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A Sediment Budget of the Lower Fraser River

A SEDIMENT BUDGET OF THE LOWER FRASER RIVER

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ABSTRACT

A comprehensive sediment budget was developed for the lower 85 km of the Fraser River, British Columbia. The analysis involved comparing the bed material loads, dredging quantities and channel changes over the periods 1963 - 1974 and 1974 - 1984. The results of the budget were used to make preliminary estimates of the sediment outflows to the delta front and to assess the long term impacts of dredging on the regime of the river. The average annual total load of the Fraser River at Mission and Port Mann, at the upstream end of the study reach, was estimated to be 17.3 million tonnes/year. The average annual bed material load (sand coarser than 0.18 mm) was estimated to vary from 3.9 million tonnes/year between 1963 - 1974 to 2.4 million tonnes/year between 1974 - 1984. The net quantity of material removed from dredging exceeded the incoming bed material load by nearly a factor of two in the period 1974 - 1984. As a result, the river bed has been lowering at a rate of about 8 cm/year. The study demonstrates the usefulness of long term sediment measurement programs and the importance of integrating these programs with other data collection activities (monitoring dredging and hydrographic surveys).

INTRODUCTION

Purpose

This report describes the progress that has been made towards developing a comprehensive sediment budget for the Lower Fraser River (Figure 1). The study area extends 85 km from Mission City to the mouth of the river at Sand Heads and includes the main navigable portion of the river below New Westminster. The analysis provides a means for evaluating the relation between the incoming sediment loads, the past dredging activities and the channel changes that have taken place along the river over the last 20 years. These results will assist other agencies in planning and evaluating future dredging and river training programs on the river. A secondary objective of the study is to provide an estimate of the long term sediment outflow from the main channel to the delta front off Sand Heads. These estimates should assist in developing a better understanding of the likely impacts of continued dredging and river training activities on the long term stability of the delta front.

Description of the Study Area

The Fraser is the largest river in British Columbia draining an area over 234 000 square kilometres and travelling approximately 1 400 kilometres from its headwaters in Mount Robson Provincial Park to its mouth near Vancouver, British Columbia. In this report, the Lower Fraser River refers to the 165-kilometre reach between Hope and Sand Heads, the lighthouse marking the channel entrance at the estuary mouth.

Runoff in the basin is dominated by spring snowmelt and generally produces a bell-shaped hydrograph. Peak annual flows normally occur between the first of May and the end of June. Annual peaks at Hope, since 1912, have ranged from 5 130 m^3/s to 15 200 m^3/s with a mean of 8 770 m^3/s.

The tidal reach of the Fraser varies with flow. At low flows it extends to Sumas Mountain (km 98); for flows at Hope greater than 5 000 m^3/s, the tidal effects at Mission (km 85) become very small. At Port Mann (km 42) flows reverse until the flow at Hope exceeds 4 000 m^3/s (Ages and Woolard, 1976). Depending on flow and tide range, salt water from the Straight of Georgia can intrude some distance into the Fraser estuary. With low discharge flows and large tides the salt wedge may reach New Westminster (km 35), but for flows exceeding 5 000 m^3/s, it rarely extends beyond the Steveston Bend (km 10) (Beak, 1980).

The lower Fraser can be divided into three morphologic reaches. From Hope to Sumas Mountain, the river displays a wandering or anastomosed channel pattern with a gravel bed. The channel is frequently confined by bedrock outcrops and by rip-rap-protected embankments. Below Sumas Mountain, there is an abrupt transition to a single, sinuous, sand bed channel, frequently confined by Pleistocene uplands. The modern delta reach begins at New Westminster, where the river splits into three distributary channels.

Methodology

A sediment budget for any reach of the Lower Fraser River can be written as:

$$(1) \quad \Delta S_{CHAN} = S_{IN} - S_{OUT} - S_{DREDGE}$$

where:
- S_{OUT} = sediment outflow from the reach
- S_{IN} = sediment inflow to the reach
- S_{DREDGE} = the net mass of sediment dredged from the reach
- ΔS_{CHAN} = the net change in sediment stored within the channel

This equation shows that the long term channel change (ΔS_{CHAN}) will be determined by the loads coming into and exiting from the reach and the net effective dredging that has been carried out. The equation can be re-arranged to provide estimates of the past sediment outflows from a reach provided the inflows, net dredging quantities and past channel changes are all known:

$$(2) \quad S_{OUT} = S_{IN} - S_{DREDGE} - \Delta S_{CHAN}$$

The time period considered in this type of analysis is usually chosen to be in the order of years to decades, although shorter time periods could also be considered. Furthermore, the analysis must consider the size distribution of the channel sediments, the dredged materials and the incoming sediment load. As this analysis was applied only to the sediments that make up the bed material in the main stem of the river, the sediment budget is restricted to only the bed material load.

AVAILABLE DATA

Sediment Load

A comprehensive data collection program on the Lower Fraser was established by the Water Survey of Canada (WSC) at Hope, Agassiz, Mission and Port Mann. The program has included the measurement of suspended sediment, bed load and bed material. The initial planning and establishment of these stations was described in detail previously (WSC, 1970) and the history and evolution of the sediment network has been outlined by Zrymiak (1982) and Kellerhals (1984).

Based on 18 years of sediment data at Mission, the mean annual total sediment load is 17.3 million tonnes/year. This load is composed of approximately 35 percent sand (particles > 0.063 mm), 50 percent silt (0.004 - 0.063 mm) and 15 percent clay (< 0.004 mm).

A substantial effort was recently made to estimate the annual total load at Mission by grain size fraction using the discharge and sediment data (McLean and Church, 1986). A comparison between sediment transport measurements at Port Mann and Mission indicated that the annual loads agreed reasonably closely, which is not surprising since there are no major tributaries or sediment sinks between the two stations. A comparison of the size distributions of the loads also showed good agreement. Therefore, on this basis it appears that the annual loads measured at Mission provide reliable estimates of sediment inflows to the estuary.

Although some miscellaneous suspended sediment concentration measurements have been made in the estuary, these data are inadequate for estimating annual loads. This is because the unsteady nature of the tidal flows, and the effects of salinity intrusion greatly complicate any data collection program.

Channel Data

Complete hydrographic surveys of the 42 km reach between Port Mann and Sand Heads have been carried out on an annual basis for the last 30 years by Public Works Canada (PWC). These annual surveys have all been made during the low flow season usually between October - January when the bed is relatively inactive. Additional earlier surveys are also available at less frequent intervals with some soundings dating back to the 1880s. Hydrographic data upstream of Port Mann are available only for 1952, 1963 and 1984.

Dredging Data

PWC records of historical dredging volumes were reviewed and the methods, locations, disposal and grain size characteristics of the dredged sediments were assessed. Two types of dredging records are maintained; navigation dredging, dredging performed to maintain drafts in the 200 m wide navigation channel, and borrow dredging material removed for use in construction projects; it may or may not be from the navigation channel.

Bed Material Data

Bed material samples have been collected regularly at Mission and Port Mann by WSC using BM-54 samplers. Samples were also collected along the centre of the channel between Sand Heads and New Westminster by PWC in 1986. Comparison of the bed material samples collected between Mission and Sand Heads has shown that the composition of the river bed is fairly uniform. Using the criterion suggested by Einstein, (1950) a grain size of 0.18 mm was adopted in this study to represent the break between wash load and bed material load. Therefore, the bed material load was estimated on this basis.

SEDIMENT BUDGET RESULTS AND DISCUSSION

The sediment budget for the bed material load was computed for two time periods; 1963 to 1974 and 1974 to 1984. Figure 2 shows the estimated quantities of bed material load transported along the main stem as computed from the budget. An overall summary of the sediment budget for the two periods is shown in Table 1.

Table 1
Sediment Budget - Mission to Sand Heads

	1963-1974 10^6 t/year	1974-1983 10^6 t/year
average inflow of bed material (at Mission)	3.93	2.41
average net mainstem dredging	1.86	4.20
average net channel change	-1.16	-2.95
estimated losses to tributaries	0.47	0.25
average outflow of bed material (at Sand Heads)	2.76	0.91

A reliable check of the sediment budget results might be made by performing additional surveys and collecting sediment samples off the delta front near Sand Heads and estimating the long term sand accumulation that has taken place at the mouth of the river. However, due to the unsteady nature of flows in the estuary, this will be a difficult undertaking.

The budget shows that in response to the dredging program, the river has degraded. Figure 3 illustrates the overall net channel changes that have occurred between New Westminster and Sand Heads. This shows that the bed has lowered at a fairly consistent rate of 8 cm/year, or 2 m over the last 25 years. In the individual reaches (Figure 2) the mean bed levels have lowered on average by 2 m - 4 m (10 - 20 cm/year). However, in most reaches there is no consistent relation between rate of bed level change and dredging effort. For example, in the Sand Heads reach, the bed appears to have aggraded between 1974 - 1983 even though the dredging effort increased to near record levels. A similar pattern occurred at Steveston Cut where in recent years the dredging effort has nearly doubled while the bed level has remained virtually static.

The sediment budget analysis provides a good basis for illustrating how sedimentation processes have influenced the navigation improvements that have been achieved from the dredging program. The period between 1963 - 1974 extends before and after the construction of the Trifurcation Project at New Westminster. As a result, major channel adjustments were taking place during this time in response to these river training works. This period also includes some very large sediment inflow and runoff years such as 1972 and 1967. The analysis between 1974 - 1984 covers the period when increased dredging operations were carried out to increase the available drafts. This period was characterized by lower than average sediment inflow and runoff conditions. Therefore, the channel response during these two periods should be very different.

The analysis for the 1963 - 1974 period shows that the net dredging (20.5×10^6 t) comprised less than one half of the total bed material load (43.2×10^6 t) inflows at Mission. The resulting channel degradation (12.76×10^6 t) represented approximately 62% of the net dredging quantity. The estimated sediment outflow of bed material at Sand Heads amounted to 30.4×10^6 t over the period or about 2.8×10^6 t/year. This amount corresponds to 76% of the inflows at Mission which indicates the channel had a very high transport efficiency during this period.

The main features of the 1974 - 1984 analysis are the net dredging (46.1×10^6 t) exceeded the total bed material load at Mission (26.5×10^6 t) by 75%. The net channel degradation that occurred during this period (32.4×10^6 t) corresponds to about 70% of the net dredging quantity. The estimated outflow of bed material at Sand Heads was only about 40% of the load at Mission and about 45% of the estimated load immediately downstream of the Trifurcation. This indicates that the channel's transport capacity decreases substantially downstream of New Westminster and that without ongoing dredging this reach would have aggraded.

The higher transport efficiency during the 1963 - 1974 period may be due to two factors. First, although the sediment inflows were higher than average between 1963 - 1974 the peak flows were also persistently higher than the long term average. Therefore the capacity to flush the sediment out of the river was higher between 1963 - 1974 than between 1974 - 1984. Also the shallower depths and higher velocities in this earlier period would also increase the channel's transport capacity.

The results of the sediment budget analysis can be used to provide a first order estimate of the long term maintenance dredging requirements that would maintain the channel in equilibrium over a number of years. The analysis between 1974 - 1984 showed that the overall net trap efficiency of the main stem channel (for bed material load) amounted to nearly 60%. Assuming a long term inflow of 3.2×10^6 t/year this suggests that in the order of 2×10^6 t/year of sediment would have to be removed from the channel to maintain a long term equilibrium condition. However, this equilibrium condition would take a number of years to become established since channel adjustment and redistribution of sediment from the channel sides might continue for a number of years. Therefore, this figure represents a lower bound or end condition for the maintenance dredging requirements.

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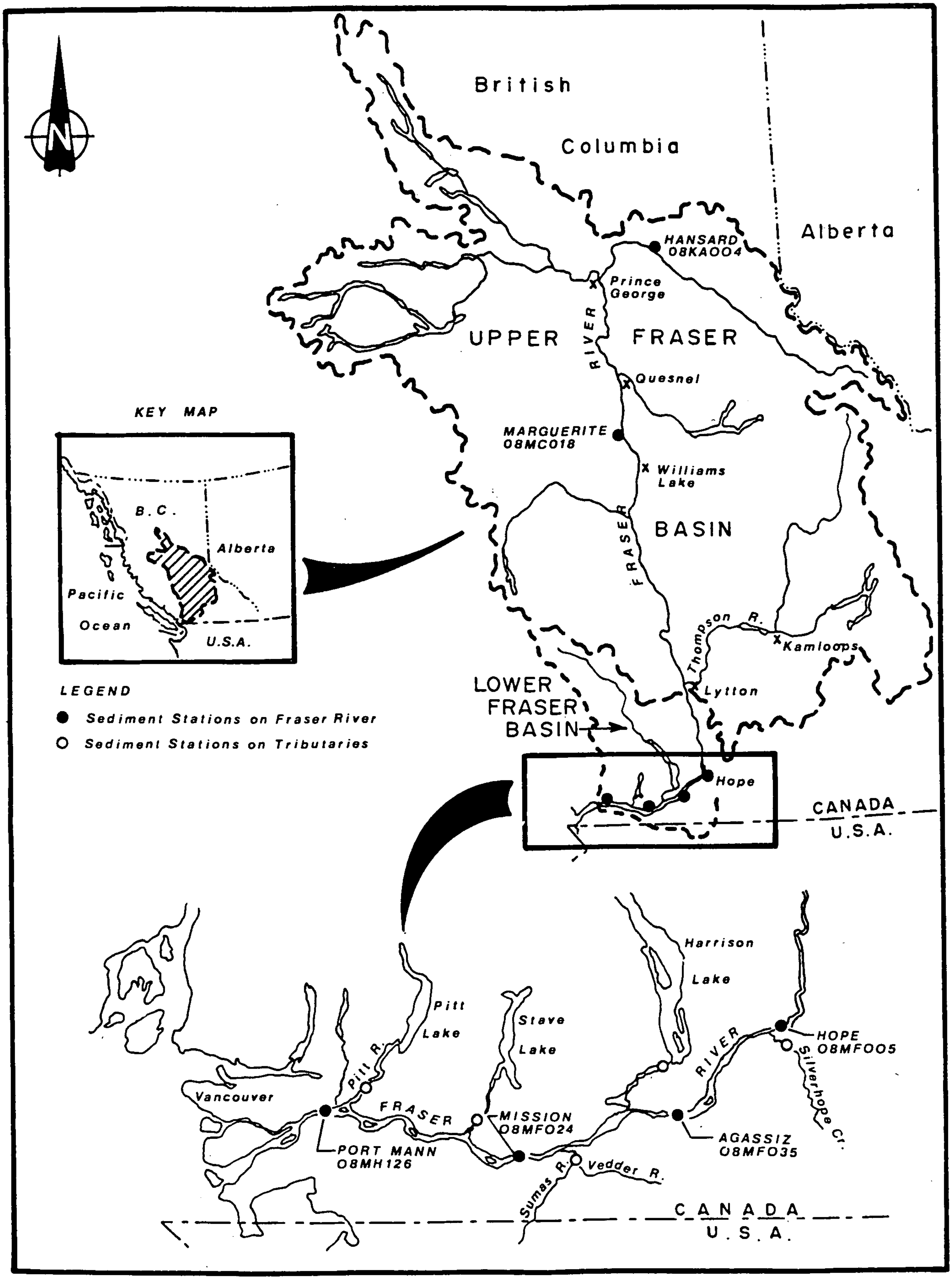

Figure 1. The Fraser River Basin

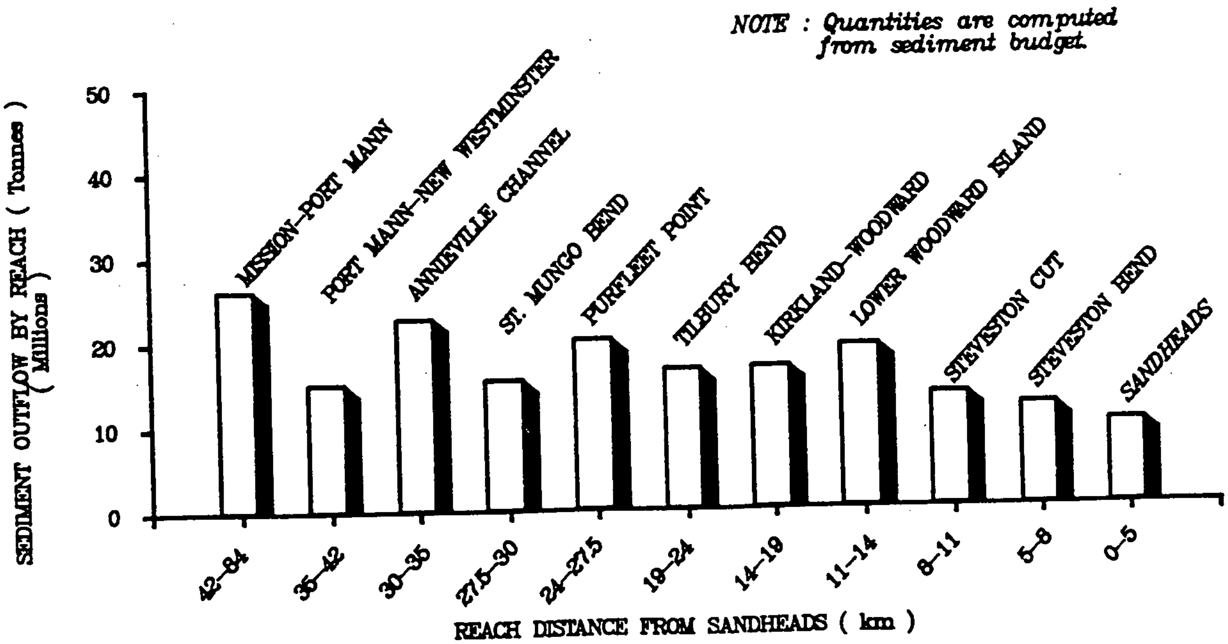

Figure 2. Total Bed Material Transport 1974 – 1984

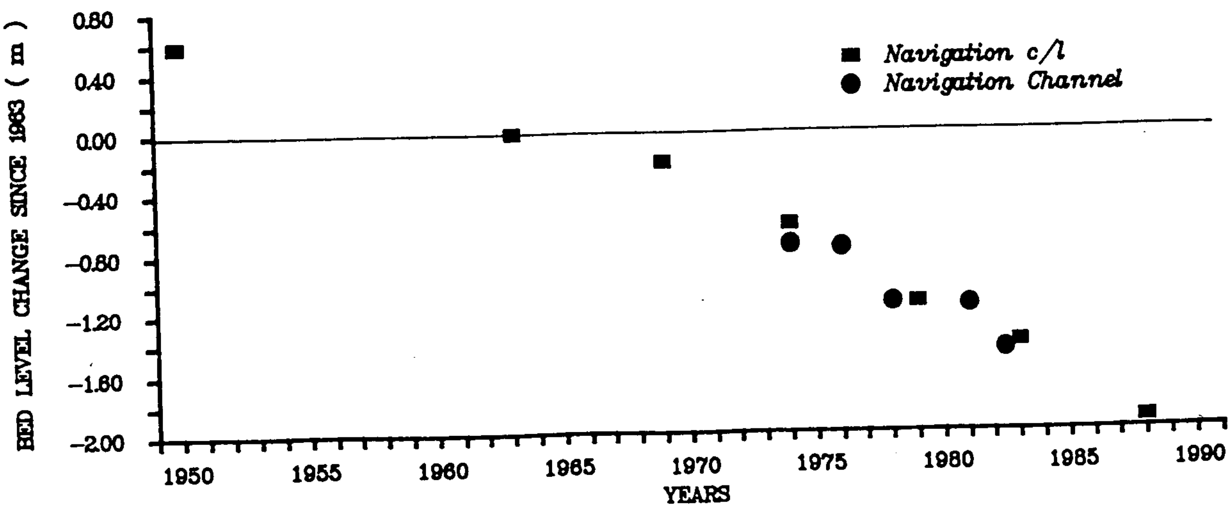

Figure 3. Average Channel Changes below New Westminster

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