the floodplain was defined during mapping.
The changes from island to fan and from fan to island were omitted as no such changes were observed.

PEACE RIVER: Summary of morphology and vegetation changes - Reach 1

"Reach-wide changes"
1966-69 to 1993

	Total Area (sq. m)								
	Reach 1.1 Pouce Coupe River	Reach 1.2 Clear River	Reach 1.3 Campbell's Lease	Reach 1.4 Many Islands	Reach 1.5 Montagneuse Islands	Reach 1.6 Highland Park	Reach 1.7 Pratt's Landing	Reach 1.8 Dunvegan	REACH 1 TOTAL
1966-69									
bar (bare)	1281534	128582	1050101	1774257	925616	262779	1001210	327260	6751340
bar (vegetated)	372213	308216	792519	383235	685069	210683	62669	380057	3194661
island	336524	20739	1459866	1167168	1207453	0	37800	106866	4336416
river	6911593	6190773	9131747	5639180	6847928	6036640	6031307	6065301	52854469
floodplain	80997	454245	2720167	517855	1028284	101246	881267	1297623	7081683
fan	44093	196303	11893	12417	15292	1997	28071	15668	325734
1993									
bar (bare)	304993	83662	591574	871716	680901	399734	456925	304381	3693886
bar (vegetated)	1596177	416111	1695339	1651169	1617314	484247	988671	926691	9375718
island	360420	22140	1696578	1357656	1316862	0	31329	120980	4905965
river	6665606	6120585	8536357	5086271	6116062	5709248	5876970	5627316	49738416
floodplain	70283	443111	2667936	514701	998848	95324	822403	1227156	6839762
fan	75686	364076	73335	16179	79236	12107	5376	19931	645927
Absolute change									
bar (bare)	-976541	-44920	-458528	-902541	-244715	136955	-544285	-22879	-3057454
bar (vegetated)	1223964	107895	902820	1267934	932244	273564	926002	546633	6181058
island	23896	1401	236712	190488	109409	0	-6472	14114	569548
river	-245987	-70188	-595390	-552909	-731866	-327392	-154336	-437985	-3116054
floodplain	-10713	-11134	-52231	-3154	-29436	-5921	-58865	-70468	-241921
fan	31593	167773	61442	3762	63944	10110	-22695	4264	320192
% change									
bar (bare)	-76.2	-34.9	-43.7	-50.9	-26.4	52.1	-54.4	-7.0	-45.3
bar (vegetated)	328.8	35.0	113.9	330.9	136.1	129.8	1477.6	143.8	193.5
island	7.1	6.8	16.2	16.3	9.1	0.0	-17.1	13.2	13.1
river	-3.6	-1.1	-6.5	-9.8	-10.7	-5.4	-2.6	-7.2	-5.9
floodplain	-13.2	-2.5	-1.9	-0.6	-2.9	-5.8	-6.7	-5.4	-3.4
fan	71.7	85.5	516.6	30.3	418.1	506.2	-80.8	27.2	98.3
Reach length (m):	19630	16200	19830	13010	15060	16500	16970	15630	132830
Average width, 1966-69 (m):	417	390	513	570	516	382	414	409	449
Average width, 1993 (m):	355	383	460	458	451	370	373	379	402
Absolute change in width (m):	-62	-7	-53	-112	-65	-12	-41	-30	-46
% change in width:	-14.9	-1.8	-10.4	-19.6	-12.6	-3.0	-9.9	-7.2	-10.4

Note: Reach length is measured down center-line of channel, and average width is calculated by dividing the sum of the river and bar (bare) areas by reach length.

PEACE RIVER: Summary of morphology and vegetation changes - Reach 2

"At-a-point changes"
1966-69 to 1993

1966-69	1993	Process: Morphology	Process: Vegetation	Area (sq. m): Reach 2.1 Shaftesbury Ferry	Reach 2.2 Smoky Confluence	Reach 2.3 Peace River	Reach 2.4 Carmon Creek	Reach 2.5 Whitemud River	Reach 2.6 Cadotte River	Reach 2.7 Sunny Valley	REACH 2 TOTAL
bar (bare)	bar (bare)	stable		250867	385643	732241	273032	7937	257726	190121	2097567
bar (bare)	bar (vegetated)	stable	recovery	583350	381330	613402	581179	48615	596819	528114	3332809
bar (bare)	island	stable	recovery	6915	14838	17452	6190	0	24816	39235	109447
bar (bare)	river	erosion		130055	64427	29253	1346	903	6491	4621	237096
bar (bare)	floodplain	stable	recovery	9884	32721	21161	2007	2108	7337	16696	91915
bar (bare)	fan	stable		0	0	37822	0	0	13804	0	51626
bar (vegetated)	bar (bare)	stable	removal	125481	285928	299184	221341	338270	98462	377384	1746051
bar (vegetated)	bar (vegetated)	stable	stable	907844	990128	1250246	1138792	1088494	636764	1356914	7369182
bar (vegetated)	island	stable	recovery	138967	76983	89051	312618	66133	66876	970895	1721524
bar (vegetated)	river	erosion	removal	86024	160444	52934	35471	89279	5332	18523	428008
bar (vegetated)	floodplain	stable	recovery	7105	35040	106168	3440	8115	822	22098	182787
bar (vegetated)	fan	stable	stable	0	0	0	14908	0	0	0	14908
island	bar (bare)	erosion	removal	4876	28944	19150	13012	230	1712	4312	70237
island	bar (vegetated)	erosion	removal	70815	49541	79035	26815	10033	4599	11506	252345
island	island	stable	stable	745349	795785	1429534	860352	496194	375784	889004	6592002
island	river	erosion	removal	8009	67014	18559	172	3027	98	0	96880
island	floodplain	accretion	stable	0	0	437964	0	0	0	0	437964
river	bar (bare)	deposion		88205	611574	670521	723105	779268	1341242	1254673	5468588
river	bar (vegetated)	deposition	recovery	228831	354783	251731	302390	345747	210039	364819	2058341
river	island	deposition	recovery	1360	1354	6237	1742	2849	4125	10999	28665
river	river	stable		6902525	4960618	9909929	8431835	10148914	9766746	11070573	61191140
river	floodplain	deposition	recovery	46816	40703	140768	61098	72349	77223	107351	546308
river	fan	deposition		4083	0	2995	32187	1681	28114	15932	84993
floodplain	bar (bare)	erosion	removal	3137	3330	12449	14399	27825	86249	17735	165124
floodplain	bar (vegetated)	erosion	removal	75492	46144	12578	32121	23246	72233	69233	331047
floodplain	island	avulsion	stable	0	0	0	0	0	0	0	0
floodplain	river	erosion	removal	96540	60352	80520	182688	173503	94465	156433	844500
floodplain	fan	erosion	removal	199	0	8257	13480	392	5374	3109	30810
fan	bar (bare)	stable		0	0	0	0	14520	4489	31612	50621
fan	bar (vegetated)	stable	recovery	0	0	0	0	35729	38991	43196	117917
fan	river	erosion		0	0	1852	99	2795	1843	5	6594
fan	floodplain	stable	recovery	0	0	615	966	1950	1702	2890	8123
fan	fan	stable		0	0	8542	44660	0	15125	14429	82755

CUMULATIVE AREA:

Morphology

	Reach 2.1	Reach 2.2	Reach 2.3	Reach 2.4	Reach 2.5	Reach 2.6	Reach 2.7	REACH 2 TOTAL
Net erosion (sq. m):	475148	478197	314587	319603	311233	278396	285476	2462640
Net deposition (sq. m):	369296	1008413	1072252	1120521	1201895	1660743	1753774	8186894
Stability (sq. m):	9678288	7959014	14515348	11891321	12292707	11945254	15596358	83878290
Avulsion (sq. m):	0	0	0	0	0	0	0	0
Accretion (sq. m):	0	0	437964	0	0	0	0	437964

Vegetation

	Reach 2.1	Reach 2.2	Reach 2.3	Reach 2.4	Reach 2.5	Reach 2.6	Reach 2.7	REACH 2 TOTAL
Removal (sq. m):	470574	699697	582666	539499	645806	368524	658234	3965000
Recovery (sq. m):	1023229	937751	1246586	1271630	583596	1028750	2106294	8197836
Stability (sq. m):	1653193	1785913	3117744	2014052	1584688	1012548	2245918	13414056

Note: The change from floodplain to floodplain was omitted as no outer limit of the floodplain was defined during mapping.
The changes from island to fan and from fan to island were omitted as no such changes were observed.

PEACE RIVER: Summary of morphology and vegetation changes - Reach 2
"Reach-wide changes"
1966-69 to 1993

	Total Area (sq. m)							
	Reach 2.1 Shaftesbury Ferry	Reach 2.2 Smoky Confluence	Reach 2.3 Peace River	Reach 2.4 Carmon Creek	Reach 2.5 Whitemud River	Reach 2.6 Cadotte River	Reach 2.7 Sunny Valley	REACH 2 TOTAL
1966-69								
bar (bare)	981072	878960	1451331	863754	59563	906994	778787	5920460
bar (vegetated)	1265421	1548523	1797584	1726571	1570291	808256	2745814	11462459
island	829050	939284	1984241	900352	509484	328193	904822	6395427
river	7271821	5969031	10982182	9552356	11350809	11427490	12824347	69378036
floodplain	6295257	1399625	5167601	5669207	2400169	8240682	7160610	36333151
fan	0	0	11009	45724	54993	62151	92132	266010
1993								
bar (bare)	472566	1313420	1733544	1244888	1168051	1789881	1875837	9598186
bar (vegetated)	1866333	1821926	2206994	2081298	1551864	1559444	2373782	13461641
island	892592	888960	1542274	1180902	565176	471601	1910134	7451638
river	7223154	5312855	10093047	8651611	10398420	9874976	11250155	62804218
floodplain	6231406	1408816	5773002	5593569	2360775	8104513	7172123	36644205
fan	4282	0	57616	105234	2072	62417	33470	265091
Absolute change								
bar (bare)	-508506	434460	282213	381135	1108488	882887	1097050	3677726
bar (vegetated)	600912	273403	409409	354727	-18426	751189	-372032	1999182
island	63542	-50324	-441968	280550	55692	143408	1005311	1056211
river	-48667	-656176	-889135	-900745	-952388	-1552514	-1574192	-6573818
floodplain	-63850	9191	605402	-75637	-39394	-136169	11513	311054
fan	4282	0	46607	59510	-52921	266	-58663	-919
% change								
bar (bare)	-51.8	49.4	19.4	44.1	1861.0	97.3	140.9	62.1
bar (vegetated)	47.5	17.7	22.8	20.5	-1.2	92.9	-13.5	17.4
island	7.7	-5.4	-22.3	31.2	10.9	43.7	111.1	16.5
river	-0.7	-11.0	-8.1	-9.4	-8.4	-13.6	-12.3	-9.5
floodplain	-1.0	0.7	11.7	-1.3	-1.6	-1.7	0.2	0.9
fan	0.0	0.0	423.4	130.1	-96.2	0.4	-63.7	-0.3
Reach length (m):	16410	9390	20340	20950	24330	24620	27220	143260
Average width, 1966-69 (m):	503	729	611	497	469	501	500	526
Average width, 1993 (m):	469	706	581	472	475	474	482	505
Absolute change in width (m):	-34	-24	-30	-25	6	-27	-18	-20
% change in width:	-6.8	-3.2	-4.9	-5.0	1.4	-5.4	-3.5	-3.8

Note: Reach length is measured down center-line of channel, and average width is calculated by dividing the sum of the river and bar (bare) areas by reach length.

PEACE RIVER: Summary of morphology and vegetation changes - Reach 3

"At-a-point changes"

1966-69 to 1993

1966-69	1993	Process: Morphology	Process: Vegetation	Area (sq. m): Reach 3.1 Tompkins Landing	Reach 3.2 Moose Island	Reach 3.3 La Crete	Reach 3.4 Prairie Point	Reach 3.5 Blumenort	Reach 3.6 Fort Vermilion	REACH 3 TOTAL
bar (bare)	bar (bare)	stable		1418379	2366592	834235	2311566	1433418	905774	9269964
bar (bare)	bar (vegetated)	stable	recovery	766034	2633354	1028093	6078522	3116012	3172253	16794268
bar (bare)	island	stable	recovery	49199	27491	22891	57595	29475	113350	300002
bar (bare)	river	erosion		669903	1113965	884238	3869403	2652238	2213124	11402871
bar (bare)	floodplain	stable	recovery	45915	59291	12499	146484	153523	173843	591555
bar (bare)	fan	stable		0	0	0	0	0	0	0
bar (vegetated)	bar (bare)	stable	removal	17849	3102	950	8626	22570	601	53698
bar (vegetated)	bar (vegetated)	stable	stable	1026398	928509	61991	1774200	1216219	406665	5413981
bar (vegetated)	island	stable	recovery	43181	63946	18962	668458	193285	470681	1458513
bar (vegetated)	river	erosion	removal	24564	4741	1914	98862	146018	73588	349687
bar (vegetated)	floodplain	stable	recovery	0	0	0	0	82310	64860	147171
bar (vegetated)	fan	stable	stable	0	0	0	0	0	0	0
island	bar (bare)	erosion	removal	6195	2674	5757	29018	9631	20021	73295
island	bar (vegetated)	erosion	removal	32927	68363	2044	91999	194075	95820	485228
island	island	stable	stable	2771590	5859216	1082492	5583978	5226581	10302085	30825942
island	river	erosion	removal	18936	43564	0	85006	74988	242788	465281
island	floodplain	accretion	stable	0	0	0	0	0	0	0
river	bar (bare)	deposion		1743428	765518	125317	1392846	1045998	1487140	6560247
river	bar (vegetated)	deposition	recovery	201639	155316	44849	669155	784252	936082	2791293
river	island	deposition	recovery	43728	26837	0	11917	9216	2137	93834
river	river	stable		9321618	11772246	6631128	18579932	12297702	15638412	74241037
river	floodplain	deposition	recovery	116291	126724	126794	137363	118172	123437	748782
river	fan	deposition		0	0	0	0	0	0	0
floodplain	bar (bare)	erosion	removal	4642	12130	6701	28533	3033	21578	76617
floodplain	bar (vegetated)	erosion	removal	10301	15583	41586	71163	23383	47166	209182
floodplain	island	avulsion	stable	0	0	0	0	0	0	0
floodplain	river	erosion	removal	96683	241243	57969	260034	99336	196285	951549
floodplain	fan	erosion	removal	0	0	0	0	0	0	0
fan	bar (bare)	stable		0	0	0	0	0	0	0
fan	bar (vegetated)	stable	recovery	0	0	0	0	0	16991	16991
fan	river	erosion		0	0	0	0	0	2227	2227
fan	floodplain	stable	recovery	0	0	0	0	0	3	3
fan	fan	stable		0	0	0	0	0	0	0

CUMULATIVE AREA:

Morphology

	Reach 3.1	Reach 3.2	Reach 3.3	Reach 3.4	Reach 3.5	Reach 3.6	REACH 3 TOTAL
Net erosion (sq. m):	864150	1502262	1000208	4534019	3202702	2912597	14015938
Net deposition (sq. m):	2105086	1074395	296961	2211281	1957638	2548797	10194157
Stability (sq. m):	15460164	23713746	9693241	35209362	23771093	31282510	139130116
Avulsion (sq. m):	0	0	0	0	0	0	0
Accretion (sq. m):	0	0	0	0	0	0	0

Vegetation

	Reach 3.1	Reach 3.2	Reach 3.3	Reach 3.4	Reach 3.5	Reach 3.6	REACH 3 TOTAL
Removal (sq. m):	212096	391398	116921	673241	573034	697847	2664537
Recovery (sq. m):	1265987	3092959	1254088	7769495	4486245	5073640	22942413
Stability (sq. m):	3797989	6787725	1144483	7358178	6442799	10708749	36239923

Note: The change from floodplain to floodplain was omitted as no outer limit of the floodplain was defined during mapping.
The changes from island to fan and from fan to island were omitted as no such changes were observed.

PEACE RIVER: *Summary of morphology and vegetation changes - Reach 3*

"Reach-wide changes"
1966-69 to 1993

	Total Area (sq. m)						
	Reach 3.1 Tompkins Landing	Reach 3.2 Moose Island	Reach 3.3 La Crete	Reach 3.4 Prairie Point	Reach 3.5 Blumenort	Reach 3.6 Fort Vermilion	REACH 3 TOTAL
1966-69							
bar (bare)	2949430	6200693	2781956	12463571	7384666	6578344	38358661
bar (vegetated)	1111992	1000298	83817	2550145	1660402	1016396	7423049
island	2829648	5973816	1090293	5790001	5505274	10660715	31849748
river	11426704	12846641	6928089	20791214	14255339	18187208	84435195
floodplain	9245576	13841341	11825828	22060915	12565355	20676117	90215133
fan	0	0	0	0	0	19222	19222
1993							
bar (bare)	3190493	3150015	972961	3770590	2514650	2435114	16033823
bar (vegetated)	2037300	3801124	1178563	8685039	5333939	4674978	25710943
island	2907699	5977490	1124345	6321948	5458556	10888254	32678292
river	10131702	13175759	7575248	22893237	15270283	18366424	87412653
floodplain	9240975	13761458	11755874	22053200	12690491	20801097	90303094
fan	0	0	0	0	0	0	0
Absolute change							
bar (bare)	241063	-3050678	-1808995	-8692982	-4870016	-4143230	-22324838
bar (vegetated)	925307	2800827	1094747	6134894	3673537	3658582	18287893
island	78051	3674	34052	531947	-46719	227539	828544
river	-1295002	329118	647160	2102024	1014943	179215	2977458
floodplain	-4602	-79883	-69954	-7715	125136	124979	87961
fan	0	0	0	0	0	-19222	-19222
% change							
bar (bare)	8.2	-49.2	-65.0	-69.7	-65.9	-63.0	-58.2
bar (vegetated)	83.2	280.0	1306.1	240.6	221.2	360.0	246.4
island	2.8	0.1	3.1	9.2	-0.8	2.1	2.6
river	-11.3	2.6	9.3	10.1	7.1	1.0	3.5
floodplain	0.0	-0.6	-0.6	0.0	1.0	0.6	0.1
fan	0.0	0.0	0.0	0.0	0.0	-100.0	-100.0
Reach length (m):	20230	26200	14550	43980	23815	25025	153800
Average width, 1966-69 (m):	711	727	667	756	909	990	798
Average width, 1993 (m):	659	623	588	606	747	831	673
Absolute change in width (m):	-52	-104	-80	-150	-162	-158	-126
% change in width:	-7.3	-14.3	-12.0	-19.8	-17.8	-16.0	-15.8

Note: Reach length is measured down center-line of channel, and average width is calculated by dividing the sum of the river and bar (bare) areas by reach length.

PEACE RIVER: Summary of morphology and vegetation changes - Reach 4

"At-a-point changes"
1966-69 to 1993

		Process		Area (sq. m)				Area (sq. m)							
1966-69	1993	*Morphology*	*Vegetation*	Reach 4A.1 Little Red River	Reach 4A.2 Fox Lake	Reach 4A.3 Fifth Meridian	REACH 4A TOTAL	Reach 4B.1 Garden Creek	Reach 4B.2 Big Island	Reach 4B.3 Little Fishery	Reach 4B.4 Gambling Point	Reach 4B.5 Big Slough	Reach 4B.6 Portage Lake	Reach 4B.7 Jackfish River	REACH 4B TOTAL
bar (bare)	bar (bare)	stable		0	0	60579	60579	896038	2501120						3397159
bar (bare)	bar (vegetated)	stable	recovery	12499	0	42520	55018	525269	2056666						2581935
bar (bare)	island	stable	recovery	4829	0	11409	16238	987094	1350137						2337231
bar (bare)	river	erosion		1489	0	91403	92892	2165367	2423808						4589175
bar (bare)	floodplain	stable	recovery	14886	0	143441	158327	13521	743959						757480
bar (bare)	fan	stable		0	0	0	0	0	0						0
bar (vegetated)	bar (bare)	stable	removal	24304	52086	10051	86442	279317	633014						912331
bar (vegetated)	bar (vegetated)	stable	stable	111199	41999	154727	307926	207599	438492						646091
bar (vegetated)	island	stable	recovery	614363	2265579	2242133	5122074	439498	904558						1344056
bar (vegetated)	river	erosion	removal	313339	425737	125744	864821	530807	175178						705985
bar (vegetated)	floodplain	stable	recovery	679436	846366	2263	1528066	6	1139228						1139234
bar (vegetated)	fan	stable	stable	0	0	0	0	0	0						0
island	bar (bare)	erosion	removal	7189	17700	26334	51223	60603	141341						201945
island	bar (vegetated)	erosion	removal	6279	33701	2631	42611	2698	32817						35515
island	island	stable	stable	891150	8681279	2294080	11866509	2216737	40976512						43193250
island	river	erosion	removal	254031	331833	60982	646845	220746	1083851						1304597
island	floodplain	accretion	stable	541481	0	35519	577000	0	0						0
river	bar (bare)	deposion		2323784	3366725	2244708	7935218	821747	1778110						2599858
river	bar (vegetated)	deposition	recovery	1442502	2020046	2029953	5492501	782910	277776						1060686
river	island	deposition	recovery	33874	463976	452579	950430	35975	313392						349367
river	river	stable		29627318	17996563	15170017	62793898	4002698	7977161						11979858
river	floodplain	deposition	recovery	686499	886227	291905	1864631	372	35812						36184
river	fan	deposition		0	0	0	0	0	0						0
floodplain	bar (bare)	erosion	removal	4600	11356	18393	34349	11865	24942						36808
floodplain	bar (vegetated)	erosion	removal	20438	31811	5775	58024	0	5756						5756
floodplain	island	avulsion	stable	0	0	0	0	0	0						0
floodplain	river	erosion	removal	246377	202110	753598	1202085	398536	1197609						1596144
floodplain	fan	erosion	removal	0	0	0	0	0	0						0
fan	bar (bare)	stable		0	0	0	0	0	0						0
fan	bar (vegetated)	stable	recovery	0	0	0	0	0	0						0
fan	river	erosion		0	0	0	0	0	0						0
fan	floodplain	stable	recovery	0	0	0	0	0	0						0
fan	fan	stable		0	0	0	0	0	0						0

CUMULATIVE AREA:

Morphology

	Reach 4A.1	Reach 4A.2	Reach 4A.3	REACH 4A TOTAL	Reach 4B.1	Reach 4B.2	Reach 4B.3	Reach 4B.4	Reach 4B.5	Reach 4B.6	Reach 4B.7	REACH 4B TOTAL
Net erosion (sq. m):	853743	1054249	1084860	2992852	3390623	5085302						8475925
Net deposition (sq. m):	4486660	6736974	5019146	16242780	1641004	2405090						4046094
Stability (sq. m):	31979983	29883873	20131220	81995076	9567777	58720847						68288624
Avulsion (sq. m):	0	0	0	0	0	0						0
Accretion (sq. m):	541481	0	35519	577000	0	0						0

Vegetation

	Reach 4A.1	Reach 4A.2	Reach 4A.3	REACH 4A TOTAL	Reach 4B.1	Reach 4B.2	Reach 4B.3	Reach 4B.4	Reach 4B.5	Reach 4B.6	Reach 4B.7	REACH 4B TOTAL
Removal (sq. m):	876558	1106335	1003508	2986401	1504572	3294509						4799081
Recovery (sq. m):	3488888	6482194	5216203	15187285	2784644	6821528						9606172
Stability (sq. m):	1543830	8723278	2484327	12751435	2424336	41415005						43839341

Note: The change from floodplain to floodplain was omitted as no outer limit of the floodplain was defined during mapping.
The changes from island to fan and from fan to island were omitted as no such changes were observed.

Photos for the 1966-69 period were not available for reaches 4B.3 - 4B.7

PEACE RIVER: Summary of morphology and vegetation changes - Reach 4

"Reach-wide changes"

1966-69 to 1993

	Total Area (sq. m)			
	Reach 4A.1 Little Red River	Reach 4A.2 Fox Lake	Reach 4A.3 Fifth Meridian	REACH 4A TOTAL
1966-69				
bar (bare)	33702	0	349352	383054
bar (vegetated)	1742641	3631768	2534919	7909329
island	1700129	9064513	2419546	13184188
river	34113978	24733537	20189162	79036678
fan	0	0	0	0
1993				
bar (bare)	2359877	3447868	2360065	8167811
bar (vegetated)	1592918	2127557	2235606	5956080
island	1544215	11410834	5000202	17955251
river	30442555	18956243	16201744	65600542
fan	0	0	0	0
Absolute change				
bar (bare)	2326175	3447868	2010713	7784757
bar (vegetated)	-149724	-1504211	-299313	-1953248
island	-155915	2346321	2580656	4771063
river	-3671423	-5777294	-3987418	-13436136
fan	0	0	0	0
% change				
bar (bare)	6902.2		575.6	2032.3
bar (vegetated)	-8.6	-41.4	-11.8	-24.7
island	-9.2	25.9	106.7	36.2
river	-10.8	-23.4	-19.8	-17.0
fan	0.0	0.0	0.0	0.0
Reach length (m):	23980	19910	17740	61630
Average width, 1966-69 (m):	1424	1242	1158	1289
Average width, 1993 (m):	1368	1125	1046	1197
Absolute change in width (m):	-56	-117	-111	-92
% change in width:	-3.9	-9.4	-9.6	-7.1

	Total Area (sq. m)							
	Reach 4B.1 Garden Creek	Reach 4B.2 Big Island	Reach 4B.3 Little Fishery	Reach 4B.4 Gambling Point	Reach 4B.5 Big Slough	Reach 4B.6 Portage Lake	Reach 4B.7 Jackfish River	REACH 4B TOTAL
1966-69								
bar (bare)	4587290	9075690						
bar (vegetated)	1457226	3290470						
island	2500785	42234522						
river	5643702	10382251						
fan	0	0						
1993								
bar (bare)	2069571	5078528	1720263	1917062	957661	646439	1136291	13525816
bar (vegetated)	1518475	2811508	1565825	6148929	2637504	2519108	2285479	19486827
island	3679304	43544599	1700050	1966074	126200	317059	4127828	55461114
river	7318154	12857606	6948375	10664191	10456189	9461443	11510727	69216685
fan	0	0	0	0	0	0	0	0
Absolute change								
bar (bare)	-2517718	-3997161						
bar (vegetated)	61250	-478963						
island	1178519	1310078						
river	1674452	2475355						
fan	0	0						
% change								
bar (bare)	-54.9	-44.0						
bar (vegetated)	4.2	-14.6						
island	47.1	3.1						
river	29.7	23.8						
fan	0.0	0.0						
Reach length (m):	9360	19840	15170	22500	19650	16160	18220	120900
Average width, 1966-69 (m):	1093	981						
Average width, 1993 (m):	1003	904	571	559	581	625	694	684
Absolute change in width (m):	-90	-77						
% change in width:	-8.2	-7.8						

Note: Reach length is measured down center-line of channel, and average width is calculated by dividing the sum of the river and bar (bare) areas by reach length.

Photos for the 1966-69 period were not available for reaches 4B.3 - 4B.7

PEACE RIVER: Summary of morphology and vegetation changes - Reach 4B

"At-a-point changes"
1950 to 1993

1950	1993	Process: *Morphology*	Process: *Vegetation*	Area (sq. m): Reach 4B.1 Garden Creek	Reach 4B.2 Big Island	Reach 4B.3 Little Fishery	Reach 4B.4 Gambling Point	Reach 4B.5 Big Slough	Reach 4B.6 Portage Lake	Reach 4B.7 Jackfish River	REACH 4B TOTAL
bar (bare)	bar (bare)	stable		400082	784594	135821	52397	5261	82583	119640	1580378
bar (bare)	bar (vegetated)	stable	recovery	114946	941225	594596	2120382	113750	983831	848182	5716911
bar (bare)	island	stable	recovery	1597129	1354213	308905	389025	0	8134	228106	3885513
bar (bare)	river	erosion		978573	643502	161698	140982	22300	417716	451258	2816029
bar (bare)	floodplain	stable	recovery	26273	1440360	818028	617648	488282	412811	68544	3871945
bar (bare)	fan	stable		0	0	0	0	0	0	0	0
bar (vegetated)	bar (bare)	stable	removal	46791	71183	0	119	1060	2672	11943	133769
bar (vegetated)	bar (vegetated)	stable	stable	27173	11427	21572	229873	176383	26337	22911	515676
bar (vegetated)	island	stable	recovery	888327	1092779	1256744	588629	124225	62770	121538	4135012
bar (vegetated)	river	erosion	removal	137996	200518	0	51367	134955	55609	177596	758040
bar (vegetated)	floodplain	stable	recovery	5885	1280793	472144	1668583	1569345	1079804	0	6076554
bar (vegetated)	fan	stable	stable	0	0	0	0	0	0	0	0
island	bar (bare)	erosion	removal	132075	532876	0	9339	0	0	15113	689403
island	bar (vegetated)	erosion	removal	0	62152	0	9123	0	0	79799	151074
island	island	stable	stable	537324	39258250	0	917814	0	0	3673233	44386621
island	river	erosion	removal	149108	2146898	0	8111	0	0	197489	2501607
island	floodplain	accretion	stable	0	78484	0	1375804	1615175	0	0	3069463
river	bar (bare)	deposion		1476577	3209547	1579932	1568682	785342	561183	955219	10136461
river	bar (vegetated)	deposition	recovery	1376356	1788342	926549	3716118	2300602	1440817	1318461	12867246
river	island	deposition	recovery	656524	1779486	134401	70606	1974	246155	104952	2994098
river	river	stable		5105508	7601626	3741191	5490376	7062819	7370848	10009636	46382004
river	floodplain	deposition	recovery	3828	1608601	942838	282137	1465018	236372	108817	4647611
river	fan	deposition		0	0	0	0	0	0	0	0
floodplain	bar (bare)	erosion	removal	14047	480329	4510	286525	165998	0	34376	985785
floodplain	bar (vegetated)	erosion	removal	0	8362	23108	73432	46769	68133	16126	235930
floodplain	island	avulsion	stable	0	59870	0	0	0	0	0	59870
floodplain	river	erosion	removal	946969	2265062	3045485	4973355	3236115	1617271	674749	16759005
floodplain	fan	erosion	removal	0	0	0	0	0	0	0	0
fan	bar (bare)	stable		0	0	0	0	0	0	0	0
fan	bar (vegetated)	stable	recovery	0	0	0	0	0	0	0	0
fan	river	erosion		0	0	0	0	0	0	0	0
fan	floodplain	stable	recovery	0	0	0	0	0	0	0	0
fan	fan	stable		0	0	0	0	0	0	0	0

CUMULATIVE AREA:

Morphology

	Reach 4B.1 Garden Creek	Reach 4B.2 Big Island	Reach 4B.3 Little Fishery	Reach 4B.4 Gambling Point	Reach 4B.5 Big Slough	Reach 4B.6 Portage Lake	Reach 4B.7 Jackfish River	REACH 4B TOTAL
Net erosion (sq. m):	2358768	6339699	3234802	5552234	3606137	2158728	1646506	24896872
Net deposition (sq. m):	3513285	8385976	3583719	5637543	4552936	2484528	2487449	30645437
Stability (sq. m):	8749437	53836450	7349000	12074847	9541126	10029790	15103732	116684383
Avulsion (sq. m):	0	59870	0	0	0	0	0	59870
Accretion (sq. m):	0	78484	0	1375804	1615175	0	0	3069463

Vegetation

	Reach 4B.1 Garden Creek	Reach 4B.2 Big Island	Reach 4B.3 Little Fishery	Reach 4B.4 Gambling Point	Reach 4B.5 Big Slough	Reach 4B.6 Portage Lake	Reach 4B.7 Jackfish River	REACH 4B TOTAL
Removal (sq. m):	1426986	5827250	3073104	5411371	3584897	1743684	1207191	22274483
Recovery (sq. m):	4669267	11285799	5454204	9453129	6063197	4470695	2798600	44194890
Stability (sq. m):	564497	39348162	21572	2523491	1791557	26337	3696143	47971760

Note: The change from floodplain to floodplain was omitted as no outer limit of the floodplain was defined during mapping.
The changes from island to fan and from fan to island were omitted as no such changes were observed.

PEACE RIVER: *Summary of morphology and vegetation changes - Reach 4B*
"Reach-wide changes":
1950 to 1993

	Total Area (sq. m)							
	Reach 4B.1 Garden Creek	Reach 4B.2 Big Island	Reach 4B.3 Little Fishery	Reach 4B.4 Gambling Point	Reach 4B.5 Big Slough	Reach 4B.6 Portage Lake	Reach 4B.7 Jackfish River	REACH 4B TOTAL
1950								
bar (bare)	3117003	5163893	2019048	3320434	629594	1905074	1715730	17870776
bar (vegetated)	1106172	2656700	1750459	2538571	2005968	1227193	333988	11619051
island	818507	42078660	0	2320191	1615175	0	3965634	50798167
river	8618792	15987603	7324911	11127919	11615755	9855366	12497085	77027431
fan	0	0	0	0	0	0	0	0
1993								
bar (bare)	2069571	5078528	1720263	1917062	957661	646439	1136291	13525816
bar (vegetated)	1518475	2811508	1565825	6148929	2637504	2519108	2285479	19486827
island	3679304	43544599	1700050	1966074	126200	317059	4127828	55461114
river	7318154	12857606	6948375	10664191	10456189	9461443	11510727	69216685
fan	0	0	0	0	0	0	0	0
Absolute change								
bar (bare)	-1047431	-85364	-298785	-1403373	328067	-1258636	-579439	-4344960
bar (vegetated)	412303	154808	-184635	3610357	631536	1291916	1951491	7867776
island	2860797	1465939	1700050	-354117	-1488975	317059	162194	4662947
river	-1300639	-3129997	-376536	-463728	-1159566	-393923	-986358	-7810747
fan	0	0	0	0	0	0	0	0
% change								
bar (bare)	-33.6	-1.7	-14.8	-42.3	52.1	-66.1	-33.8	-24.3
bar (vegetated)	37.3	5.8	-10.5	142.2	31.5	105.3	584.3	67.7
island	349.5	3.5		-15.3	-92.2		4.1	9.2
river	-15.1	-19.6	-5.1	-4.2	-10.0	-4.0	-7.9	-10.1
fan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reach length (m):	9360	19840	15170	22500	19650	16160	18220	120900
Average width, 1950 (m):	1254	1066	616	642	623	728	780	785
Average width, 1993 (m):	1003	904	571	559	581	625	694	684
Absolute change in width (m):	-251	-162	-45	-83	-42	-102	-86	-101
% change in width:	-20.0	-15.2	-7.2	-12.9	-6.8	-14.1	-11.0	-12.8

Note: Reach length is measured down center-line of channel, and average width is calculated by dividing the sum of the river and bar (bare) areas by reach length.

APPENDIX D: EXAMPLES OF MAPS AND LEGENDS

LEGEND

Channel boundary
(lower limit of terrestrial vegetation)

Interpolated channel boundary

Islands
(lower limit of terrestrial vegetation)

Bars
(sand and gravel)
(vegetated and unvegetated)

Subaerial dunes
(present on date of photography)

Miscellaneous water bodies

Tributary streams

Tributary fans

Roads (paved or gravel)

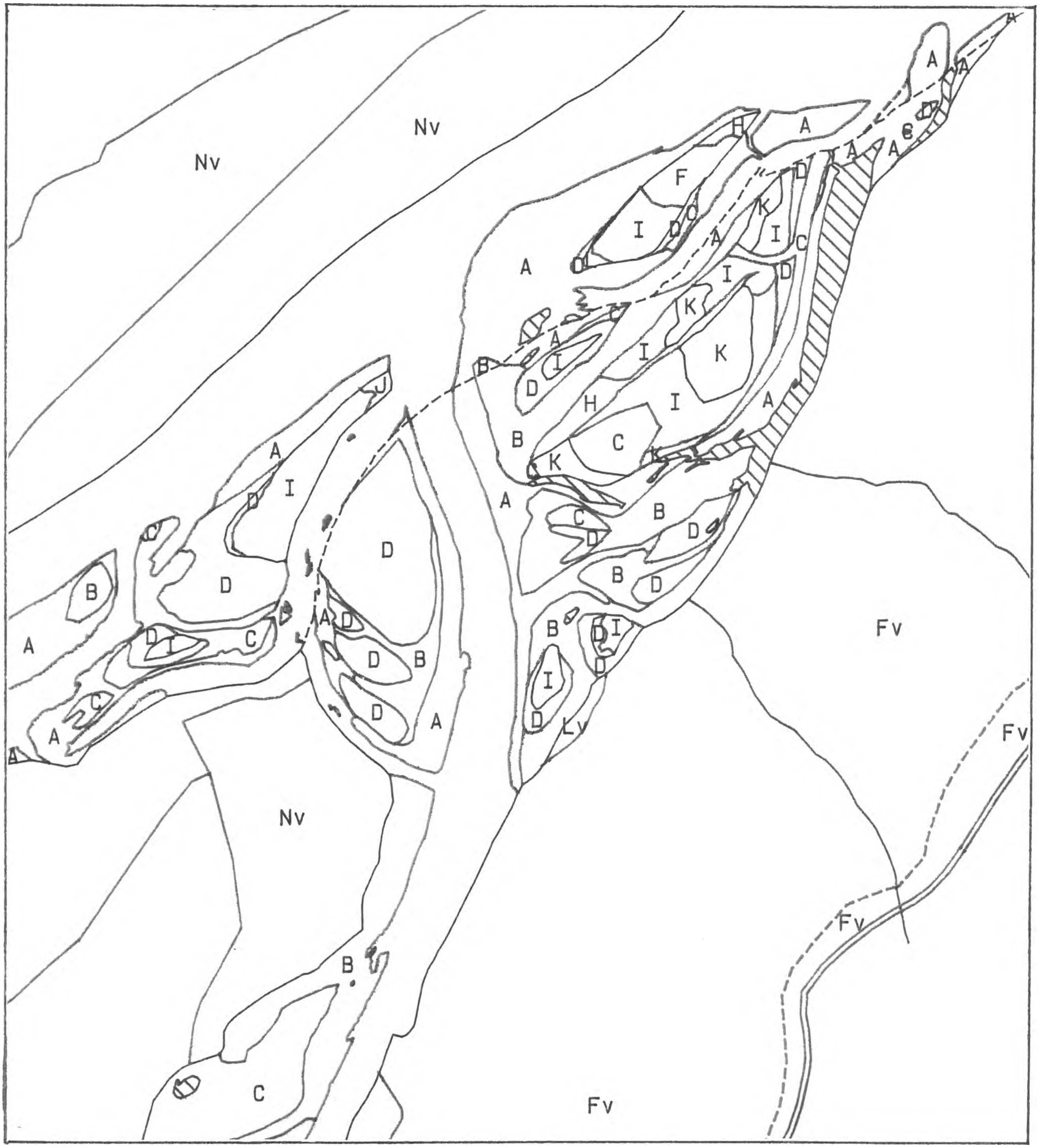
Railroads

Vegetation mapping limits

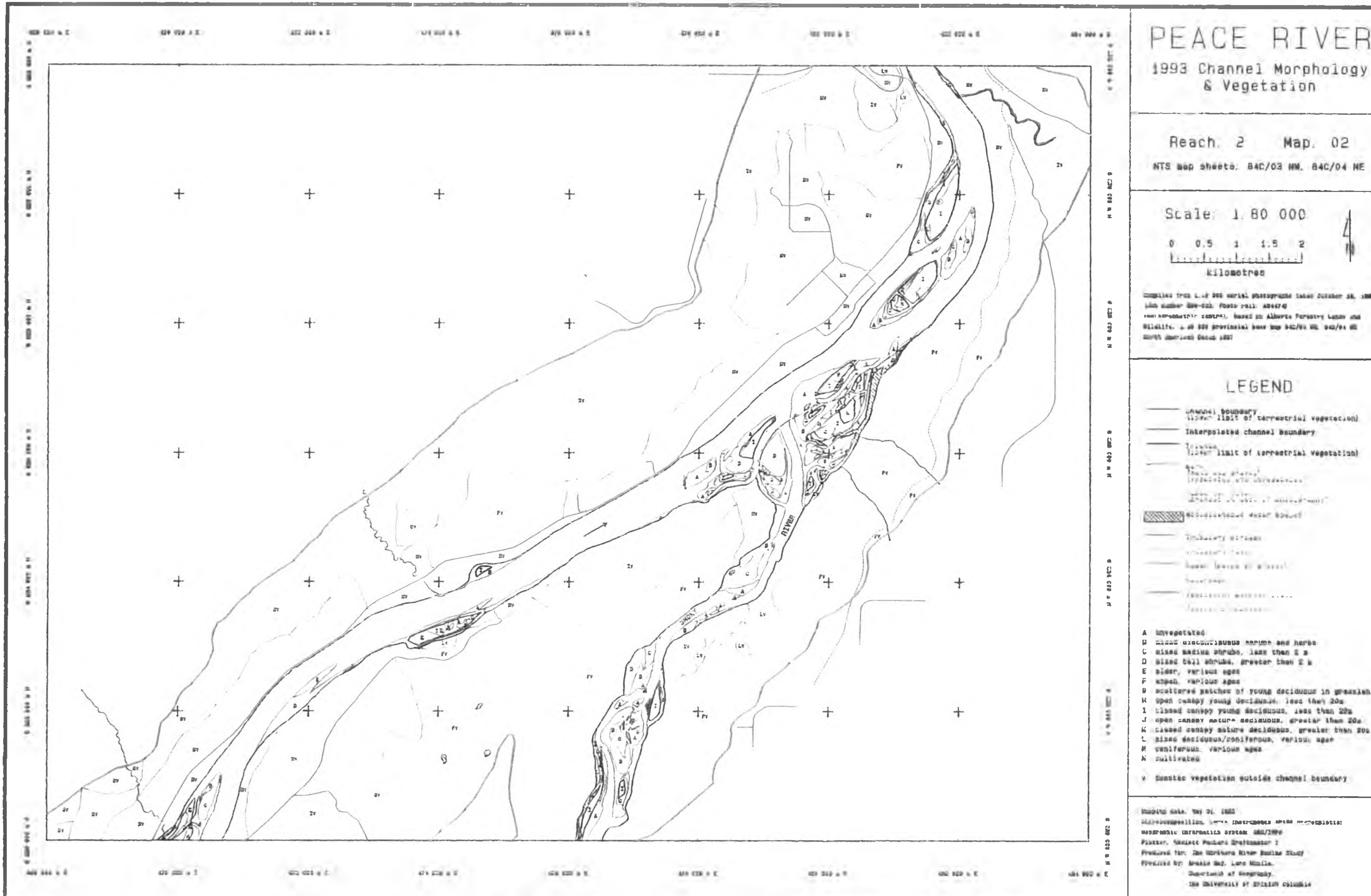
Vegetation boundaries

A unvegetated
B mixed discontinuous shrubs and herbs
C mixed medium shrubs, less than 2 m
D mixed tall shrubs, greater than 2 m
E alder, various ages
F aspen, various ages
G scattered patches of young deciduous in grassland
H open canopy young deciduous, less than 20m
I closed canopy young deciduous, less than 20m
J open canopy mature deciduous, greater than 20m
K closed canopy mature deciduous, greater than 20m
L mixed deciduous/coniferous, various ages
M coniferous, various ages
N cultivated

v denotes vegetation outside channel boundary



Segment of Map 2/02 at full presentation scale (1:20 000), showing the Smoky River confluence



Complete map (Reach 2/02) at 1:80 000 (4x linear reduction)