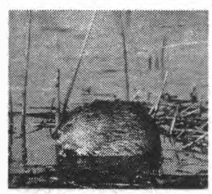
Canada Alberta Northwest Territories

Northern River Basins Study



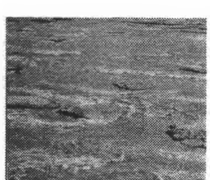




NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 74

ASSESSMENT OF IMPACTS ON THE SLAVE RIVER DELTA OF PEACE RIVER IMPOUNDMENT AT HUDSON HOPE





DATE DUE

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Northern River Basins Study
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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,

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F J Wrona — 4 Apr 96

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

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

P A Larkin — March 26/96

(Dr. P. A. Larkin, Ph.D., Chair) — (Date)

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 — March 20/96

(Lucille Partington, Co-chair) — (Date)

Robert McLeod — 01/04/96

(Robert McLeod, Co-chair) — (Date)

ASSESSMENT OF IMPACTS ON THE SLAVE RIVER DELTA OF PEACE RIVER IMPOUNDMENT AT HUDSON HOPE

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 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 Slave River Delta. The effect of flow regulation on Great Slave Lake levels was not investigated.

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 Peace-Athabasca and Slave River Deltas are dynamic systems continually changing to variations in flow and sediment transport. Alteration of flow on the major tributary to the Slave River was likely to have impacts on the Slave River Delta. The report is describes the results of an investigation into the likely impacts of flow regulation on the Peace River on the natural propagation of the Slave River Delta into Great Slave Lake. Investigators used a combination of aerial photography from 1946, 1966, 1977 and 1994 and ground truthing to interpret changes in plant assemblage patterns and delta channel geomorphology at selected locations. Collected information aided an assessment of pre-regulation and post-regulation delta growth.

The growth rate of the cleavage bar islands in the Slave River Delta for the period 1977 to 1994 was less than that for other periods of study. The reduction in the growth of the selected cleavage bar islands is being attributed to a reduction in the suspended sediment load since 1968. This suggests there is a positive link between reduced flows in the Slave River as a consequence of the Bennett Dam and altered delta development. The research documented a narrowing in the width of three of the four distributary channels, while a fourth expanded in the period 1946 to 1994. Subsequent changes appear to continue without regard to changes in flow regime. With the drier environment on the four representative cleavage bar islands, there has been an increase in plant species favourable to these conditions. These changes appear to be made at the expense of more biologically important plant species preferred by migratory birds and muskrats.

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. Further study of the effects of flow regulation on Great Slave Lake is needed.

REPORT SUMMARY

The objective of this study is to examine the impact of regulating the Peace River in 1968 on the natural progradation of the Slave River Delta into Great Slave Lake. The report describes the hydrological relationship between the Peace and Slave Rivers both before and after impoundment. Changes in the flow regime of the Peace River that have occurred since impoundment and impacts of this change on the sediment transport regime of the Slave River are discussed. Implications of the altered sediment regime on the continued progradation of the Slave River Delta into Great Slave Lake are presented by examining change in the geomorphological and botanical dynamics of the Slave River Delta both before and after impoundment.

Hydrometric data collected by the Water Survey of Canada is used to compare mean monthly discharge of the Peace River at Peace Point with the Slave River at Fitzgerald. The percentage contribution of Peace River water to the Slave ranges from a low of 42% in September to a high of 77% in April. In the post-impoundment period, the monthly discharge of the Peace River has declined 16% for the ice-off period but increased 40% during ice-on periods.

There is no pre-impoundment sediment data for the Slave River. Therefore, a sediment rating approach is used, which incorporates the mean monthly discharge of Peace River at Peace Point, to predict mean monthly sediment load for the Slave River at Fitzgerald. Projections based on this approach indicate a 33% (372,491 t yr^{-1}) reduction in the average annual sediment load of Slave River at Fitzgerald in the post dam period. The seasonal shift in the hydrograph has changed the sediment transport dynamics of the Slave River for ice-on and ice-off periods. Sediment load has increased 315% during ice-on flow, which represents approximately 24% of the total annual load. In contrast, sediment transport has decreased 46% for ice-off flow. Flow reduction during ice-off periods will cause an increase in fine-grained sediment transport to the delta. The change in sediment transport regime has implications for the progradation of the Slave River Delta into the Great Slave Lake.

In order to compare geomorphological and botanical change in the delta before and after impoundment, two sets of aerial photographs taken 20 and 18 years apart respectively were examined. As the outer portion of the Slave Delta is the most productive and rapidly changing, geomorphological and botanical change are examined primarily in this area by comparing the aerial photographs for 1946, 1966, 1977 and 1994. This analysis is further supported by field work conducted on the delta from May to July, 1995. Generally, the growth rate of cleavage bar islands has reduced from 1946 to 1994 and is related, in part, to changes in morphology of the distributary channels. The widths of Old Steamboat Channel and East Channel have decreased 59 and 45% respectively, while ResDelta Channel has increased by 47% between 1946 and 1994. ResDelta Channel transports approximately 90% of the flow and sediment through the delta. In addition, bars have formed at the mouths of several of the smaller distributary channels. Partial closure of channel entrances and reduction in channel width has reduced the capacity of these channels to effectively transport sediment which, in turn, has affected the growth rate of cleavage bar islands.

Plant assemblage patterns on the cleavage bar islands at the mouths of Old Steamboat Channel, Mid Channel West, East Channel and ResDelta Channel are examined to assess botanical change from 1946 to 1994. General trends in the wetter outer delta cleavage bar islands include a general shift toward a drier environment characterized by the increased areal coverage of Salix, Salix-Alnus and Alnus assemblages. On the Mid Channel West and East Channel islands there is a noticeable decrease in the aerial coverage of Equisetum assemblages.

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The University of Alberta Press has generously given permission to use Figures 1.1, 2.1, 2.2 and 2.3 from M.C. English, 1984, in *Northern Ecology and Rsource Management* (R. Olson, *et al.*, eds). The University of Alberta Press.

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This research is undertaken to investigate the impacts of damming the Peace River in 1968 on the natural progradation of the Slave River Delta into Great Slave Lake.

1.2 OBJECTIVES

There are several steps involved in arriving at the principal objective of determining how Peace River regulation has impacted the Slave River Delta. The first involves understanding the hydrological relationship between the Peace and Slave Rivers both prior to and after regulation. Allied with understanding the seasonal influence of the Peace flow upon the Slave River is the timing of peak flows and spring breakup of the river ice cover.

The second step focuses on changes in the suspended sediment regime in the Slave River before and after impoundment. Changes in the quantity and quality of the suspended sediment load have important implications for the continued progradation of the Slave Delta into Great Slave Lake.

The third step examines two distinct periods of development on the Slave River Delta: a twenty year period of time prior to, and a seventeen year period after impoundment, as defined by aerial photography taken in 1946 and 1966, and 1977 and 1994 respectively. The reasoning behind selection of these dates for comparison is that they: 1. represent periods of time when aerial photography is available and 2. characterize development of the Slave River Delta during non-regulated and regulated periods of time.

The fourth step examines geomorphological and botanical change on the Slave Delta over the course of the forty eight years of change that have been documented photographically. In addition results of the 1995 field season will be used to assist in understanding some of the fluvial geomorphological processes ongoing within the delta environment which may help explain patterns of channel closure and changing transport of sediment along channel distributaries.

1.3 HISTORICAL PERSPECTIVE

The formation of the Slave River Delta began approximately 10,000 years before present with the retreat of the Keewatin Ice Sheet. Prior to this time, ice extended across the southwestern corner of the Northwest Territories and well into the Peace and Athabasca River valleys (Cameron 1922). The retreating ice eventually lead to the formation of glacial Lake McConnell which, in turn, was drained through the present day Churchill River system into Hudson Bay. Isostatic rebound in this region restricted flow to the east after melting of the Selwyn ice tongue, which blocked northern drainage, Glacial lake McConnell began draining north through the Mackenzie valley. After a period of time when the lakes boundaries were significantly reduced, the distinct present day features of Lake

Athabasca and Great Slave Lake were formed. Since that time sediment carried by the Peace, Athabasca and Slave Rivers has deposited in the southern arm of Great Slave Lake **(fig 1.1)**. Since 8070 BP the deltaic deposits of the Slave River Delta have prograded into Great Slave Lake at an average rate of 20.7 metres per year (Vanderburgh and Smith 1988). Today sedimentary deposits from the Slave River cover approximately 8300 km^2 (Vanderburgh and Smith 1988); however only about 5% of this area is classified as the actively prograding portion of the delta (English 1984).

Hydrologically the Slave River provides a very significant portion of the water contribution to Great Slave Lake. This point is underlined when examining the relationship between monthly discharge in the Slave River and Great Slave Lake water levels **(fig 1.2)**. The relationship is significant at the 99% confidence level. As well, the Slave River provides approximately 80% of the flow of the Mackenzie River. So, aside from potential repercussions on the natural progradation of the Slave River Delta into Great Slave Lake caused by altering the flow regime of the Peace, there are potential but as of yet unmeasured implications on Great Slave Lake and the Mackenzie River. For example, reduction of ice-free season flows and increase in ice season flows in the Slave River could potentially affect the heat budget of Great Slave Lake and concomitantly affect the spatial and temporal variability of ice cover.

2.0 The Slave River Delta

2.1 INTRODUCTION

The active delta of the Slave River is approximately 400km^2 which represents approximately 5% of the total area of deltaic deposits laid down by the Slave River over the past 10,000 years (Cameron 1922, Vanderburgh and Smith 1988). This active arcuate delta has, for the past several hundred years, been directly influenced by the bifurcating nature of its distributaries, **(fig 2.0)** by annual or periodic flooding, significant sediment accumulation and erosional influences of Great Slave Lake.

2.2 THE ACTIVE DELTA AREA

Based on botanical and geomorphological differences which affect flooding frequency, the delta is broken into three areas of interest: the outer delta, the mid delta and the apex **(fig 2.1)**. As a transect is drawn from the outer perimeter of the delta to the apex, a distance of approximately 15km, levee height increases **(fig 2.2)**. Spatial distribution of flooding in the delta is governed, in part, by levee height but instances of ice jamming during mechanical or even radiation ice breakup can elevate flooding levels considerably.

Fig.1.1: Location of the Slave River Delta, NWT

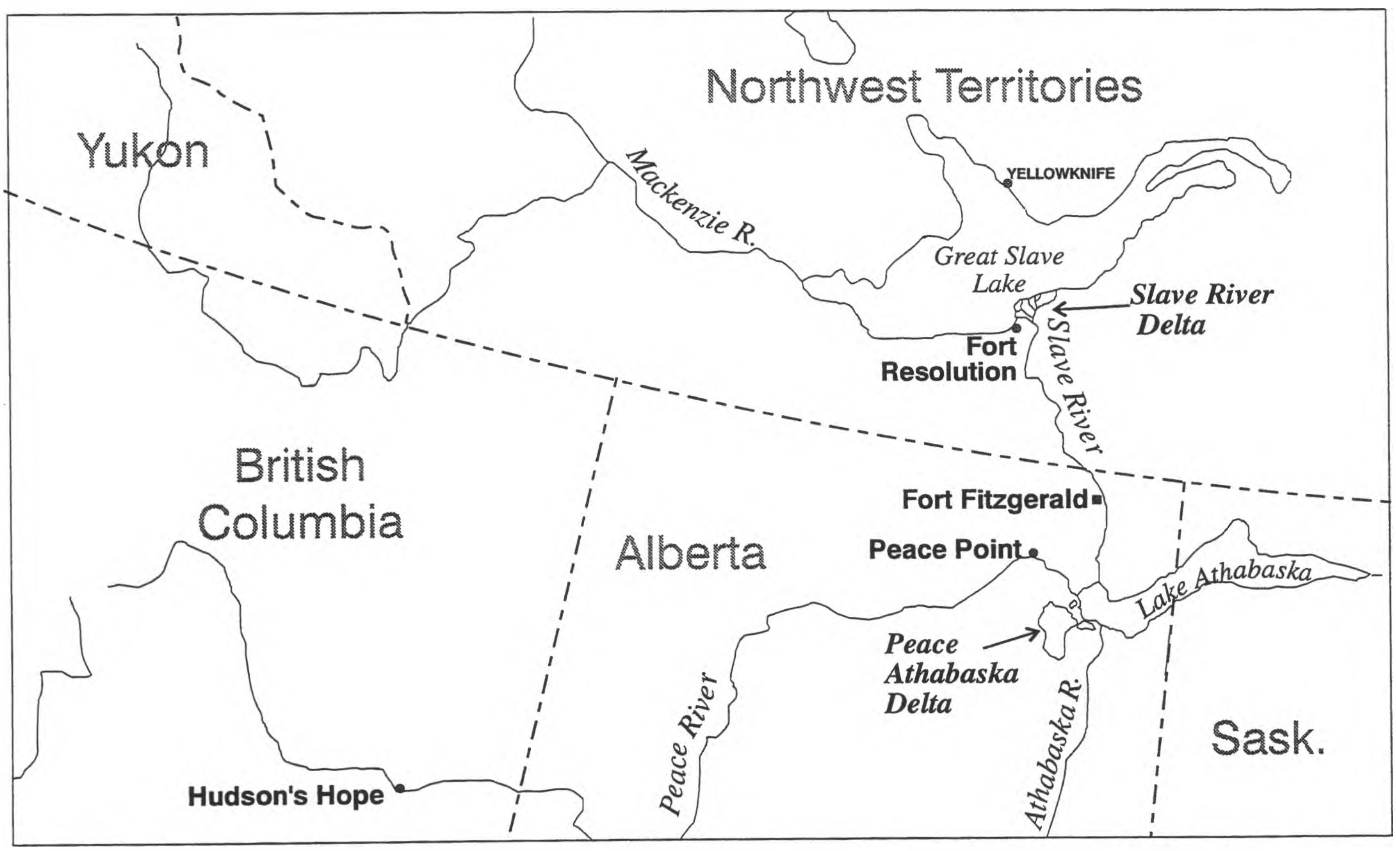
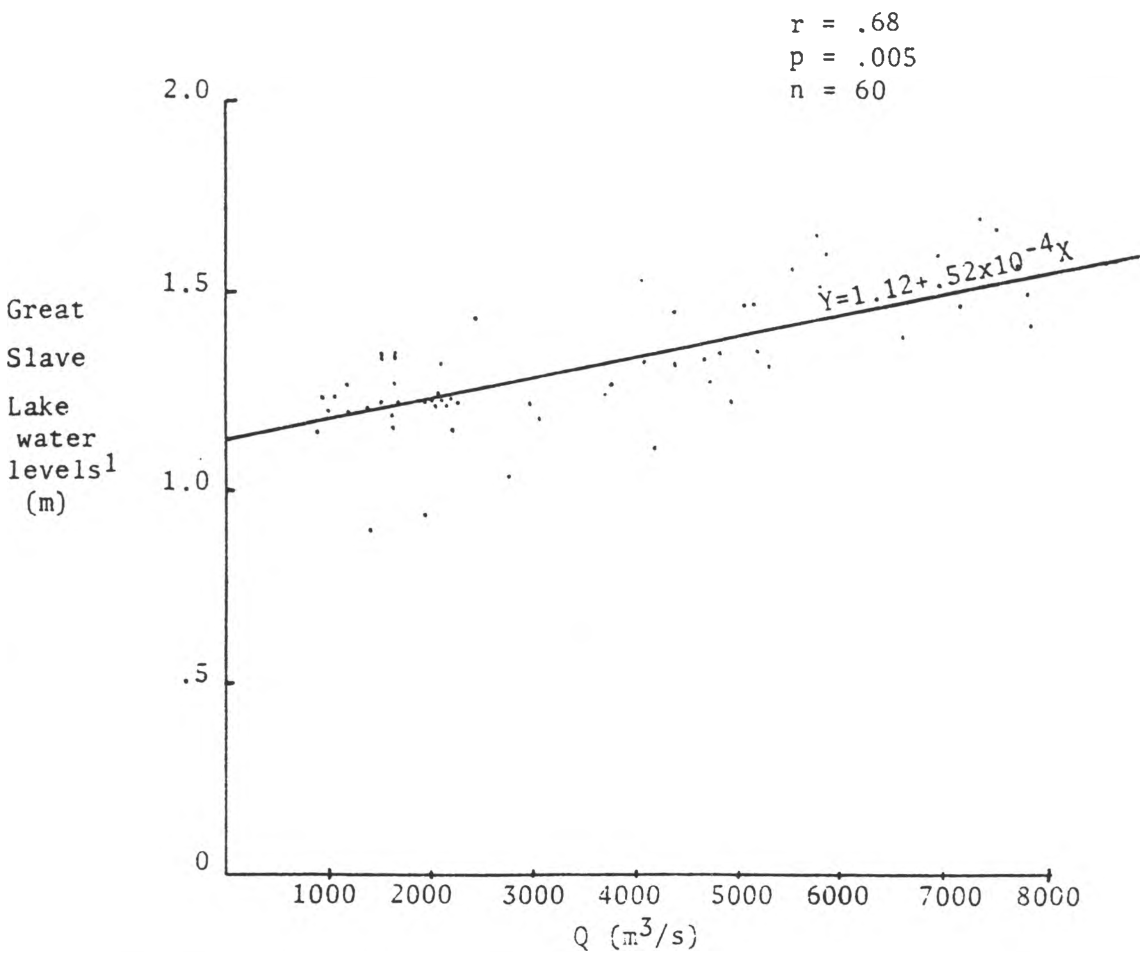


Fig.1.2: Great Slave Lake water level vs. Slave River discharge



1. Convert to G.S.C.Datum add 155.1m (a.s.l.)

Fig.2.0: Major channels of the Slave River Delta

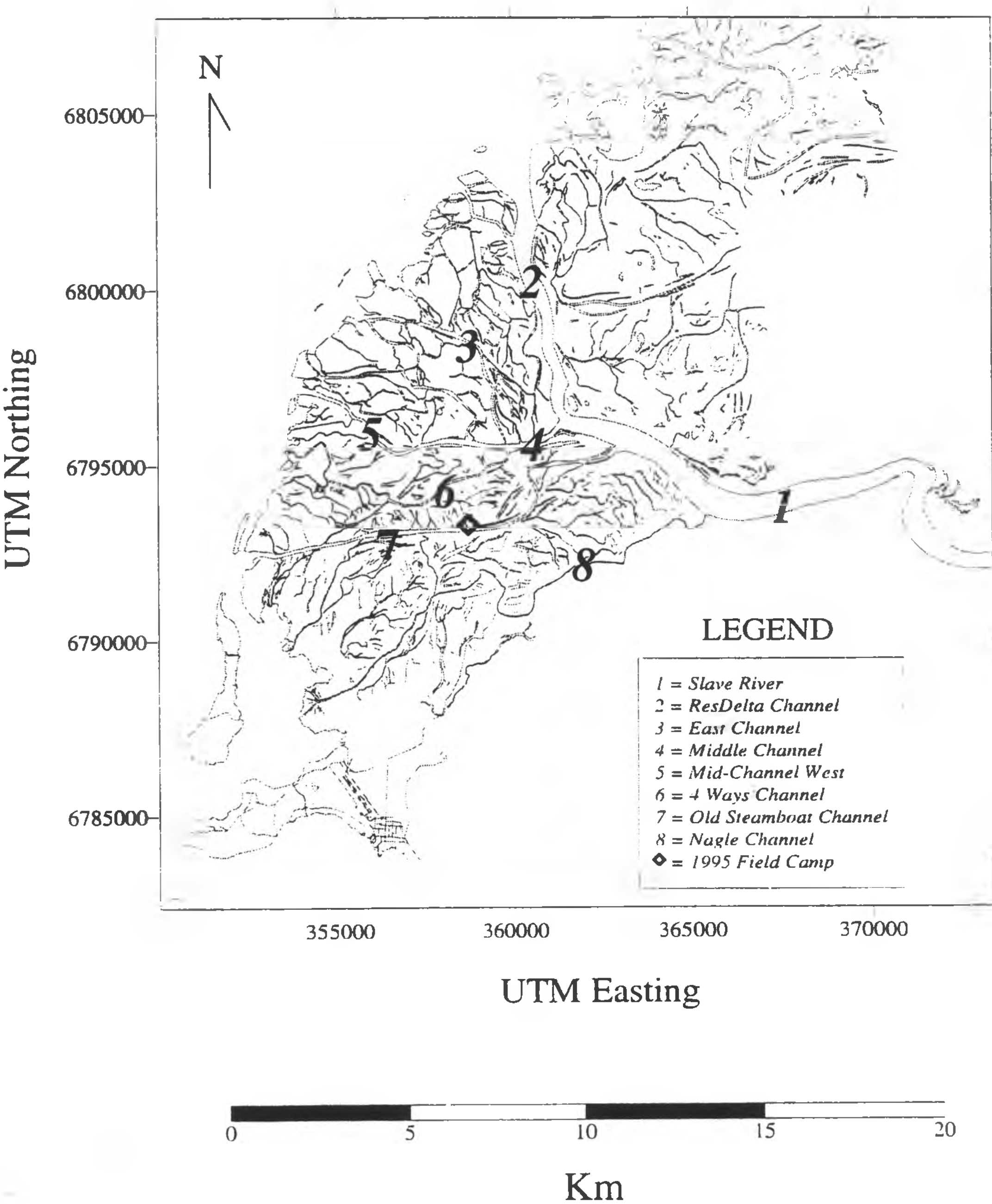


Fig.2.1: Outer, Mid and Apex areas of the Slave River Delta, NWT

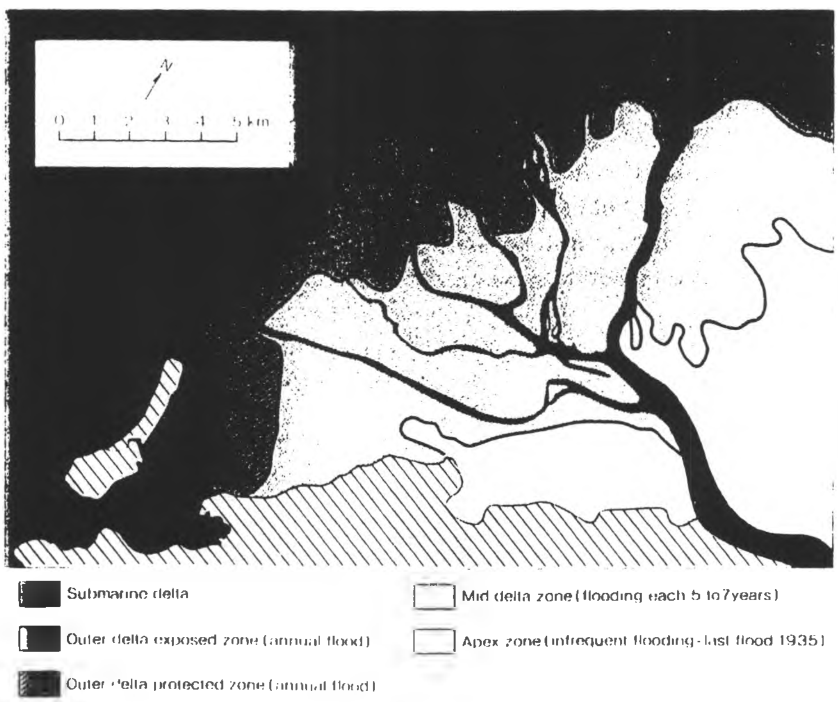


Fig.2.2: Levee elevation within the Outer, Mid and Apex areas of the Slave River Delta, NWT

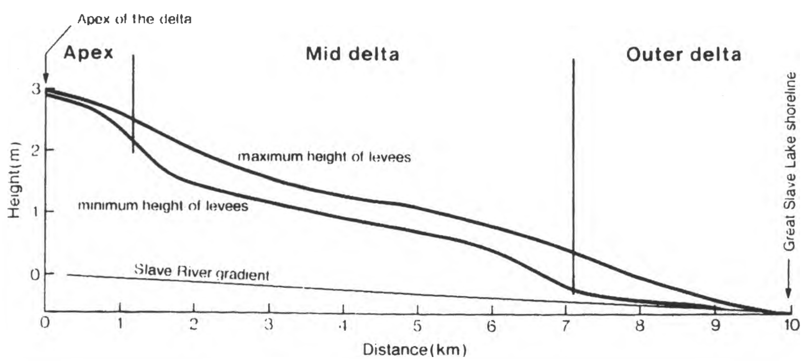


Fig. 4. Levee elevation on the three flood frequency zones of the Slave River Delta, Northwest Territories.

2.2.1 <u>Outer Delta</u>

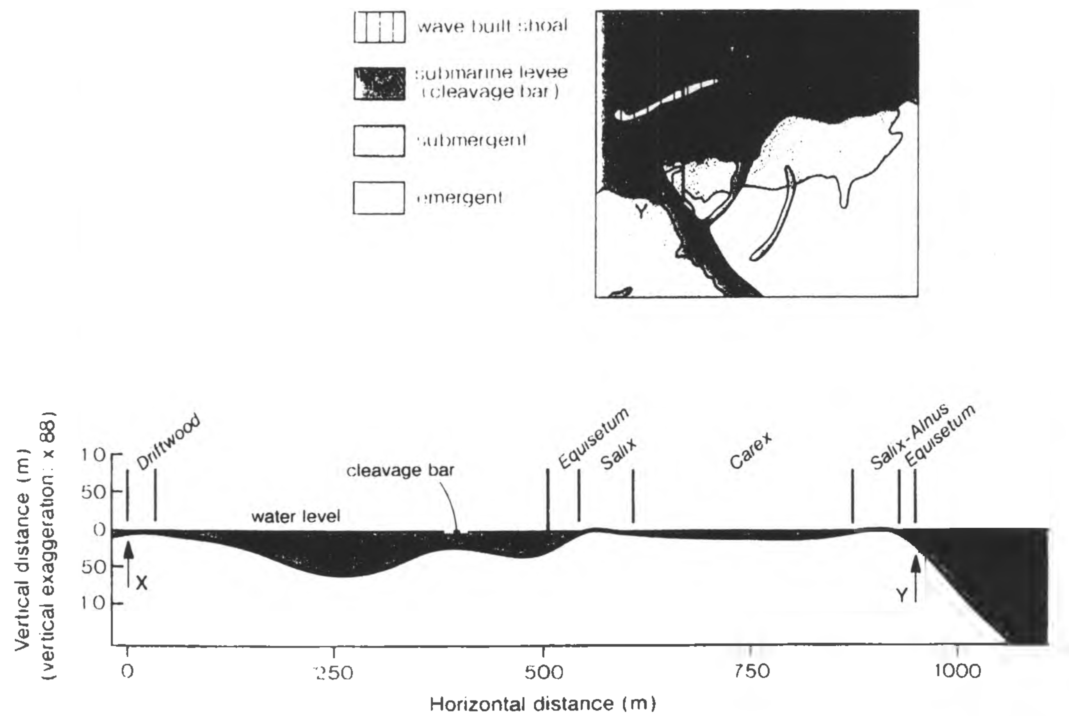
Ninety-five percent of the outer subaerial delta supports aquatic and/or emergent vegetation. The outer delta is essentially a large marsh flat which is an important staging, breeding and feeding ground for migratory bird species. Additionally the *Equisetum fluviatile* and other emergent species of aquatic vegetation attract a diverse range of wildlife including muskrat and moose. As a consequence of annual spring flooding, nutrient rich sediment is deposited on the large expanses of *Equisetum* plant assemblages occupying the interlevee depressions in the outer delta. The principal depositional structures forming in the outer delta are cleavage bar islands and wave-built barrier bars. Cleavage bar island development is discussed by Dahlskog et al (1972) for deltas in Swedish lakes and for the Slave River Delta in English (1984). **Fig 2.3** illustrates cleavage bar development at the mouth of Old Steamboat Channel on the Slave River Delta. In this figure, the submerged levee is forming in a 'V' or cleavage shape. The buildup of the submerged levee is largely due to deposition of bedload during spring flood (Dahlskog et al 1972). When the levee builds up to a sufficient elevation, driftwood plays a major role in stabilizing the landform. Emergent vegetation such as *Equisetum fluviatile* initially colonize the landform. The oldest part of the cleavage bar, the upstream portion, is also the most elevated and once it becomes subaerial, *Salix* spp. invade and further stabilize the landform. Allogenic succession, where plant succession is controlled by environmental factors, is predominant in the outer delta area where the levees are either submergent or elevated above the water level by a few centimetres (English 1984). Continued development of the cleavage bar into an enclosed island is further aided by the formation of wave built barrier bars along the open end of the V-shaped cleavage bar.

The erosional influences of Great Slave Lake are important for limiting the sediment accumulation on the subaqueous topset beds of the delta but once the island landform is elevated above Great Slave Lake water levels and plants have taken root, the effectiveness of waves or currents to alter the landform are much reduced. In many places the barrier bars running parallel to the arcuate shape of the outer delta afford protection from the significant wave action of the lake. The distance between the barrier bars and the cleavage bar islands along the perimeter of the delta can range from 100 to 250m and the backwater aquatic environment between the islands and the bars is typically shallow (< 2m). The barrier bars provide protection against the forces of the lake and, in the backwater, provide an aquatic environment of reduced turbulence wherein fine-grain sediment can settle out and accumulate.

2.2.2 <u>Mid delta</u>

The mid delta area is transitional between the water-dominated landscape of the outer delta and the elevated, relatively dry apex area and comprises approximately 45% percent of the active delta area. The levees in the mid delta area average approximately 1m above Great Slave Lake summer water levels **(fig 2.2)**. Continued sedimentation and buildup of these landforms over long periods of time results in a transition in the major controls of plant succession. Assessing flooding frequency from soil pit evidence is problematic. The soils are cumulic regosols and the stratigraphy consists of alternating deposits of organic material and sediment deposited during floods. Historical flooding

Fig.2.3: Cleavage bar development at the mouth of Old Steamboat Channel, Slave River Delta, NWT



frequency is determined by measuring the thicknesses of organic deposits between flooding events. The thinnest deposit is assumed to represent one year of litter. The thickness of the organic layers is then divided by the thickness of the thinnest layer to derive a crude approximation of flooding frequency. For periods assumed to be before impoundment of the Peace River the flooding frequency is assumed to be each 5-7 years. Evidence after impoundment is sketchy however excavation of the 1977 field season fire pit during the 1995 field season reveals sediment accumulation in two flood events totalling 15cm over the past 18 years. Based on little evidence we cannot state with any confidence that flooding frequency has increased from 5-7 years before impoundment to each 9 years after impoundment.

The landforms in the mid delta elevated above that of the wetter outer delta support plant species adapted to a mesic environment including *Equisetum arvense, Cornus Stolonifera, Salix* spp, *Alnus tenuifolia* and *Populus balsamifera* . The *Alnus-Salix*-plant assemblage is by far the most representative in the mid delta zone. Plant succession on the Slave River Delta is discussed in detail by English (1979,1984). The shift from allogenic to autogenic succession, where ecological factors are the principal control, occurs where flooding frequency is much reduced and is prevalent in the mid delta.

2.2.3 Apex

The average elevation of levees above summer water levels in the apex zone is approximately 2.0m. Flooding frequency in the apex zone was reported to be approximately 35 years (English 1984). This interval was based on interviews with elders in Fort Resolution in 1977, particularly Mr. John Beaulieu and Mr. Angus Beaulieu. English (1984) reports that the presence of a significant bryophyte carpet over large portions of the forest floor in the apex area is indicative of low flooding frequency as the bryophytes cannot tolerate the sediment that accompanies flooding on the Slave Delta. Approximately 6% of the apex zone is classified as aquatic and most of these areas are elevated and cutoff from the Slave River flow. Autogenic succession dominates in the apex area. A significant portion of this zone has reached the climax forest stage of *Picea glauca*. The climax forest stage in the mid delta zone is decadent poplar as the flooding frequency within the mid delta area is sufficient enough to prevent bryophyte colonization. When bryophytes are able to grow successfully they are very efficient insulators of the ground. Due to this factor large areas of the apex zone covered by carpets of bryophytes have permafrost. The cold ground conditions are reported to promote the efficient germination of *Picea glauca* (Gill 1975). Where the bryophyte carpet is of significant depth (ie., $\geq$ 30cm) the active layer in the soil beneath the bryophytes in late July is approximately 15cm (English 1979).

3.0 HYDROLOGY

The source of the Slave River flow is principally the Peace River and the Lake Athabasca-Peace Athabasca delta system. The proportion of flow which originates from each of these sources varies seasonally and is a function of ice jamming conditions. As the Athabasca River is unregulated, winter flows are very low relative to the regulated Peace River. Ice jamming in the Slave River and/or the Peace River can significantly impact the hydraulics and thus the flow of water from the Peace River into the Slave and the Peace-Athabasca Delta (Prowse, Pers. Comm 1995) .

An understanding of the impacts of damming the Peace River on the Slave River Delta, several hundred kilometers downstream must begin with some qualification of how closely linked the flow in the Peace River is with that of the Slave River. To do this the monthly mean flows on the Peace River at Peace Point, Alberta are compared with the monthly mean flows recorded at Fort Fitzgerald, approximately 180 kilometers downstream on the Slave River. Assuming a mean velocity of 1m/second, the travel time between the sites is approximately fifty hours. As such a comparison of monthly flow values between sites introduces a small amount of error. The Peace Point data base has been collected from 1959 to present. The Fort Fitzgerald data base is sporadic from 1921 to 1958 and then more or less continuous to the present time. Both stations are regularly sampled by the Water Survey of Canada.

Accounting for all data for all years (regardless of impoundment on the Peace) the percentage contribution of the Peace to Slave River flow remains quite significant for all months, from a low of 41.7% in September to 76.5% in April (**fig 3.1**). For all years the proportion of contribution of Peace River water to the Slave River is highest in April, May and June and lowest in August, September and October.

Examining the data base for the period prior to and after Peace River impoundment reveals interesting differences (**fig 3.2**). Averaged over 12 months, the Peace River contributes 54% of the Slave flow during preimpoundment years (before 1968). After impoundment this average increases to 66% due primarily to higher winter (ice-on) period flows in the Peace River. In May, June and July postimpoundment contributions of Peace flow to the Slave River are notably lower than preimpoundment years. The overall flow records, pre and post impoundment, for the Slave River indicate that there is virtually no change in total annual discharge for the two periods of time. The preimpoundment mean value is 3468.08 m^3/sec (σ2062.46 m^3/sec) and the post impoundment mean value is 3368.5 m^3/sec (σ1183.91 m^3/sec) Therefore we can assume that year to year climatic differences influencing our interpretation of flow differences before and after the period of filling the W.A.C. Bennett dam reservoir are negligible.

Figure 3.3 illustrates the annual hydrograph for the Slave River at Fort Fitzgerald for all recorded years prior to 1968 and after 1970 when the Bennett Dam reservoir was filled. The apparent change is typical of rivers which have undergone alteration due to impoundment (Townshend 1973, Aitken

Fig.3.1: Percent Slave River flow from Peace River

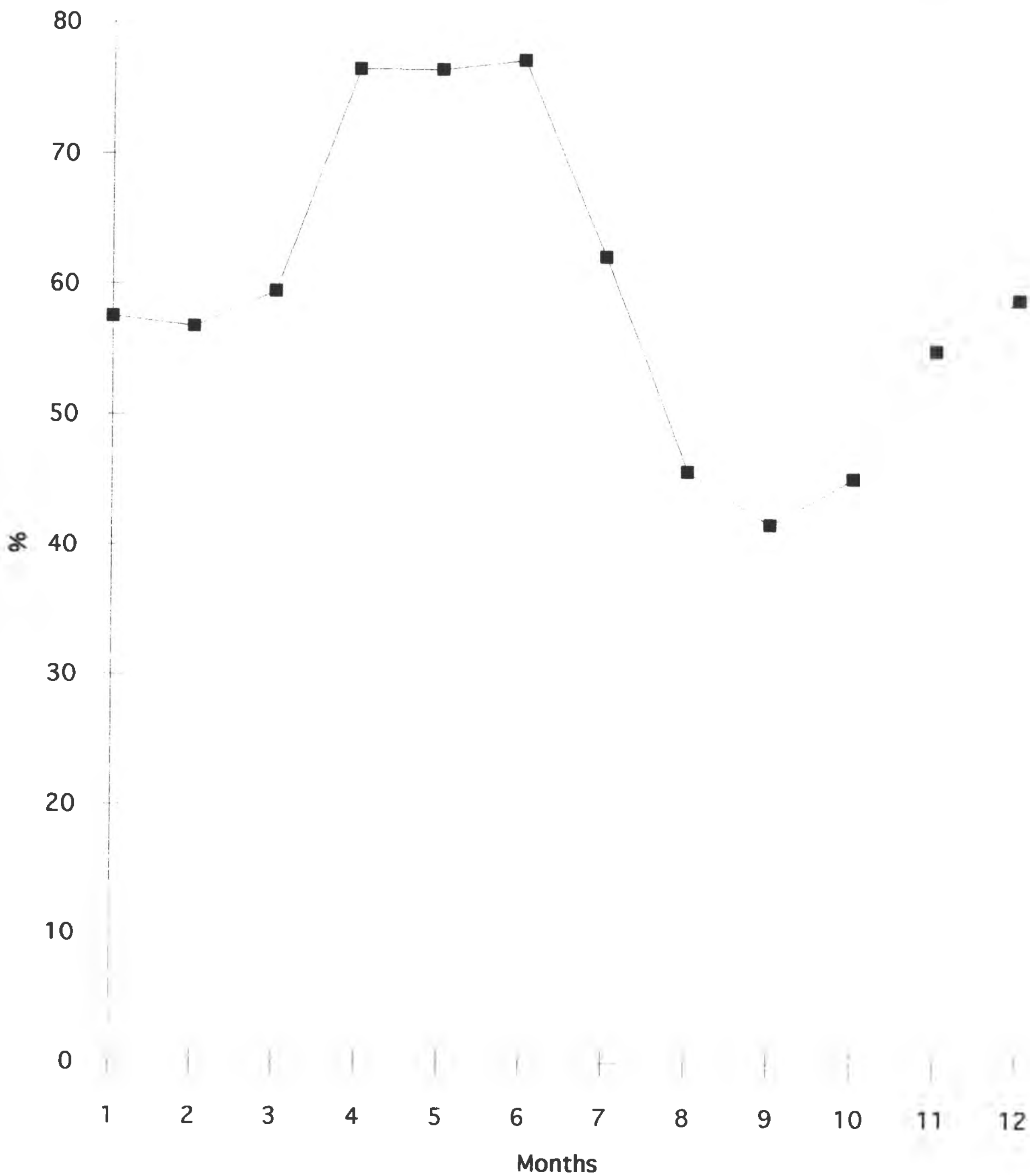


Fig.3.2: Peace River contribution to Slave River flow: Predam (1959-1967) and Postdam (1971-1993)

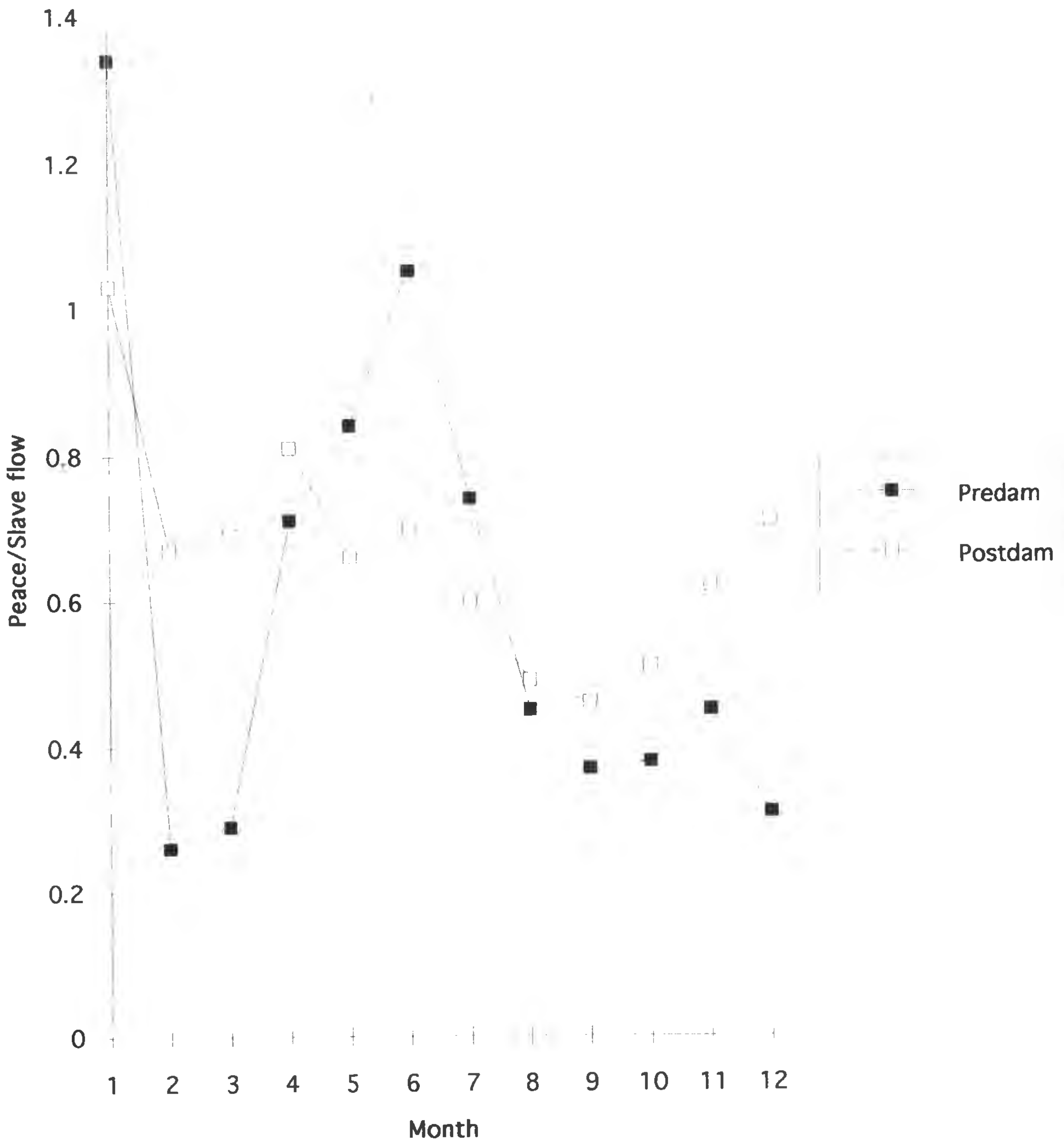
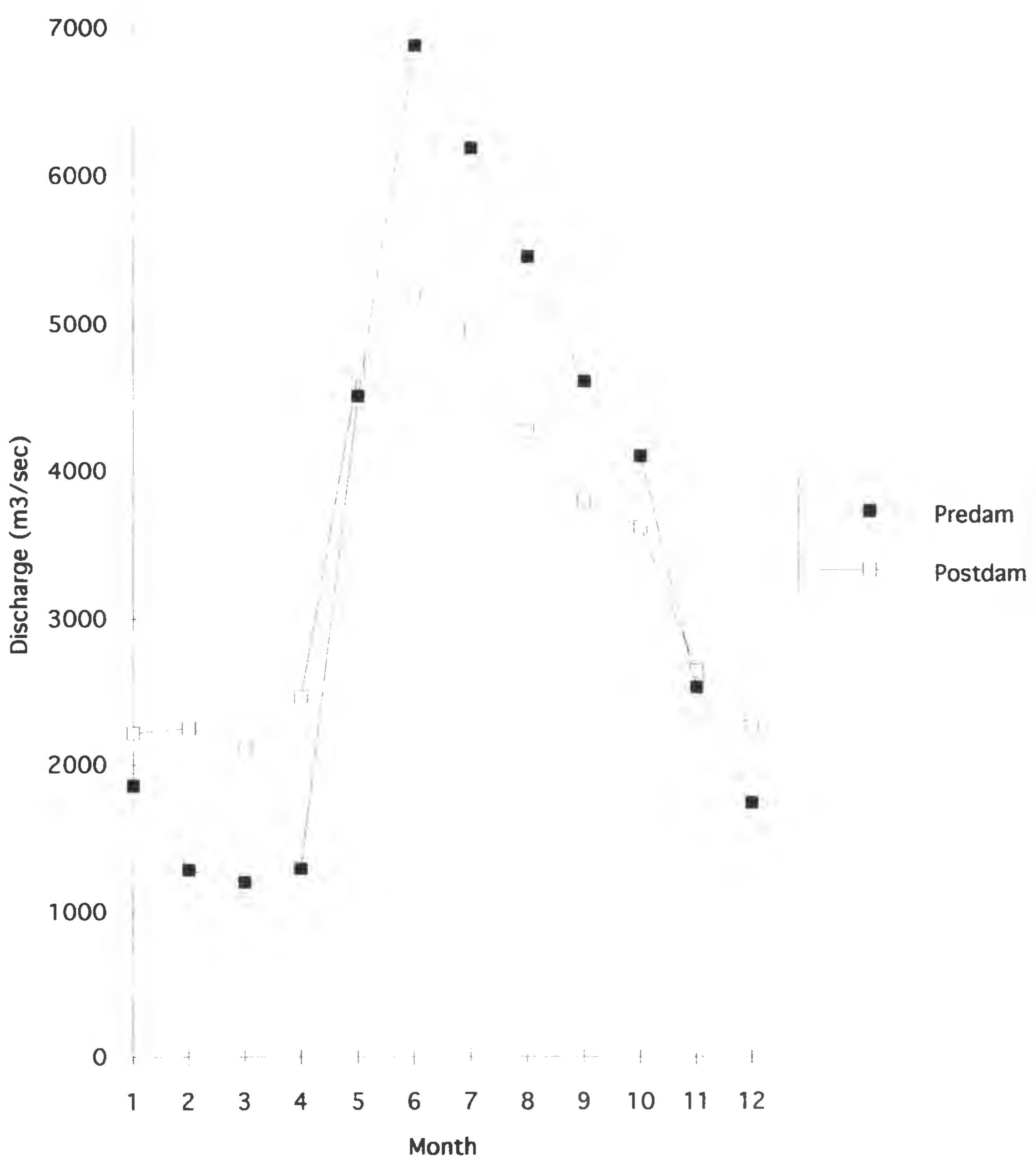


Fig.3.3: Slave River mean monthly discharge Predam and Postdam



and Sapach, 1993). The peak flows occurring during the ice-free months have been dampened as the Bennett reservoir is filled to capacity after winter drawdown and winter flows are elevated above preimpoundment levels. If we define the ice-free period as being between May and October (inclusive) there is a 16% reduction in Slave River flow after impoundment. This figure is based upon all existing discharge data for the Slave River recorded at Fort Fitzgerald intermittently from 1921-1958 and from 1959 continuously to 1967. Similar statistics for the ice-on period (October-April, inclusive) reveals a mean increase of 40% in under-ice flow.

3.1 RIVER ICE HYDROLOGY AND ICE JAMS

The winter hydrology of a large, northern river such as the Slave can be complex. **Figure 3.4** is a schematic plan which describes the various hydrologic scenarios during the winter for a river. It should be noted that for most northern rivers such as the Slave, mid-winter break-ups are very rare. Otherwise, the flow chart covers all the processes.

3.2 FREEZE-UP

Average ice thickness on the Slave River at the end of the winter range from 0.9 to 1.25 m, with an average maximum thickness of 1.1 m (Environment Canada, 1974). Thinner ice is found in areas with strong currents and there is a total absence of ice throughout the winter on some areas of the rapids (Jones, pers. comm., 1995). In fact, at the Water Survey of Canada site at Fitzgerald, portions of the river never freeze over because of turbulence above the rapids (the site is approximately 500 m above the top of the rapids). On account of the open water, ice thickness and winter stream velocity measurements since 1993 have been carried out at a location approximately 3 km upstream from the Fitzgerald site (Jones, pers. comm., 1995).

3.3 SLAVE RIVER BREAK-UP

The Slave River breaks up relatively late (last week of April to the first or second week of May), which allows a large amount of deterioration of the river ice surface by sensible heat and solar radiation. The maximum annual discharge in the Slave River normally occurs in June and July due to a combination of alpine snowmelt and rainfall. However, in 1974, 79, 81, 85, 92 and 93 maximum annual discharge occurred during break-up. It is likely that at the location where ice jams form, they can result in peak annual water levels. The average date of break-up for the 1960-1993 period for the Slave River at Fitzgerald is May 9, although break-up has been recorded over a 26 day period, as early as April 25 (1980) and as late as May 20 (1979) (Table 3.1).

3.3.1 Ice Jams: types and characteristics

An ice jam is defined as "a stationary accumulation of fragmented ice or frazil that restricts flow" (IAHR, 1986). Such jams may occur during freeze-up, because of the accumulation of ice pans as

Fig. 3.4 The General Sequence of Events during the Freeze-up and Winter Spring Breakup Periods for a Northern River

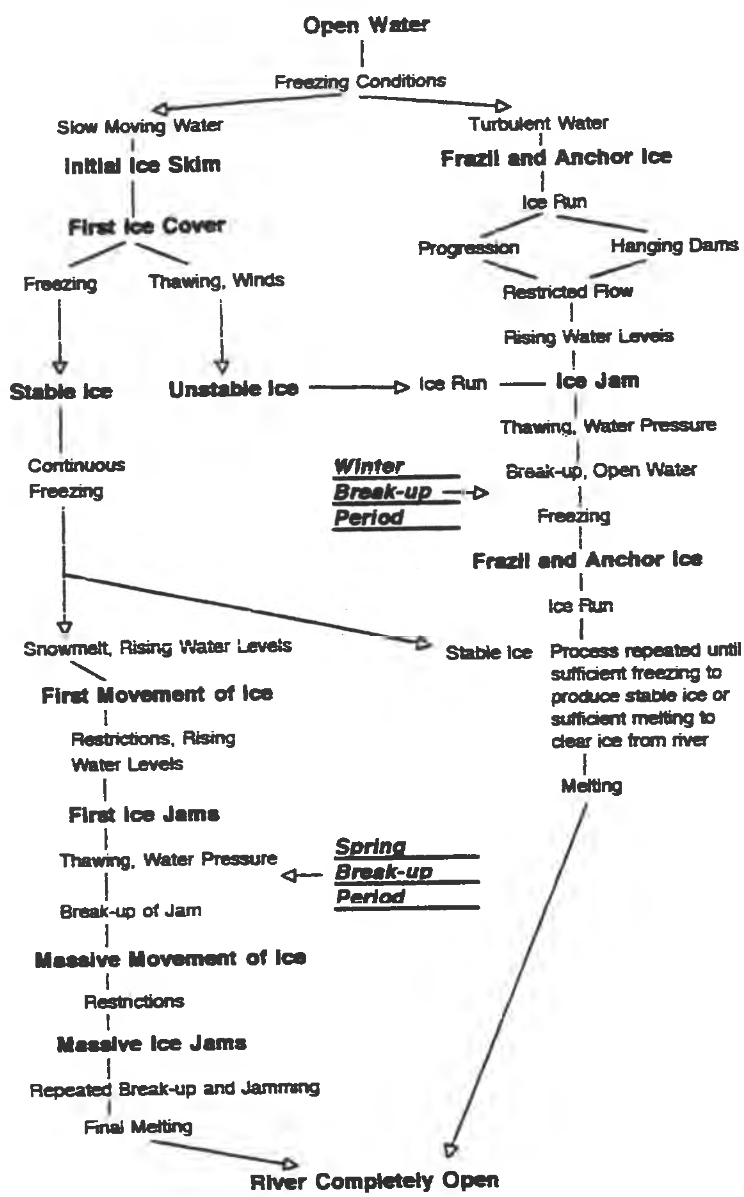


Table 3.1

Summary of break-up conditions for the Slave River at Fitzgerald, 1960-1993

Date	Last Back Water	Break-up	Description of break-up period
1960	13-May	11-May	May 4 solid, 7th ice weak, v quiet break-up, clear of ice 10hrs after break-up
1961	19-May	18-May	May 7 solid, 10-12th drop 60cm jam upstrm?, 14-18th rise 114cm, gauge broke
1962	15-May	15-May	May 4 solid, 7th drop 37cm - jam upstream?, 13th candling, drop >60cm 14th
1963	11-May	7-May	Apr 30 ice start to candle, stage rise 105cm 5-6th, 7th river 60-90cm over bank
1964	15-May	13-May	gradual rise 90cm Apr 26-May 7, May 11-13, rise 100cm to quiet break-up
1965	10-May	9-May	rise 35cm May 1-2, 3rd candling, 7th ice v weak, rise 115cm 5th-7th
1966	14-May	13-May	snow gone 4th, cks running 6th, ice v weak 12th, rise 145cm 11th-14th, no flood
1967	17-May	15-May	May 8 cks running, 11th ice solid, 15th weakening, rise 90cm May 13-14
1968	12-May	12-May	gradual rise 67cm May 6-11, anchor block moved May 12
1969	5-May	3-May	gradual rise 180cm Apr 18-24, rise 45cm Apr 30-May 3, line break
1970	10-May		no record
1971	5-May	3-May	rise 75cm Apr 25-29, drop 40cm May 1, rise 160cm May 3-4
1972	12-May	10-May	rise 45cm May 2-3, drop 50cm May 5, orifice cut May 10 at 20cm rise
1973	7-May	7-May	30cm rise Apr 30, 75cm fall to May 4, 150cm rise to May 7
1974	8-May		
1975	8-May		
1976	30-Apr	29-Apr	stage rise 80cm from April 26-29, maj. fluctuations April 29-30
1977	3-May	28-Apr	drop in stage 30cm from April 27-28, anchor out by ice 28th
1978	14-May	11-May	sm peak May 8 =30cm, 9-11th 76cm rise, anchor out by ice 11th
1979	21-May	20-May	stage drop May 13-18 120cm, rise 120cm May 18-20, anchor out 20th
1980	26-Apr	25-Apr	stage rise of >40cm from April 23-25, anchor taken out by ice April 24
1981	11-May	9-May	stage fluctuations May 2-3, drop 40cm May 4-6, rise 100cm May 6-9
1982	18-May	15-May	April 29-May 7 rise of 80cm, May 15 orifice cut by ice, >35cm rise
1983	13-May	11-May	orifice buried in silt on 13th, estimated peak on 11th
1984	2-May	2-May	50cm rise since 27th, fluctuations on May 1, no record for actual peak
1985	11-May	10-May	stage fluctuations since 6th, 50cm rise of 10th, orifice torn evening 10th
1986	14-May	13-May	record starts 13 May, break-up uncertain, stage drop 30cm after 13th
1987	3-May	2-May	May 1 60cm drop in stage, orifice line torn May 2?
1988	8-May	7-May	break-up observed v little increase in stage (35cm); ice just let go
1989	11-May	9-May	no maj. stage var., May 8-9 45cm rise
1990	7-May	5-May	May 3-5 45cm rise, 25cm rise on 5th
1991	8-May	7-May	orifice line torn 1830h, 60cm stage var., May 6-8 80cm rise
1992	3-May	2-May	orifice line torn mid-aft, Apr 28-29 45cm drop, Apr29-May 2 85cm rise
1993	1-May	30-Apr	30cm stage var., Apr 29-May 1 fluctuations, drop in stage after break-up

the initial ice cover forms, or during break-up, on account of highly unsteady flow caused by significant rainfall, snowmelt, or surges in discharge caused by ice jam releases upstream. **Figure 3.5** shows the stage record for the 1971 break-up at Fitzgerald and the 1973 break-up at Peace River. During the latter break-up, an ice jam occurred, increasing the stage by over 4 m, while during the 1971 break-up at Fitzgerald, the stage increased by just over 1 m with no ice jam. It is break-up ice jams which have the greatest potential for creating large increases in river stage, and are of primary interest here.

Table 3.2 lists 20 possible ice jam regions along the length of the Slave River, which were identified from the 1:50 000 topographic maps of the river. Although such sites can easily be identified from topographic maps or during field reconnaissance, it is impossible to predict where and when an ice jam may occur in any given year. This is because an intact river ice cover downstream of open water is capable of withstanding an ice run and may exist at almost any location along a river, making the locational possibilities for ice jams almost limitless.

3.4 ANALYSIS OF SLAVE RIVER DISCHARGE AND STAGE DATA (FITZGERALD, ALBERTA) AND METEOROLOGICAL DATA TO DETERMINE FREQUENCY AND MAGNITUDE OF ICE EFFECTS

The entire stage chart record from the Water Survey of Canada site on the Slave River at Fitzgerald have been analyzed for the break-up period (April-May). The characteristics of break-up have been analyzed for the period of 1960-1993 (see Table 3.1). In some cases, observers reports give the exact date and time of break-up, while in other years break-up is assumed to occur when there is a rapid increase in stage, or when the water level recorder orifice is torn by ice movement. In no years were ice jams actually described at the Fitzgerald site. However, in 1963, break-up flooding occurred, with water 60-90 cm over the bank, and it is likely that high water levels at break-up in 1974 and 1979 also caused flooding. The Fitzgerald site is located just above a rapids and will not register the affect of ice jams downstream with an increase in stage. However, it is possible that ice jams upstream will register at Fitzgerald as a decrease in stage just prior to or during break-up. In fact, such drops in stage, 30-120 cm, occurred in 1961, 62, 71, 73, 77, 79, 81, 87, and 92. In many cases, the maximum stage reached during break-up is not known because of the loss of the recording device when break-up occurs. The record of break-up has been limited by ice damage to the recorder in 1961, 68-70, 74, 75, 77-80, 82, 84, 85, 87, 91, and 92, or on 16 of the 34 years of record.

Average daily discharge and stage were obtained for break-up and freeze-up. Commonly, higher discharges and stages will occur at break-up than at freeze-up, as the ice needs to be lifted and broken up before it will move downstream. Higher break-up discharges were measured in all but three years, 1960, 77 and 80 (**fig 3.6**). In these three years, the decay of the river ice must have been sufficient for break-up to occur at a very low stage. In cases where the break-up discharge is much higher than the freeze-up discharge, it is likely that the river ice was still relatively intact and withstood a significant increase in stage before failing. Break-up discharges significantly higher than freeze-up discharges occurred in 1963, 73, 74, 79, and 81 (**fig 3.7**). In such cases, the probability for ice jamming is high because of the relatively strong river ice and the high discharges. Flooding during break-up in the Slave River was recorded in 1963, 74 and 79. Ice jam flooding in

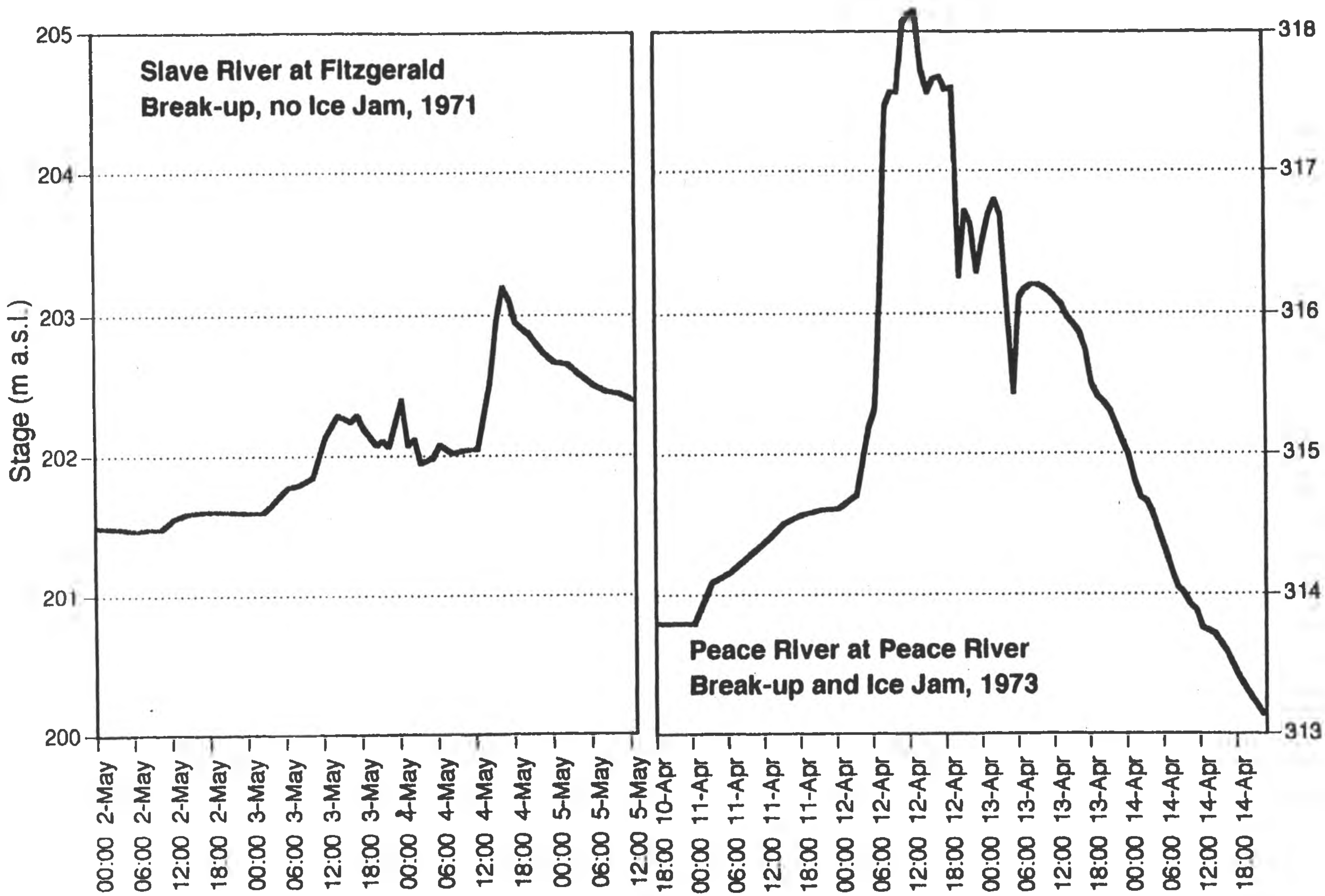


Fig.3.5: Slave River at Fitzgerald breakup, No ice jam, 1971; Peace River at Peace River Breakup and Ice Jam, 1973

Fig. 3.6 Freeze-up and Breakup Discharges for the Slave River at Fitzgerald

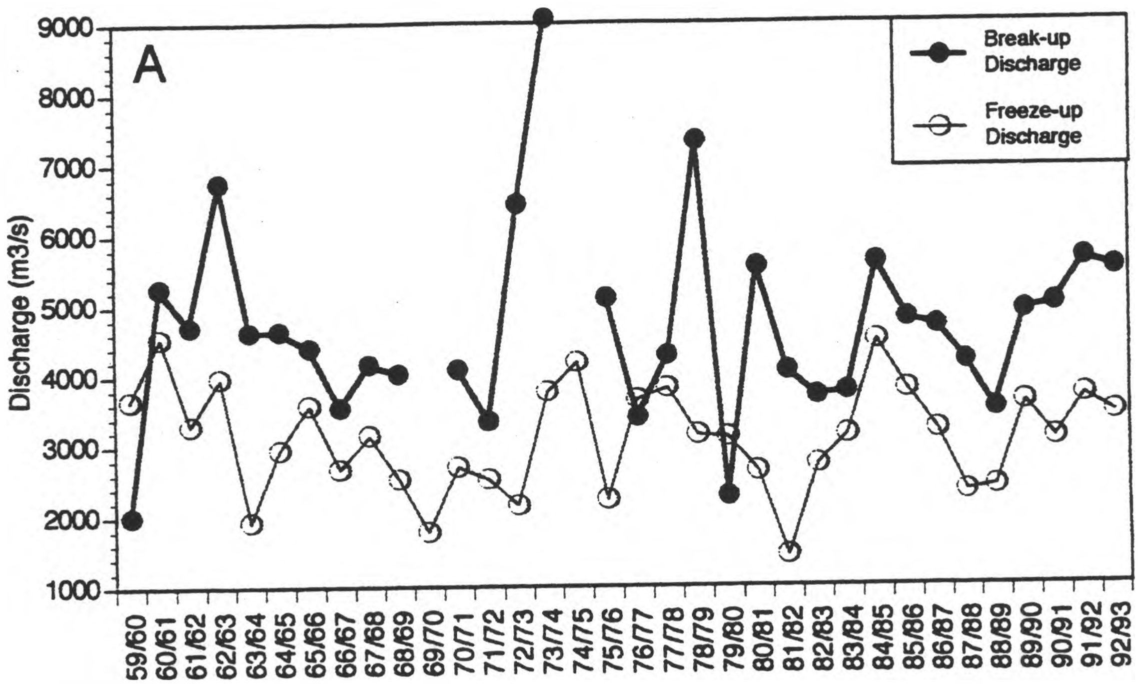
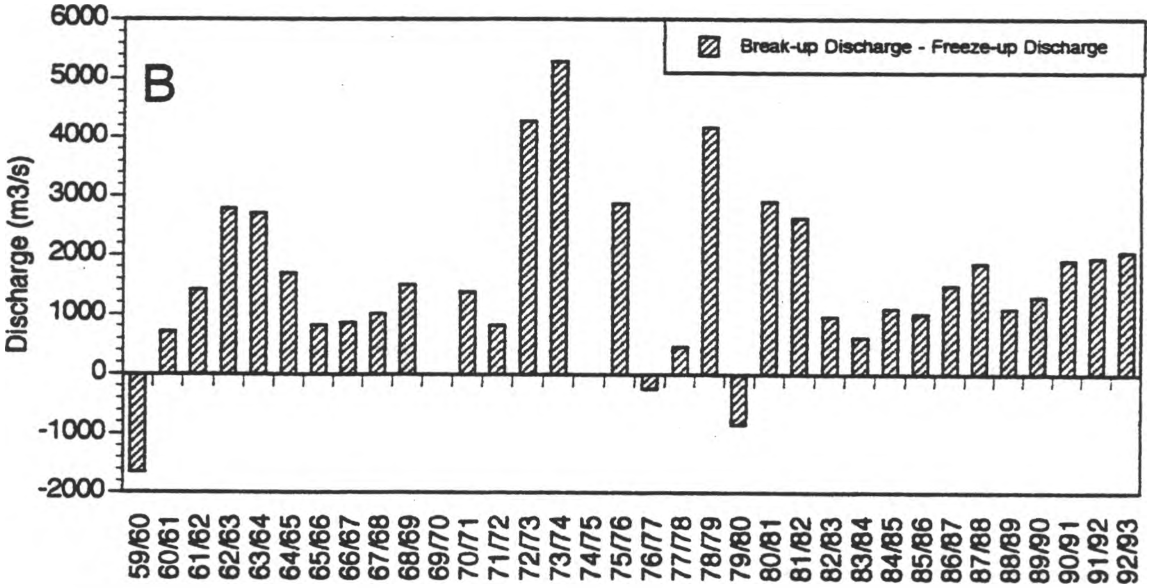


Table 3.2

Probable frequent ice jamming locations along the Slave River as identified by river channel geometry

Kilometres from mouth of Resdelta Channel		**Description of site**
7.5		Beginning of Resdelta Channel; channel becomes 2 and bend 400m wide
18		Severe bend 450m wide
34-40		Large bend
52-57		Bend with 2 islands in mid-stream
72-79		McConnell Island and bend; 350-600m wide
88.5		River split by island; shoals in right channel
95-120		Channel split into 2-4 by Long Island, numerous shoals and smaller islands
126-148		Bends at Pointe Ennuyeuse
178-181		Two islands and severe bends as river passes them
203-206		Two islands split channel into 3 thin channels
219-230		Big bend with 2 islands and several shoals at Grand Detour
293-295		Rapids of the Drowned at Fort Smith
304		Mountain Rapids; bend and narrowed channel
322.5		*Fitzgerald site - no chance of ice jamming here*
326-332		Ryan Island; two narrow channels around large island
357-359		Stony Islands; 3 channels; widest 350m
367.5		Near Hay Camp; large island dissects flow
378		Island splits channel, widest 250m
389.5		Demicharge Rapids; 200m widest; several islands
409		Sharp 90 degree bend; whole channel only 300m wide
423-427		Scow Channel (Peace R.) enters at several islands in the Slave

Fig. 3.7 Breakup Discharge Minus Freeze-up Discharge



the Peace River at Peace River during break-up was recorded in 1973, 74, 79 and 92 (Nuttall, 1974; Warner and Thompson, 1974; Fonstad, 1994). Ice jam flooding in the Athabasca River at Fort McMurray during break-up was recorded in 1977, 78 and 79.

Meteorological data from Fort Smith and Fort Resolution was analyzed to determine the likely extent of decay of the river ice at break-up. River ice will not begin to decay until the snowpack has ablated. It is assumed that the measured snow on the ground at Fort Smith is reasonably well-correlated with the snow cover on the river ice at Fitzgerald. The number of days and positive degree days (PDD) between the ablation of the snowpack and break-up at Fitzgerald were calculated, giving two rough measures of the decay of the river ice. The years with the longest period between the ablation of the snowpack and break-up (>14 days), thereby signifying the weakest ice, are 1960, 69, 70, 82, 83, 84, and 86. The years with the shortest period between the ablation of the snowcover and break-up (<7 days) are 1966, 68, 72, 73, 87, 91, and 92. The years with the lowest PDD totals between the ablation of the snowpack and break-up (<125 °C) are 1961, 62, 64, 67, 73, 74, 83, 88, 90, 91, and 92 (**fig 3.8**). Years with low PDD totals and with a short time period between snow ablation and break-up are potential years of ice jamming because of the presence of relatively strong ice at break-up.

Ice jamming and flooding in the Slave River delta is most likely to occur if the break-up front arrives when the delta river ice is still intact and relatively unaffected by radiation melt. Comparing the last date of snow on the ground at Fort Resolution and Fort Smith, it was discovered that for several years, the disappearance of the snowpack was considerably later (≥7 days) in the Slave delta (**fig 3.9**). These years are 1961, 62, 63, 64, 67, 69, 70 and 92. Comparisons for the years 1974-80, and 1982-89 were not possible because of missing data from Fort Resolution. High break-up discharges were recorded at Fitzgerald in 1963 (6740 m3/s) and 1992 (5640 m3/s), which suggests ice jamming and flooding in the delta to be a definite possibility. Ice jamming and flooding likely also occurred in 1974 and 1979 on account of very high break-up discharges, 9060 m3/s and 7310 m3/s respectively.

3.5 CLIMATE WARMING

Several climatic trends are evident in the records from Fort Smith, Fort Resolution, Peace River, and Fort McMurray. The Fort Smith average annual temperature ten year running mean shows an increase from -3.6°C in the mid-1960s to -2.3°C in the late 1980s. Average winter temperatures (October 15-May 15) have changed to a greater degree, rising from -14.4°C in the mid-1960s to -12.5°C in the late 1980s (**fig 3.10**). Perhaps more importantly, most of the winter warming has occurred during the break-up period (April 15 to May 15), rising from 1.6°C to 4.2°C. **Figure 3.11** shows that a basin-wide warming has been underway since the mid-1960s, reaching close to 3°C at Peace River. The warming during April and May is probably the cause of the advanced break-up date at Fitzgerald, which comes 5 days earlier than it did in the 1960s. Paralleling closely the earlier date of break-up, the average last date of snowcover at Fort Smith has moved from May 1 from 1960-67 to April 25 from 1968-1992. The overall snow depth throughout the winter is also less. Snow depths in late April and early May have decreased by approximately 2-4 cm, which is significant to the decay of the river ice. On account of the marked climate warming in the Slave

Fig. 3.8 Positive Degree Days (max + min) at Ft. Smith between the Last Day of Snow Cover and Breakup of the Slave River at Fitzgerald, 1960-1992

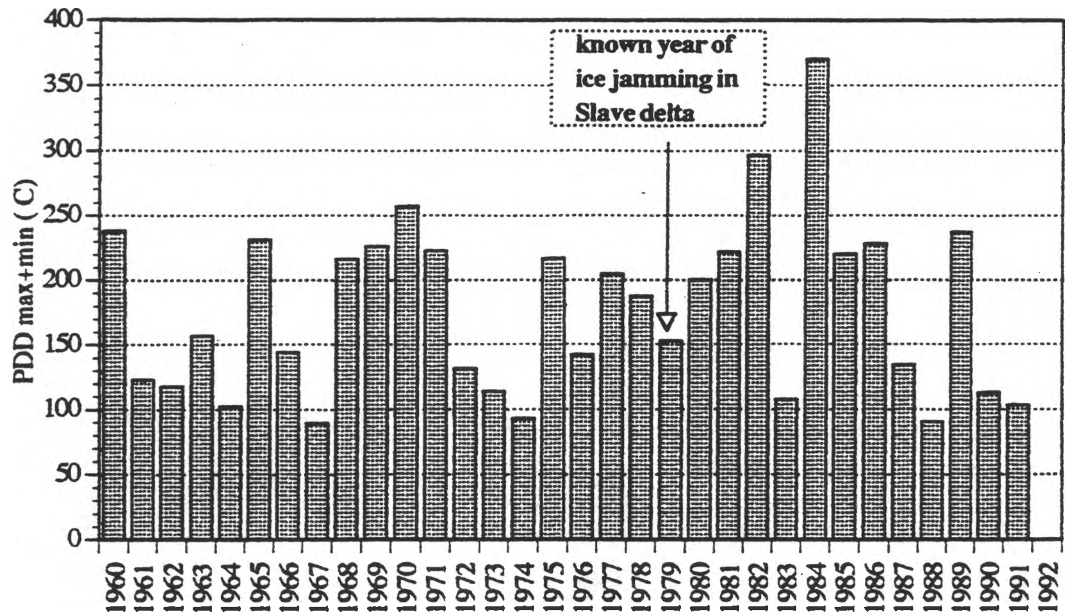


Fig. 3.9 Date of Last Snow on Ground at Ft. Smith and Ft. Resolution, 1960/61, 1972/73, 1980/81 and 1989/90-1991/92

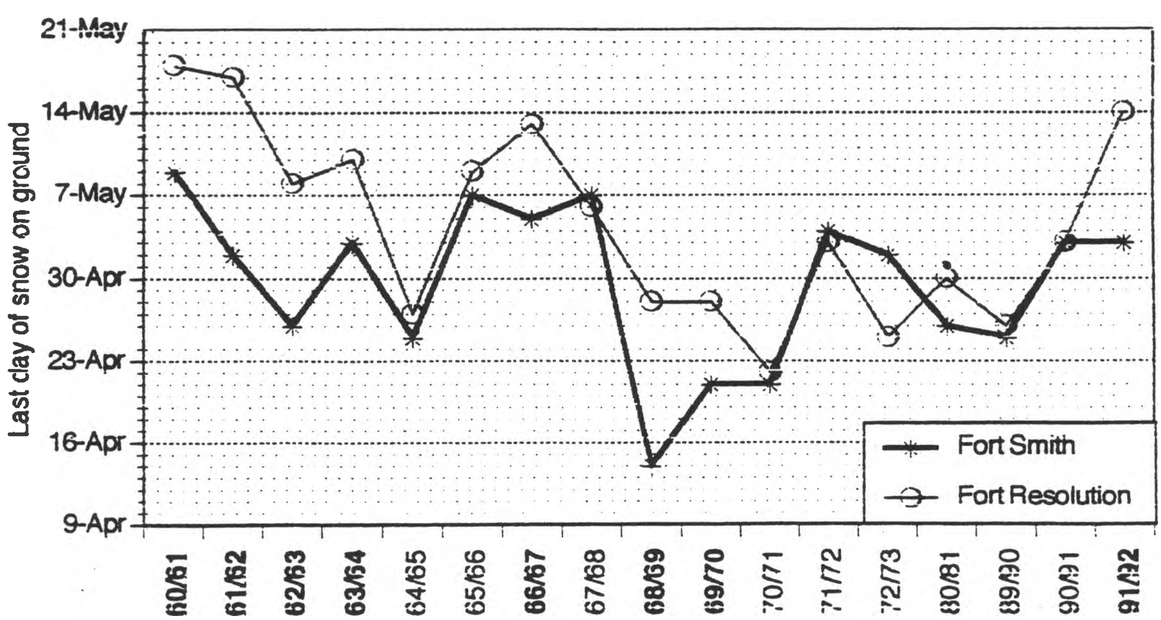


Fig. 3.10 Average Winter Temperature (Oct 15 - May 15) at Ft. Smith, 1960-1992

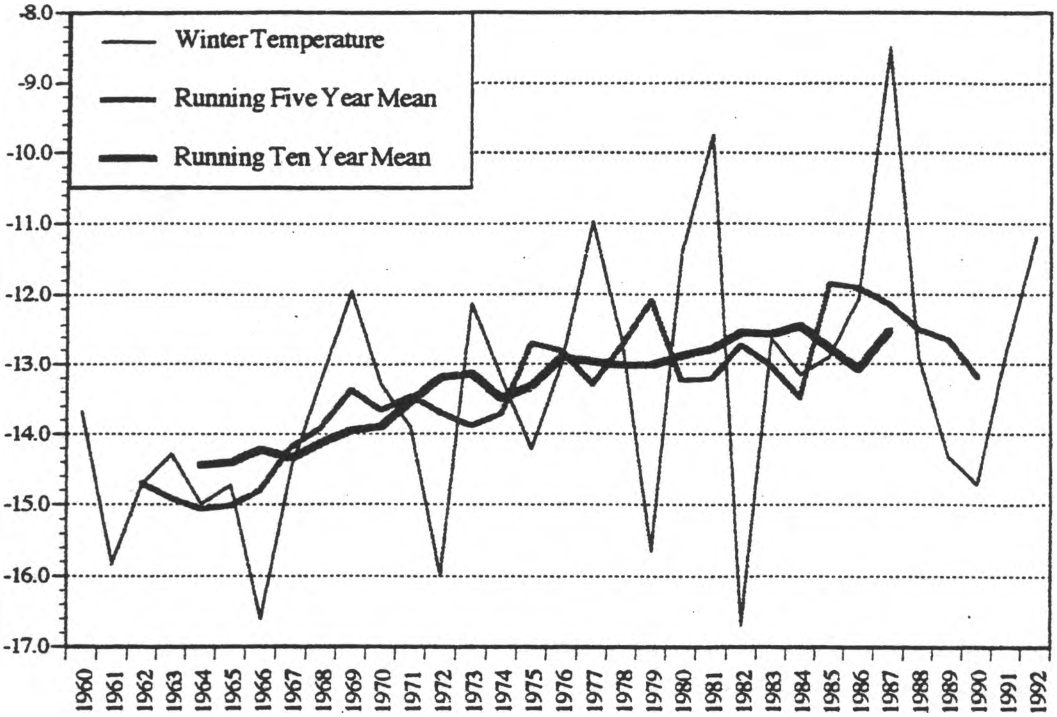
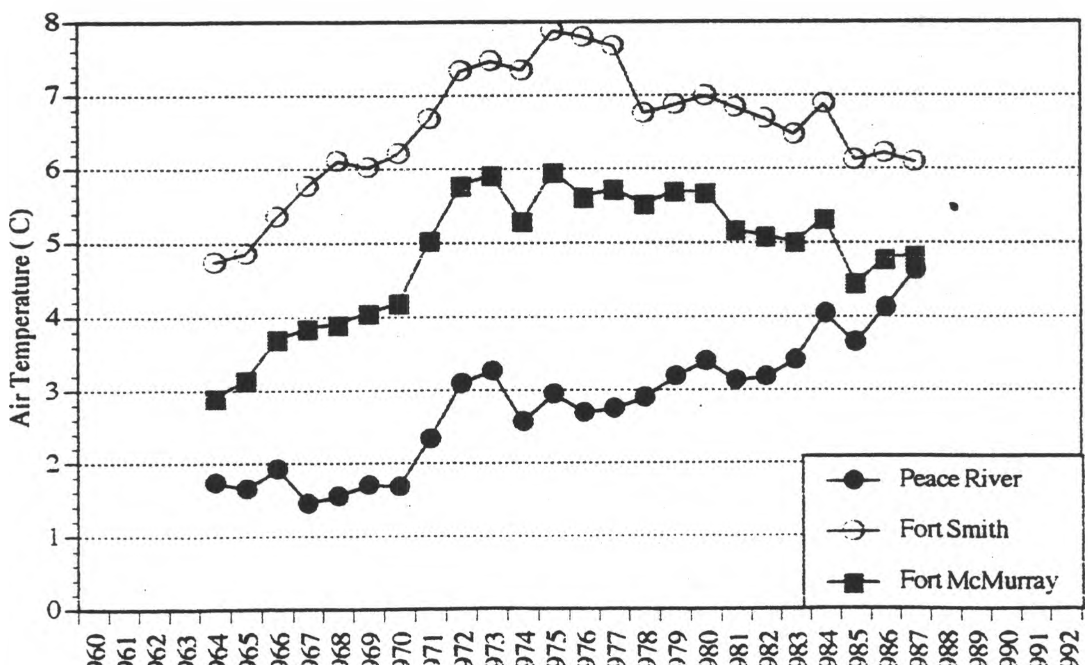


Fig. 3.11 Average Breakup Air Temperatures (10 year running means) at Three Locations in the Slave River Basin, 1960-1992



River basin during the break-up period, it is unlikely that the earlier break-up dates in the post-regulation period are as a result of the altered flow regime.

3.6 CONCLUSIONS

Flow from the Peace River constitutes a significant proportion of the flow in the Slave River which ranges from a low of 41.7% in September to a high of 76.5% in April. The proportion of Peace River flow contributing to Slave River flow averaged over the year during preimpoundment is 54%. After impoundment this average increases primarily due to higher winter (ice-on) period flows in the Peace River. For ice-free periods (May to October), there is a 16% reduction in the Slave River flow after impoundment. However, for the ice-on period (October to April) the flow has increased on average 40% for under-ice-flow.

Given the lack of data pertaining to ice jamming in the Slave River, no definite statement can be made in terms of a decrease or an increase of ice jamming as a result of the instalment of the W.A.C. Bennett Dam. It has been confirmed that ice jams occurred in the Slave delta in 1979, and ice jamming is considered likely in 1963, 1974, and 1992. In theory, ice jamming should be less common in the delta and along the length of the river after the implementation of the dam because of the smaller increases in discharge during the break-up period. This reduction in the spring surge should result in a lessened frequency of mechanical break-ups, the type of break-up which is in all cases responsible for the formation of ice jams. In a study which examined ice scars on trees along the Peace River near Fort Vermillion, Gerard (1981) dated scars from the 1910s to 1980. Results showed that much higher levels of scarring were found previous to the regulation of the Peace. The highest pre-regulation flood scars were up to 8 m above summer flood stage, while the highest post-regulation floods reached only 5 m above summer flood stage. A warming of the regional climate, predominantly in the April-May break-up season, has lead to earlier melting of the snowpack and may be responsible for earlier break-up dates. It is possible that this warming may be creating more over-mature or thermal break-ups and therefore is at least partially responsible for the suggested reduction in ice jam flooding in the Slave River.

4.0 ALTERED SEDIMENT REGIME

4.1 INTRODUCTION

The transport of solid and dissolved materials by rivers varies over time and space with changes in environmental controls. The major controls affecting riverine transport of sediment include climate and watershed characteristics such as geology, vegetation, relief, land use, discharge and sediment availability. A change in one or any combination of these variables will alter the timing as well as the rate and magnitude of sediment delivery (Richards, 1982).

In northern river basins, the timing and delivery of sediment to downstream environments is affected by flow regulation. In the case of the Peace River, the natural flow has been altered because of the W.A.C. Bennett dam near Hudson's Hope, British Columbia. In the post-impoundment period (1971 to present), the monthly discharge of the Peace River for the ice-off period has decreased 16% but increased 40% during ice-on periods (**fig 4.1**). As demonstrated in the Hydrology section, outflow from the Peace River provides a major portion of the flow in the Slave River and effects of regulation alter the Slave's seasonal flow regime. The corresponding change in discharge characteristics of the Slave River will also affect the rate and magnitude of sediment delivery to its deltaic environment.

4.2 GENERAL APPROACH

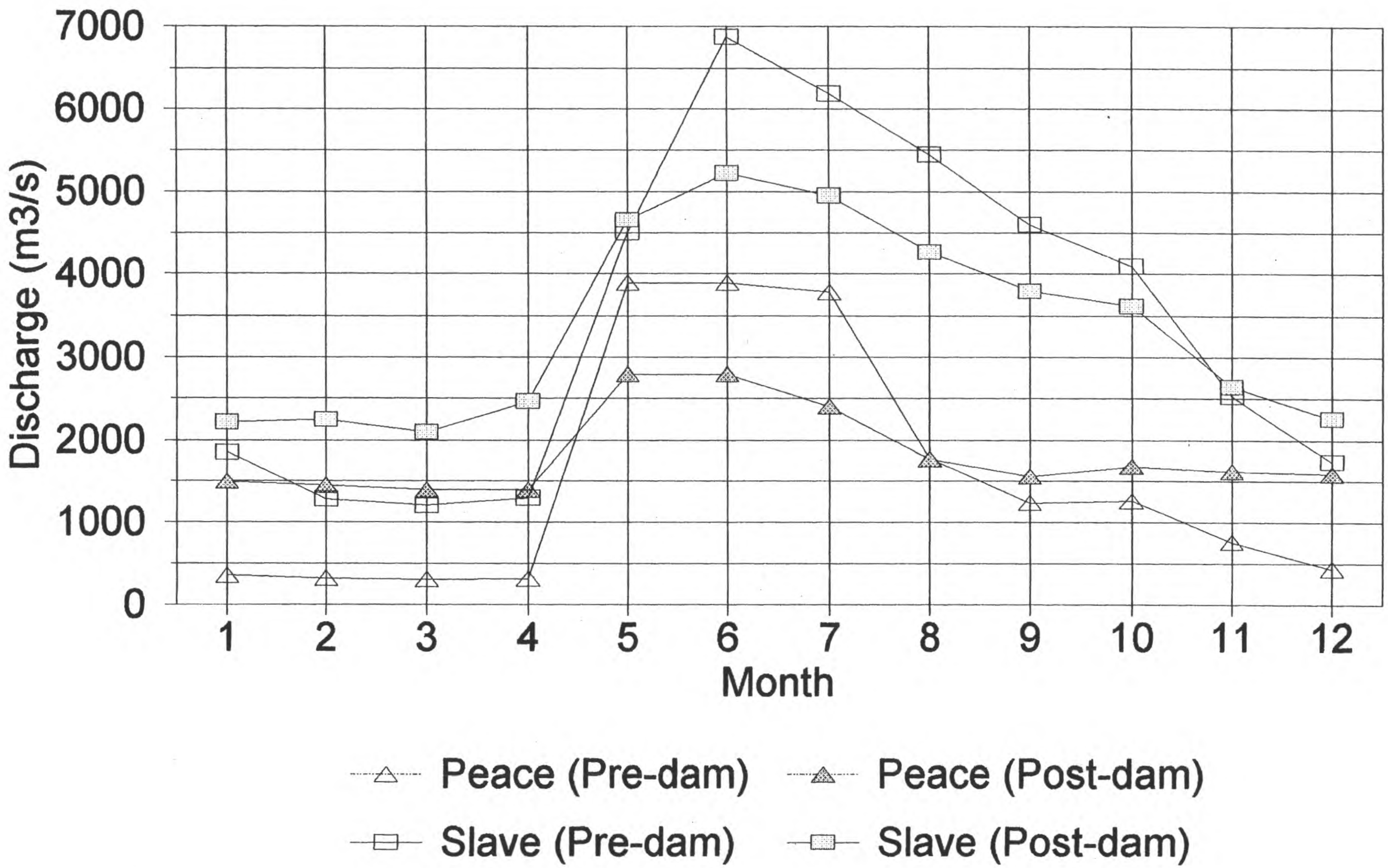
This section reviews available evidence as it pertains to the impact of the W.A.C Bennet Dam on the sediment regime of the Slave River and discusses its potential for change in the structure of the Slave River Delta. Changes in delta structure are later related to changes in channel morphology and sediment transport within the Slave Delta.

A sediment rating approach is used in this study to infer change in sediment source, availability and transport dynamics of the Slave River for periods of pre-impoundment (prior to 1968) and post-impoundment (1971 to present). This approach is used because no pre-impoundment sediment data is available for the Slave River at Fitzgerald. Also, sediment data for this river is only available for the months of May to October in the post-impoundment period. Since the Peace River is recognized as a key factor in providing outflow to the Slave River, a sediment rating curve has been constructed based on the mean monthly discharge for Station 07KC001(Peace River at Peace Point) to predict mean monthly sediment load at Station 07NB001 (Slave River at Fitzgerald). In this manner, existing pre-impoundment discharge data of the Peace River can be used to estimate sediment loading of the Slave River for ice-on and ice-off conditions during this period. The approach has some statistical rigor and serves the useful purpose of providing practical results in a simple and meaningful way.

The rationale for comparing historical data at these two stations is based partly on the findings of previous work as well as the close geographical proximity of the two stations. The Peace River has a significant impact on the sediment transport regime of the Slave River at Fitzgerald (Carson, 1992). The Peace River provides 45 to 78% of the flow to the Slave River and mean monthly discharge for the hydrometric stations of Peace River at Peace Point and Slave River at Fitzgerald are similar. During the post-impoundment period, mean annual suspended sediment loads for the two stations were: Peace Point 36.4 Mt ± 20.0 and Fitzgerald 33.6 Mt ± 16.4 (Carson, 1992). It is assumed this similarity holds true for the pre-impoundment period.

Because of its long period of historical record, some consideration was given towards comparing the sediment transport regime of Slave River at Fitzgerald with Peace River at Peace River. Although strong statistical relationships were found between these stations, this approach was abandoned because of the masking effects of tributary flow from contributing watersheds between Peace River at Peace River and the Slave River at Fitzgerald. Also because of autocorrelation, no attempt was made use discharge/sediment data for the Slave River at Fitzgerald.

Fig. 4.1 MEAN MONTHLY DISCHARGE



The relationship between mean monthly discharge for Peace River at Peace Point and mean monthly sediment load for Slave River at Fitzgerald is shown in **Figure 4.2**. From these data, a sediment rating curve was constructed. The rating curve

$$\text{Load}_{(sed)} = 0.669\ Q^{1.502} \qquad (1)$$

is based on 97 observations and uses the mean monthly discharge for Peace River at Peace Point to predict mean monthly sediment load for Slave River at Fitzgerald. The predam discharge in the Slave River ranges between 1000 and 6000 m^3/sec (mean annual discharge: 3468 m^3/s). In the post dam period the maximum discharge is 5000 m^3/s (mean annual discharge: 3368 m^3/s). Confidence in equation 1 is highest between 1000 and 4000 m^e/s). At discharges greater than 4000 ^{3}m /s confidence in the prediction is reduced due to a few notable outliers. These data reflect periods of extremely high discharge and sediment load (>500,000 tonnes) which often follow years of low annual flow. The sediment pulse evident in the data effectively skews the relationship between discharge and suspended sediment load. Despite the effect of the outliers on this relationship the equation has an r^2 value of 0.59 and is significant at α - 0.01. Most of the projections employing this equation fall within the 95% Confidence Limits. In this regard we believe the equation represents a reasonable predictive tool given the lack of supporting data in this subarctic river system for the preimpoundment years.

4.3 IMPLICATIONS OF ALTERED SEDIMENT REGIME

Based on the above sediment rating curve, comparisons of sediment transport during pre and post-impoundment flow conditions are shown in **Figure 4.3**. This figure is based on projected sediment loads for ice-on and ice-off periods (Table 4.1 - Columns b and e). Adjusted sediment loads corrected for ice-on conditions are listed in Columns c and f of Table 4.1 and plotted in **Figure 4.4**. A complete discussion of the use of correction factors for ice-on periods is presented below.

In the post-impoundment period, the annual sediment load at Fitzgerald has decreased by 33% (372,491 t/yr) (Table 4.2). According to projections (Table 4.2), the sediment load of the Slave River has increased 314% from 57,126 t to 179,895 t during the post-impoundment period for ice-on flow. For ice-off flow, the sediment load has decreased 46% from 1,077,581 t to 582,321 t. The percent change in pre/post sediment load and discharge for the Slave River at Fitzgerald is shown in **Figure 4.5**.

The seasonal shift in the hydrograph of the Slave River resulting from regulation will alter the source, availability and texture of sediment delivered to the delta. The changes in sediment transport at Fitzgerald during ice-on and ice-off periods are discussed in the following.

4.3.1 Ice-on Conditions

Rivers in high latitude regions are often ice-covered in winter which can significantly affect hydraulic and fluvial processes. Although an extensive literature on fluvial processes under ice-free surface conditions exists studies for ice-covered conditions are limited. Krishnappan (1983)

Fig. 4.2

Peace Point discharge versus Slave River suspended sediment

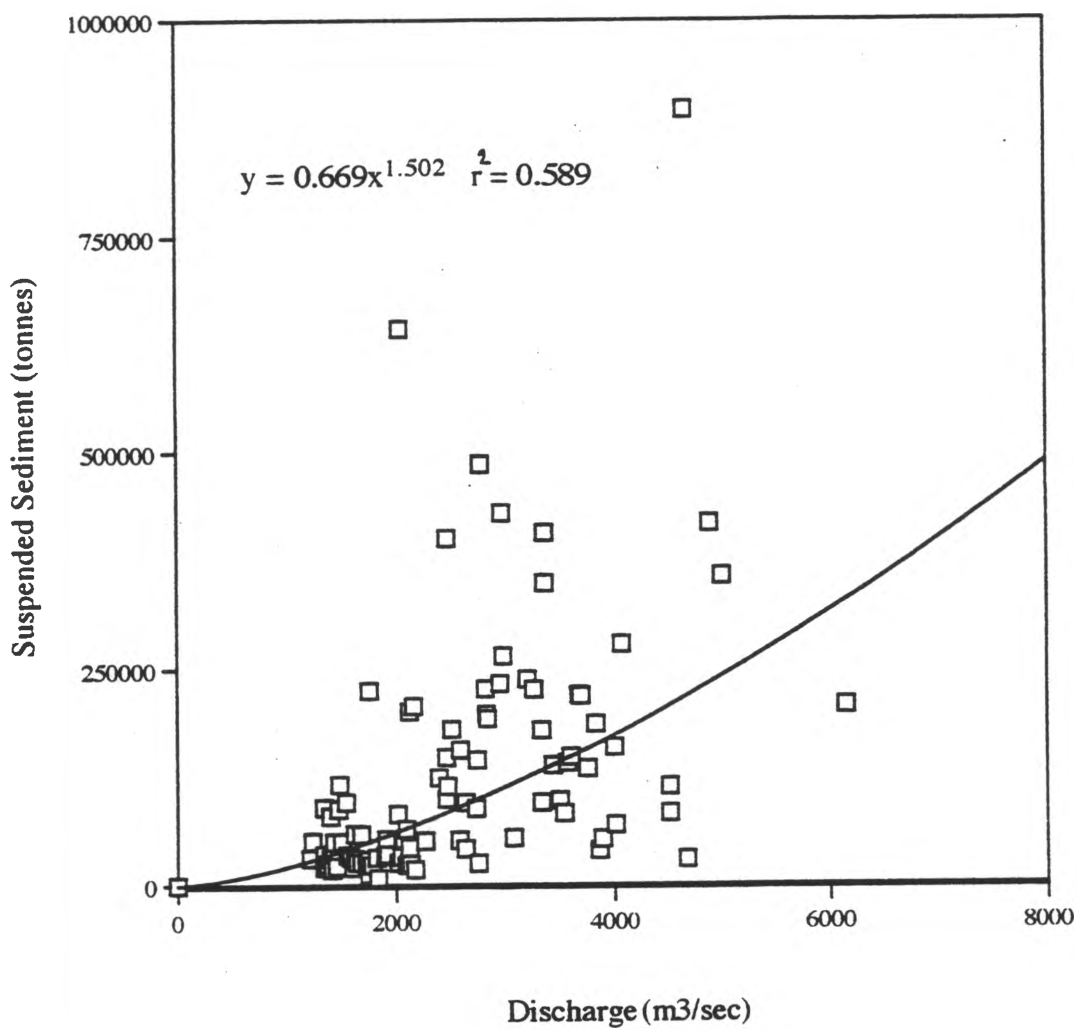


Fig. 4.3 Mean Monthly Sediment Load
Slave River at Fitzgerald

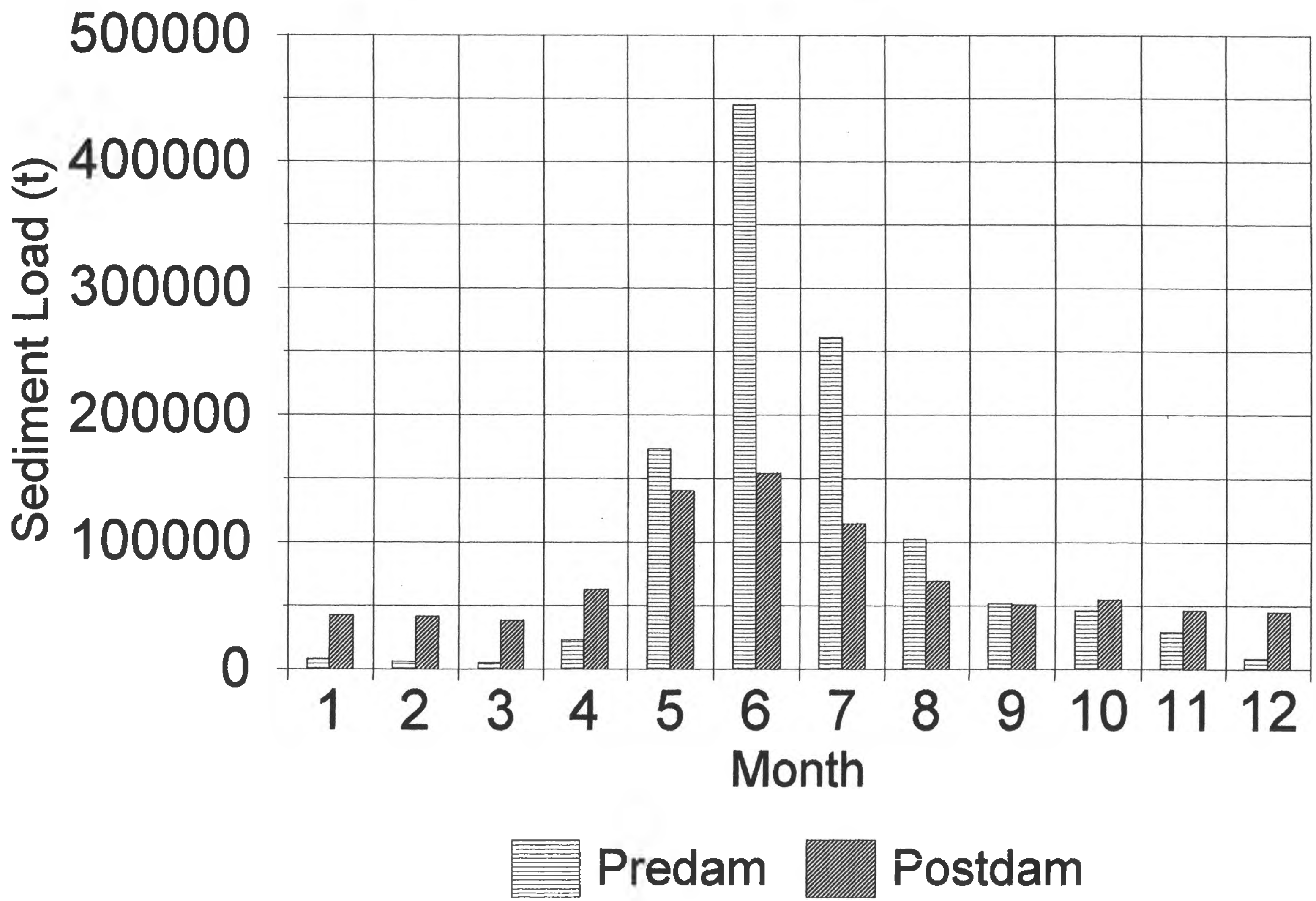


Table 4.1: Projected Change in Discharge and Adjusted Sediment Load for the Slave River at Fitzgerald

	Pre Impoundment			Post Impoundment			% Change		
Month	Sediment Load (t)	Adjusted Sediment Load (t)	Q	Sediment Load (t)	Adjusted Sediment Load (t)	Q	Sediment Load (t)	Q	Ice-on conditions adjustment factor for pre-dam period
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)*
1	8250.7	7178.1 *	1855	42024.9	29383.6 *	2215	75.6	16.3	-13%
2	6298.6	3590.2 *	1285	40837.1	23277.1 *	2246	84.6	42.8	-43%
3	5288.9	2750.2 *	1202	38061.2	19791.8 *	2097	86.1	42.7	-48%
4	22642	12679.5 *	1294	62441.9	34967.5 *	2466	63.7	47.5	-44%
5	172762.8	172762.8	4504	140211.4	140211.4	4659	-23.2	3.3	
6	444407.2	444407.2	6880	153763.2	153763.2	5218	-189.0	-31.9	
7	260727.4	260727.4	6189	114613.2	114613.2	4951	-127.5	-25.0	
8	102718.2	102718.2	5451	68964.4	68964.4	4263	-48.9	-27.9	
9	51156.3	51156.3	4603	50514.5	50514.5	3794	-1.3	-21.3	
10	45808.7	45808.7	4093	54254.9	54254.9	3614	15.6	-13.3	
11	29112.9	23872.6 *	2529	45641.8	37426.3 *	2640	36.2	4.2	-18%
12	8931.3	7055.7 *	1739	44365.9	35049.1 *	2258	79.9	23.0	-21%
Total	1158105.0	1134707.0	41624.0	855694.4	762216.9	40421.0			
Mean	96508.8	94558.9	3468.7	71307.9	63518.1	3368.4			

Fig. 4.4 Slave River-Mean Monthly Load Adjusted For Pre-dam Ice-on FLows

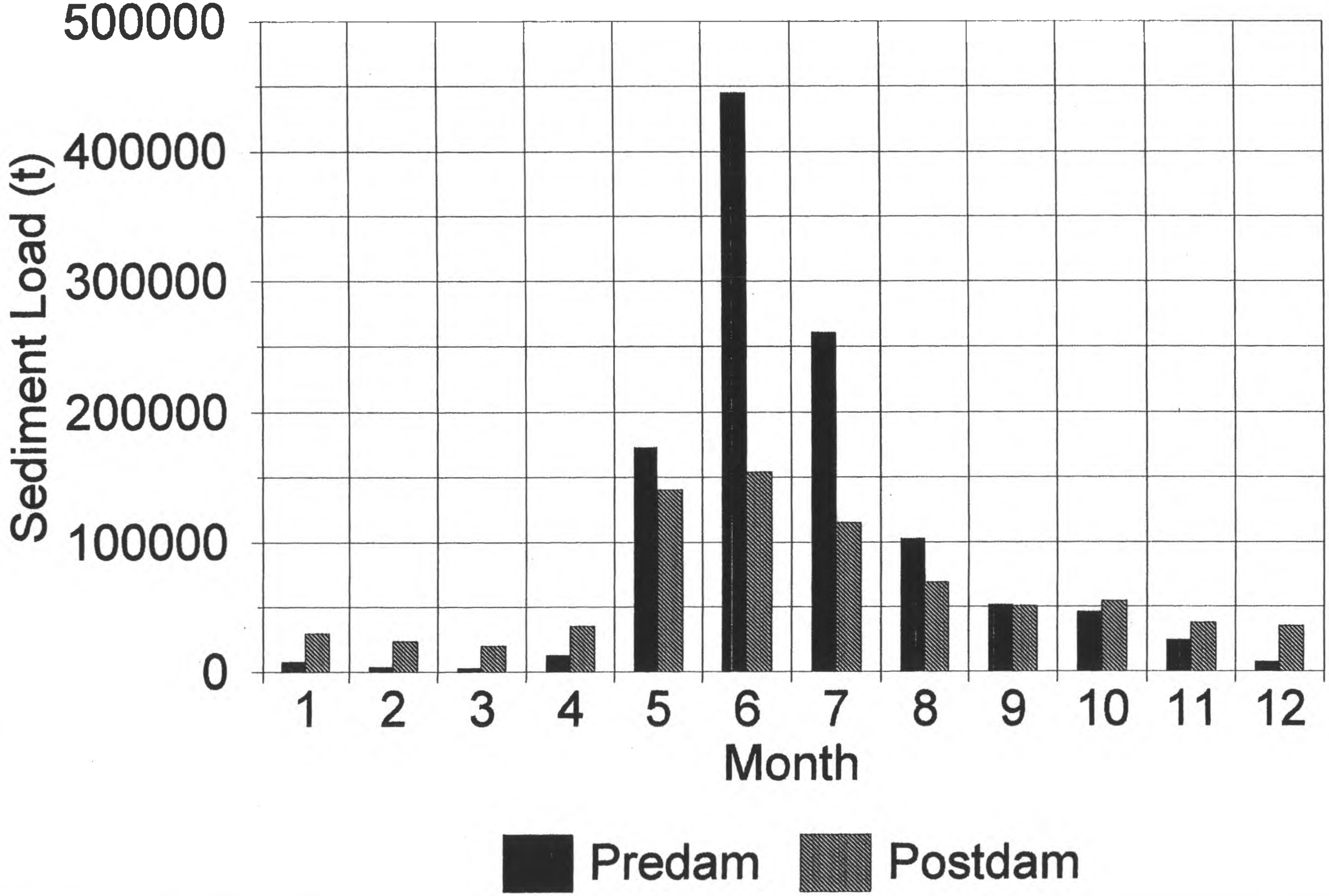


Table 4.2: Projected Change In Sediment Load of the Slave River at Fitzgerald (t) Adjusted for Ice-On Conditions

		Pre-dam	Post-dam	Change	%
Ice-on	Total Load	57,126	179,895	122,769	+314
	Mean Monthly Load	9521	45,562		
Ice-off	Total Load	1,077,581	582,321	-495,260	-46%
	Mean Monthly Load	179,596	97,053		
	Avg Total Annual Load	1,134,707	762,216	-372,491	-32.8%

Fig. 4.5 Change in Pre/Post Sediment Load and Discharge @ Fort Fitzgerald

analyzed vertical sediment concentration profiles under ice and Lau and Krishnappan (1985) developed a method of calculating sediment transport in ice covered channels. Additional research was conducted by Al-Abed (1989) to examine sediment transport under ice in a laboratory flume. The above studies indicate that sediment transport will be substantially reduced under a floating ice-cover.

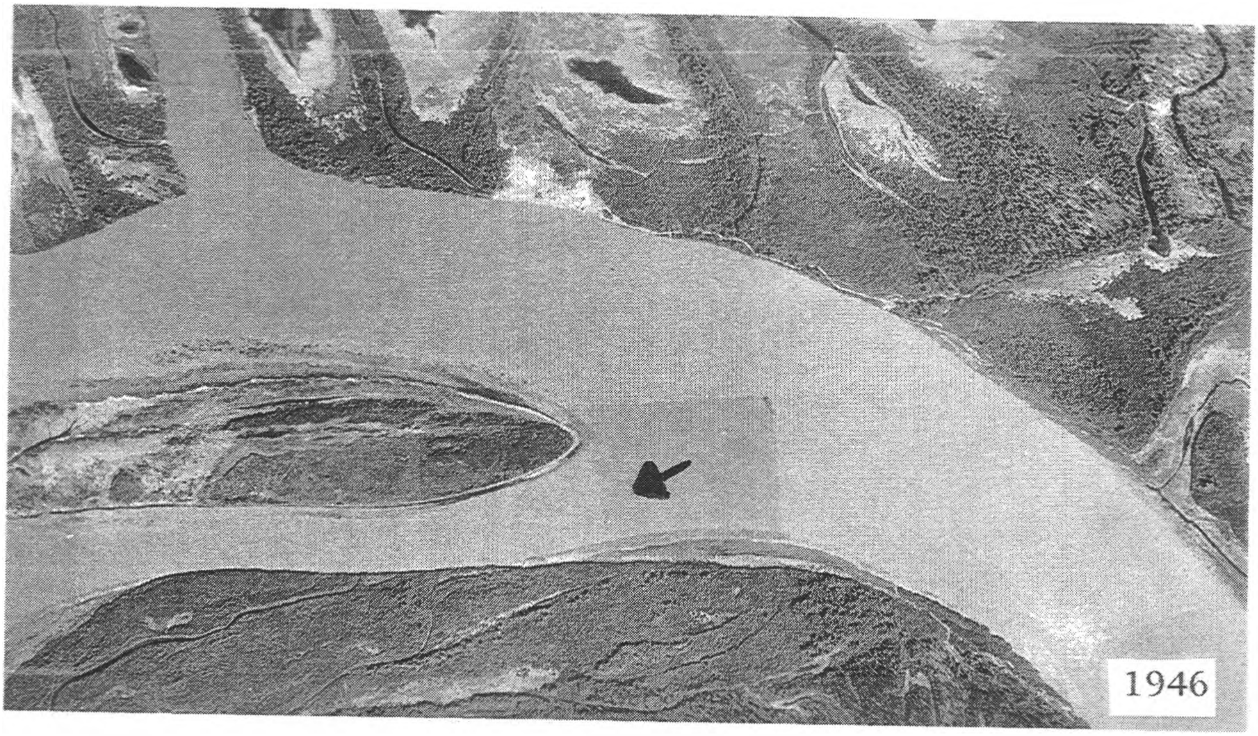
Little is known about sediment transport dynamics (as suspended or bedload) under-ice in the Slave River. However, in a recent study of under-ice sediment transport, Milburn and Prowse (1995), constructed pre-breakup and post-breakup rating curves for the Liard River. Their work shows that, for a specific range of discharge conditions (300 to 2100 m^3s^{-1}), suspended sediment concentrations are 10 to 40% lower during pre-breakup conditions for a similar range of discharge. In northern river basins, this in part is related to the effects of permafrost on sediment source and availability prior to and during break-up. Studies have shown that bank materials are frozen in these environments and bottom-fast ice can reduce bed sediment scour (Scott, 1978; Walker, 1970). Freezing limits bank and bed sediment availability during spring breakup. After breakup, bank undercutting characterized as thermo-erosional niches are one of the dominant causes of bank retreat in northern areas (Scott, 1978). This causes bank stability to decrease as the active layer develops. Therefore, during ice-on conditions, the Slave River is supply limited.

In the present study, the rating curves of Milburn and Prowse (1995) are used to correct projected mean monthly sediment loads for pre-breakup. This correction corresponds to a reduction of the pre-impoundment sediment loads of January, February, March, April, November and December by 13, 43, 48, 44, 18 and 21%, respectively (Table 4.2). Adjusted sediment loads for pre-dam ice-on conditions are shown in **Figure 4.4**. During ice-on conditions, flow regulation has resulted in a 16 to 48% increase in discharge for the preimpoundment period. This has resulted in a projected increase of 36 to 86% in sediment load at Fitzgerald for ice-on conditions (Table 4.1).

During the post-impoundment period, bars have continued to form at the mouths of distributary channels in the Slave River Delta such as Nagle and Old Steamboat. This observation is based both on field work and an examination of aerial photographs of the delta. These depositional features narrow channel entrances and reduce the input of larger sand size materials from the Slave River into smaller distributary channels **Figure 4.6**. Due to its longer residence time in the water column, only the finer-grained silt and clay size fractions, rather than coarser sand fractions, will enter the smaller channels of the delta. We conclude therefore that a process of selective sorting by grain size is occurring within in the smaller distributaries. During winter, the combined effect of ice formation and bar development will further reduce sediment transport through the smaller distributary channels. Progradation of the delta front is most pronounced near the mouth of ResDelta channel (Vanderburgh and Smith, 1988). The depth of ResDelta channel ranges from 10 to 20 m. It is likely that sediment will continue to be transported in this major distributary under ice conditions to Great Slave Lake.

During field work in May 1995, massive boils were observed on the surface of the Slave River between Nagle channel and Steamboat channel. These surface water features indicate the morphological structure of the river bed. Vanderburgh and Smith (1988) conducted a longitudinal

Fig.4.6: Old Steamboat Channel entry point ( )



profile of this portion of the river and reported the presence of sand waves 0.5 - 1.2 m in height and averaging 30 m in length. The presence of these major bedforms suggests that coarse materials are transported as bedload in this section of the river. Unless bed sediments freeze in deeper sections of ResDelta channel, coarse-grained bottom materials will be transported as bedload under ice conditions. This would have the effect of transporting sediment to the delta front; thus, further promoting progradation of the delta during a period when the effects of wave action are reduced.

4.3.2 Ice-off Conditions

Based on projections, flow regulation has reduced the mean monthly discharge of the Slave River by 25% after breakup (**fig 4.5**). The flow reduction during this period has resulted in an 46% reduction of sediment load (Table 4.2). The reduced flow during this time has the effect of decreasing stream power which in turn reduces sediment transport rate. The reduced competency and capacity of the river will increase the transport and delivery of fine grained materials (silt and clay) to the delta.

There is a lack of flow and sediment data for the distributary channels of the Slave River Delta. A small data set was collected by the Water Survey Branch of Environment Canada in May and August, 1980 during low flow (Table 4.3). During this period, flow and discharge were monitored in seven major distributary channels of the Slave River Delta. Here the Environment Canada data is used to estimate the proportion of sediment load and discharge routed through each distributary channel as well as to compare the total sediment loads measured at Fitzgerald and the Slave River Delta. The comparisons are based on a three day time lag between Fitzgerald and the Slave River Delta. Approximately 90% of the flow and sediment is routed through ResDelta channel (Table 4.3). This further suggests that progradation of the delta front is most pronounced near the mouth of ResDelta channel. For the two periods of low flow, the data suggests that sediment loads measured at Fitzgerald provide a reasonable approximation of sediment loading at the delta. For May 14, 1980 and August 20, 1980, sediment loads at Fitzgerald were higher than at the delta by 751 and 1468 t yr^{-1}, respectively. This suggests that some sediment is deposited between Fitzgerald and the delta. This is not surprising given that over 90% of the sediment transported at Fitzgerald is $< 63\ \mu m$ (Table 4.4). Because of the turbulence in the Slave River most of this fine-grained material will remain suspended in the water column during lower flows and therefore be transported to the delta. During break-up and associated flooding, some of this material would be deposited on levees and perched basins of the floodplain.

4.4 CONCLUSIONS

Flow regulation of the Peace River from 1971 to present has reduced its discharge by 40% during ice-off but increased the ice-on flow by 16% compared to pre-impoundment conditions. The Peace River provides 45 to 78% of the Slave River discharge. Changes to the seasonal flow regime in the Peace have affected the stream power and carrying capacity of the Slave River which have altered the timing and magnitude of sediment delivery to the Slave River Delta.

Table 4.3: Comparison of Sediment Loads Between the Slave River Delta and the Slave River at Fitzgerald

Channel	May 14, 1980					Aug 20, 1980				
	Q	SS	Load	% Load	% Q	Q	SS	Load	% Load	% Q
Resdelta	2510	152	32963.33	90.19	88.76	2640	79	18019.58	86.08	89.68
West	51.7	122	544.96	1.49	1.83	53.4	73	336.80	1.61	1.81
Old Steamboat	35.4	100	305.86	0.84	1.25	46.5	62	249.09	1.19	1.58
Middle Channel - East	148	152	1943.65	5.32	5.23	132	173	1973.03	9.43	4.48
Middle Channel - West	33	123	350.70	0.96	1.17	24.1	52	108.28	0.52	0.82
East Channel	40.1	105	363.79	1.00	1.42	33.8	54	157.70	0.75	1.15
Nagel Channel	9.54	94	77.48	0.21	0.34	14	73	88.30	0.42	0.48
Observed Load @ Delta	2827.74		36550	100	100	2943.8		20933	100	100
Load @ Fitzgerald			37300					22400		

Q (m3/s)
SS (mg/L)
Load (t)

Table 4.4: Mean Textural Composition of Suspended Sediment

River	Season	n	% sand	SD	% silt	SD	% clay	SD
Peace @ Peace	Fall	11	16.09	8.04	47.73	9.25	36.18	8.52
07HA001	Spring	138	17.58	9.02	54.03	10.9	28.39	9.98
	Summer	105	17.95	8.3	53.95	10.17	28.1	9.54
Slave @ Fitzgerald	Fall	18	44.28	9	41.44	5.25	14.28	6.1
07NB001	Spring	14	39.29	6.74	40.21	3.76	20.5	5.45
	Summer	116	50.07	14.96	38.87	7.52	11.06	11.13

No sediment loading data is available for the Slave River prior to impoundment. In the present study, a sediment rating approach was used to estimate sediment loading of the Slave River by relating discharge data of Station 07KC001 (Peace River at Peace Point) with Station 07NB001 (Slave River at Fitzgerald). Sediment loads measured at the delta are compared with loads at Fitzgerald and discussed in the context of sediment delivery and availability to the delta. Based on our projections of pre and post-impoundment sediment loading the following conclusions are made:

1. Flow regulation of the Peace River has increased winter (ice-on) flows but reduced spring (ice-off) flows.
2. Due to changes in flow regime, the annual sediment load of Slave River at Fitzgerald has decreased by 33% (372,491 t yr^{-1}) during post-impoundment.
3. For ice-on flow, sediment loads have increased 314% from 57,126 t to 179,895 t. For ice-off periods, sediment loads have decreased 46% from 1, 077,581 to 582,321 t.
4. During ice-on periods the Slave River is sediment limited.
5. Approximately 90% of the sediment transported at Fitzgerald is fine-grained (< 63μm).
6. Flow regulation has reduced the competency and capacity of the Slave River which has increased the delivery of fine-grained materials to the delta.
7. About 90% of the discharge and sediment load is routed through ResDelta channel. Progradation of the delta is most pronounced at the mouth of ResDelta channel.
8. Selective sorting of sediment by grain size in smaller distributaries of the delta has resulted from the formation of bars at the mouths of these channels which promotes the transport of finer grained materials through smaller channels.

5.0 GEOMORPHOLOGICAL IMPACT OF PEACE RIVER IMPOUNDMENT ON THE SLAVE RIVER DELTA

5.1 INTRODUCTION

Assessing geomorphological change on the Slave River Delta attributable to impoundment of the Peace River at Hudson's Hope, British Columbia is a difficult task. However, it has been established that there is a definite link between impoundment and change in the natural flow regime of the Slave River monitored at Fort Smith. Empirical calculations relating changes in river flow to changes in suspended sediment transport indicate the total annual suspended sediment load in the Slave River is reduced by 31%. Relating a decline in sediment load in the Slave River at Fort Fitzgerald to changes in sediment load approximately 200km downstream at the delta is problematic. However, as indicated in the previous section on altered sediment load in the Slave River, the dates when simultaneous sediment records exist at Fort Fitzgerald and the Slave River at the Slave Delta indicate very comparable suspended sediment loads. If seasonal flow and sediment transport load have changed in the river system then it follows that this change may be reflected in the geomorphological change in the delta since impoundment.

5.2 GEOMORPHOLOGICAL CHANGE DURING PREIMPOUNDMENT (1946-1966) AND POSTIMPOUNDMENT (1977-1994) PERIODS

The rate of growth of the subaerial delta has been evaluated from aerial photography between 1946 and 1966, 1966 and 1977, and 1977 and 1994 (Appendix A). The area most susceptible to geomorphic change due to annual sedimentation from the Slave River and erosional impacts from Great Slave Lake is the outer delta. **Figures 5.1a, b, c, d** illustrate the aerial growth of outer delta landforms between 1946 and 1994. The areas of pronounced growth are in the vicinity of the mouths of ResDelta and Nagle Channels. This is attributable to the significant sediment load carried by ResDelta channel (85% of the total suspended sediment load of the Slave River) and the protective environment afforded by Moose Deer Island which promotes rapid deposition of the sediment discharging from Nagle Channel.

5.2.1. <u>Changes in growth rates of cleavage bar islands in the outer delta</u>

In order to demonstrate the changes in growth rates of landforms in the outer delta prior to and after impoundment, four cleavage bar islands at the mouths of four major distributaries are examined: Old Steamboat Channel, Mid Channel West, East Channel and ResDelta Channel **(fig 5.0)**. One of the problems associated with comparing the areal dimensions of the outer delta landforms over time is that Great Slave Lake water levels vary from one year to the next. The Great Slave Lake water levels recorded at Yellowknife for the dates of photography in 1946 (11 July), 1966 (16 September), 1977 (7 September) and 1994 (17 June) are: 156.588 m asl, 156.990 m asl, 156.734 m asl and 156.750 m asl respectively. The differences from one year to next equate to over or underestimates of subaerial surface differences. The differences in elevation of Great Slave Lake from 1946-1966 (increase of .373 m) translates to a conservative estimate of subaerial landform surface change. The differences in lake surface elevation between 1977 and 1994 are negligible. From 1966 to 1977 (increase of .23 m) the measurable differences in subaerial landform surface change would slightly overestimate the real change. The observed and recorded changes between 1977 and 1994 of 0.16m results in a small underestimate of the areal change during this time period. Thus change recorded from 1946 to 1966 compared to changes in the 1977 to 1994 period are therefore conservative estimates.

The year to year change in areal extent of the cleavage bar islands is listed in Table 5.1. **Figure 5.3** illustrates the percent surface area change of these features through time. Generally the results indicate that the growth rate for all cleavage bar islands has reduced from 1946 to 1994. The relative positive change between 1946-66 and 1966-77 for Old Steamboat Channel and East Channel may not be as pronounced as indicated or perhaps may not exist in light of the much lower 1946 water levels. However, examination of the suspended sediment load record for the Slave River between 1966 and 1977 (1971-1977) reveals that during June and July there is a significant increase in mean monthly suspended sediment load above that recorded for the 1977-1994 period **(fig 5.4)**. Of particular note is the cessation of growth of the monitored landforms at the mouth of East Channel and some erosion of the island at the mouth of Mid Channel West during the 1977-1994 period of time. In **Figure 5.4** changes in surface area are shown for the three periods of time: 1946-66, 1966-77 and 1977-94. For the three cleavage bar islands which are geomorphologically and botanically representative of landforms in the outer delta, the rate of subaerial surface growth decreases from the pre-impoundment (1946-66) to the post-impoundment (1977-94) period.

Fig. 5.1a

S. R. D.

1946

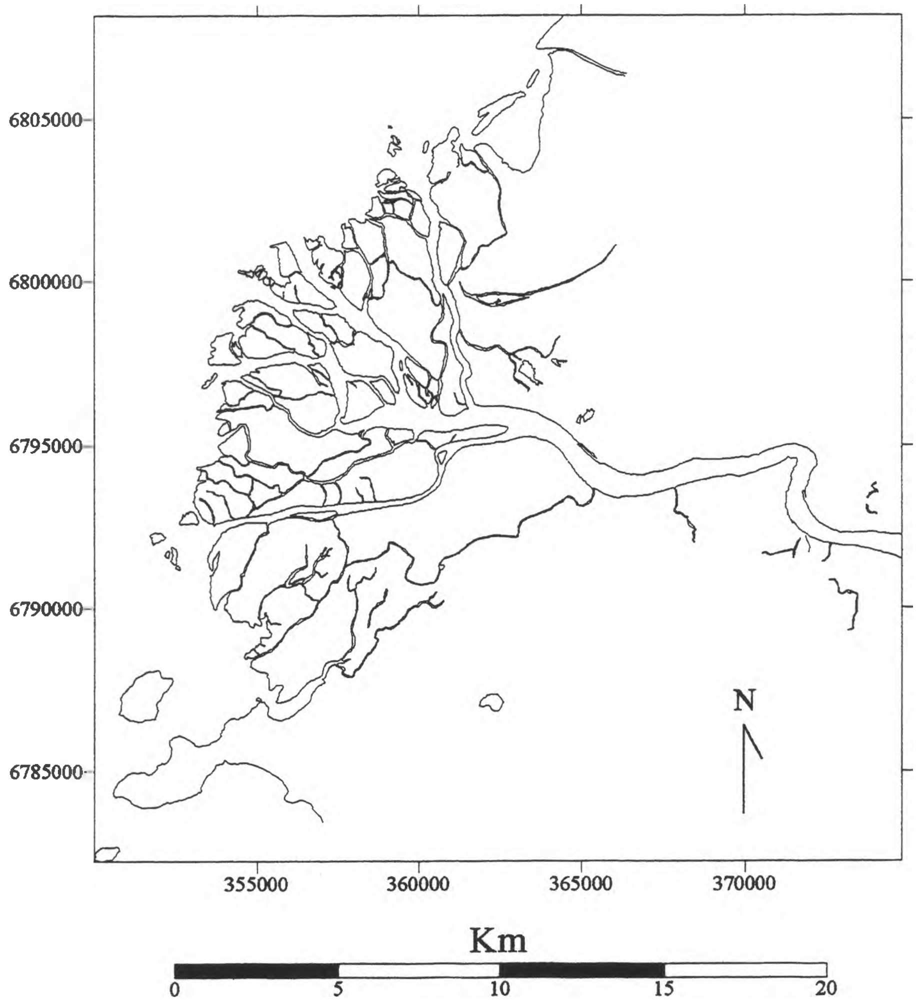


Fig. 5.1b

S. R. D.
1966

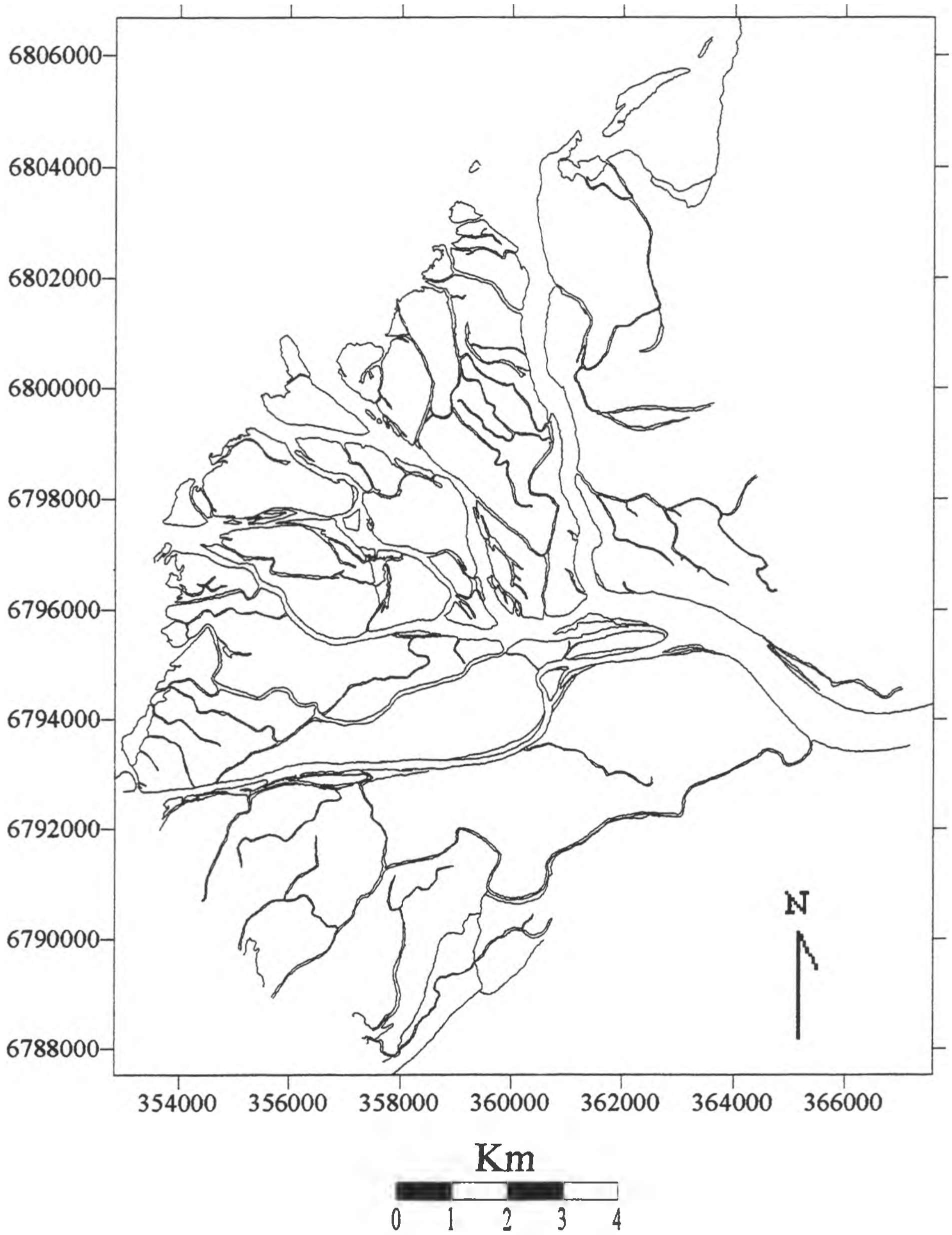


Fig. 5.1c

S. R. D.

1977

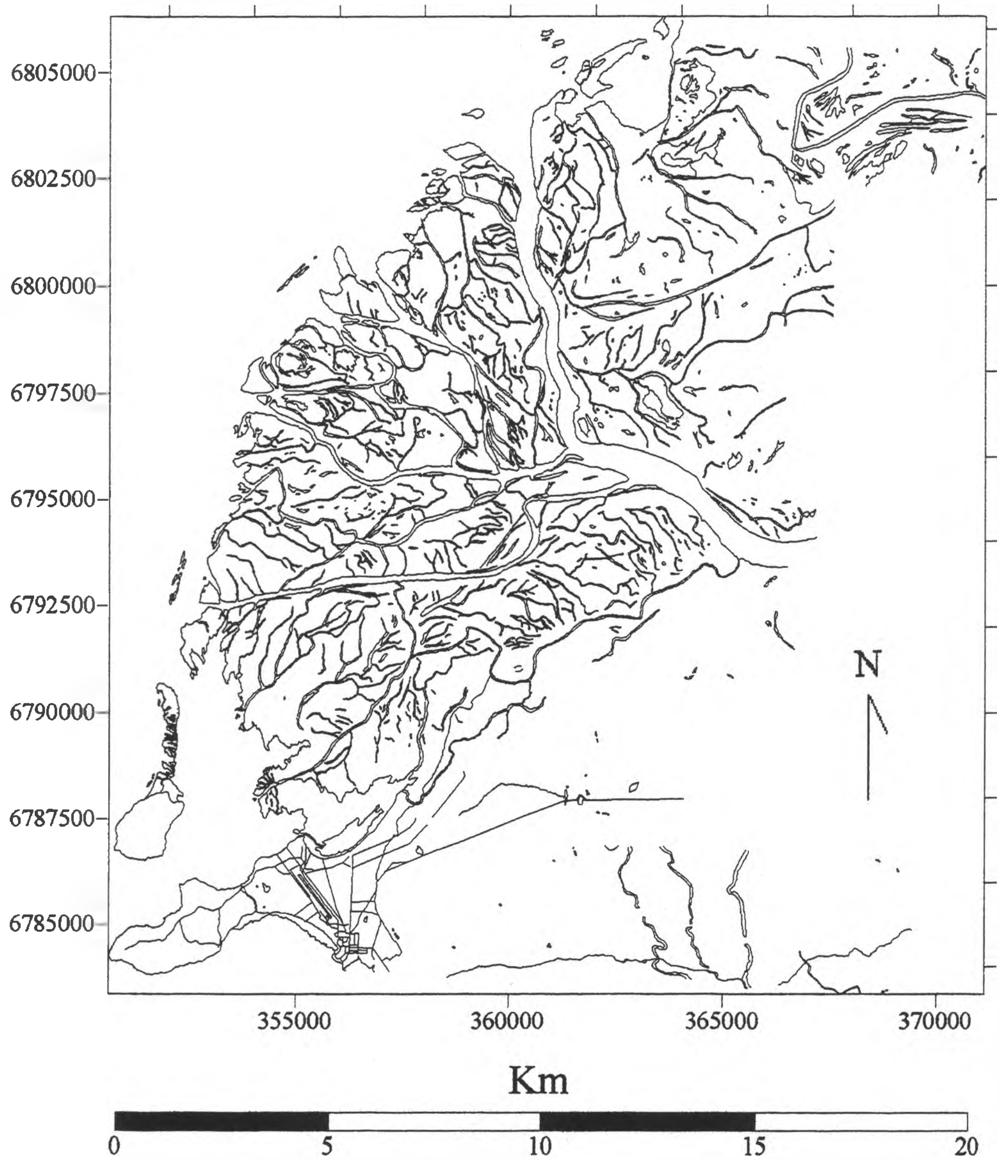


Fig. 5.1d

S. R. D.
1994

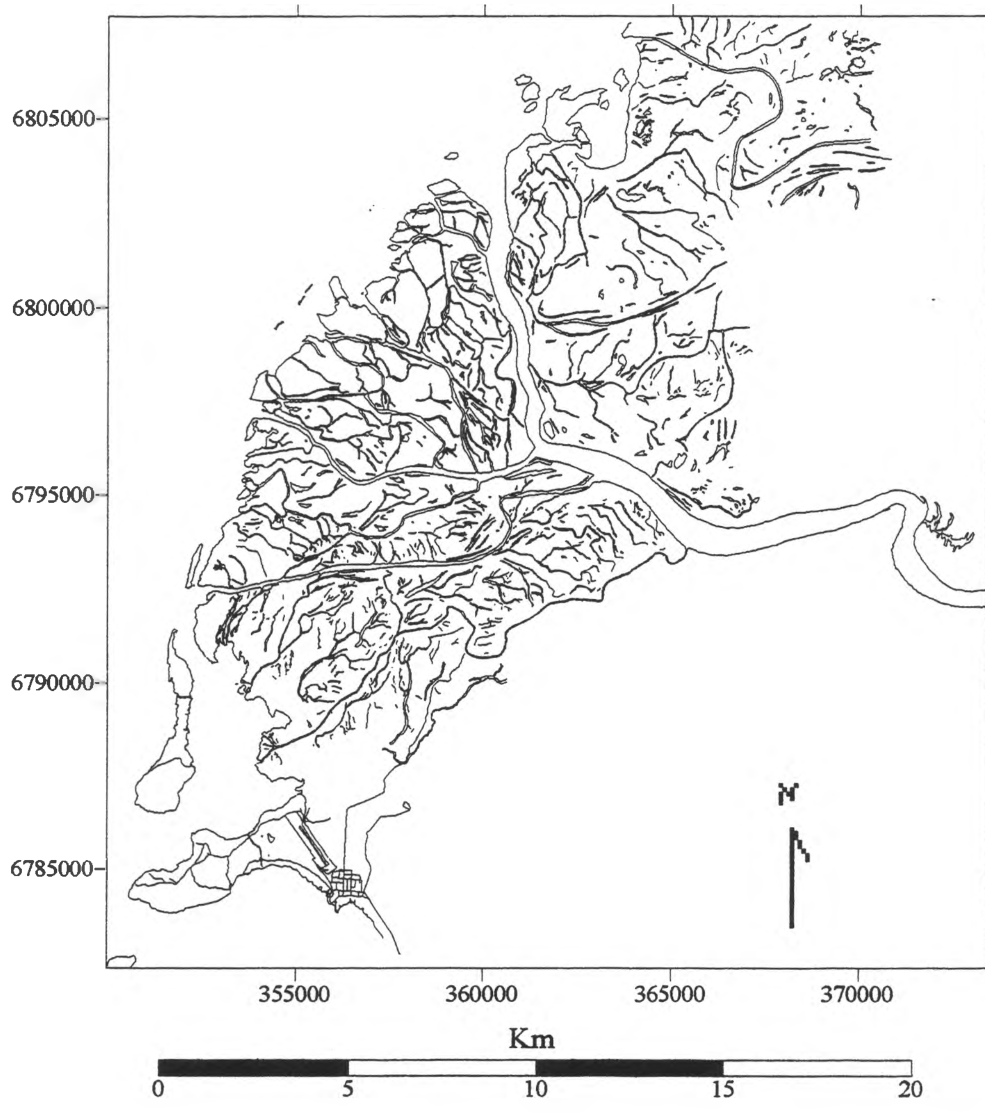


Fig. 5.2: Location of cleavage bar study sites

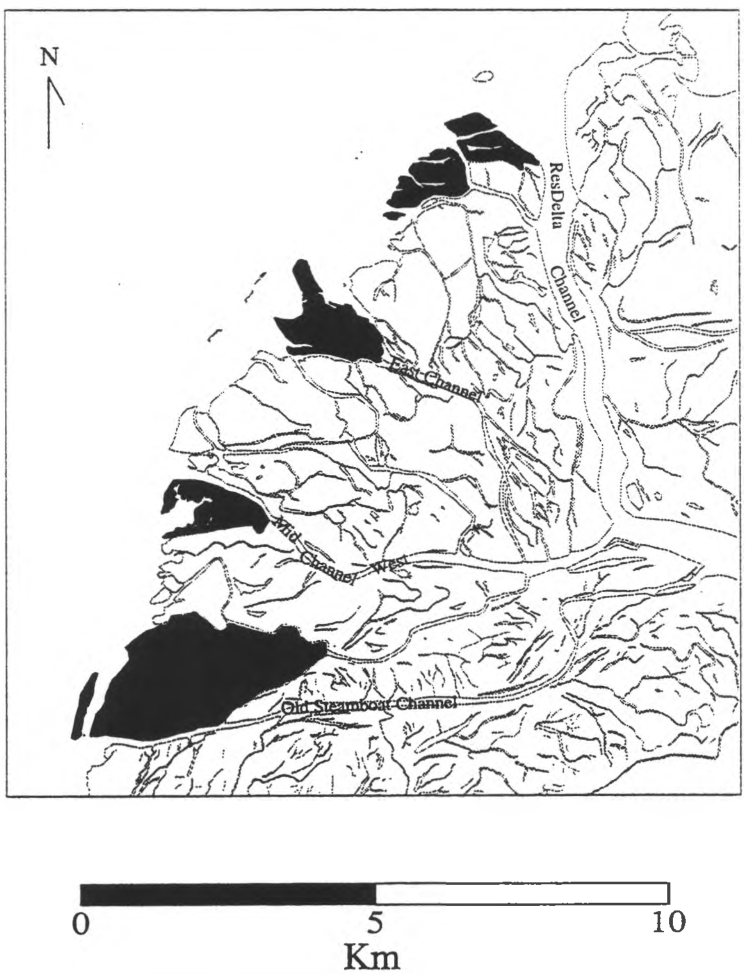


Table 5.1 Area of cleavage bar islands, Slave River Delta, NWT

Year	Channel 1	Channel 2	Channel 3	Channel 4
1946	111.5*	47.49	108.19	408.97
1966	154.91	85.9	119.94	432.38
1977	198.18	101.03	142.09	476.31
1994	226.69	99.63	142.81	493.75

1. ResDelta Channel
2. Mid Channel West
3. East Channel
4. Old Steamboat Channel

* all areas in hectares

Fig. 5.3: Subaerial surface area change of cleavage bar islands, Slave River Delta

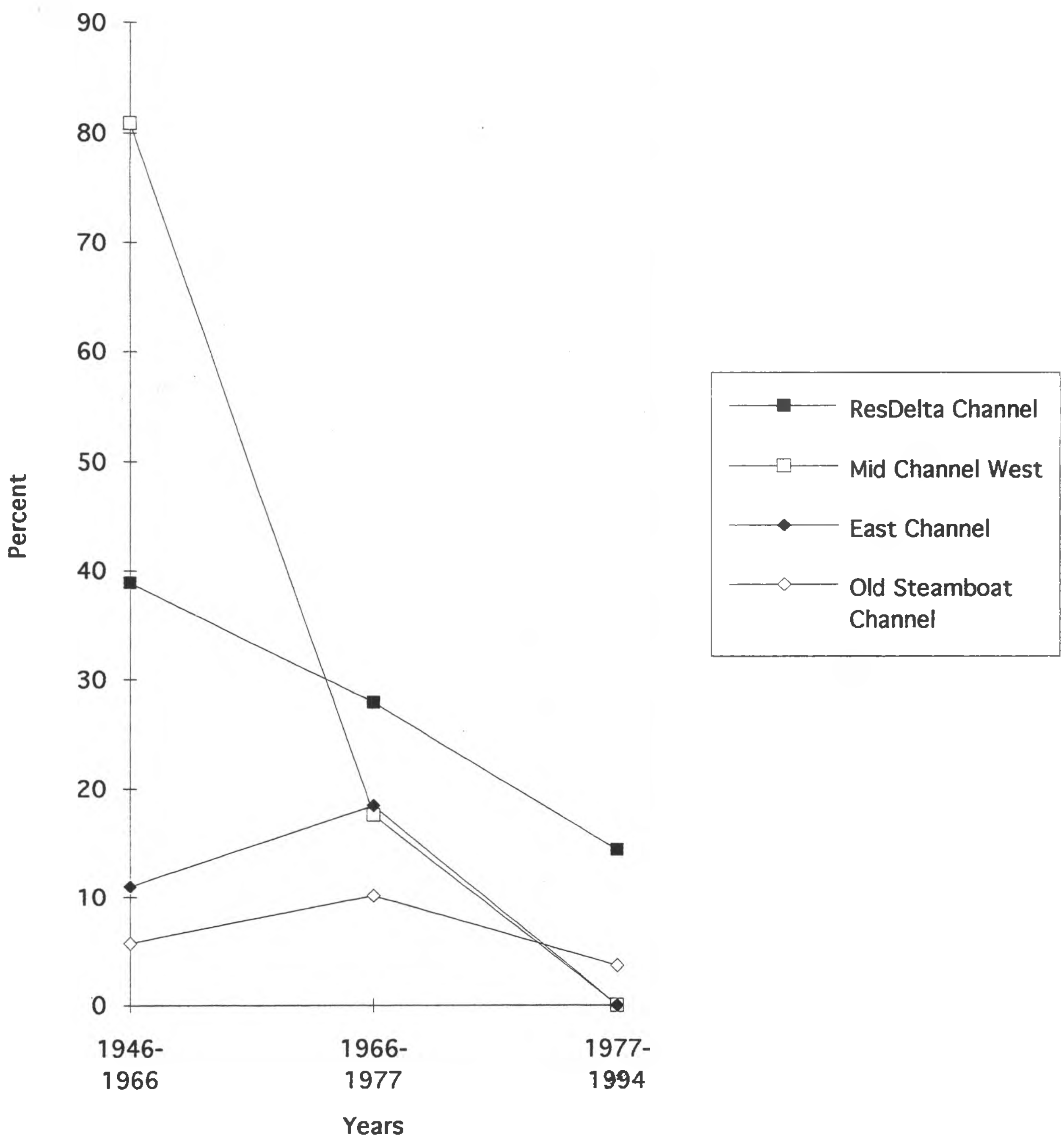


Fig. 5.4: Slave River suspended sediment comparison

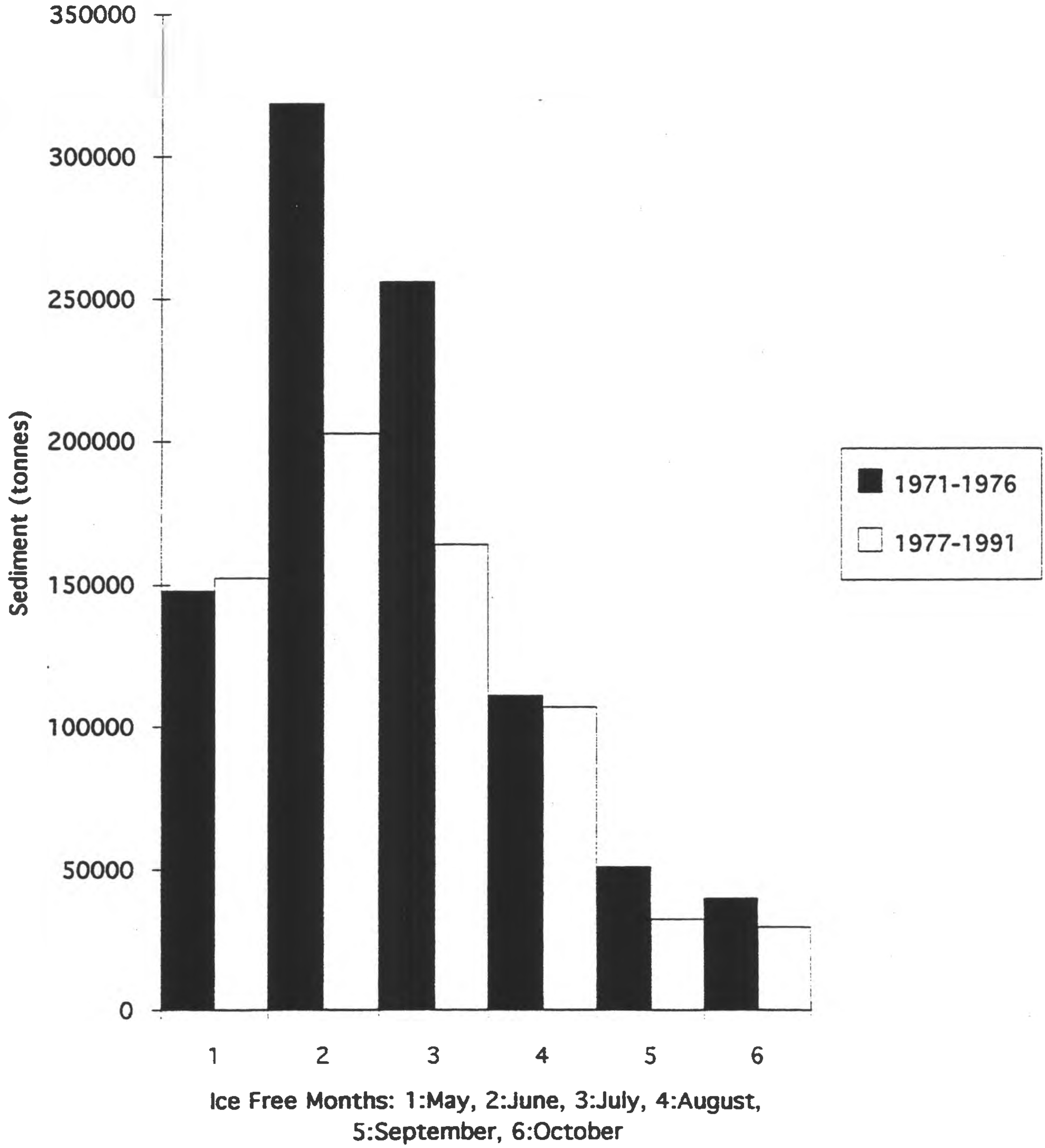
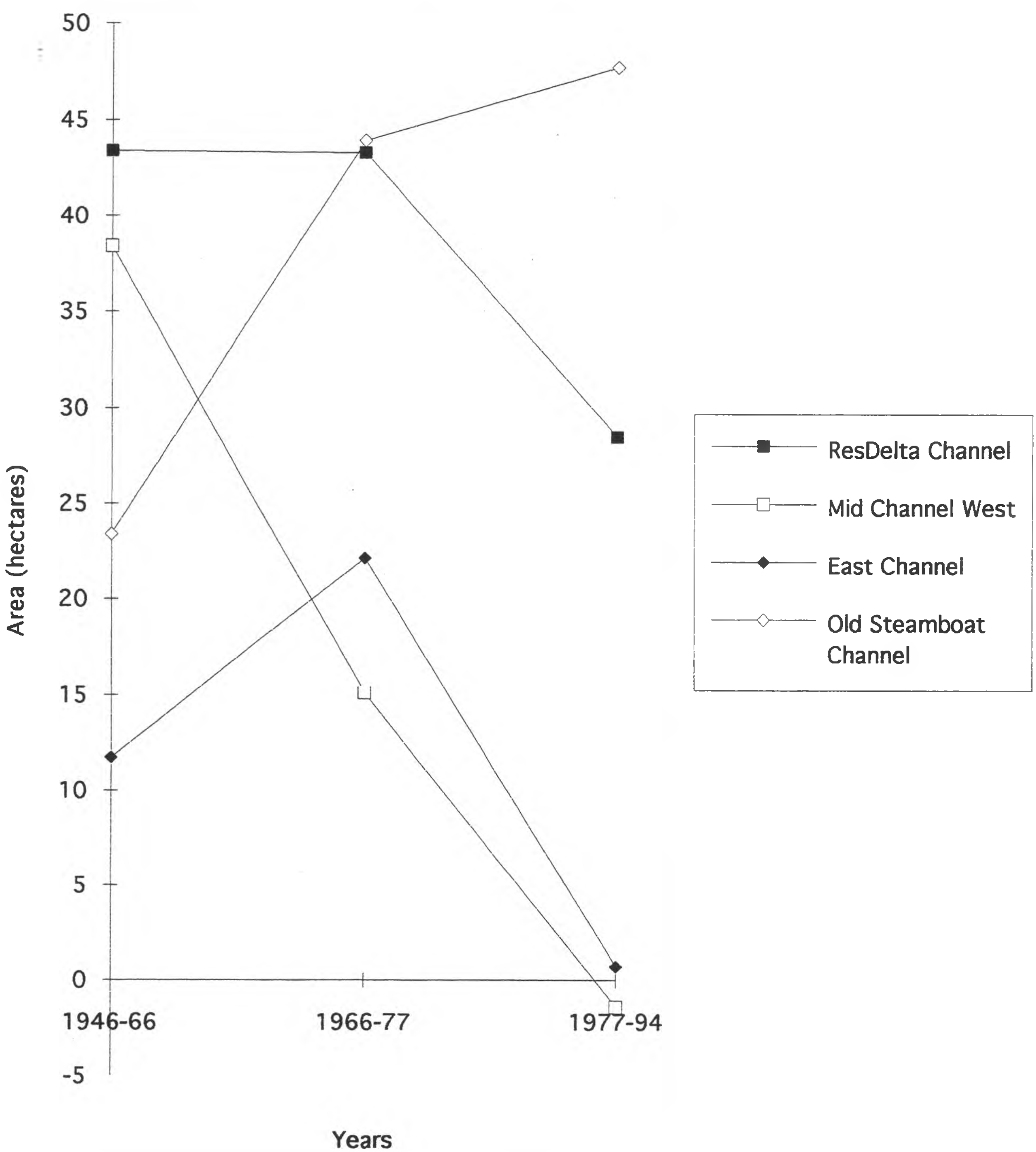


Fig. 5.5: Cleavage bar island changes in surface area, Slave River Delta



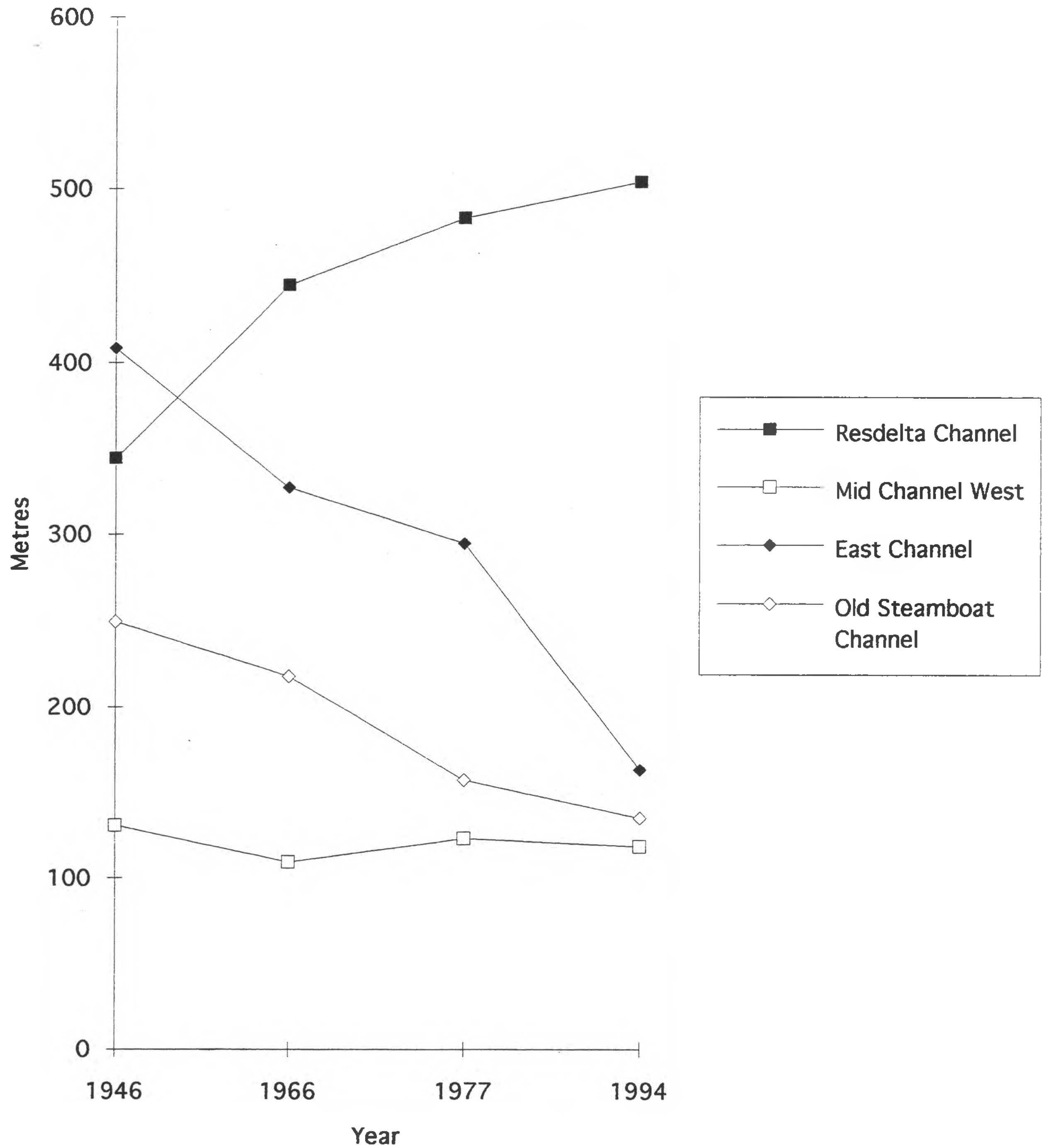
The reduction in the rate of surface area increase in the subaerial landforms may be a function of a reduction in suspended sediment load in the Slave River after impoundment. Calculations for total mean annual sediment for pre-impoundment years is 1,134,707 tonnes and post-impoundment years: 762,216 tonnes, a 33% reduction in total suspended sediment load. During the ice free year (May through October, inclusive), when the water levels in the Slave Delta are historically the most elevated, calculations indicate a 46% reduction in suspended sediment transport. There is strong probability that this may equate to reduced sediment accumulation rates on the outer delta landforms. Winter flows (November-April, inclusive), though elevated above the preimpoundment levels, and carrying a 315% increase in suspended sediment (relative to the pre-impoundment ice-free period), are restricted from providing sediment to the cleavage bar islands of the outer delta because of ice. Even though there is a predicted increase in post-impoundment winter sediment transport, it equates to a small fraction (24%) of the annual sediment load in the Slave River. Therefore, the probable reduction in sediment accumulation rates on the delta during the ice-off period is probably not offset in any significant way by an increase in postimpoundment winter period under-ice sediment transport.

5.2.2 Changes in channel morphology

Reduction in the growth rate of cleavage bar islands in the outer delta may be, in a large or small part, affected by changes in channel morphology. A reduction in the effectiveness of the distributaries to transport sediment efficiently may play a significant role in the reduced rates of growth. Changes in channel morphology may refer to features that are difficult to ascertain from the photographs available for assessing longer term change between 1946 and 1994. Such features may include submerged bars forming along channels or at the channel entry points. There are, however, certain channel features that are easily observed. One obvious physical feature that can be measured from the aerial photography and provides some indication of change in the channels capacity to maintain discharge is channel width. For example, the entry point to Old Steamboat Channel from 1946 to 1994 reveals that it has been reduced in width by approximately 55% **(fig 4.6)**. Notable reductions in the entry point widths to Mid Channel West and East Channel are illustrated in **Figures 5.1a, b, c, d.**

Changes in channel width over time are measured for Old Steamboat Channel, Mid Channel West, East Channel and ResDelta Channel. These channels provide sediment to the four cleavage bar islands examined for subaerial change during1946, 1966, 1977, and 1994. To evaluate change in width and total area of the channel, water surface is calculated using the TERRASOFT and ARCINFO GIS software. Length is determined by tracing the cursor along the middle of the channel from its entry point to its mouth. The area is determined by creating a polygon by tracing the cursor along the distributary shorelines extending from the same upstream and downstream boundries used to determine channel length. The mean width of the channel for each time period is determined by dividing the area by the length. Figure **5.6** illustrates changes in mean width through time for each channel. Of particular note is the 47% increase in the width of ResDelta Channel from 1946 to 1994 and the noteable decrease in the widths of East Channel and Old Steamboat Channel by 59% and

Fig. 5.6: Slave Delta changes in distributary width



45% respectively. The change in Mid Channel West width from year to year is slight. If the 1946 water levels of Great Slave Lake were at the same elevation as the other years, the calculated 1946 channel widths might be somewhat wider.

There is a positive relationship between river channel width and discharge (Leopold and Wolman 1957, Knighton 1984, Petts and Foster 1985). Similar calculations were constructed for all recorded data in the Slave River Delta. This relationship is shown in **Figure 5.7** and is statistically significant at the 99% Confidence Interval. The power equation describing this relationship is employed to predict how discharge has changed in the four channels given the measured channel widths for the four years in question. The results are illustrated in Figure **5.8**.

The projected discharge in ResDelta Channel increases by approximately 100% from 1946 to 1994. The period of most rapid increase in predicted discharge is between 1946 and 1966 when there is a major change in channel configuration in the central portion of the active delta **(figs 5.1a, b)** and ResDelta Channel increases in importance to become the major distributary of the delta. It is interesting to note that despite the apparent increase in flow and assumed concomitant increase in sediment load, there has been an overall reduction in the rate of subaerial growth of the cleavage bar island at the mouth of ResDelta Channel. This may be attributable to the noteable reduction in Slave River suspended sediment after impoundment of the Peace River. The significant reduction in predicted flow in East Channel and less so in Old Steamboat Channel may relate to reductions in the subaerial rate of growth of the cleavage bar islands at the mouths of those channels. A reduction in flow may equate to a reduction in the capacity of the channel to transport sediment. As such the effectiveness of certain channels to transport suspended sediment may have been reduced because of a reduction in channel width.

5.3 CONCLUSIONS

The growth rate of the outer delta is evaluated with aerial photographs for the years 1946, 1966, 1977 and 1994. The areas of pronounced growth in the vicinity of the mouths of ResDelta and Nagle Channels are due to the significant sediment load carried by ResDelta Channel and the protective environment afforded by Moose Deer Island which promotes rapid sedimentation of the sediment discharging from Nagle Channel. In general, there has been a decrease in the growth rate of cleavage bar islands from 1946 to 1994. The cessation of growth of the monitored landforms at the mouth of Mid Channel West and East Channel during the 1977-1994 period is a function of the reduced sediment load in the Slave River after impoundment

Reduction in the growth rate of the cleavage bar islands is attributeded to changes in the morphology of distributary channels in the delta. Coupled with the formation of bars at the mouth of the smaller channels, such as Steamboat and Nagle Channel, is a reduction of channel width. The widths of East Channel and Old Steamboat Channel have decreased 59% and 45 % respectively from 1946 to 1994 and therefore reduced the sediment transport potential in these channels. In contrast, ResDelta channel which transport most of the sediment and flow through the delta has increased 47% in width.

Fig. 5.7: Channel width vs. discharge for Slave River Delta

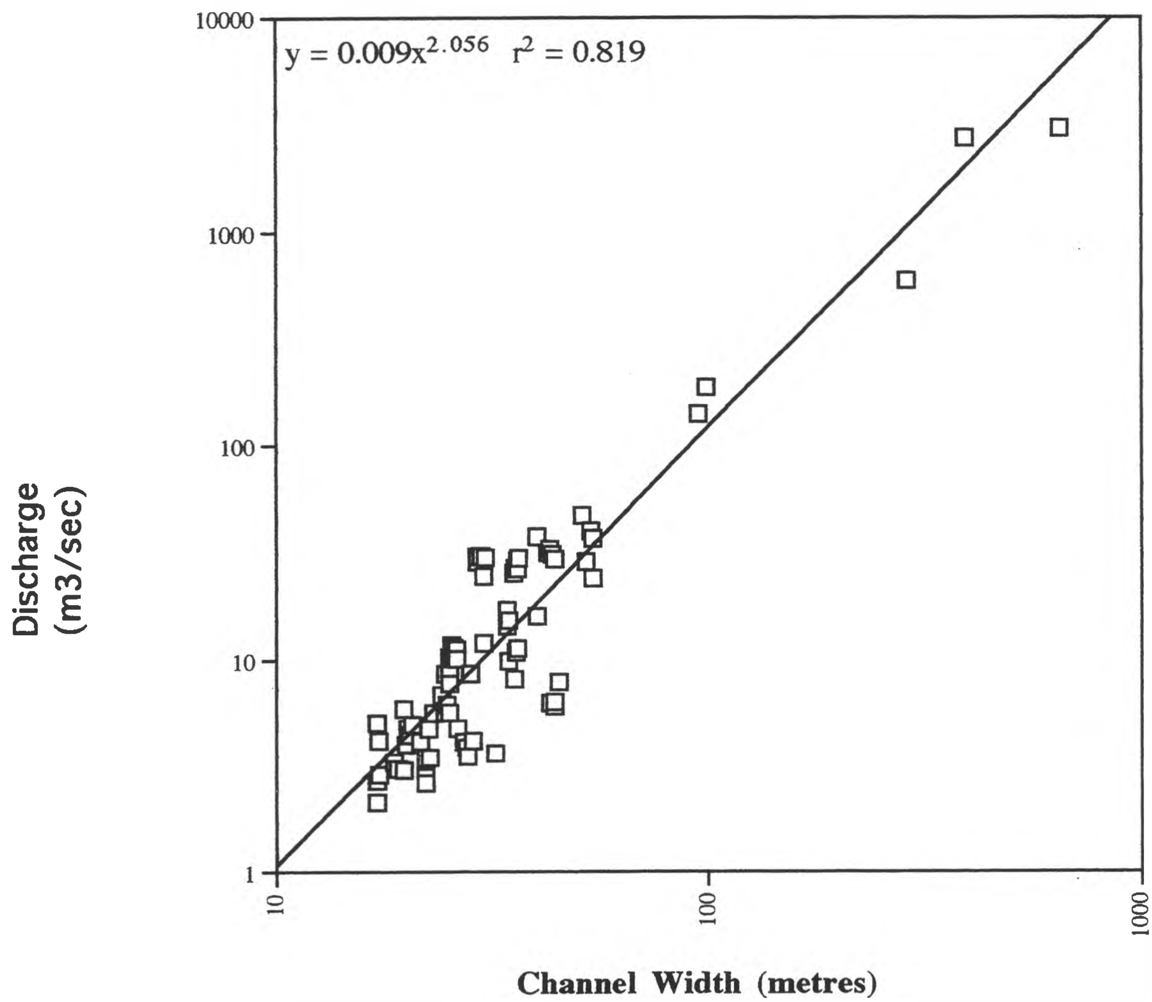
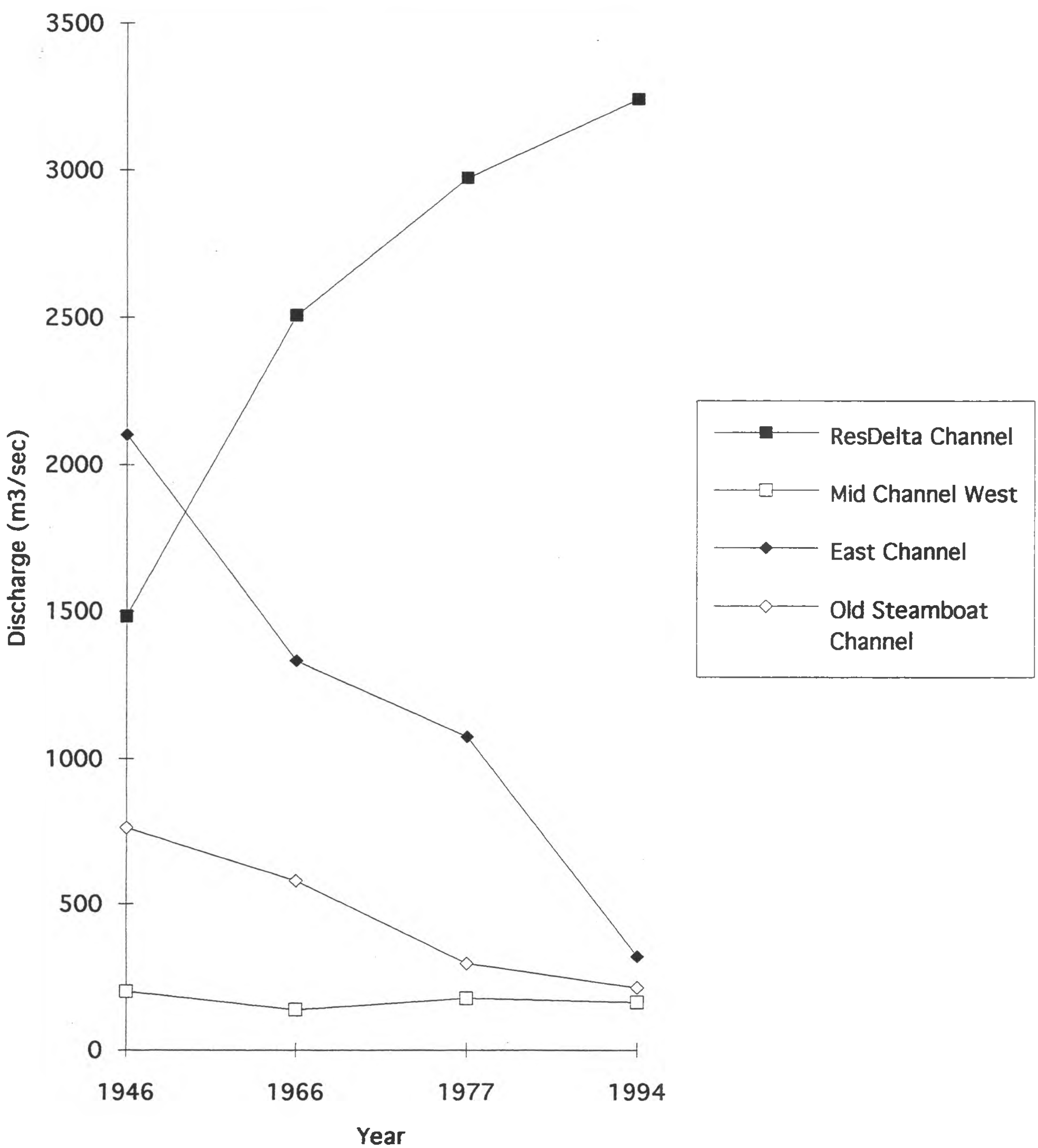


Fig. 5.8: Slave River Delta predicted changes in channel flow



6.0 PLANT ASSEMBLAGE CHANGE DURING PREIMPOUNDMENT (1946-1966) AND POSTIMPOUNDMENT (1977-1994) PERIODS.

6.1 INTRODUCTION

The natural succession of plant assemblages on the Slave River Delta is discussed in English (1979, 1984). The sequence of allogenic succession of plant assemblages on the outer delta is *Equisitum, Salix-Equisetum, Salix, Salix-Alnus, Alnus-Salix* and *Alnus*. The environmental controls on succession on cleavage bar islands in the outer delta include levee avulsion, sediment accumulation and, to a lesser extent, erosional impacts of the lake. Freezing of the saturated sediments in the winter months is reported to damage root stalks of emergent vegetation (English 1984). In section 5 the rate of growth of the cleavage bar islands is reported to have significantly reduced from the 1946-1966 period to the 1977-1994 period.

Important to the maintenance of high biological productivity on the outer delta is the continued development of cleavage bar islands. These landforms provide the environment for highly productive stands of *Equisetum fluviatile*, an emergent plant species of significant biological and economic importance on this delta. Cessation or reduction of growth of the outer islands due to a reduction in suspended sediment from the Slave River may result in reduction of the areal coverage of the *Equisetum* assemblage. As the levees of these outer delta features are either below or slightly above the low water summer levels of Great Slave Lake, annual sediment accumulation does occur even with the calculated 33% reduction in suspended sediment load in the river after impoundment of the Peace River. Over a period of years the levees and interlevee depressions of these cleavage bar islands will increase in elevation to a point where *Salix* spp. will succeed *Equisetum fluviatile* as the latter is shade intolerant. Because *Equisetum fluviatile* is a food source for muskrat, many species of migratory birds, and large mammals, a reduction in the areal expanse of this emergent plant species will have significant repercussions on the biological diversity and productivity of this delta.

6.2 PLANT ASSEMBLAGE CHANGE 1946-1994

To assess botanical changes during the pre (1946- 1966) and post (1977-1994) impoundment periods the spatial plant assemblage pattern on the cleavage bar islands described in section 5 at the mouths of Old Steamboat Channel, Mid Channel West, East Channel and ResDelta Channel is examined. These landforms were selected as they are on the mouths of major distributaries and thus reflective of changes ongoing within the distributary system over long periods of time. The boundaries of plant assemblages were mapped from the aerial photography and digitized into TERRASOFT GIS for calculation of plant assemblage areas for each year. The aerial photography used for 1946 is black and white and the scale is 1:25200; for 1966: colour at 1:24000, for 1977: colour infrared at 1:25000 and for 1994: colour infrared at 1:24000.

The quality of the 1946 and 1966 images is not as good as those taken in1977 and 1994. It is impossible to ascertain error of the plant assemblage boundaries for the early photography. The 1977 images were rigorously ground truthed in 1977 and small portions of the 1994 aerial photography were ground truthed during the spring and summer of 1995.

Figures 6.1, 6.2, 6.3, 6.4 illustrate the spatial and temporal changes in plant assemblages for the cleavage bar islands at the mouths of Old Steamboat Channel, Mid Channel West, East Channel and ResDelta Channel. Figures **6.5, 6.6, 6.7, 6.8** summarize the plant assemblage changes from year to year in a easily comparable format. The cleavage bar islands at the mouths of Mid Channel West, East Channel and ResDelta Channel are, in 1946, essentially submergent whereas the island at the mouth of Old Steamboat Channel is significantly drier, more representative of the mid delta area **(figs 6.9, 6.10, 6.11, 6.12)**. General trends in the wetter, outer delta cleavage bar islands include a general shift toward a drier environment characterized by the increased areal coverage of *Salix, Salix-Alnus, Alnus-Salix* and *Alnus* assemblages. On the Mid Channel West and East Channel islands there is a noteable decrease in the areal cover of the *Equisetum* assemblage from 1977 to 1994. The loss of *Equisetum* assemblage cover observed in the 1994 photography is, in part, related to river erosion of part of the cleavage bar island at the mouth of Mid Channel West. The island at the mouth of Old Steamboat Channel increases in surface area from 1977 to 1994 (note: the summer water levels in Great Slave Lake are slightly higher in 1994 than 1977, so the estimates of change here are conservative) yet this increase in area is not accounted for in any increase in plant assemblages, such as *Equisetum*, normally associated with new subaerial sediment deposits.

6.3 CONCLUSION

Plant assemblage change on the outer delta as represented by the cleavage bar islands examined at the mouths of Mid Channel West, East Channel and ResDelta Channel indicates a trend towards a drier environment. On these islands where subaerial growth between 1977 and 1994 has either stopped (East Channel and ResDelta Channel) or some erosion of the landform has taken place (Mid Channel West), the area occupied by the biologically important *Equisetum* assemblage is either reducing (Mid Channel West and East Channel) or, expanding slightly (ResDelta Channel).

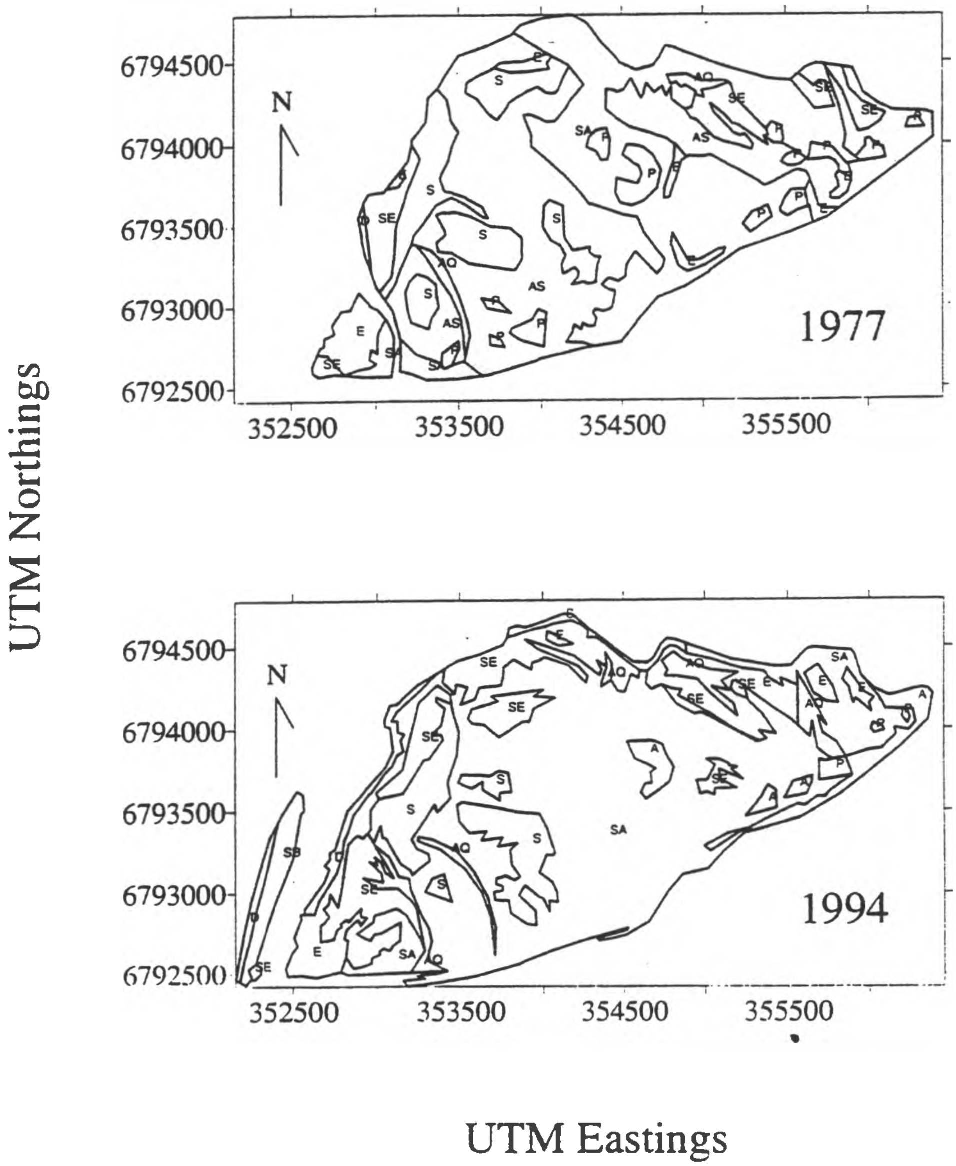
The cleavage bar island at the mouth of Old Steamboat Channel is, in the upstream portion, botanically and geomorphologically more representative of the mid delta. The plant assemblages normally associated with the wetter environments on the Slave Delta, *Equisetum* and *Salix-Equisetum* have, over the years of observation, occupied a decreasing proportion of the islands environment and typify the transition period from an outer delta landform to mid delta landform.

7.0 IMPLICATIONS OF ALTERED SEDIMENT REGIME ON NUTRIENT TRANSPORT

Phosphorus (P) is the limiting nutrient in many aquatic ecosystems and its distribution is linked to sediment transfer and conveyance processes between the land and receiving waters (Miller et al.

Fig. 6.1a

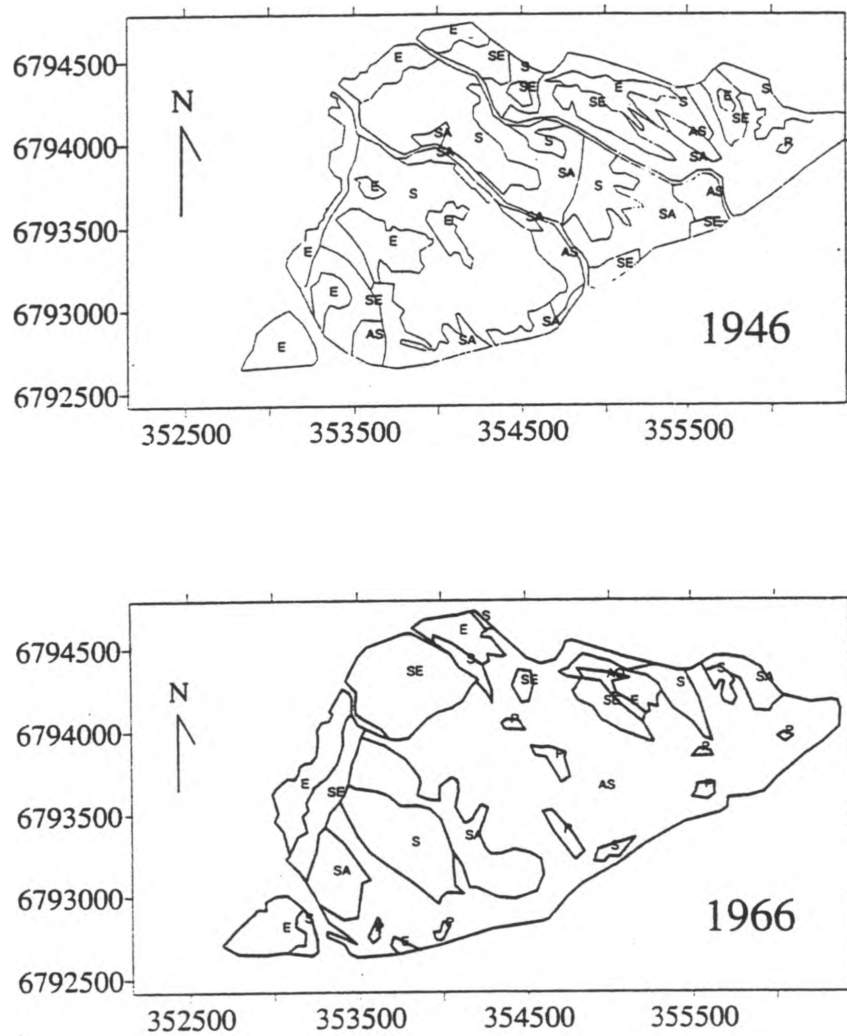
Old Steamboat Channel Vegetation



A = Alder	P = Poplar
AS = Alder/Salix	S = Salix
AQ = Aquatic	SA = Salix/Alder
D = Driftwood	SB = Sand
E = Equisetum	SE = Salix/Equisetum

Fig. 6.1b

Old Steamboat Channel Vegetation



UTM Northings

UTM Eastings

A = Alder	P = Poplar
AS = Alder/Salix	S = Salix
AQ = Aquatic	SA = Salix/Alder
D = Driftwood	SB = Sand
E = Equisetum	SE = Salix/Equisetum

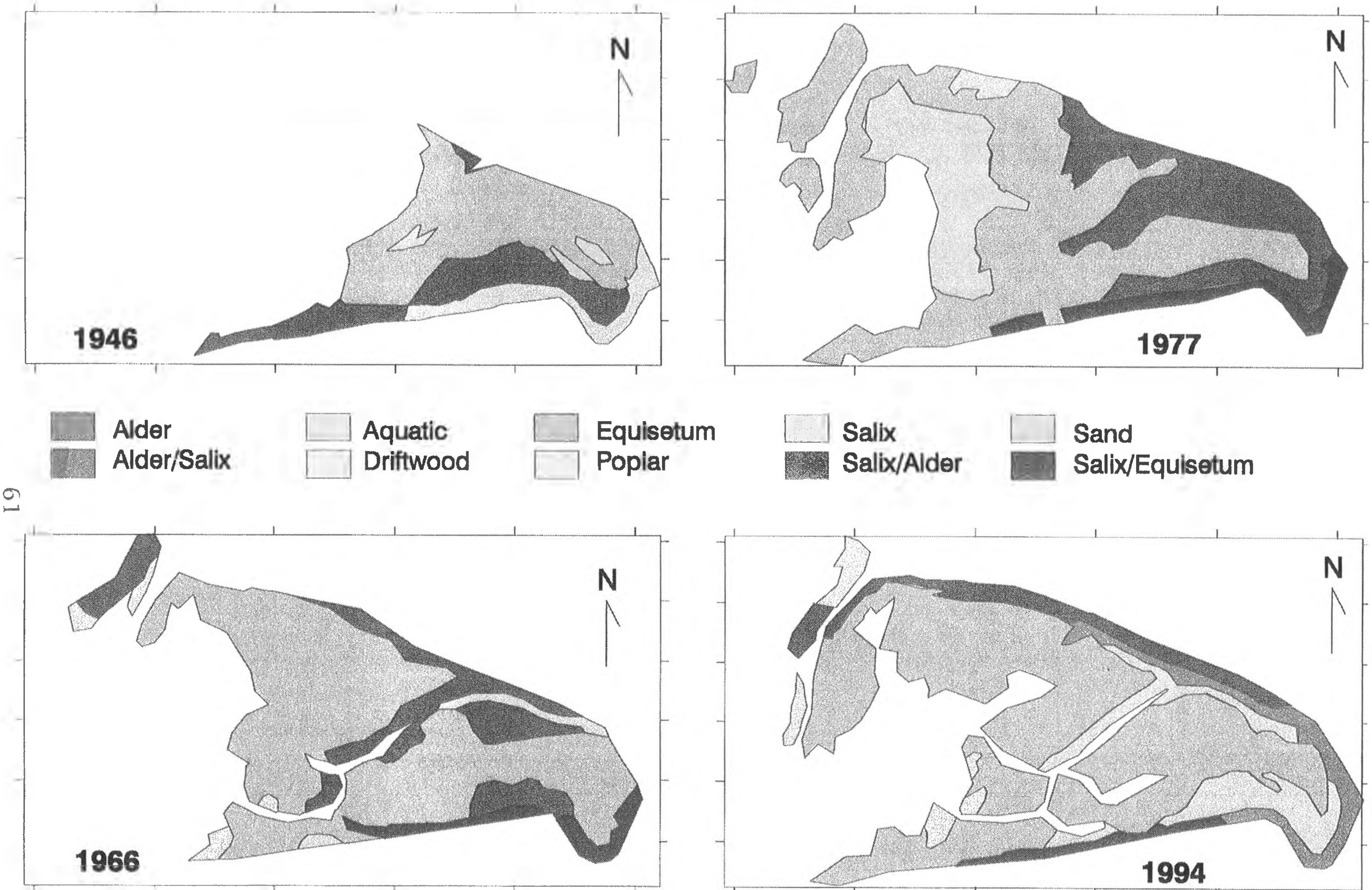


Fig.6.2: **Mid Channel West Vegetation**

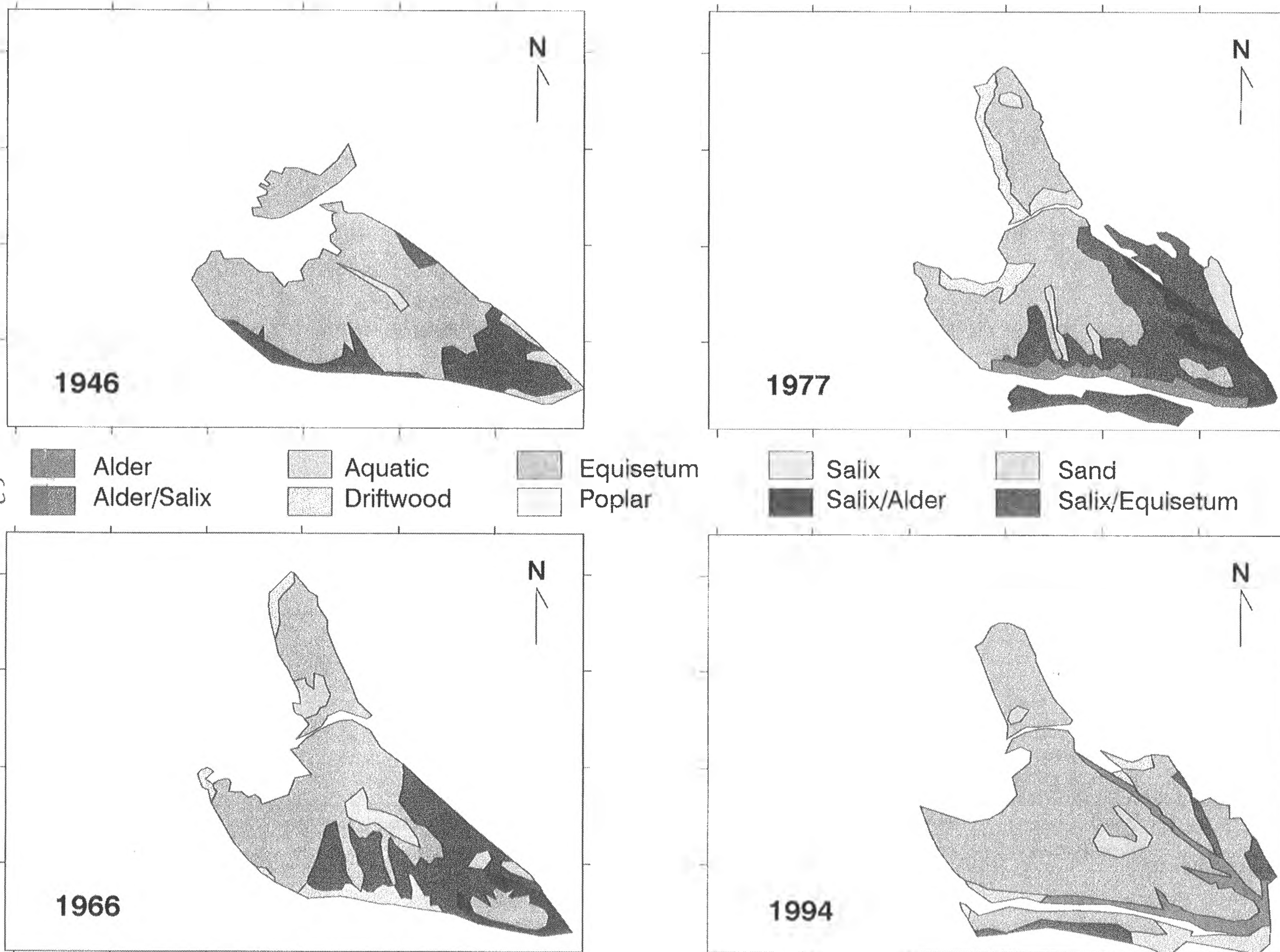


Fig.6.3: **East Channel Vegetation**

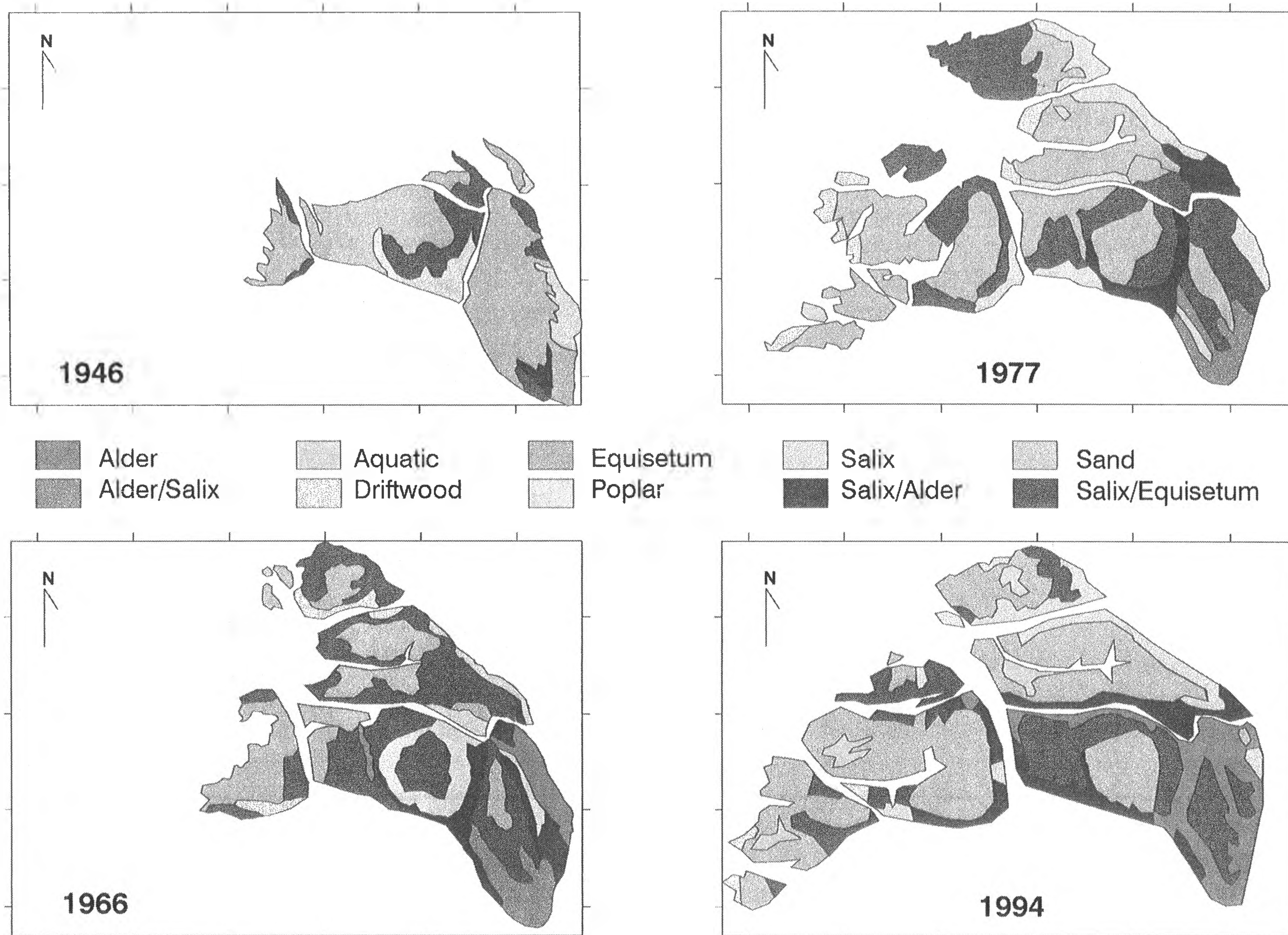


Fig.6.4: **Resdelta Channel Vegetation**

Fig.6.5:
Slave River Delta, Old Steamboat Channel: Cleavage Bar Island, Plant Assemblage Change

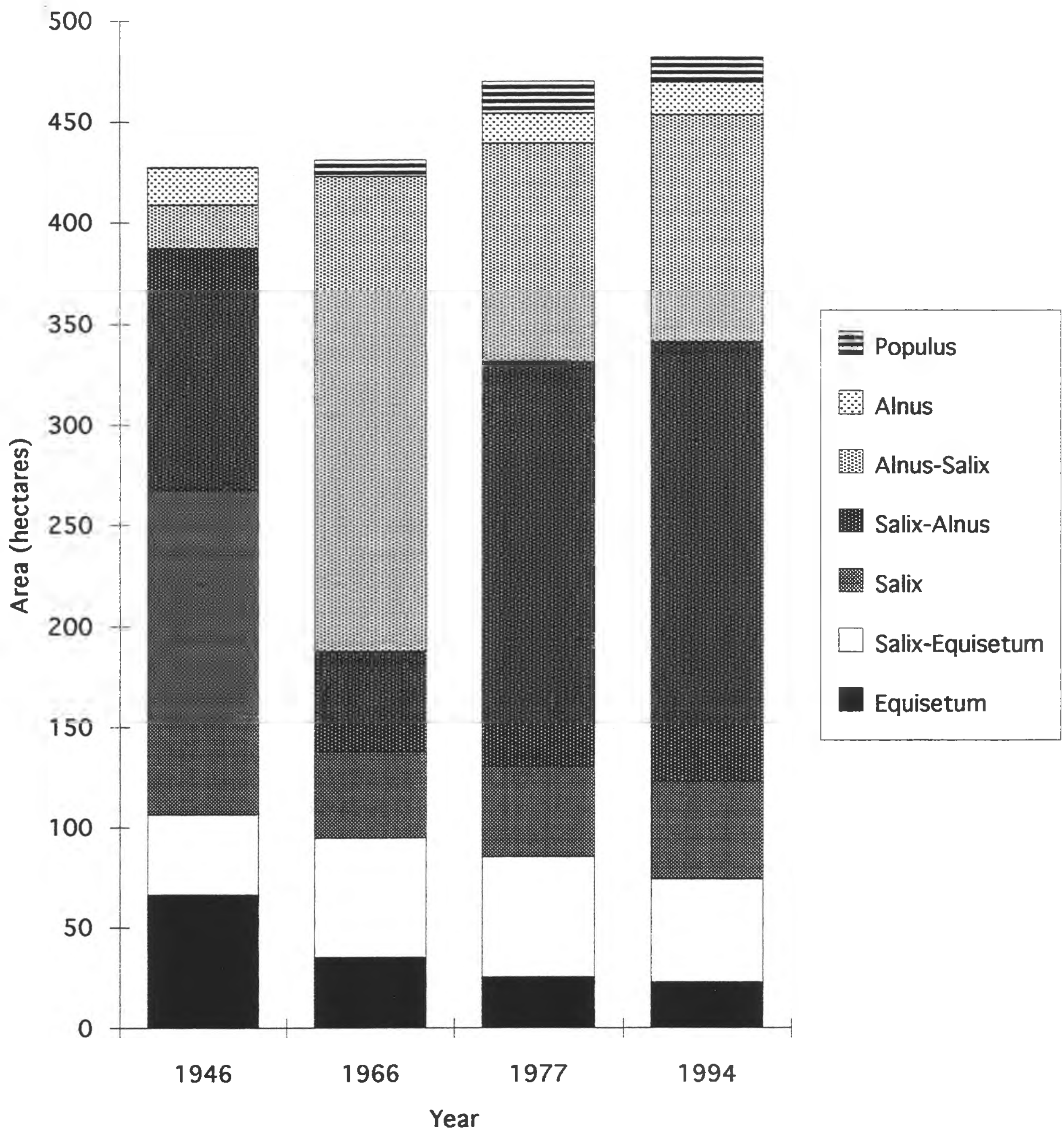


Fig.6.6:

Slave River Delta, Mid Channel West: Cleavage Bar Island,
Plant Assemblage Change

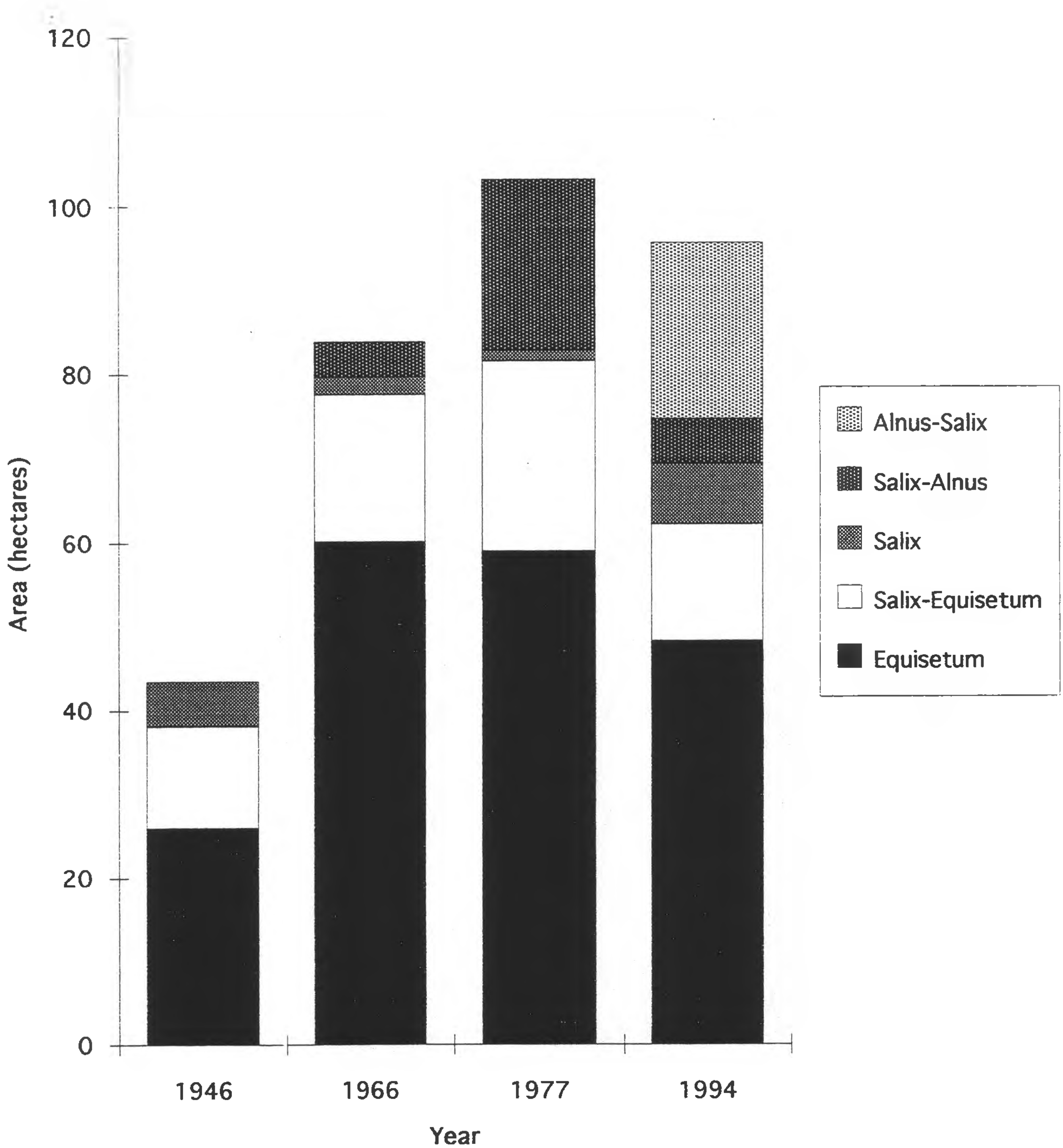


Fig.6.7:
Slave River Delta, East Channel: Cleavage Bar Island, Plant Assemblage Change

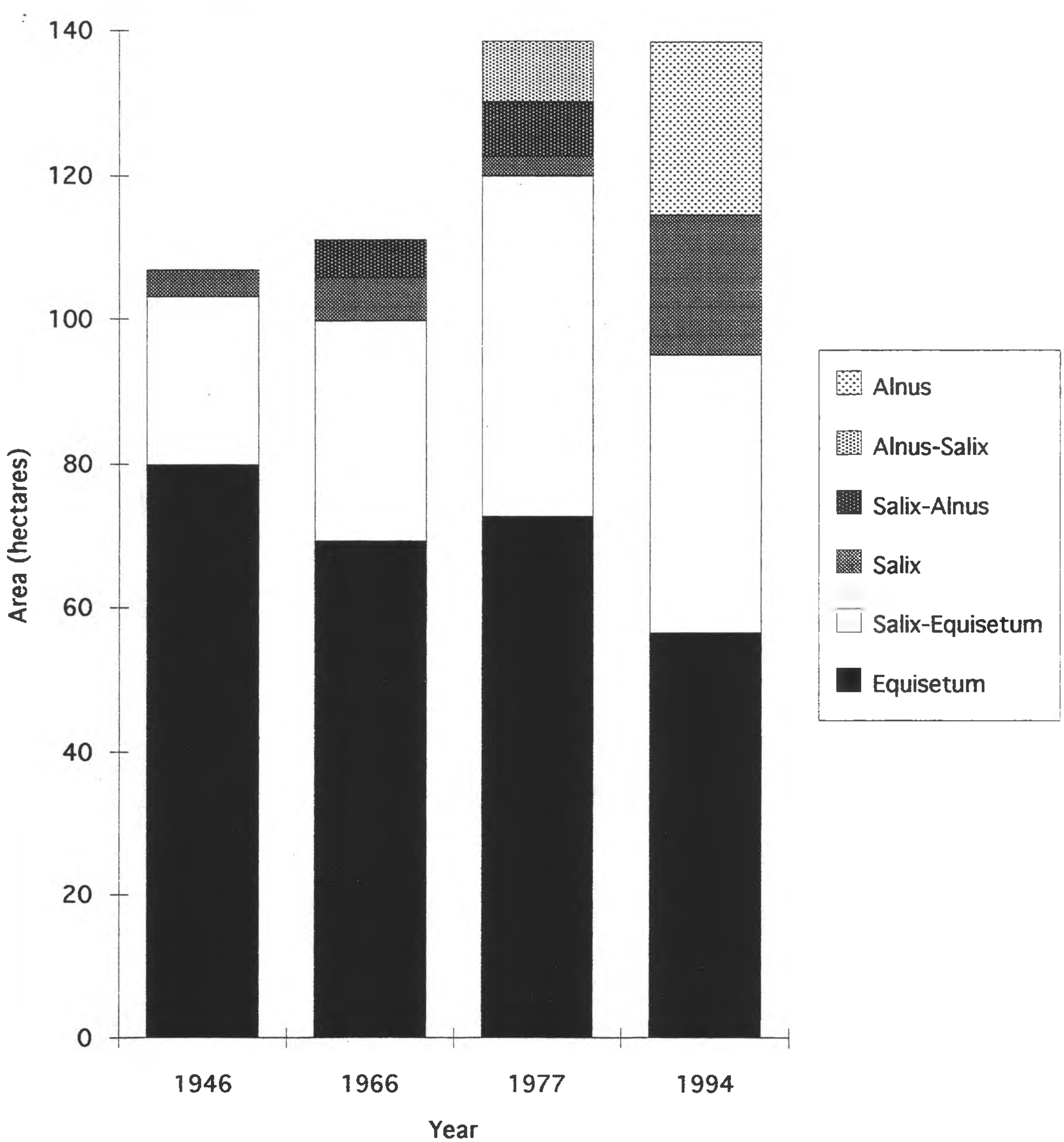


Fig.6.8:

Slave River Delta, ResDelta Channel: Cleavage Bar Island, Plant Assemblage Change

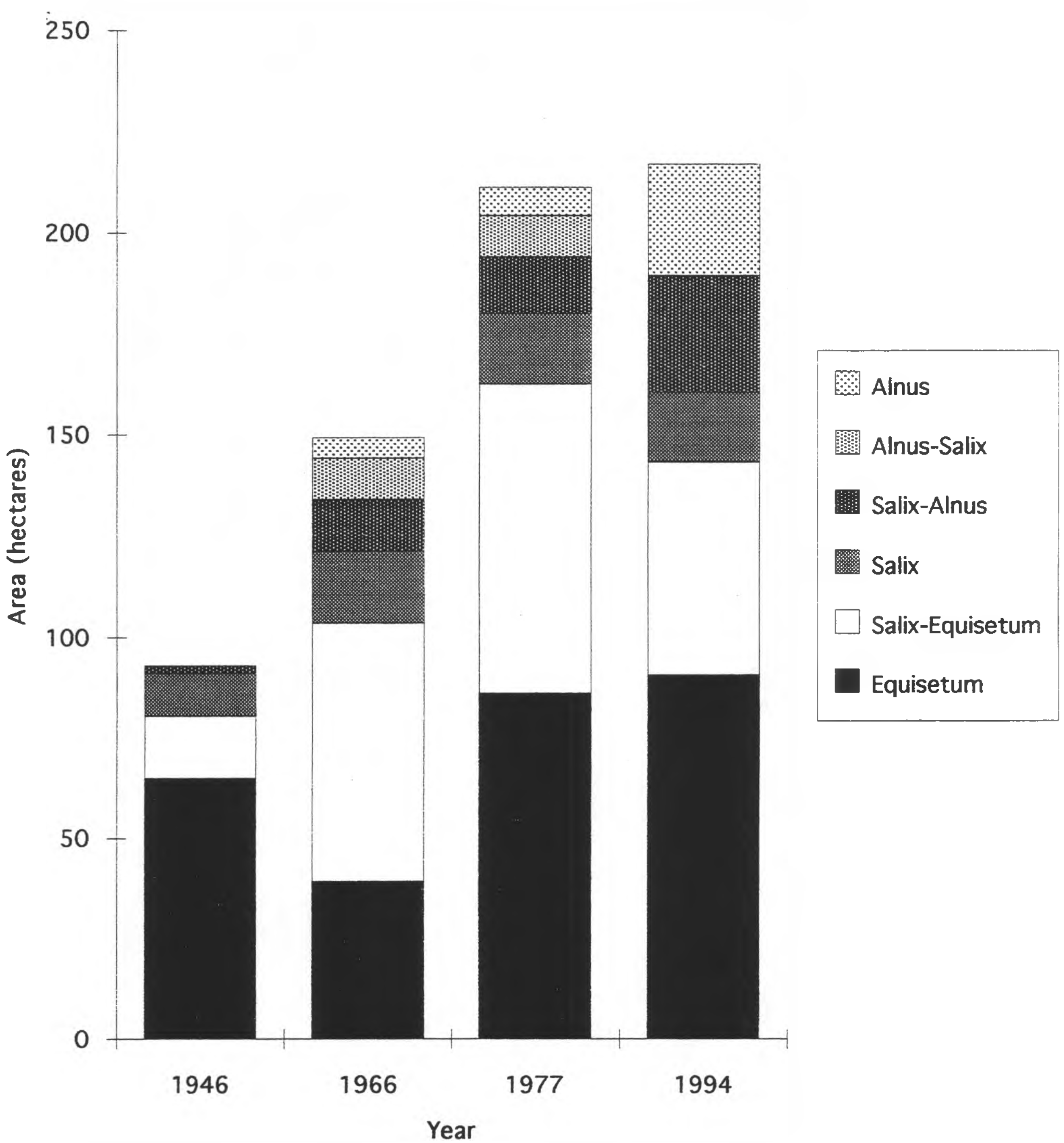


Fig.6.9: Cleavage bar island, Old Steamboat Channel: Slave River Delta

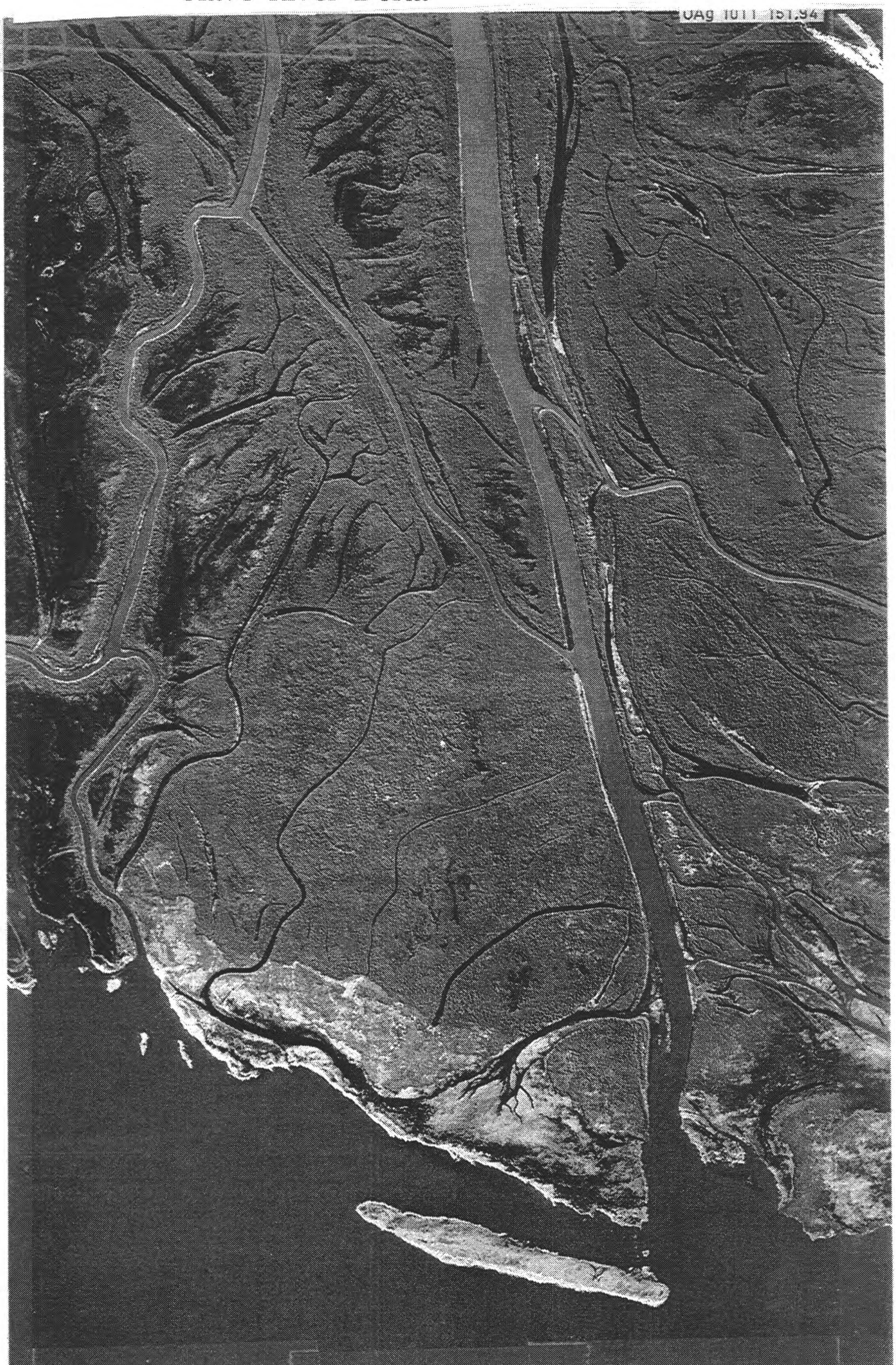


Fig.6.10: Cleavage bar island, Mid-Channel West: Slave River Delta

Fig.6.11: Cleavage bar island, East Channel: Slave River Delta

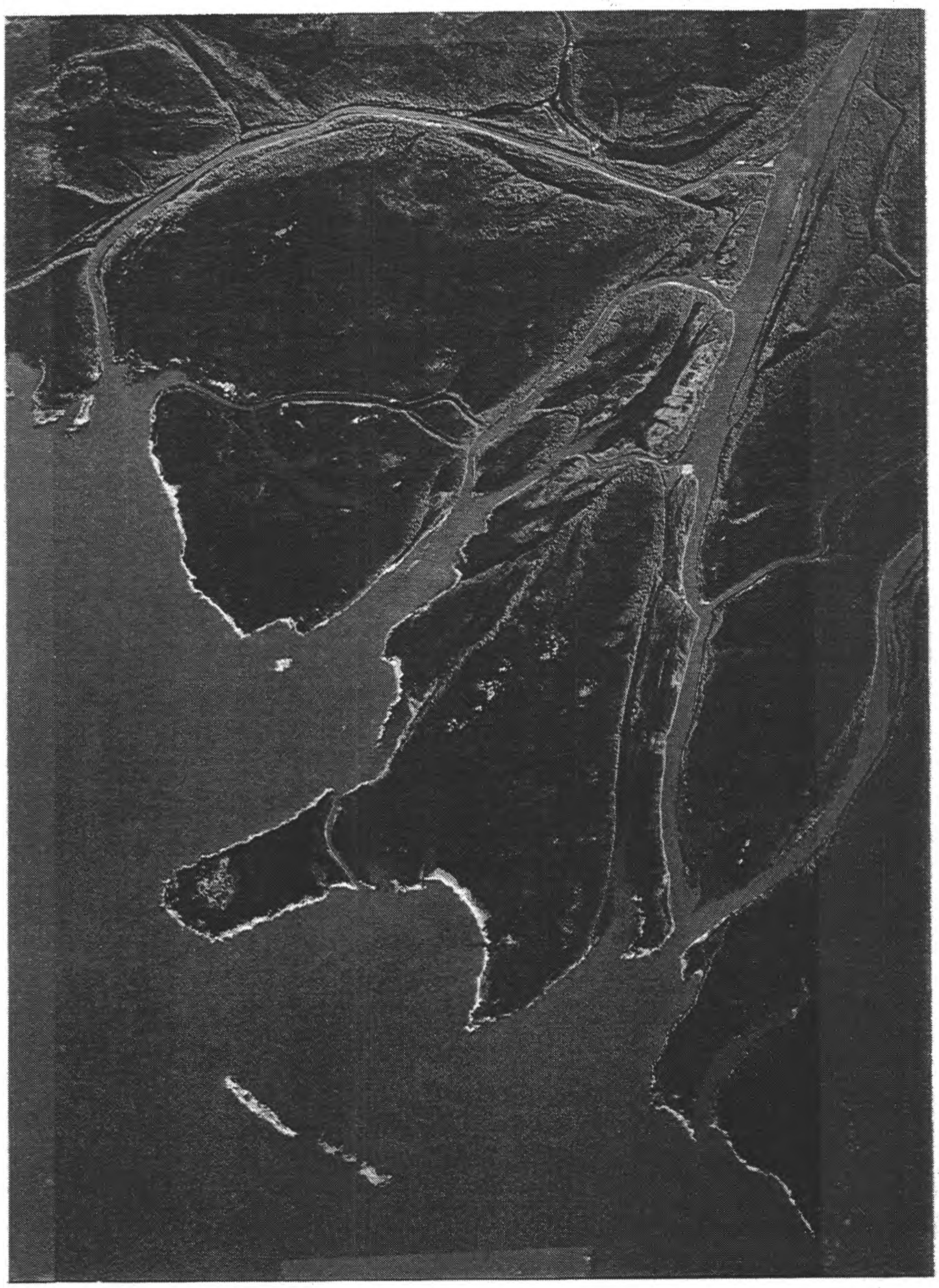
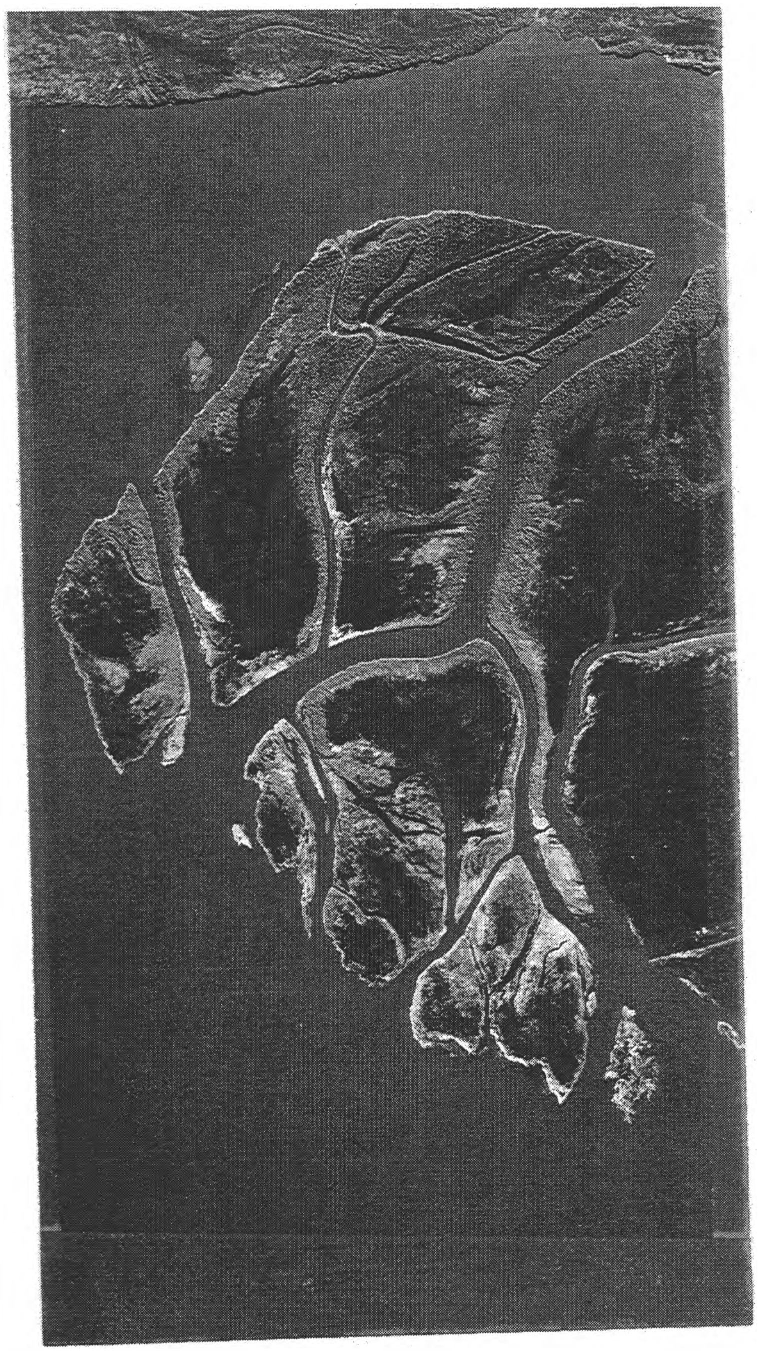


Fig.6.12: Cleavage bar island, ResDelta Channel: Slave River Delta



1982). The forms and amounts of P in aquatic ecosystems are a function of the input, output and interchange between sediment and water compartments. The relative mobility of P in these systems is a highly complex phenomenon, dependent upon the rates of interrelated physical-chemical processes (adsorption/desorption, precipitation/dissolution), biological processes (bioturbation, microbial induced dissolution of particulate P) and mechanical processes (wave induced suspension, mixing dynamics) (Bostrom et al. 1988).

The release of P from sediment in rivers is governed primarily by adsorption/desorption processes (Stone et al. 1991). The extent to which this occurs is a function of temperature, competitor ions, sediment type, particle size and oxidation-reduction status. Laboratory and field studies show that finer grain size fractions of sediment are enriched in P (Stone and English, 1993) and the most active for P release (Stone and Mudroch, 1989; Stone et al. 1991; Stone et al. 1995).

Due to the lack of data regarding the nutrient dynamics of the Slave delta, it is only possible to infer how the hydrograph shift and subsequent altered sediment regime in the Slave River might impact the delivery of nutrients. Flood frequency and subsequent sediment loading have been reduced during spring breakup in the post-dam period. This will affect the delivery of sediment bound P to the lower and middle sections of the delta. The reduced flooding will reduce the delivery of nutrient rich sediments to the middle and upper parts of the delta. Also, the potential shift in texture of suspended sediment to finer grained materials suggests that P bound to these fine-grained materials will be transported through the distributary network directly into the lake where release is likely to occur.

8.0 CONCLUSION

The degree to which impoundment has influenced the natural growth and development of the active delta of the Slave River is a difficult problem to assess. The W.A.C. Bennett dam and the Slave River Delta at Great Slave Lake are separated by several hundred kilometers and the basin of the Slave River is approximately 660,000 km². Therefore, the first question is how much has impoundment influenced the natural flow regime of the Slave River. The Water Survey of Canada site at Fort Fitzgerald, Alberta is the sole gauging station on the Slave River, some 200 km upstream from the Slave Delta at Great Slave Lake. Examination of the annual hydrograph prior to and after impoundment reveals a significant change in the flow. Ice-free period (May-October) discharge levels are 16% lower after impoundment; and ice-on period flows (October-April) are 40% higher. Changes of this nature in river systems which have been regulated are widely reported. When month to month comparisons of flows between the Peace River at Peace Point and the Slave River at Fort Fitgerald are examined, it is found that there is significant seasonal variation in the contribution of water from the Peace River to the Slave River. For most of the ice-on period the contribution of Peace River water to Slave River flow is higher during the postimpoundment period. The reverse occurs for the ice-free portion of the year. During the preimpoundment period, the mean monthly contribution of water from Peace River to the Slave River is 54%; after impoundment this increases to 66%. These data verify that the Peace River regulated flow does impact the natural flow of the Slave River and that the influence of the Peace River upon the flow of the Slave varies on a seasonal basis.

A lack of data on ice jamming in the Slave River and particularly in the Slave River Delta, makes it difficult to conclude whether impoundment of the Peace River may have resulted in a decrease or an increase in ice jamming. In theory, ice jamming should be less common in the delta and along the length of the river after the implementation of the dam because of smaller increases in discharge during the break-up period. A reduction in the spring surge should result in a lessened frequency of mechanical break-ups, the type of break-up which is responsible for the formation of ice jams. A warming of the regional climate, mainly in the April-May spring break-up period, has lead to earlier melting of the snowpack and may be responsible for earlier break-up dates. It is possible that this warming may be creating more thermal break-ups and therefore is at least partially responsible for the suggested reduction in ice jamming in the Slave River and Slave River Delta.

A reduction of ice jamming in the Slave Delta will decrease the flooding frequency on the more elevated portions of the delta and potentially will affect the pattern of plant succession. A reduction in flooding frequency and concomitant reduction in sediment deposition may result in the successful growth of bryophytes on the ground surface of the mid delta area. This would eventually result in a change in the microclimate of the soil and invasion of *Picea glauca* (English 1984). The timing on this is highly speculative.

It is expected that a change in the flow regime of the Slave River will result in a change in the suspended sediment load. Suspended sediment load has only been sampled at Fort Fitzgerald since 1971 and only during the period: May to October. In order to determine suspended load in the Slave River prior to and after impoundment of the Peace River, a sediment rating curve was constructed from the mean monthly discharge for Peace Point, Alberta to predict mean monthly sediment load in the Slave River at Fort Fitzgerald. Carson (1992) reports that the Peace River has a significant impact on the suspended sediment regime in the Slave River at Fort Fitzgerald. The results of this sediment rating curve project that the annual suspended load in the Slave River has been reduced by 33% (372,491 tonnes). On a seasonal basis, the suspended sediment load of the Slave River has reduced 46% during the ice-off period and increased 314% during the ice-free period of the year. According to Milburn and Prowse (1995), under-ice suspended sediment loads in the Liard River are significantly less than would be expected during the ice-free period. Imposing the under-ice sediment reduction coefficients determined by Milburn and Prowse (1995) for flow in the Slave River results in an increase of 314% increase in suspended sediment transport. There are only two dates in 1980 when it is possible to compare the flow in the Slave River at Great Slave Lake with that recorded at Fort Fitzgerald. The differences, accounting for lag in water movement between the two sites, are minimal. As such it is possible that there is little change in the total suspended sediment load between Fort Fitzgerald and Great Slave Lake. However, comparative data for particle size distribution in suspension at both sites is not available. Approximately 90% of the sediment transported at Fitzgerald is fine-grained (< 63um). As the flow competency and capacity of the Slave River has been reduced, it is assumed that there is an increase in the delivery of fine-grained aterials to the delta.

To assess geomorphological and botanical change on the Slave Delta before and after impoundment of the Peace River, aerial photographs of the delta were examined from 1946, 1966, 1977 and 1994. Digitizing of the perimeters of the delta landforms for all years using TERRASOFT and ARC INFO GIS was completed and allowed for detailed comparison of the changes in subaerial surface area, changes in lengths and widths of channels and plant assemblage distribution. As the outer delta area is the most rapidly changing part of the delta, selected cleavage bar islands at the mouths of four major distributaries are compared over the 48 year period of time. Rates of change before and after impoundment are compared. The areas of pronounced subaerial surface area increase are in the vicinity of the mouths of ResDelta and Nagle Channels. This is attributable to the significant sediment load carried by ResDelta Channel (85% of the total suspended load of the Slave River) and the protected environment afforded by Moose Deer Island which promotes rapid deposition of the sediment discharging from Nagle Channel.

Evaluation of growth rates of the selected cleavage bar islands indicates that there has been a general reduction from 1946 to 1994. Of interest is the cessation of growth of the islands at the mouth of Mid Channel West and East Channel during the 1977-1994 period. The overall reduction in growth rates may be attributed to the reduction of the suspended sediment load in the Slave River since 1968. Changes in channel width of the four major distributaries from 1946 to 1994 indicate that ResDelta Channel has increased by 47% while East Channel and Old Steamboat Channel have decreased by 59% and 45% respectively. Mid Channel West has basically maintained the same width for the past 48 years.

Evaluation of the change in the temporal and spatial distribution of plant assemblages on the four representative cleavage bar islands over the course of the aerial photography coverage indicates that there is a noteable shift to a drier environment as the areas occupied by the biologically and economically important emergent species. *Equisetum fluviatile* are being reduced and replaced by assemblages which are less productive and less biologically important to species such as migratory birds and muskrat.

In summary, the Slave River flow regime has been significantly altered by impoundment of the Peace River. Ice-free period flows have been reduced by 16% and ice-on flows have increased by approximately 40%. It has been established that the influence of Peace River water on Slave River flow varies seasonally.
A lack of data on ice jamming in the Slave River and particularly in the Slave River Delta make it difficult to conclude whether impoundment of the Peace River may have resulted in a decrease or an increase in ice jamming. Because of lower discharge levels in the Slave during break-up, it is thought that the probability of mechanical break-up will be reduced. In addition, a warming in the regional climate especially during the break-up period, over the past several years has resulted in earlier melting of the snowpack and may result in earlier break-up dates. This warming may be promoting more over-mature or thermal break-ups and thus accentuating any tendancy the altered river regime has to undergo thermal break-up. Reduction in flooding frequency due to reduction in ice jamming in the Slave River Delta will result in reduced sediment accumulation in the mid delta area which may promote vegetation succession to a less productive *Picea glauca* assemblage. Reduction in flooding of any portion of the delta will result in a loss of productivity as the sediment is a significant source of nutrients for plants.

Sediment rating curves relating flow in the Peace River at Peace Point to the suspended sediment load in the Slave River at Fort Fitzgerald, some 180km downstream, indicate that there has been a 33% reduction in suspended sediment transport in the Slave River since 1968. Cleavage bar islands examined from aerial photographs in the outer delta indicate cessation of surface area growth in 50% of the cases examined. Changes in the temporal and spatial distribution of plant assemblages on cleavage bar islands of the outer delta indicate a transition to a drier, less productive environment. Whether this change is related to the change in the Slave flow and sediment transport regime is debateable. As the Slave River Delta progrades into Great Slave Lake the basin of the lake becomes much deeper at the leading edge of the subaqueous topset beds. As such the amount of time to build up the beds so that subaerial features are evident may take a longer period of time. As the sediment load in the Slave River is predicted to have decreased 33% since impoundment the projected lengthening time period necessary for creation of subaerial features may be accentuated by the reduction in sediment.

9.0 FUTURE RESEARCH

A comprehensive assessment of the impacts of impoundment on the progradation of the Slave River Delta into Great Slave Lake is hampered by the lack of historical data as well as quantification of the rates and magnitudes of physical processes in the delta region. This goal is further complicated by the cost and logistical problems associated with research in such an environment. Several recommendations for future research are presented here.

One of the fundamental requirements to assess geomorphic change over time is knowledge of hydrological and sediment transport processes both for ice-on and ice-off conditions. Such information is required to model sediment delivery to the delta and to address seasonal change in sediment source and availability in the Slave River system. No information is available concerning the sediment transport in ResDelta Channel during ice-on flow. Since ResDelta Channel transports 90% of the sediment through the delta, it is necessary to understand progradation rates under ice which may be significant in light of increased winter flow and reduced effects of wave action. It is also necessary to develop and refine sediment transport models to simulate sediment transport between Fitzgerald and the Slave River Delta as well as the routing of sediment through the distributary channel network of the delta into Great Slave Lake. Further quantification of channel parameters such as channel morphology, slope, discharge and bed characteristics are required for sediment transport models. In addition, a regional assessment of sediment transport in the Slave River is required to examine change in sediment source and availability over time. This could be accomplished by using multiquadric equations to generate a surface of sediment yield for the basin and to assess annual and seasonal variability in sediment dynamics.

There is a lack of information concerning the transport of sediment-associated nutrients and contaminants through the Slave River system and their biological impact on the Slave River Delta. Changes in flow of the Peace River system have affected both the competence and capacity of the Slave River. This has implications for change in the textural (grain size) composition of sediment and associated nutrient and contaminant transport characteristics. Further studies of the grain size and associated sediment chemistry are required to model nutrient and contaminant dynamics in the delta.

An assessment of botanical change in the delta was conducted by examining two sets of aerial photographs taken 20 and 18 years apart. This analysis permits gross scale changes in plant assemblages to be discerned. However, detailed field scale investigations are required to properly assess how botanical composition of the plant assemblages has changed over time.

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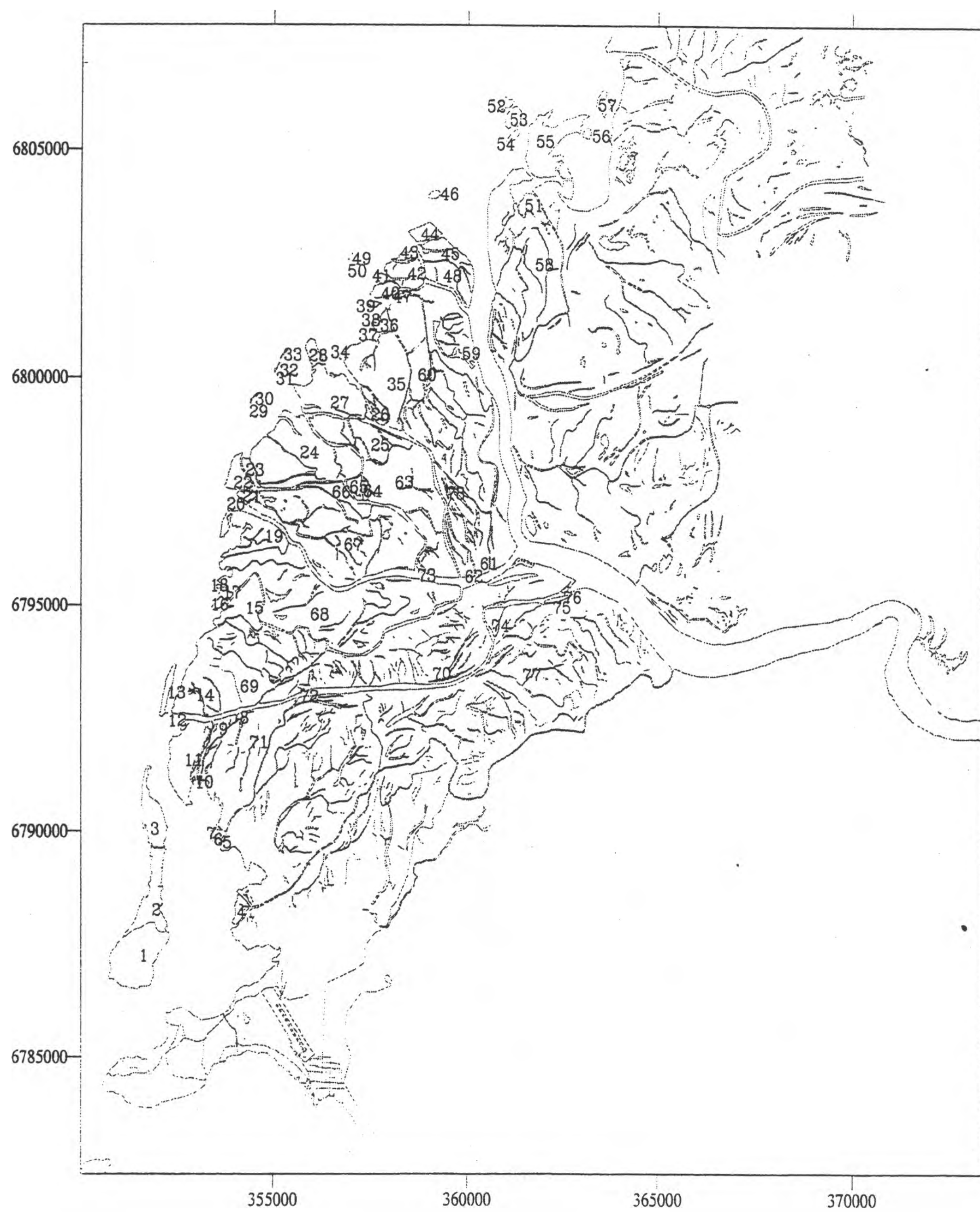
11. APPENDICES

Island I.D. #'s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6795000
6790000
6785000
355000
360000
365000
370000

island id #	1946 area (m^2)	1966 area (m^2)	1977 area (m^2)	1994 area (m^2)
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3			0.000	5638.109
4			4445.398	31553.750
5			4003.156	618.273
6		57325.400	190872.2	275029.913
7		12752.300	0.000	35703.910
8	105265.8	322590.300	732162.300	1160901.000
9	153556.900	134402.200	0.000	148.930
10			38327.320	151730.800
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15			0.000	3023.820
16			45762.495	94429.130
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18	72117.500	106064.100	102603.700	133425.200
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20	1047514.3	507606.000	507282.100	512359.600
21		42261.500	121821.670	234348.300
22	1255246.8	1014189.100	1043554.000	1302082.000
23	496713.600	216661.100	190602.900	156164.300
24			37401.300	4806.172
25			37401.300	2701.984
26			0.000	2821.039
27			0.000	1494.563
28			2440.891	5844.258
29			0.000	1356.656
30	2114560.2	1854255.500	1810748.900	1986899.000
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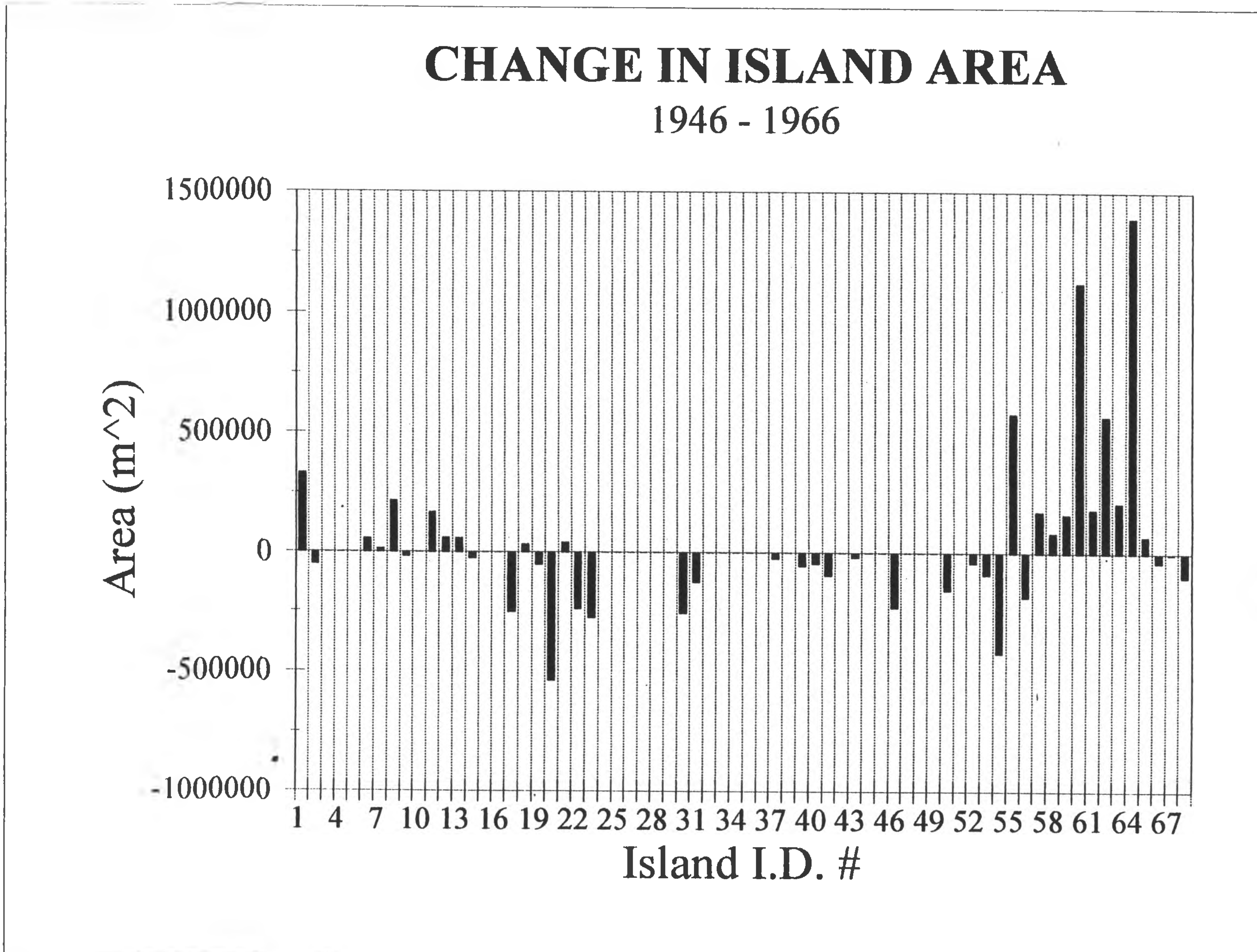
33			0.000	2637.828
34			0.000	29294.960
35			86499.071	176481.400
36			0.000	52840.650
37	214607.900	188284.400	360099.020	444949.800
38			39226.876	75784.470
39	195549.900	136731.800	21982.800	214469.000
40	423765.9	376187.200	382338.000	453131.900
41	120046.1	22826.300	56585.050	41661.390
42			0.000	19988.510
43	815021.8	795517.000	706847.747	715034.700
44			0.000	152.711
45			0.000	395.750
46	5432727.8	5197500.500	4506407	4911908.8
47			30858.225	71454.830
48			23033.534	159710.400
49			44907.437	49187.350
50	588275.400	427733.300	659249.900	1225239.000
51			7848.484	36119.800
52	66732.500	21877.500	92746.200	122662.400
53	2189854.800	2096625.200	1922521.000	1977521.000
54	7508245.1	7084435.300	6799971.000	6921915.000
55	625262.1	1205031.300	1234893	1278786.477
56	292636.900	102003.300	271087.610	350699.600
57	3261798.4	3435464.600	2932238.7	3888061.82
58		83633.200	167337.98	195262.97
59	118868.200	280592.200	285851.800	366231.000
60	3501921	4626348.800	4776493.000	4985698.000
61	6192215.6	6374987.000	4851774.000	6454703.000
62	6518481.3	7088071.200	6747199.861	7085894.000
63	2327796.500	2539787.000	2473701.000	2928270.000
64	25169965.9	26565860.700	23401342.58	25950485.92
65	66164.800	138180.400	175746.100	197045.400
66	40608.800			
67	4796.100			
68	101389.900			
Total:	**82012971.600**	**84149068.100**	**78213657.634**	**90519423.068**


CHANGE IN ISLAND AREA
1946 - 1966
Area (m^2)
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1000000
500000
0
-500000
-1000000
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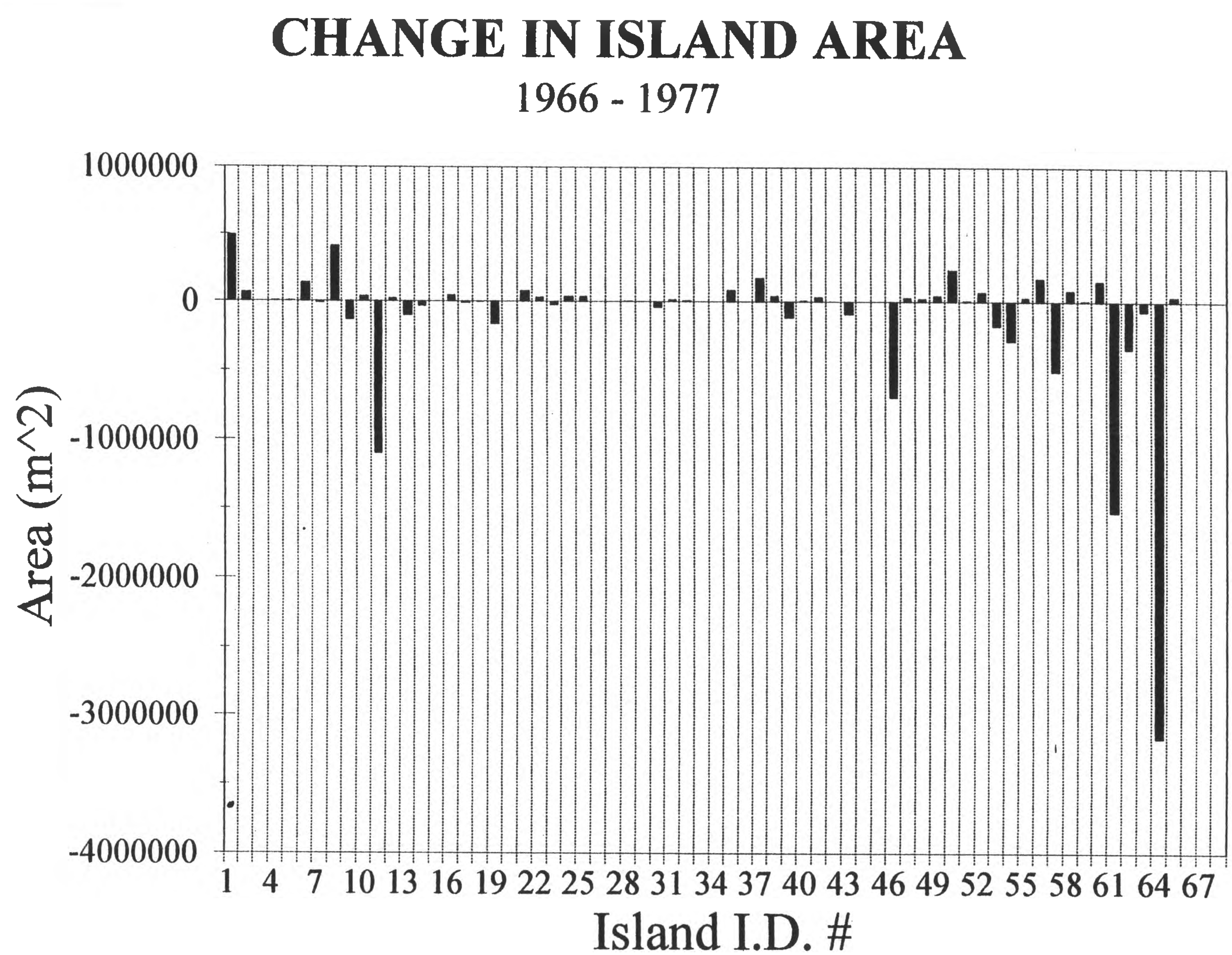
Island I.D. #


CHANGE IN ISLAND AREA
1966 - 1977
Area (m^2)
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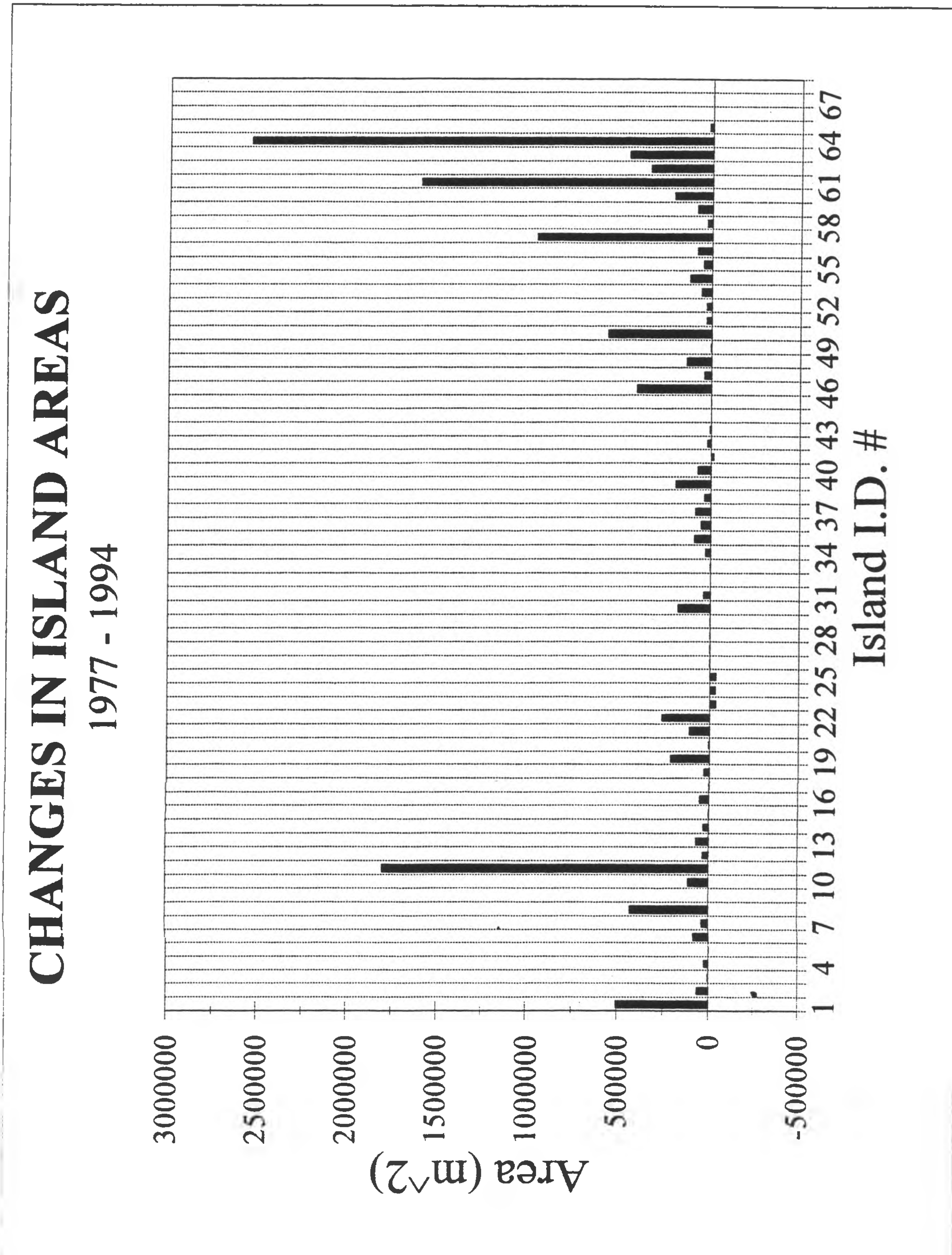
-1000000
-2000000
-3000000
-4000000
Island I.D. #
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67



CHANGES IN ISLAND AREAS
1977 - 1994
Area (m^2)
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25000000
20000000
15000000
10000000
5000000
0
-5000000
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67
Island I.D. #

NORTHERN RIVER BASINS STUDY

APPENDIX B - TERMS OF REFERENCE

1521-D1: Regulation Effects on the Slave River delta: Landform and Distributary Sensitivities to Changes in River Regime

I. BACKGROUND & OBJECTIVES

Since 1968, the flow of the Peace and Slave Rivers has been regulated by the Bennett dam in British Columbia. Such regulation is believed to alter the morphology and the related ecosystem habitat of the downstream river channel. In response to the NRBS Study Board Question #10 ("How does and how could river flow regulation impact the aquatic ecosystem?"), research has been initiated to study the effects of flow regulation on the morphology and riparian vegetation of the Peace River main stem (Project 1321-C1). This study serves to extend this type of assessment to the downstream end of the flow system ie., the Slave River Delta (SRD); an important freshwater-delta ecosystem, the health of which depends upon the seasonal rise and ebb of the river and the significant sediment load which the river transports. Some research was conducted in the late 1970's to ascertain the potential impacts of flow regulation resulting from a proposed hydroelectric project on the Slave River system. The principle investigator of this study conducted these studies, based on photogrammetric analyses and detailed field studies. The objective of the current study is to evaluate how the hydrologic flow regime from 1977 and 1994/95 has modified the morphological features sensitive to flow changes and of the major changes that have resulted from the regulation of the Peace/Slave River system. These assessments will rely on historic flow records, ice regime conditions, a comparison of aerial photography from 1977 and 1994, (note that this latter photographic record will be obtained on an extremely cost effective basis as part of general surveys being conducted by the Government of the Northwest Territories in the summer of 1994), and a 1995 field program to verify the results of the photogrammetric comparative analyses.

A secondary benefit of this study is to identify long-term, sediment deposition zones for use in identifying long-term deposition zones of fine sediment in the Slave River Delta. This is to be used in guiding future contaminant-sediment sampling in this area.

II. OBJECTIVES

1. Determine changes in the channel morphology, spatial coverage of notable bars, shoals and the main islands of the delta by photogrammetric comparisons.

2. Perform a field check of the results found in the photogrammetric study.

3. Interpret observed geomorphic changes relative to hydrologic regime changes that have occurred from approximately 1960 to present.

III. REQUIREMENTS

1994/95

1. Determine changes in the channel morphology, spatial coverage of notable bars, shoals and the main islands of the delta by photogrammetric comparisons.

2. Submit interim report on results of photogrammetric comparisons.

1995/96

3. Perform a field check of the results found in the photogrammetric study.

4. Interpret observed geomorphic changes relative to hydrologic regime changes that have occurred from approximately 1960 to present.

5. Submit final interpretive report summarizing results of 1, 3 and 4, above.

IV. DELIVERABLES

1994/95

1. Interim report of preliminary results from photogrammetric comparisons. Due March 1, 1995

1995/96

2. Draft "Final" report including results from ground-truth surveys. Due September 30, 1995

3. Six to ten 35 mm slides that can be used at public meetings to summarize the results and major findings along with relevant photographs. Due September 30, 1995

V. REPORTING REQUIREMENTS

1. The Contractor is to provide draft, interim and final reports in the style and format outlined in the NRBS Style Manual. A copy of the Style Manual entitled "A Guide for the Preparation of Reports" will be supplied to the contractor by the NRBS.

2. Ten copies of the Draft, Interim and "Final" reports along with an electronic disk copy are to be submitted to the Project Liaison Officer by March 1, 1995 and September 30, 1995.

Three weeks after the receipt of review comments on the draft reports, the Contractor is to provide the Project Liaison Officer with two unbound, camera ready copies and ten cerlox bound copies of the final report along with an electronic version.

3. The "Final" report is to include the following: an acknowledgement section that indicates any local involvement in the project, Project Summary, 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 set up in the following format:

a) Times Roman 12 point (Pro) or Times New Roman (WPWIN60) font.
b) Margins; are 1" at top and bottom, 7/8" on left and right.
c) Headings; in the report body are labelled with hierarchical decimal Arabic numbers.
d) Text; is presented with full justification; that is, the text aligns on both left and right margins.
e) Page numbers; are Arabic numerals for the body of the report, centred at the bottom of each page and bold.

- If photographs are to be included in the report text 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 or Word Perfect for Windows Version 6.0 format.
- Electronic copies of tables, figures and data appendices in the report are also to be submitted to the Project Liaison Officer 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 (latitude and longitude).

4. All figures and maps are to be delivered in both hard copy (paper) and digital formats. Acceptable formats include: DXF, uncompressed E00, VEC/VEH, Atlas and ISIF. All digital maps must be properly geo-referenced.

5. All sampling locations presented in report and 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).

VI. CONTRACT ADMINISTRATION

The Project Liaison Officer (Component Coordinator) for this project is:

Firstly;

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