CHAPTER 59

SEDIMENT BUDGET OF THE LOWER FRASER RIVER

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ABSTRACT

The Lower Fraser River, being continually developed for better navigation and larger port facilities, is an area of active sedimentation. The dynamic processes influenced by river discharge, tides and winds are probably the most important factors in the transport and deposition of sediments in the estuary. The main part of the Fraser Estuary is vertically homogeneous (non-stratified) and the sediments are transported progressively seaward and are accumulated near the limit of net landward flow. The lower estuary is stratified and coarse sediments are trapped near the toe of the salt wedge while the fine sediments are carried seaward with the outflowing river water.

The hydrometric and sediment survey of the lower Fraser River are described. Survey results are used in determining the sediment balance of the river reach. In the budget analysis, the river and estuary are divided into four consecutive reaches, the sediment discharges are subdivided to represent about 10 particle size ranges and the balance is then determined for each reach and particle size range.

Conclusions are drawn with respect to the sediment transport and depositional characteristics, annual variations, and the agreement between the sediment entering the estuary and the sediment dredged.

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INTRODUCTION

A comprehensive hydrometric and sediment survey was started on the Lower Fraser River by the Water Survey of Canada in 1965. Flow and sediment data were required in the assessment of problems related to the maintenance and improvement of the navigation channel of the Lower Fraser River. Proper economic and engineering design for increased depths and widths, whether by dredging, training works or combinations of these two, required reliable and accurate data. Decisions related to extension of the deep sea channel to Mission City and of improvements to the navigation channel for barge traffic between Mission City and Hope awaited more reliable hydraulic and geomorphologic data in the Lower Fraser River reaches.

Navigation was only one of several problems associated with the Fraser River which would benefit from a comprehensive hydrometric and sediment survey. The data obtained would be essential in design of projects related to bank stabilization, protection dykes, land reclamation, harbour and mooring facilities, flood control and fisheries. The availability of these type of data for possible litigation during construction and operation of hydraulic projects should not be overlooked.

The analysis of data included the computation of a sediment budget. In this analysis, the sediment balance was determined for four consecutive parts of the lower river reach or estuary. The sediment discharges were subdivided to be representative of several particle size ranges and the balance was then determined for each part and each particle size range.

A general description of the hydrometric and sediment survey, the details of the budget analysis and some of the results are described and illustrated in this paper.

RIVER HYDRAULICS

The Fraser River with its tributaries drain 90,000 square miles of central and northern British Columbia into the Pacific Ocean near Vancouver. At the Fraser River at Hope, approximately 100 miles upstream from the mouth, the mean discharge is 94,600 cfs; the average annual runoff is in the order of 68,500,000 acre-feet. The Lower Fraser River, the reach between Hope and the Strait of Georgia, is illustrated in Figure 1.

The station, Fraser River at Hope, has been operational since March 1912, and has served as a useful base station in the prediction and calculation of flows below this point. The daily discharge at this station has varied from a low of 12,000 cfs on January 8, 1916 to a high of 536,000 cfs on May 31, 1948. The tributary inflow between Hope and Port Mann is about 30 percent of the total flow at Hope.

The suspended sediment discharge at the Fraser River at Hope is 20.6 million tons per year (average of 1966 to 1970 inclusive) and has varied from a daily low of 119 tons per day on January 16, 1967, to a daily high of 911,000 tons per day on May 11, 1966.

To further illustrate the river hydraulics, a flow duration curve obtained using daily flows for the Fraser River at Hope for the period October 1, 1946 to September 30, 1966, is shown in Figure 2. A frequency curve is shown in Figure 3 for this same station. The frequency curve was developed by the method of maximum likelihood (Chow, 1964) and is in terms of natural flows; that is, the flows have been adjusted to compensate for the effect of upstream river regulation.

Between Hope and the mouth, the natural channel has an average width of 2,000 feet, which expands to more than 3 miles in some areas. In this reach, Hope to the Strait of Georgia, the river falls approximately 125 feet of which the first 100 feet occur within the first 43 miles. In this eastern reach of the Lower Fraser River, particularly just east of the Sumas River, the spring freshets deposit coarse gravel material in the form of gravel bars. West from the mouth of the Sumas River the river slope is smaller and sands are deposited.

A large portion of the Lower Fraser River reach is affected by tides. During low flow the upstream limit of tidal effect is Chilliwack Mountain, approximately 15 miles east of Mission City. The high flow limit falls between Mission City and Whonock. This tidal effect within the survey reach has made the survey extremely complex. Deviation from standard methods of hydrometric and sediment measurement and computation were required in the determination of unsteady flows and the resulting sediment movement. A comparatively large amount of data were required to determine the pattern of sediment movement and to obtain a suitable understanding of unsteady flow in tidal portions of the study reach.

The complexity of the river hydraulics downstream from Port Mann is further increased by river branching. The approximate branching and flow distributions are illustrated by Figure 4 (Keane, 1957).

HYDROMETRIC AND SEDIMENT SURVEY

Some hydrometric data for the Lower Fraser River date back to 1876. However, it is only during the last 15 or 20 years in which a comprehensive hydrometric program in this area has been made operational. (Water Survey of Canada, 1970).

Much of the data that are collected in the lower tidal reaches are in the form of water surface elevations rather than discharge data normally required by the design engineer. Measurement and computation of tidal flow is relatively complex. Daily water level fluctuations which can exceed ten feet, variations and reversals in river flows, and the relatively large river depths, widths and velocities have produced a need for deviation from standard hydrometric techniques and have resulted in development of more sophisticated methods in the study of hydrometry of this river reach.

Discussion of the hydrometric survey of the Lower Fraser River cannot be entirely separated from the sediment survey since some of the recent developments in hydrometry have resulted from the needs of the sediment survey. The main sediment survey stations which required as a basis a complete hydrometric program were as follows: the four Fraser River stations located at Hope, Agassiz, Mission City and Port Mann; and the five tributary stations Pitt River near Port Coquitlam, Stave River at Stave Falls, Chilliwack River at Vedder Crossing, Harrison River near Harrison Hot Springs and Silverhope Creek near Hope. This network of stations is illustrated in Figure 1. Continuous daily sediment and flow data have been obtained by the Water Survey of Canada at these stations since 1965.

The sediment data are of two types: suspended sediment and bed load. Bed load is the sediment that moves in essentially continuous contact with the bed of the stream whereas suspended sediment is the sediment supported by the flow. Bed load data were collected at only three stations of the main channel of the Fraser River; at Port Mann, Mission City and Agassiz.

Complementary to the sediment survey, records of public and private dredging have been kept by several agencies. These dredging data were used in the sediment budget analysis as these were the only quantitative data for the river downstream from Port Mann.

ANALYSIS DETAILS AND RESULTS

A number of simplifications or assumptions were made to facilitate the analysis. These were as follows: suspended sediment and bed load inflow from the tributaries could be ignored; the density of the material dredged was 90 pounds per cubic foot; the provisional data, some of which were used in these analysis were accurate; and the dissolved solids component was negligible. These assumptions could be readily justified, for example: suspended sediment inflow from four main tributaries is in the order of one percent of the suspended sediment discharge of the Fraser River at Hope; densities of deposited sands vary from 10 to 120 pounds per cubic foot (Inter-Agency Committee on Water Resources, 1963) and so on.

The budget is based on daily flow, suspended sediment and bed load data. The sediment discharge at a station is represented by:

$$QS(QB,QSB) = \sum_{i=1}^{n} QS(QB,QSB)_i \tag{1}$$

Continuity within a reach is represented by:

$$QS(QB,QSB)_{xi} = QS(QB,QSB)_{yi} - SS_{xyi} \tag{2}$$

Also of interest is a comparison of sediment measured at Port Mann with the material dredged downstream:

$$QSB_i - DSB_i = OSB_i \tag{3}$$

In these equations, QS, QB and QSB are suspended sediment, bed load, and total load respectively. DSB and OSB are respectively the total load dredged and outflowing total load, that is, total load transported past the area of dredging. The particle size ranges are represented by subscript i, number of particle size ranges by n, upstream and downstream stations of a reach by x and y, and storage or deposition within a reach by SS, SB and SSB for suspended sediment, bed load and total load respectively.

The particle size distributions for both the suspended sediment and the bed load were determined for each day for the Fraser River stations from available data. The seasonal variations were found to be quite significant. These are illustrated in Tables 1 and 2, showing the particle size distributions for January 10 and June 10, 1969 for suspended sediment and bed material respectively. (The flow at Hope on January 10 was 42,000 cfs and on June 10, 274,000 cfs).

With the daily particle size distributions, and daily flow and sediment discharges, it was possible to perform the budget analyses on a daily basis using equations 1 and 2. Thus, the suspended sediment transported by the river was computed for the four Fraser River stations on a daily basis for the particle size ranges 0.000 - 0.062, 0.062 - 0.125, 0.125 - 0.500, and 0.500 - 1.000 mm. Bed load transported was also computed on a daily basis for these particle size ranges and also, where applicable, for the ranges 1.000 - 2.000, 2.000 - 4.000, 4.000 - 8.000, 8.000 - 19.10, 19.10 - 38.10, 38.10 - 76.20 and 76.20 - 152.4 mm. Bed load data were not available for the Fraser River at Hope.

The daily details are too numerous for illustrating in this paper. Furthermore, these are more meaningful on an annual basis and are thus represented for each main channel station in Tables 3, 4 and 5. These tables show, respectively, the annual suspended sediment, bed load and total load discharges for the four main channel stations for the years of available data. Partial year data are not shown.

The total load budgets, as determined by equation 2, are illustrated in Figures 5 and 6 for the Agassiz to Mission City and Mission City to Port Mann reaches respectively. Similar budgets could be prepared for suspended sediment and bed load discharges from data shown in Tables 3, 4 and 5.

Finally, annual data were used in equation 3 for comparing the total sediment discharge at Port Mann with the material dredged downstream from this location. It is convenient to illustrate these results in terms of percent of material dredged of the total sediment discharge at Port Mann. The percentages for the various particle size ranges are shown in Figure 7.

CONCLUSIONS

A number of observations with respect to the sediment balance in the Lower Fraser River can be made.

Gravels and boulders are transported by the river during very high flow only and are deposited at about the tidal limit between Agassiz and Mission City. Within the tidally influenced reach, a natural sorting of grain sizes occurs, the coarser particles being deposited in the upstream reaches. In the most active dredging reach, between Port Mann and Steveston, which is also within the reach of salt water intrusion, the sorting appears to terminate resulting in a river bed composed of relatively uniform grain sizes. The results shown in Tables 1 to 5 inclusive illustrate this phenomenon.

It is evident from Table 2 that clay and silt sizes (sizes finer than 0.062 mm) constitute only a very small fraction of the bed material at the four Fraser River stations and in the main channel downstream from Port Mann. For this reason the silt and clay sizes were not subdivided for the budget computations but were instead treated together in the particle size range 0.000 to 0.062 mm. The absence of this fraction in the dredging region, as far downstream as Steveston indicates that the silts and clays are transported into the Strait of Georgia and must be deposited nearer to the foot of the delta.

The comparison of dredged and measured quantities is illustrated in Figure 7 and is perhaps relatively more difficult to interpret. The results perhaps indicate that more coarse material is dredged than is transported by the river to the dredging region considered. At least part of the difference must be the result of the settling out, in the dredging area, of some of those sediments which are in suspension at Port Mann. It has been observed in other tidal rivers that the upstream tip of a saline wedge is a focal point for sediment deposition. This factor and the fact that it is during the peak of the freshets that the bed of the river becomes most active in shoaling and scouring, could account for much of the heavy shoaling which occurs at Steveston. There is evidence that the salt water intrusion does not extend much further upstream than Steveston during a freshet. (Pretious, 1972). Other possible explanations for the measured and dredged differences are possible, for example, removal of large quantities of material for construction of the international airport and of bridge approaches; redistribution of the bed within the dredging area; undersampling of bed load, in the sense that suspended sediments in suspension at one point of measurement could become bed load at a downstream point; the distribution of total sediment load into the various channels of the lower estuary is not known and hence the possibility of overdredging of only one channel could not be evaluated; all dredged material was assumed to be represented by the average particle size distribution of the bed material in the main channel; and other factors. In summary, this part of the analysis is inconclusive because of insufficient data downstream from Port Mann.

Finally, one other observation should perhaps be noted: the sediment balance in the two river reaches Agassiz to Mission City and Mission City to Port Mann. Figures 5 and 6 illustrate that there is a net degradation of the upstream reach and a net aggradation of the downstream reach. In both reaches, however, there is an aggradation of coarse sediments. Hence these figures further verify the sorting process which is occurring in the Lower Fraser River.

ACKNOWLEDGEMENTS

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TABLE 1

Particle Size Distributions for Suspended Sediment
for January 10 and June 10, 1969.

Station	Day	Percent finer than indicated size (mm)					
		0.062	0.125	0.250	0.500	1.000	2.000
Fraser River at Port Mann	Jan. 10	100	100	100	100	100	100
	June 10	51.2	71.6	87.1	96.7	100	100
Fraser River At Mission City	Jan. 10	100	100	100	100	100	100
	June 10	42.7	58.4	82.3	96.9	100	100
Fraser River near Agassiz	Jan. 10	89.8	95.0	100	100	100	100
	June 10	59.6	72.0	88.9	97.6	100	100
Fraser River at Hope	Jan. 10	90.0	95.0	100	100	100	100
	June 10	57.1	74.0	90.4	93.3	100	100

TABLE 2

Particle Size Distributions for Bed Material
for January 10 and June 10, 1969

Station	Day	Percent finer than indicated size (mm)											
		0.062	0.125	0.250	0.500	1.000	2.000	4.000	8.000	19.10	38.10	76.20	152.4
Fraser River at Port Mann	Jan. 10	1.0	5.0	36.2	92.0	100							
	June 10	1.0	3.9	30.7	89.9	100							
Fraser River at Mission City	Jan. 10	0.0	3.0	20.0	70.1	100							
	June 10	0.0	3.0	28.8	77.9	100							
Fraser River near Agassiz*	Jan. 10	0.7	100	100	100	100	100	100	100	100	100	100	100
	June 10							0.0	0.1	24.6	64.5	89.8	100
Fraser River at Hope	Jan. 10)	No data available											
	June 10)												
Material below Port Mann**	-	0.5	2.7	29.2	90.3	95.7	96.2	98.4	100				

* Particle Size distributions of bed load which were assumed to be equivalent to bed material sizes.

** Average of 29 samples taken at 5 locations in main channel in active dredging region (March 19, 1971).

TABLE 3

Fraser River Suspended Sediment Budget (per Station)

Location	Year	0.000-[a] 0.062	0.062- 0.125	0.125- 0.250	0.250- 0.500	0.500- 1.000	Total
Hope	1966	14,400[b]	2,590	2,420	1,270	1,660	21,800
	1967	17,600	3,410	2,370	1,220	1,250	25,900
	1968	18,100	3,050	4,470	1,550	681	27,900
	1969	9,340	1,910	1,920	894	477	14,500
Agassiz	1967	17,700	4,170	3,530	2,020	536	28,000
	1968	16,100	3,710	2,600	944	258	23,600
	1969	9,580	1,690	1,680	897	252	14,100
Mission City	1966	14,400	1,900	3,360	1,160	1,110	21,900
	1967	19,300	4,850	3,700	2,810	1,490	32,200
	1968	16,800	3,080	2,760	2,590	613	25,800
	1969	9,360	3,030	2,880	1,560	503	17,300
Port Mann	1966	14,000	2,730	1,600	960	323	19,600
	1967	15,400	3,800	3,650	1,440	2,420	26,700
	1968	16,100	2,550	2,500	1,080	447	22,700
	1969	8,990	1,760	1,310	669	279	13,000

(a) figures indicate particle size ranges in millimeters.

(b) figures represent thousands of tons suspended sediment discharge per year.

TABLE 4

Fraser River Bed Load Budget (per Station)

Location	Year	0.000-[a] 0.062	0.062- 0.125	0.125- 0.250	0.250- 0.500	0.500- 1.000	1.000- 2.000	2.000- 4.000	4.000- 8.000	8.000- 19.10	19.10- 38.10	38.10- 76.20	76.20- 152.4	Total
Hope			Bed load data were not available											
Agassiz[b]	1967	146[b]	4270	4960	1620	129	25.5	4.10	383	115,000	248,000	180,000	77,100	632,000
	1968	108	3390	7150	2900	174	33.9	5.40	612	66,900	102,000	65,300	26,500	275,000
	1969	70.2	3000	5080	2850	249	48.2	7.50	710	29,400	29,500	16,500	6,370	93,800
Mission City[c]	1967	0[c]	41.6	281	724	104	27.7	27.7	97.0	83.2	0	0	0	1,390
	1968	0	28.3	181	492	52.8	18.9	9.43	37.7	123	0	0	0	943
	1969	0	19.9	161	314	63.0	6.64	6.64	26.6	59.8	6.64	0	0	664
Port Mann[c]	1966	19.7[c]	45.4	708	1030	132	39.4	0						1,970
	1967	17.2	90.8	507	976	108	17.2	0						1,720
	1968	8.98	47.6	270	475	79.0	18.0	0						899
	1969	10.6	42.8	315	595	36.3	63.8	0						1,060

(a) figures indicate particle size ranges in millimeters.

(b) figures represent tons bed load discharge per year.

(c) figures represent thousands of tons bed load discharge per year.

TABLE 5

Fraser River Total Load Budget (per Station)

Location	Year	0.000-0.062 (a)	0.062-0.125	0.125-0.250	0.250-0.500	0.500-1.000	1.000-2.000	2.000-4.000	4.000-8.000	8.000-19.10	19.10-38.10	38.10-76.20	76.20-152.4	Total
Hope		Total load data were not available												
Agassiz	1967	17,700 (b)	4,170	3,530	2,020	536	0.026	0.004	0.383	115	248	180	77.1	28,600
	1968	16,100	3,710	2,610	947	258	0.034	0.005	0.612	66.9	102	65.3	26.5	23,900
	1969	9,580	1,690	1,690	900	252	0.026	0.004	0.315	22.6	27.0	16.0	6.30	14,200
Mission City	1967	19,300	4,890	3,980	3,530	1,590	27.7	27.7	97.0	83.2	0	0	0	33,500
	1968	16,800	3,110	2,940	3,080	666	18.9	9.43	37.7	123	0	0	0	26,800
	1969	9,360	3,050	3,040	1,870	566	6.64	6.64	26.6	59.8	6.64	0	0	18,000
Port Mann	1966	14,000	2,780	2,310	1,990	455	39.4	0						21,600
	1967	15,400	3,890	4,160	2,420	2,530	17.2	0						28,400
	1968	16,100	2,600	2,770	1,560	526	18.0	0						23,600
	1969	9,000	1,800	1,630	1,260	315	63.8	0						14,100

(a) figures indicate particle size ranges in millimeters.

(b) figures represent thousands of tons total load discharge per year.

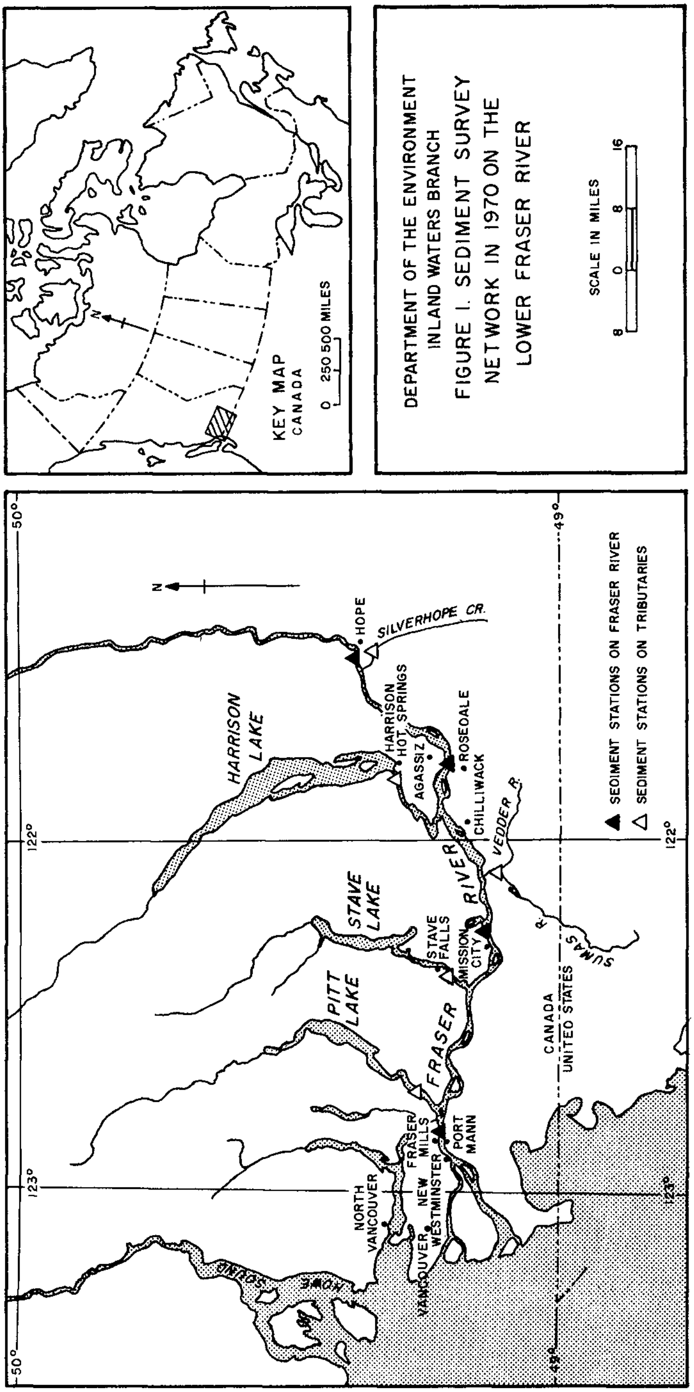

FIGURE 1. SEDIMENT SURVEY NETWORK IN 1970 ON THE LOWER FRASER RIVER

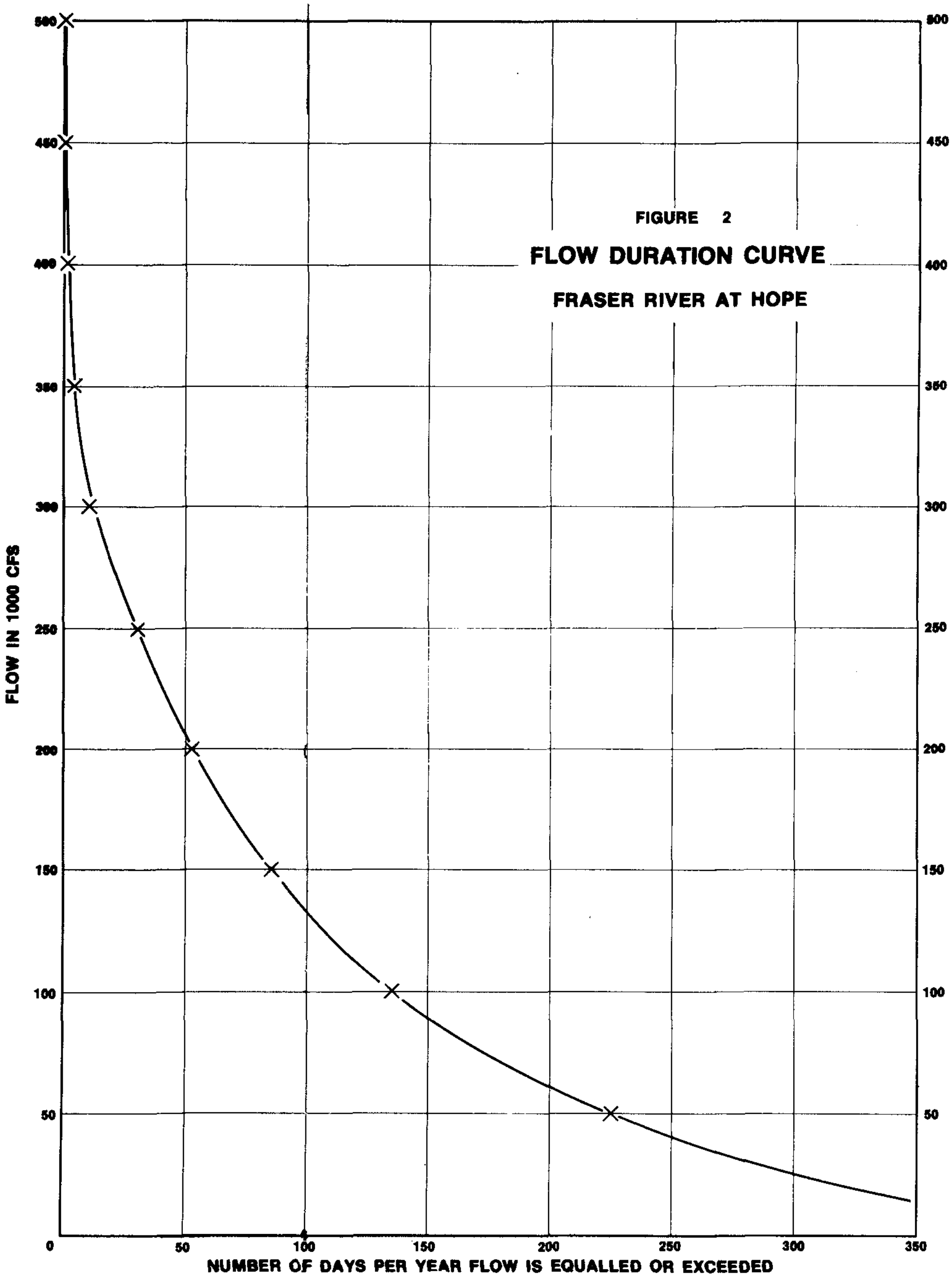
FIGURE 2
FLOW DURATION CURVE
FRASER RIVER AT HOPE
FLOW IN 1000 CFS
0
50
100
150
200
250
300
350
400
450
500
NUMBER OF DAYS PER YEAR FLOW IS EQUALLED OR EXCEEDED

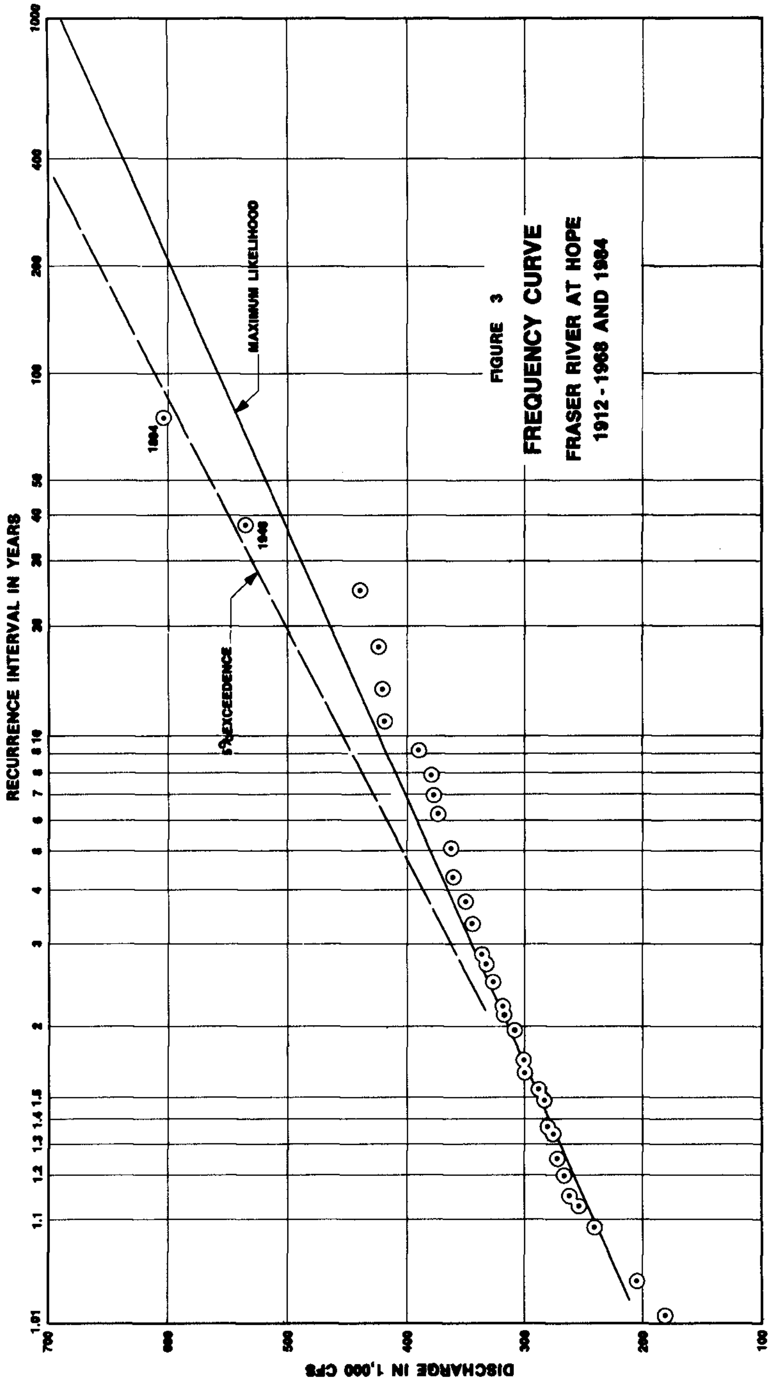
FIGURE 3
FREQUENCY CURVE
FRASER RIVER AT HOPE
1912 - 1968 AND 1984
MAXIMUM LIKELIHOOD
5% EXCEEDENCE
1894
1948
RECURRENCE INTERVAL IN YEARS
DISCHARGE IN 1,000 CFS

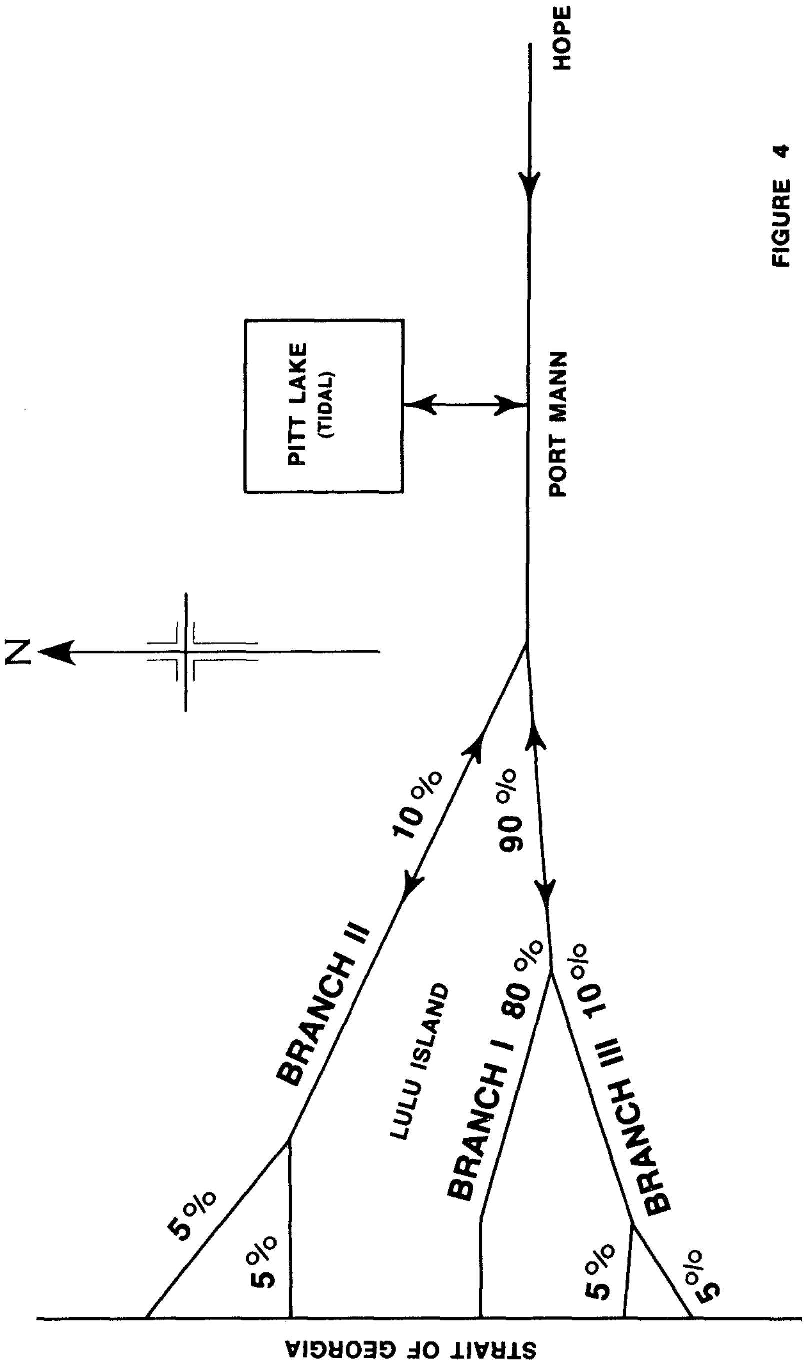

FIGURE 4
FLOW DISTRIBUTION
FRASER RIVER DELTA
(NOT TO SCALE)

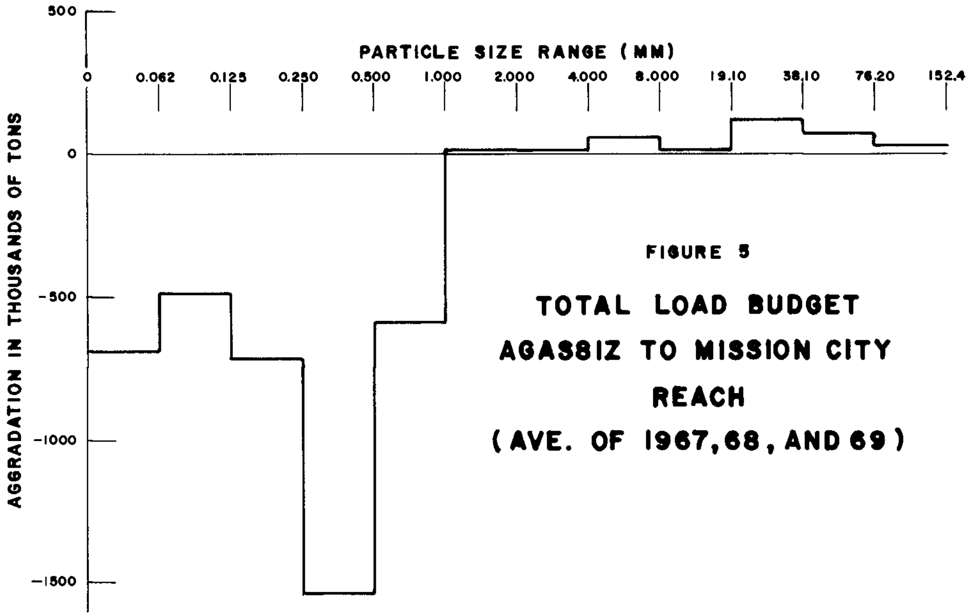

FIGURE 5

TOTAL LOAD BUDGET
AGASSIZ TO MISSION CITY
REACH
(AVE. OF 1967, 68, AND 69)

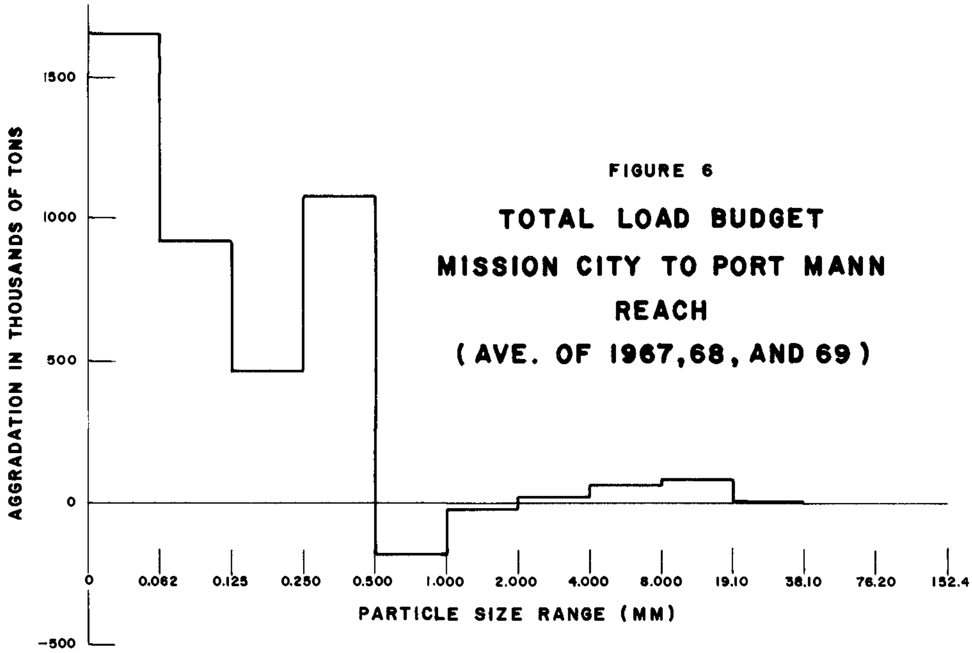

FIGURE 6

TOTAL LOAD BUDGET
MISSION CITY TO PORT MANN
REACH
(AVE. OF 1967, 68, AND 69)

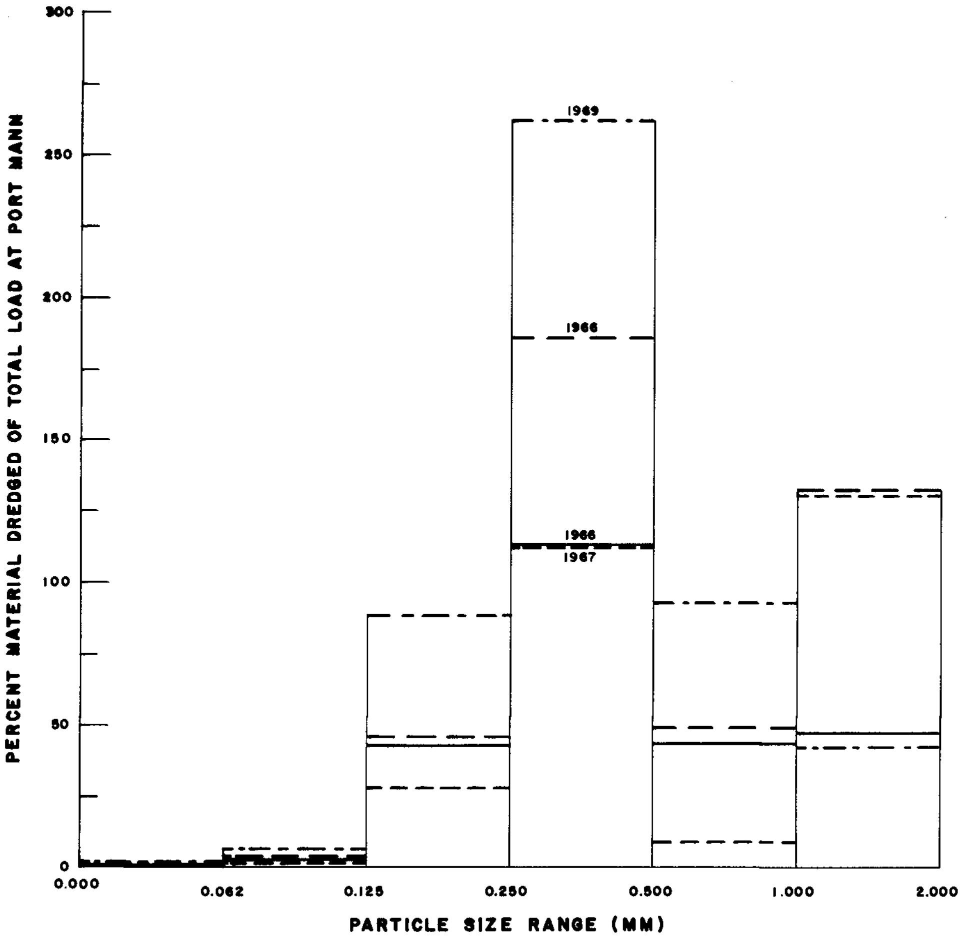

FIGURE 7

PERCENT OF MATERIAL DREDGED OF
TOTAL LOAD AT PORT MANN