CANADA

HYDROMETRIC AND SEDIMENT SURVEY LOWER FRASER RIVER

PROGRESS REPORT 1965-68

SEDIMENT SURVEY SECTION
WATER SURVEY OF CANADA
INLAND WATERS BRANCH
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ABSTRACT

The progress of the hydrometric and sediment survey of the Lower Fraser River for the period 1965 to 1968 inclusive is described in this report.

Although hydrometric data for the Lower Fraser River have been collected since 1876, the sediment survey did not become fully operational until the spring of 1965. The sediment survey program was intended to provide streamflow, suspended sediment and bed load discharge and other related data for the Lower Fraser River region. These data are used in design, operation and maintenance of river channels and hydraulic works and facilities.

The operational aspects of the survey are outlined and described in detail. These include the equipment used, the field survey conditions and survey techniques, methods of analysis and interpretation of the data.

Preliminary results of the survey are illustrated by means of tables and graphs. Some of the pertinent data are similarly compiled in the appendices of the report.

Several conclusions with respect to the hydrometric and sediment surveys are presented. Finally, recommendations are made to continue with the present surveys for at least an additional ten years and to include in these surveys the delta region downstream from the Fraser River at Port Mann.

CHAPTER I

INTRODUCTION

1.1 Purpose Of This Report

This report is intended to outline the progress made in the hydrometric and sediment surveys of the Lower Fraser during the period 1965 to 1968 inclusive. The hydrometric and sediment survey techniques are described and some of the data which have been collected are summarized. Similarly, some of the results of the survey are presented in an attempt to assess the existing survey programs and to point out the requirements for continuing surveys.

1.2 Reason For The Survey

The primary reason for the hydrometric and sediment survey has been to obtain reliable data which can be used as a basis for making decisions relating to hydraulic works and activities on the Lower Fraser River. Although a hydrometric program has been operational for a number of years, the sediment survey program was officially requested by the Assistant Deputy Minister of Public Works on August 28, 1964. Flow and sediment data were required in the assessment of problems relating 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, require 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 is 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 this type of data for possible litigation during construction and operation of hydraulic projects should not be overlooked.

1.3 Organization

Preparation for the sediment survey was begun in 1964 soon after a cost sharing co-operative program was negotiated with the Department of Public Works. The sampling operations commenced in the spring of 1965.

In an attempt to make the survey program as efficient as possible a sub-office of the Vancouver district office was set up in New Westminster. The technical and field staff assigned to the sediment and hydrometric survey of the Lower Fraser River made the New Westminster sub-office their headquarters. A full scale sediment laboratory was also established in the New Westminster sub-office. The samples collected by the field staff were analysed for weight, concentration and particle size as required.

Additional administrative and technical support and guidance for the sediment survey came from the Vancouver district office and from the Head Office in Ottawa. A number of problems relating to bed load measurement and unsteady flow measurement have been discussed with world experts.

1.4 Description

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 maximum recorded daily discharge of 536,000 cfs occurred on May 31, 1948; the average annual runoff is in the order of 68,500,000 acre-feet.

Between Hope and the mouth, the river reach shown in figure 1.1, 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 silts 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 the tidally affected portion of the study reach.

Approximately ninety percent of the total Lower Fraser River flow originates upstream from Hope. 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 flow duration curve for daily flows from 1947 to 1966 for the Fraser River at Hope is shown in figure 1.2. The published daily flows for the period October 1, 1946 to September 30, 1966 were used in preparation of this curve.

Flood frequency curves for the Fraser River at Hope, Mission City and New Westminster are shown in figures 1.3, 1.4 and 1.5 respectively. The flows used in developing the Hope and Mission City curves have been adjusted to compensate for the effect of the Nechako diversion and for Bridge River

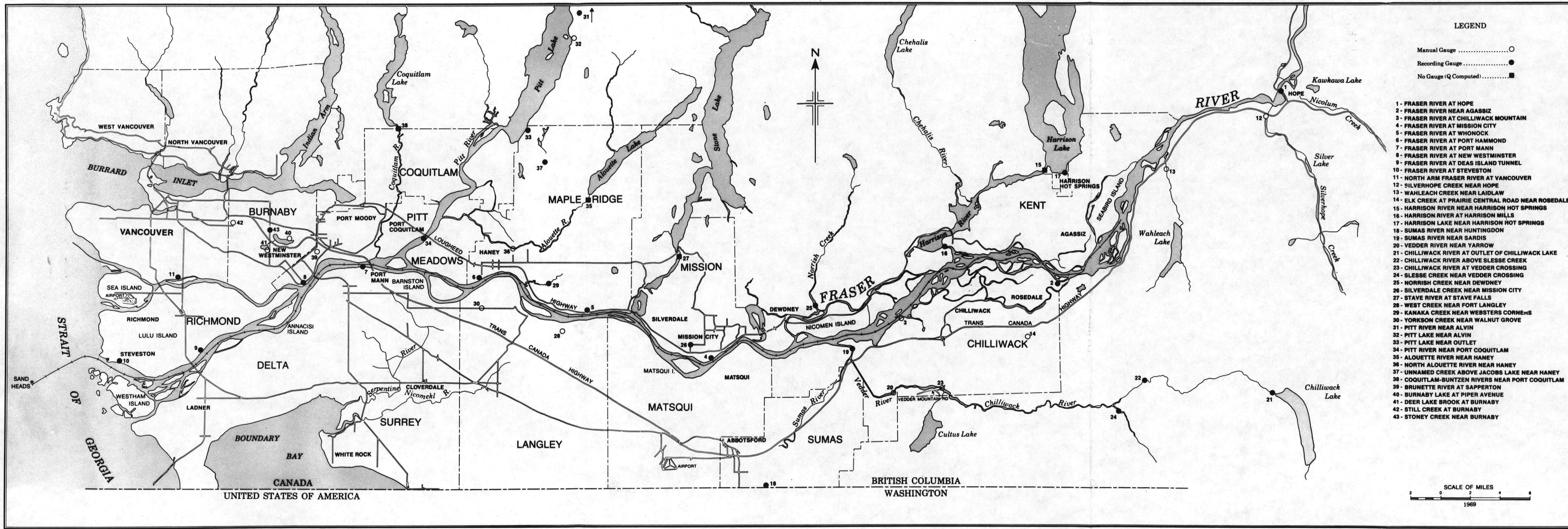


FIGURE 1-1 - STATION LOCATION PLAN 1965, LOWER FRASER RIVER

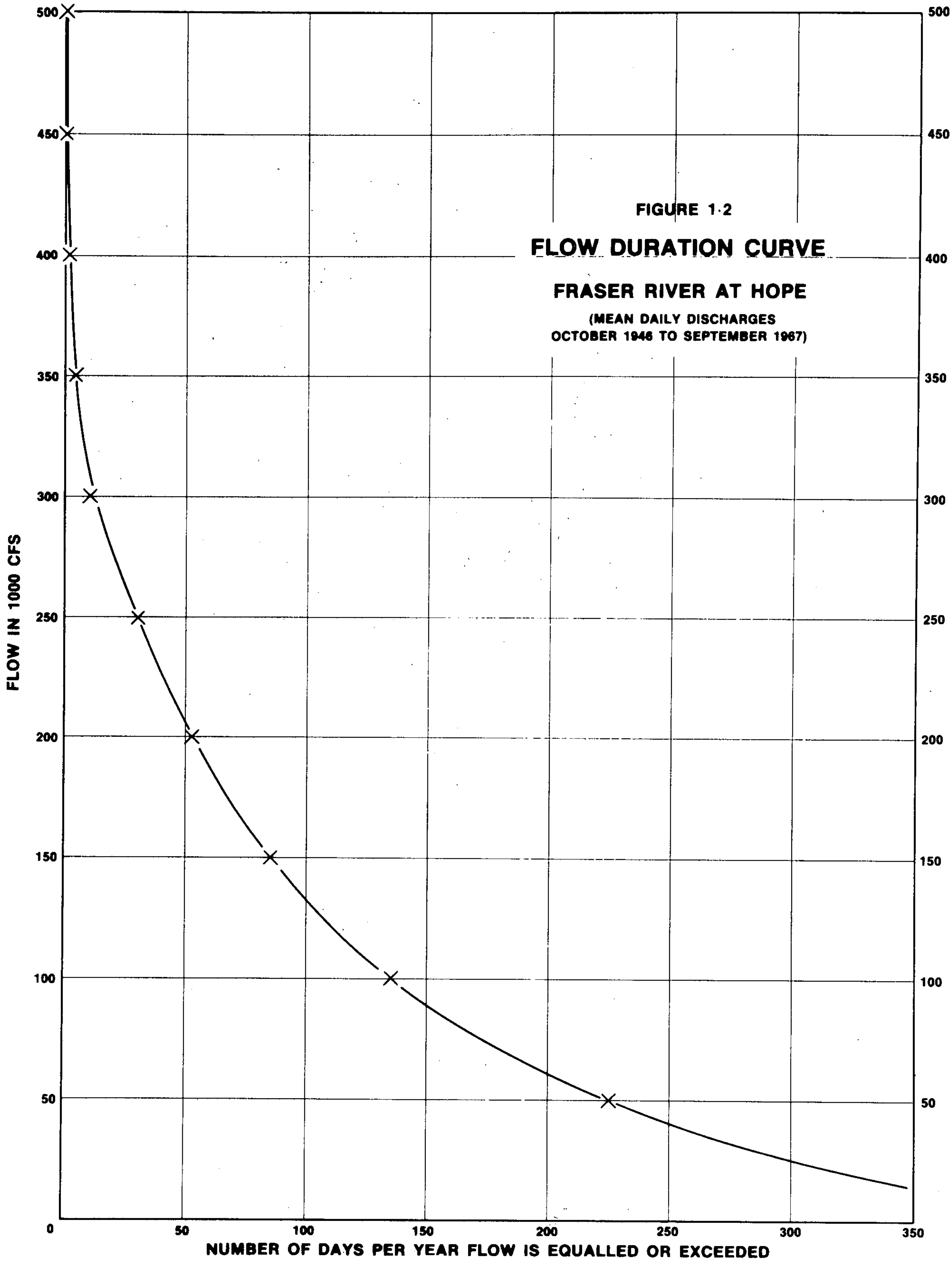


FIGURE 1-2
FLOW DURATION CURVE
FRASER RIVER AT HOPE
(MEAN DAILY DISCHARGES
OCTOBER 1946 TO SEPTEMBER 1967)
FLOW IN 1000 CFS
NUMBER OF DAYS PER YEAR FLOW IS EQUALLED OR EXCEEDED
0
50
100
150
200
250
300
350
400
450
500

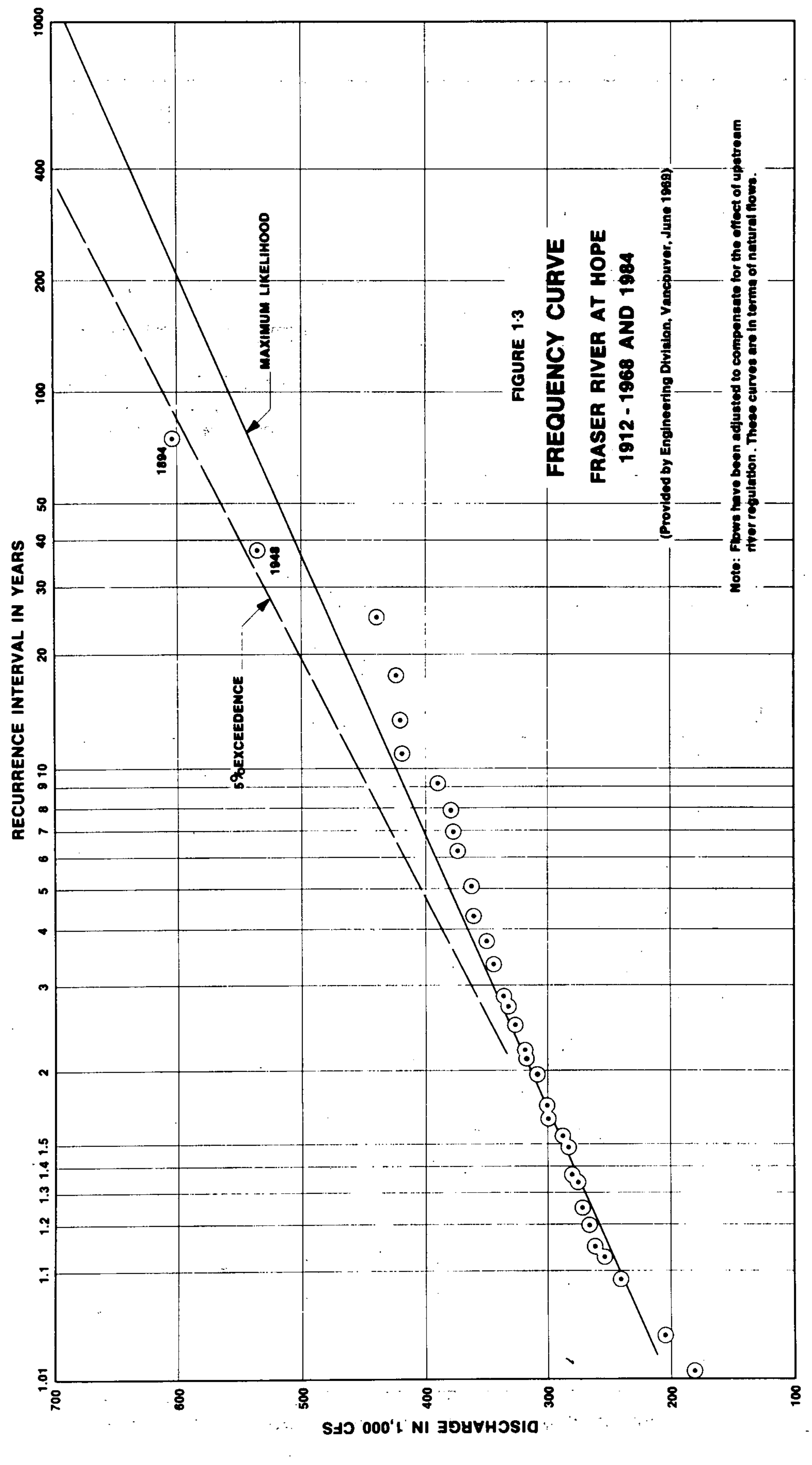
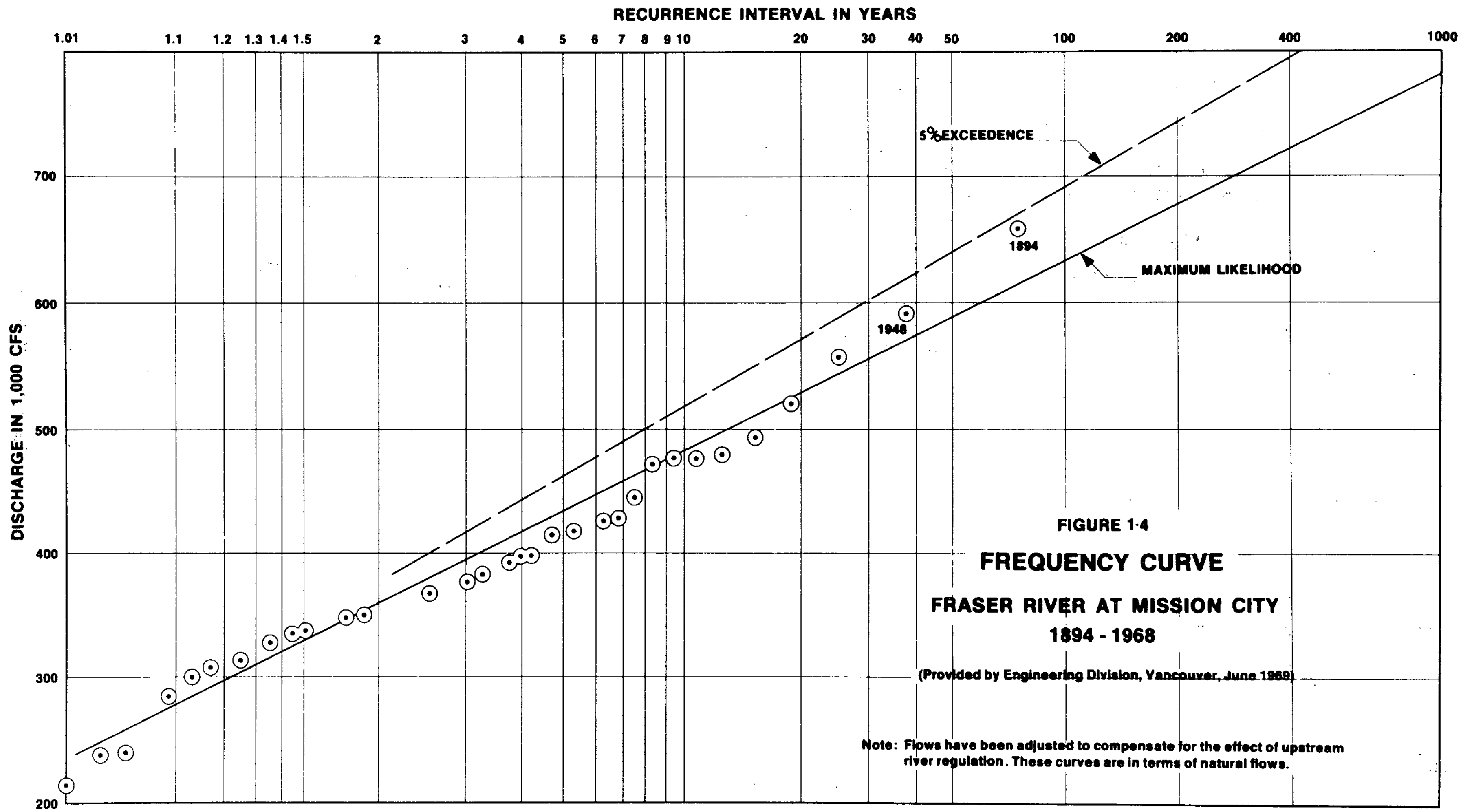


FIGURE 1·3
FREQUENCY CURVE
FRASER RIVER AT HOPE
1912 - 1968 AND 1984
(Provided by Engineering Division, Vancouver, June 1989)
Note: Flows have been adjusted to compensate for the effect of upstream river regulation. These curves are in terms of natural flows.
RECURRENCE INTERVAL IN YEARS
DISCHARGE IN 1,000 CFS
MAXIMUM LIKELIHOOD
5% EXCEEDENCE
1894
1948
1.01
1.1
1.2
1.3
1.4
1.5
2
3
4
5
6
7
8
9
10
20
30
40
50
100
200
400
1000
700
600
500
400
300
200
100



RECURRENCE INTERVAL IN YEARS
1.01
1.1
1.2
1.3
1.4
1.5
2
3
4
5
6
7
8
9
10
20
30
40
50
100
200
400
1000
DISCHARGE IN 1,000 CFS
700
600
500
400
300
200
5% EXCEEDENCE
MAXIMUM LIKELIHOOD
1894
1948
FIGURE 1-4
FREQUENCY CURVE
FRASER RIVER AT MISSION CITY
1894 - 1968
(Provided by Engineering Division, Vancouver, June 1969)
Note: Flows have been adjusted to compensate for the effect of upstream river regulation. These curves are in terms of natural flows.

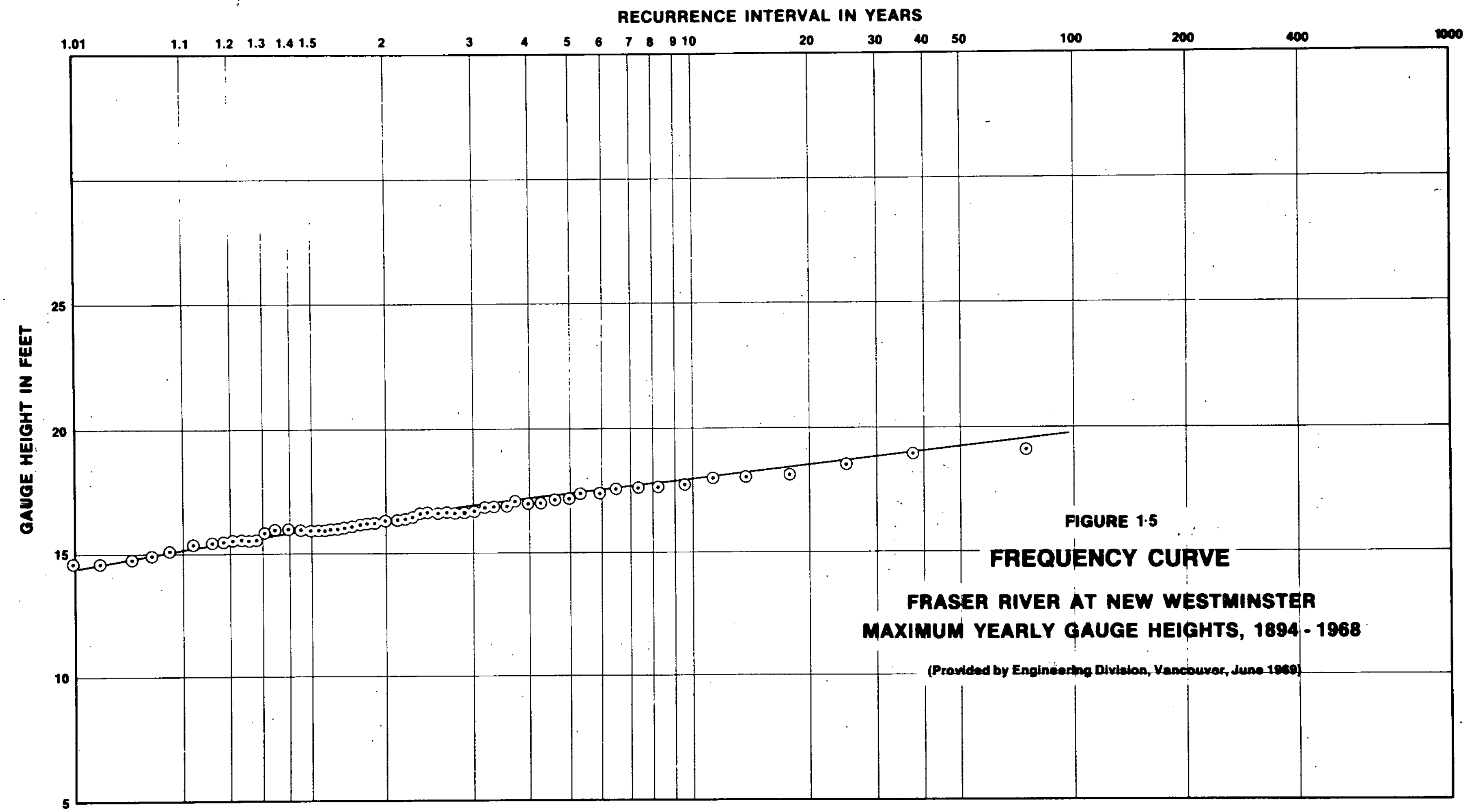


FIGURE 1·5

FREQUENCY CURVE

FRASER RIVER AT NEW WESTMINSTER
MAXIMUM YEARLY GAUGE HEIGHTS, 1894 - 1968

(Provided by Engineering Division, Vancouver, June 1969) regulation. The two curves are therefore in terms of natural flows. These curves were developed by the method of maximum likelihood (Chow, 1964) which gave best results for these stations. The curve for New Westminster was developed by standard U.S.G.S. methods.

The tidal effect in the lower reaches of the Fraser River created numerous problems to the sediment and hydrometric survey. 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 1.6 (Keane, 1957).

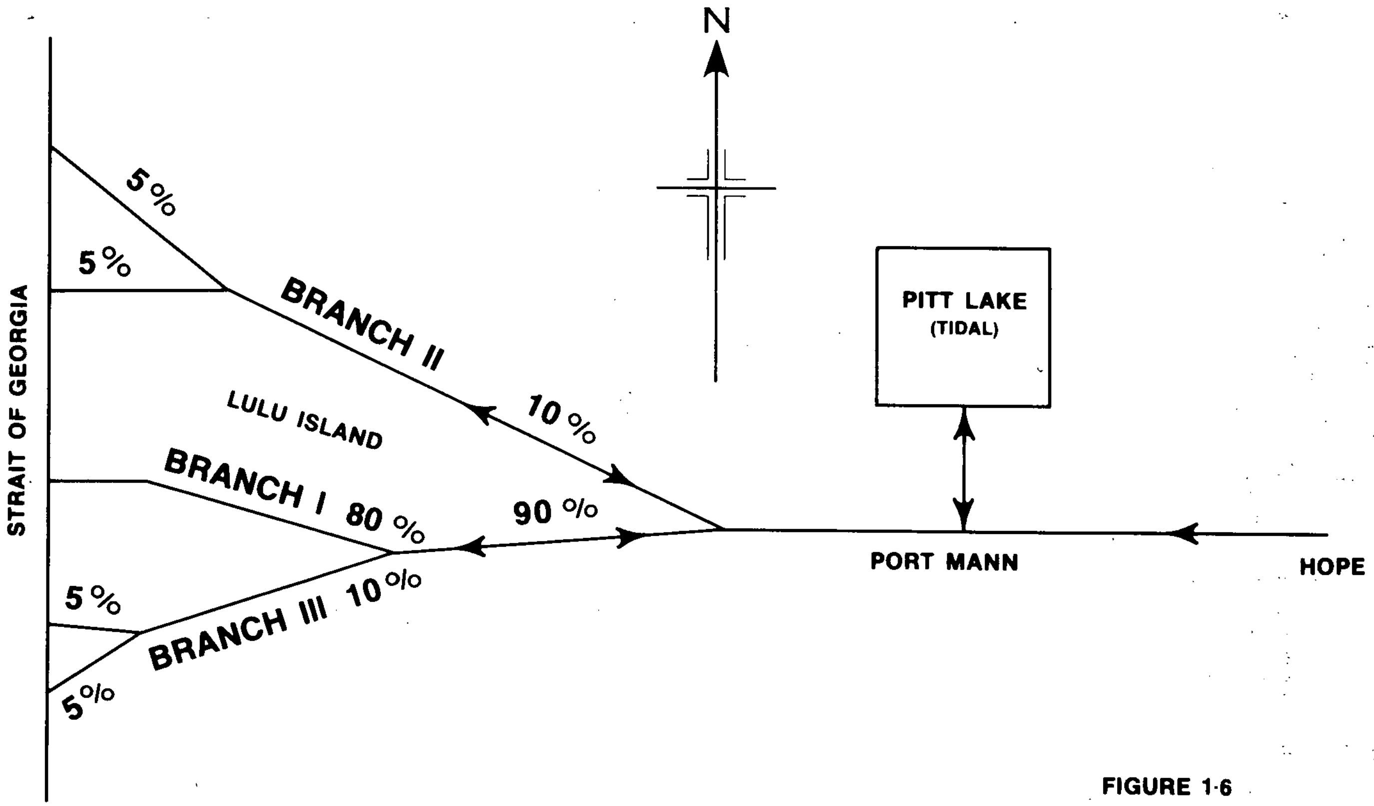


FIGURE 1·6

FLOW DISTRIBUTION

FRASER RIVER DELTA
(NOT TO SCALE)

CHAPTER II

HYDROMETRIC SURVEYS

2.1 Summary Of Available Data

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 has been made operational. The stations, years of operation and type of data collected are summarized in figure 2.1 for the 1965 active stations. The corresponding station locations are shown in figure 1.1. Additional station history such as type of gauge used, mean and extremes recorded, degree of regulation, etc. is summarized in tabular form in Appendix A. The hydrometric data are not presented since they are published annually in the Surface Water Data publications of the Inland Waters Branch.

Figure 2.1 illustrates that the data obtained in the lower tidally affected 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 extremely 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.

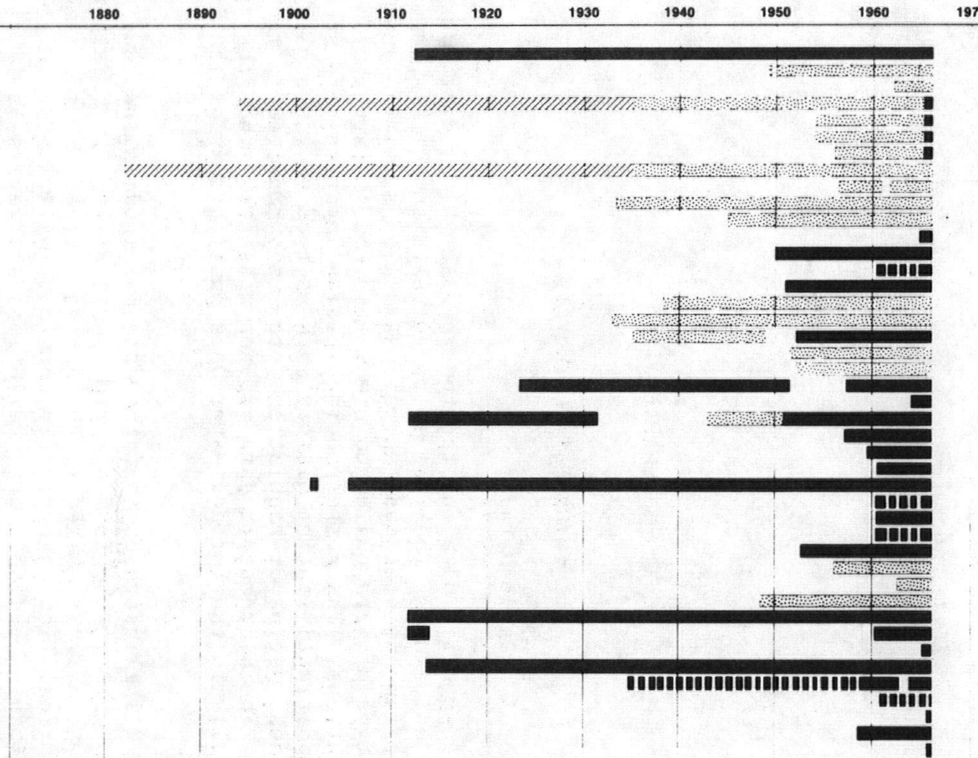
For stations not affected by tides, standard hydrometric survey and computational techniques are used in obtaining the required flow and stage data. These are summarized in Appendix B for the period 1965 to 1968 inclusive.

Figure 2.1 illustrates that the Fraser River at Hope is the only Lower Fraser River station for which a relatively long period of discharge record is available. Even at this station some deviation from standard

FIGURE 2-1- **LOWER FRASER RIVER GAUGING STATIONS TO 1965**

STATION	INDEX NUMBER	REGULATION	DRAINAGE AREA. SQ. MI.
*FRASER RIVER AT HOPE	8MF-5	MINOR	78,300
*FRASER RIVER NEAR AGASSIZ	8MF-35	MINOR	
FRASER RIVER AT CHILLIWACK MOUNTAIN	8MF-56	MINOR	
*FRASER RIVER AT MISSION CITY	8MH-24	MINOR	
FRASER RIVER AT WHONOCK	8MH-44	MINOR	
FRASER RIVER AT PORT HAMMOND	8MH-43	MINOR	
*FRASER RIVER AT PORT MANN	8MH-54	MINOR	
FRASER RIVER AT NEW WESTMINSTER	8MH-25	MINOR	
FRASER RIVER AT DEAS ISLAND TUNNEL	8MH-53	MINOR	
FRASER RIVER AT STEVESTON	8MH-28	MINOR	
NORTH ARM FRASER RIVER AT VANCOUVER	8MH-32	MINOR	
**SILVERHOPE CREEK NEAR HOPE	8MF-9	NIL	
WAHLEACH CREEK NEAR LAIDLAW	8MF-34	MINOR	44
ELK CREEK AT PRAIRIE CENTRAL ROAD NEAR ROSEDALE	8MF-48	NIL	
**HARRISON RIVER NEAR HARRISON HOT SPRINGS	8MG-13	NIL	3,220
HARRISON RIVER AT HARRISON MILLS	8MG-14	NIL	
HARRISON LAKE NEAR HARRISON HOT SPRINGS	8MG-12	NIL	
SUMAS RIVER NEAR HUNTINGDON	8MH-29	NIL	57.6
SUMAS RIVER NEAR SARDIS	8MH-39	NIL	
VEDDER RIVER NEAR YARROW	8MH-47	NIL	
CHILLIWACK RIVER AT OUTLET OF CHILLIWACK LAKE	8MH-16	NIL	131
CHILLIWACK RIVER ABOVE SLESSE CREEK	8MH-103	NIL	254
**CHILLIWACK RIVER AT VEDDER CROSSING	8MH-1	NIL	484
SLESSE CREEK NEAR VEDDER CROSSING	8MH-56	NIL	62.7
NORRISH CREEK NEAR DEWDNEY	8MH-58	NIL	44.1
SILVERDALE CREEK NEAR MISSION CITY	8MH-91	NIL	
**STAVE RIVER AT STAVE FALLS	8MH-40	R	440
WEST CREEK NEAR FORT LANGLEY	8MH-98	NIL	
KANAKA CREEK NEAR WEBSTERS CORNERS	8MH-76	NIL	
YORKSON CREEK NEAR WALNUT GROVE	8MH-97	NIL	
PITT RIVER NEAR ALVIN	8MH-17	NIL	196
PITT LAKE NEAR ALVIN	8MH-52	NIL	
PITT LAKE NEAR OUTLET	8MH-62	NIL	
**PITT RIVER NEAR PORT COQUITLAM	8MH-35	NIL	
ALOUETTE RIVER NEAR HANEY	8MH-38	R	79
NORTH ALOUETTE RIVER NEAR HANEY	8MH-6	NIL	
UNNAMED CREEK ABOVE JACOBS LAKE NEAR HANEY	8MH-108	NIL	
COQUITLAM-BUNTZEN RIVERS NEAR PORT COQUITLAM	8MH-41	MINOR	77
BRUNETTE RIVER AT SAPPERTON	8MH-26	R	26.5
BURNABY LAKE AT PIPER AVENUE	8MH-46	R	
DEER LAKE BROOK AT BURNABY	8MH-112	NIL	
STILL CREEK AT BURNABY	8MH-61	MINOR	
STONEY CREEK NEAR BURNABY	8MH-117	NIL	

PERIOD OF RECORD



LEGEND

- DISCHARGE DATA
- ELEVATION OR STAGE DATA
- MAXIMUM YEARLY ELEVATIONS ONLY
- * MAIN SEDIMENT SURVEY STATIONS
- ** SECONDARY SEDIMENT SURVEY STATIONS

methods was required because of driftwood and excessive velocities encountered during high flows. Thus during periods when the flow was in excess of approximately 350,000 cfs, it was possible to measure surface velocities only and to compute discharges on the assumptions that the depth soundings obtained during low flow were applicable, the direction of the velocity of water below the surface was the same as at the surface and that the multiplication coefficient of 0.88 to convert surface to mean velocity was applicable.

Calculation of flow for the tidal stations, such as the Fraser River at Port Mann, was made possible by special methods based on the theories of continuity and unsteady flow. Two such methods, the method of cubature and the unsteady flow mathematical modelling, are described briefly in the next two sections. Methods and equipment used in field measurement of unsteady flow are subsequently described. Although emphasis is placed on those stations which have a sediment survey program, a number of other stations are equally significant in the overall survey of the Lower Fraser River.

2.2 Method Of Cubature

The method of cubature used for calculating tidal discharge is based on the law of continuity (Keane, 1957). It consists of using the rate of rise and fall of the water surface to determine the rate of gain or loss of channel storage in a reach. The discharge at the downstream end of a reach is calculated from a known inflow and known gain or loss in channel storage during the time required for the surface to rise and fall. The details of application of the method of cubature to the Lower Fraser River are presented in Appendix B.

The method of cubature was used to compute the tidal flows for the Lower Fraser River for the period 1965 to 1968. An automated system consisting of four problem programs and a sort utility was developed (Water Survey of Canada, 1968b). The four programs and the corresponding Water Survey of Canada job numbers are:

PFDMHQ	-	J20945
PFHRGH	-	J21019
TRANSP	-	J21021
LØFRAS	-	J20916

Thirteen stations are involved in this set of programs. Hourly gauge heights are required for the following eight stations:

08MH054	Fraser River at Port Mann
08MH035	Pitt River near Port Coquitlam
08MH062	Pitt Lake at Outlet
08MH052	Pitt Lake at Little Goose Island
08MH043	Fraser River at Port Hammond
08MH044	Fraser River at Whonock
08MH024	Fraser River at Mission City
08MH039	Sumas River near Sardis.

Mean daily discharges are required for five additional stations:

08MH017	Upper Pitt River near Alvin
08MH040	Stave River
08MH041	Coquitlam River
08MG013	Harrison River
08MF005	Fraser River at Hope.

The program PFDMHQ automates the streamflow computations by using a D-Mac Pencil Follower. This program is used to remove all the errors in the cards made during digitizing of the A-35 recorder charts. After all the errors have been corrected and a successful run has been achieved, these pencil follower cards are used as the input to the next program, PFHRGH. [The operations side of the program PFDMHQ has been fully documented in the Manual of Automated Streamflow Procedures (Water Survey of Canada, 1968a)]. The input to PFDMHQ is exactly as described in the manual except that a linear stage-discharge curve is used with no shift or backwater corrections because we are only concerned with daily gauge heights.

The second program, PFHRGH, calculates the instantaneous hourly gauge heights for the eight stations previously mentioned. The output is a listing and a tape (or disc) containing the hourly gauge heights for each station. The computed hourly gauge heights and the daily discharges are then sorted in ascending order according to date (year, month, day, hour, minute) and the station number. These sorted card images on tape (disc) are next passed to program TRANSP where the complete days are processed. The data for each complete day are transformed such that the hourly gauge heights for the eight stations for each hour are on a separate card image together with daily discharges from five additional stations. Finally, the output card images (on tape or disc) are passed from TRANSP on to the last program, LØFRAS, where the mean hourly discharges and the mean daily discharges are computed using hourly gauge heights. An example of the final output is shown in table 2.1 for July 12, 1967.

Table 2.1 illustrates the method of cubature which has made possible the computation of hourly discharges for a number of tidal stations in the Lower Fraser River. The availability of hourly discharges for the Mission City and for Port Mann stations has contributed greatly towards the understanding of sediment concentrations and sediment discharges at these two stations.

The method of cubature has certain limitations or drawbacks, however, as can be seen from observing the details in Appendix B. Perhaps its greatest drawback is that errors in calculation of base or upstream flows are reflected in the flows computed for stations downstream and that the accuracy of the calculations is in the order of ± 10%. It was therefore anticipated that the tidal flow calculations could be improved by unsteady flow mathematical modelling techniques as described in the next section.

2.3 Unsteady Flow Mathematical Modelling Method

Unsteady flow mathematical models are presently being developed for two Lower Fraser River stations: Port Mann and Mission City. Modelling of this type is generally recognized as being a rational, accurate, economical,

TABLE 2.1.

Example Output of Program LOFRAS

Water Resources Branch, Vancouver, B.C.

Lower Fraser River

Daily and Hourly Mean Discharges in 1000 cfs

Daily Mean Inflows

Upper Pitt R. #	0.000
Stave R. #	3.380
Coquitlam R. #	0.000
Harrison R. #	38.200
Fraser R.%Base< #	289.542

Time	Outlet Pitt L.	Lower Pitt R.	Mission City	Whonock	Port Hammond	Port Mann	Time
0- 1	-19.76	-26.66	291.9	295.7	298.2	277.2	0- 1
1- 2	-12.16	-14.99	291.9	295.7	297.9	289.7	1- 2
2- 3	0.00	2.20	291.7	296.0	297.9	303.4	2- 3
3- 4	0.00	2.20	291.3	295.9	297.8	301.5	3- 4
4- 5	6.08	8.90	291.0	295.3	297.0	307.3	4- 5
5- 6	12.16	14.98	290.6	294.9	296.1	312.2	5- 6
6- 7	13.68	16.94	290.3	294.6	294.6	311.1	6- 7
7- 8	6.08	8.57	290.0	294.1	294.1	300.4	7- 8
8- 9	5.32	8.12	289.9	293.7	293.7	300.6	8- 9
9-10	5.32	8.11	289.8	294.1	295.3	306.2	9-10
10-11	1.52	4.93	289.6	293.7	296.1	306.8	10-11
11-12	6.08	9.48	289.5	293.4	295.5	310.2	11-12
12-13	6.08	9.47	289.5	293.4	295.7	310.2	12-13
13-14	15.96	21.18	289.3	293.8	295.9	321.7	13-14
14-15	19.00	26.33	288.7	293.9	295.7	326.1	14-15
15-16	17.48	25.07	288.0	293.2	294.1	322.4	15-16
16-17	15.96	22.60	287.4	293.1	293.9	317.1	16-17
17-18	22.04	30.44	286.7	292.1	292.8	323.2	17-18
18-19	15.20	21.46	286.1	291.5	292.6	304.1	18-19
19-20	9.88	8.10	285.4	288.6	287.1	285.0	19-20
20-21	-8.36	-15.53	284.8	287.7	286.2	258.1	20-21
21-22	-28.12	-39.56	284.4	287.1	282.3	232.3	21-22
22-23	-39.53	-56.89	284.0	286.9	280.1	216.8	22-23
23-24	-38.77	-49.24	283.7	286.2	286.0	240.8	23-24
Daily Mean	1.30	1.91	288.6	292.7	293.2	295.2	Daily Mean

as well as a generally applicable, method of obtaining a continuous record of discharge at a selected site in a tidal reach (Baltzer and Shen, 1961).

The tidal reach of the Lower Fraser River is an example of moderately unsteady flow in an open channel. With the assumptions of moderately unsteady, homogeneous, and one-dimensional flow and prismatic channel geometry, a system of unsteady flow equations can be readily set up to describe the tidal flows. (Details of the equations and their application are shown in Appendix B). Solution of the system of equations is achieved by means of a power series expansion utilizing a numerical process. The actual computation of discharge is performed by digital computer. Initial and boundary conditions must be subsequently prescribed to give the equations distinct meaning.

The boundary values are determined by field measurement. The channel geometry; channel width, depth and cross-sectional area; is evaluated using hydrographic survey data. Stages are recorded continuously at the ends of a selected reach length by use of digital recorders. This continuous record of stage, synchronized with respect to time to the nearest 15 seconds and referenced to a common datum, provides the stage and slope data required in the computations.

Two Fisher-Porter digital recorders for the Fraser River at Port Mann station were placed 22,860 feet apart (one at Port Mann and one at New Westminster) and made operational in September of 1967. At the Fraser River at Mission City, the recorders were placed 25,435 feet apart (one at Mission City and one at Cox's Landing) and were to be made operational in 1969. These recorders are to be operational during the low water periods only when the flow at Mission City is tidal.

The tidal flow computations are performed on a time interval basis of between 10 to 30 minutes. Initial conditions which must be prescribed at the start of the computations are: the initial discharge, the preceding change in discharge, and the stage at the end point of the reach where discharge is being computed for the two preceding time increments.

2.4 Special Methods and Measurements

Periodic measurements of tidal flow for checking the unsteady flow model, in addition to the requirement for initial conditions, has required some measurement of tidal flow for the Port Mann and Mission City stations. The standard method of measurement, that of obtaining water velocity at points 0.2 and 0.8 of the depth at 15 to 20 verticals, was found to be too time consuming. A change in discharge of 100 percent, or more, could occur during the time it takes to measure the discharge. The accuracy and reliability of such measurements remains questionable.

In an attempt to speed up flow measurements, a traversing measurement technique was developed and tested during steady flow conditions in 1966 for the Fraser River at Mission City (Water Survey of Canada, 1966c). The following procedure was used: The cross-section profile was first determined. The cross-section can be sounded manually or with an echo sounder. The current meter was then set at 0.2 of the average depth for the first traverse. During traversing the current meter recorded the vector sum of traversing velocity and the river flow velocity. The traverse velocity was recorded by recording the time the vessel reaches each 100 foot vertical in the cross-section. After the first traverse, the current meter was set to 0.8 feet of the average channel depth and the traversing procedure was repeated, the vector velocity being recorded continuously. By elementary vector analysis the velocity of flow for any point was determined from the measured traversing and vector velocities and the final discharge computations were done in the same way as for standard measurement methods. The traversing measurement can be done in less than half an hour as compared to two to three hours for the standard flow measurement. There are several limitations to the traversing method: a cross-section of relatively uniform depth is required; the amount of office calculations is somewhat increased; and the method cannot be effectively used for low flow velocities because of inaccuracies in determining the measured velocity vector angle. When these limitations are realized, this method of measurement can be very useful, particularly during tidal conditions when the time element in sampling and measurement can significantly affect the results.

An alternative method of tidal measurement, that of multiple time-discharge relationships or multiple hydrographs, has been used for the Fraser River at Mission City and the Fraser River at Port Mann. The river cross-section is divided into 15 to 20 areas of approximately equal discharge. The mean velocity of flow, and consequently the mean discharge, is obtained consecutively and repeatedly for each individual area of flow. A discharge hydrograph is prepared for each area and the summation of discharges of all hydrographs for a particular time gives the total instantaneous discharge for the cross-section. This method is illustrated in Figure 2.2 in which n is the number of areas of flow into which the cross-section has been divided, Q_i is the mean discharge of the entire cross-section, and t is a specified time of the hydrograph base, T. The difference between the Multiple Hydrograph Method and the Standard Measurement Method is readily evident: the Multiple Hydrograph Method is used to determine an instantaneous total discharge by interpolating between a number of measured values as compared to the standard method which gives a discrete discharge based on a series of measurements made over a short period of time.

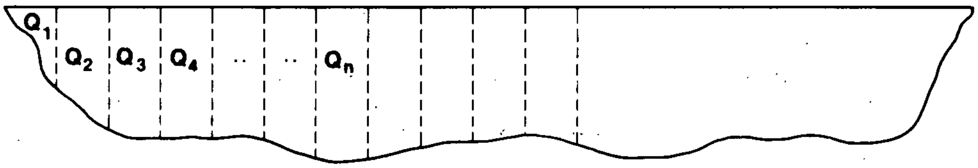
Measurement of tidal flow can be further complicated by multi-directional flow, particularly during periods of low flow or periods of flow reversals. This problem was most significantly realized at the Fraser River at Port Mann. Directional current meters were used in 1967 and 1968 to determine the fluctuations in velocity directions. Table 2.2 summarizes the possible degree of directional fluctuation in velocity at a point in a vertical as related to the mean velocity of flow at the vertical.

Table 2.2

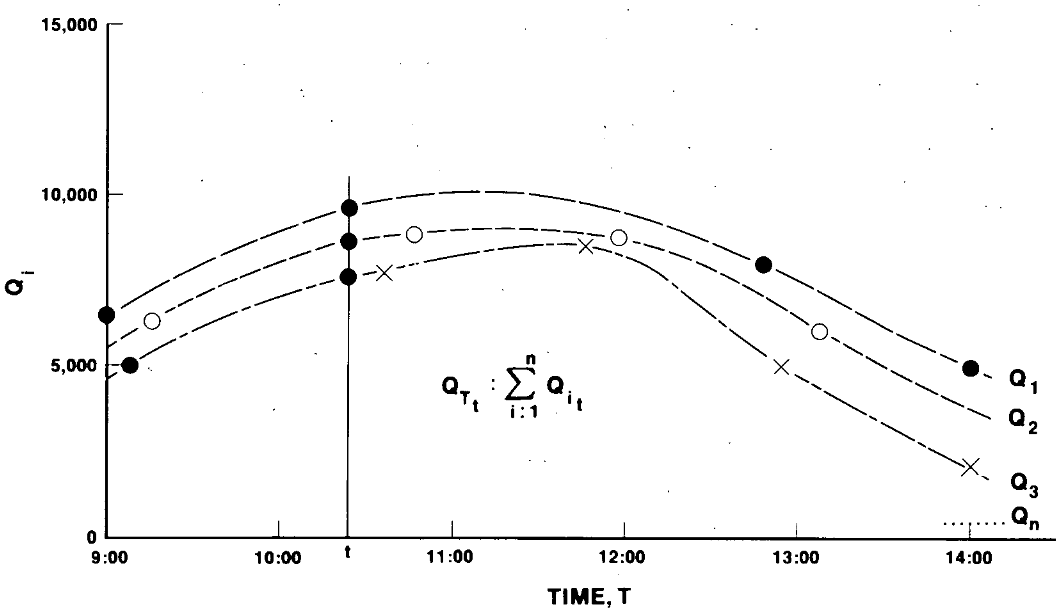
Possible Fluctuation of Direction of Point Velocity

Fraser River at Port Mann

Mean Velocity in ft/sec.	Fluctuation in degrees
<0.5	<135°
<0.5	< 90°
<1.0	< 30°
<2.0	< 15°



(a) CROSS-SECTION



$$Q_{T_t} = \sum_{i=1}^{n} Q_{i_t}$$

(b) HYDROGRAPHS

FIGURE 2-2 **TIDAL FLOW MEASUREMENT USING MULTIPLE-HYDROGRAPH METHOD**

A variation in direction of 30 degrees or more was observed in some cases for 3 consecutive readings at a point. However, the average of 7 or 8 observations was generally within 5 degrees of the longitudinal axis of the river.

In 1968, the use of VADA equipment greatly facilitated the velocity direction observations and measurement of tidal flow. The VADA unit simultaneously measures the velocity, azimuth and depth by means of an Ott velocity meter rigidly mounted above a 140-lb. streamlined brass weight, a remote-reading magnetic compass (mounted in the weight) for measuring orientation, and a sonic fathometer for measuring depth. A strip recorder records these three variables.

Discharge is measured by use of the VADA unit by observing the entire velocity profile at a series of verticals along a cross-section. For each vertical, the catamaran is positioned approximately on the cross-section line and kept as stationary as possible by heading into the current and using power. When the boat is positioned, the VADA unit is lowered to the stream-bed, raised slightly, allowed to stabilize, then raised slowly to the surface. As the unit is raised the velocity, depth and azimuth are recorded simultaneously. From these data, the discharge can be readily computed.

In summary, hydrometric data for the sediment stations on the Lower Fraser River have been very difficult to obtain because of tidal effect. Where possible, standard methods of measurement and calculation of flow were used. Computations for tidal flow stations were done by the method of cubature for the period 1965 to 1968 inclusive. Development of an unsteady flow mathematical model began in 1968 and its use is anticipated for the Fraser River at Port Mann and the Fraser River at Mission City for 1969. Tidal flow measurements have been successfully performed by traversing and multiple-hydrograph methods for use in development and checking of the computational methods. In essence, considering the complexity of the hydrometry of the Lower Fraser River, relatively reliable flow data which form the required basis for the sediment survey are being obtained.

CHAPTER III

SEDIMENT SURVEYS

3.1 General

A major study of sediment transport involves the determination of the total sediment discharge of a river and the determination of the pattern of deposition or erosion of the river channel. Evaluation of total sediment discharge at a point is accomplished by evaluation of its components: suspended sediment discharge, bed load discharge, and unmeasured sediment discharge. The unmeasured sediment discharge was assumed to be negligible in comparison to the other two components. (By bed load discharge is meant the discharge of sediment that moves along in essentially continuous contact with the bed of the stream). Evaluation of the pattern of deposition or erosion of a river reach requires some suitable network of observation points or stations throughout the length of the river reach.

The sediment sampling program consists basically of the following operations:

(a) periodic sampling of suspended sediment at a number of verticals, usually five, by the depth-integrating method for determining the average suspended sediment concentration in the cross-section, and hence, the average suspended sediment discharge.

(b) limited sampling of suspended sediment at a number of verticals by the point-integrating method for checking the depth-integrated samples and for determining the particle-size distribution in the verticals.

(c) periodic sampling of suspended sediment at a selected vertical and at a selected frequency for determining the sediment concentrations for the days for which suspended sediment measurements, described in (a) and (b) above, are not made.

(d) periodic sampling of bed load for determining bed load discharge. This sampling is done at an individual vertical and at a number of verticals, usually five, as for suspended sediment.

(e) periodic sampling of bed material at a number of verticals (commonly 5 or 7, depending on the cross-section geometry) for determining the particle-size distribution for use in empirical calculations of bed load discharge.

(f) periodic measurement of water temperature, usually at the same time as when samples are taken.

These sampling operations and the methods used in computing the sediment discharges will be described in the next two sections with specific reference to the Lower Fraser River survey.

Figure 3.1 shows the network of sediment survey stations on the Lower Fraser River. The sediment survey is concentrated on the Fraser River stations:

Fraser River at Hope

Fraser River near Agassiz

Fraser River at Mission City

Fraser River at Port Mann.

Limited or less intensive programs are also carried out at 5 tributary stations to enable evaluation of the tributary contribution to the Lower Fraser River sediment discharge. These stations are the following:

Silverhope Creek near Hope

Harrison River near Harrison Hot Springs

Chilliwack River at Vedder Crossing

Stave River at Stave Falls

Pitt River near Port Coquitlam.

Table 3.1 summarizes the types of sampling carried out at these nine stations for the period 1965 to 1968 inclusive. Reference should be made to Appendix C for an explanation of the survey and details, of those computations not done by standard methods.

The laboratory analysis should perhaps be briefly described (U.S. Inter-Agency on Water Resources, 1941). The laboratory is equipped to perform the following basic analyses:

(a) sediment concentration analysis by evaporation and filtration methods, and determination of dissolved solids by evaporation method.

(b) particle-size distribution analysis by the bottom withdrawal, pipette, visual accumulation tube, sieving, and hydrometer analysis methods.

(c) weight analysis.

Sediment concentration analysis by the evaporation method is carried out by evaporating the water from the sample after the sediment has settled to the bottom, the result being corrected for dissolved solids. (The quantity of dissolved solids is determined by evaporating a portion of the clear water decanted from the sample). Concentration analysis by the filtration method is performed by utilizing Gooch crucibles with fiber glass and asbestos filters and a vacuum system.

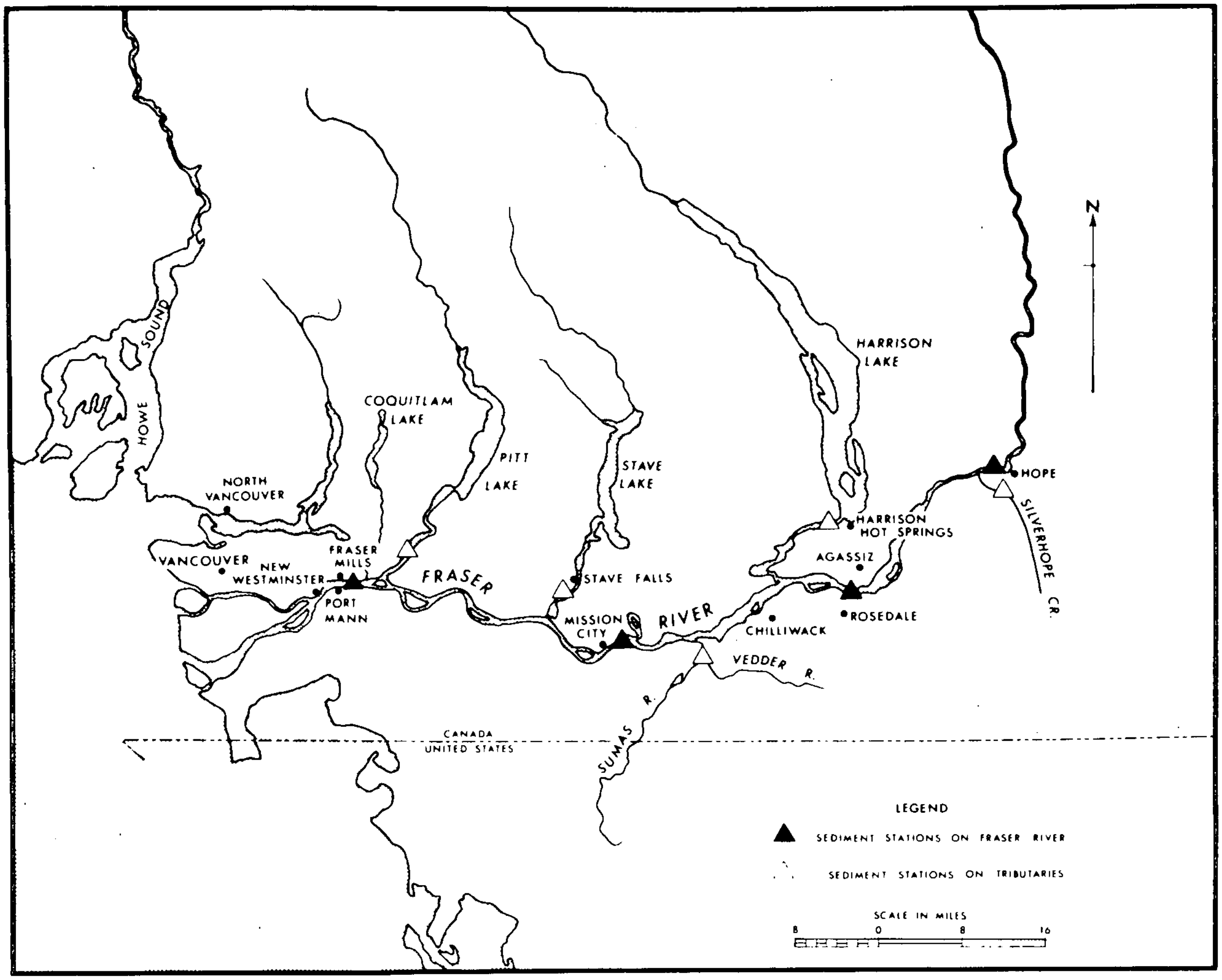


FIGURE 3-1 **SEDIMENT SURVEY STATIONS, LOWER FRASER RIVER**

TABLE 3.1

SUMMARY OF SEDIMENT SURVEY SAMPLING

Station	1965*	1966	1967	1968
Fraser River at Hope	1**,2	1,2	1,2	1,2
Fraser River near Agassiz		1*	1	1,2,4
Fraser River at Mission City	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Fraser River at Port Mann	1,2,3,4	1,2,3,4	1,2,3,4	1,2,3,4
Silverhope Creek near Hope	1	1	1	1
Harrison River near Harrison Hot Springs	1	1	1	1
Chilliwack River at Vedder Crossing	1	1	1	1
Stave River at Stave Falls	1	1	1	1
Pitt River near Port Coquitlam	1	1	1	1

*Partial year only (details in Appendix C)

**Legend

1. individual suspended sediment samples
2. suspended sediment measurements
3. bed material samples
4. bed load samples

Weight analysis is carried out for all bed load samples and simply consists of determining the dry weight of the sample.

Particle-size analysis is carried out for all bed material samples, for a relatively large number of bed load samples, and for a limited number of suspended sediment samples. Most of the suspended sediment samples with concentration less than 0.3 gm./l. are not analysed for particle size. Determination of sand sizes and sediment coarser than 0.062 m.m. is generally done by sieve analysis. Sediment with particle size finer than 0.062 is done by use of the bottom withdrawal tube, pipette or hydrometer method of analysis depending on the amount of sediment. Native or distilled water or both are used as the settling medium except in some instances when chemical dispersing agents are added to the settling medium.

3.2 Suspended Sediment Sampling and Analysis

The suspended sediment component of total load is relatively easy to measure and compute. The sampling of suspended sediment is done with relatively reliable point-integrating and depth-integrating samplers, such as the D49, P61 and P63 samplers (Stichling, 1969). The samples are readily analysed in the laboratory for concentration and for particle size as required.

To measure the suspended sediment discharge, the stream cross-section is divided into at least five equal flow portions. A representative suspended sediment sample is taken in each portion. For each part of the cross-section, the suspended sediment discharge (r) may then be computed by multiplying the flow (q) by the suspended sediment concentration (c).

$$r = qc \quad \ldots \quad 3.1$$

The suspended sediment discharge for the entire cross section, R, is computed simply by summation of the sediment discharges for the separate areas;

$$R = \sum_{i=1}^{n} r = \sum_{i=1}^{n} q_i c_i \quad \ldots \quad 3.2$$

where n is the number of sub-areas or portions into which the stream is divided.

The depth-integrating method of sampling is used to simplify the measurements of suspended sediment discharges. The samplers are designed so that they fill at a rate proportional to the velocity of the approaching flow. Thus by traversing the depth of the stream at a uniform speed, the sampler will receive a volume of water sediment mixture in proportion to the velocity at every point in the vertical.

A limited number of suspended sediment discharge measurements are made by the point-integrating method. In this measurement, samples are obtained at four or five points throughout the depth in each vertical. Five verticals are usually thus sampled. These point-integrating measurements are used to check by comparison the depth-integrating measurements and to obtain samples for particle-size distribution analysis.

Individual, or "daily", samples are collected in one vertical of the cross-section in addition to the measurements described above. The frequency of collection of these individual samples varies with the sediment concentration and with the rate of change of the concentration.

During periods of very high concentrations or rapidly changing concentrations, two or three sediment samples are taken each day. On the other hand, during periods of low concentrations and when the day to day concentrations remain relatively constant, a sampling frequency of one sample each week or one every two weeks is often considered adequate. The individual samples may be either a depth-integrating sample at a vertical or a point sample obtained from the river bank by pumping.

The relationship between the concentration of the individual samples and the average concentration which is computed from the measurements at the five verticals, $K = C_a/C_d$, is determined for each station. Using this relationship, the sediment concentrations of the individual observations are corrected to represent the average cross-section concentration. The correction is applied as follows:

$$C_a = C_d/K \qquad 3.3$$

where C_d is the concentration of the individual sample and C_a is the concentration representative of the cross-section. These average sediment concentrations are plotted with respect to time and the points are joined with a smooth curve to obtain a continuous concentration graph. The daily mean concentrations are determined directly from the graph.

The daily suspended sediment load is computed in tons per day for each day multiplying the product of the mean daily discharge and the mean daily concentration by an appropriate conversion factor.

In the case of the Lower Fraser River, a number of deviations from standard techniques was required in order to make possible the collection of the large volume of data required. This applies especially to the tidal reaches in which the sediment concentrations often vary by as much as 300 and 400 percent within one tidal cycle. Because of this variation or unsteady discharge of suspended sediment the sampling techniques had to be such that produced usable and representative data. Thus it was required that a sediment measurement be done "instantaneously" in order to be representative of some certain condition. A continuous record of the variables, discharge and concentration would provide ideal results if such could be obtained.

The deviations from standard methods included such items as width integrating sampling using a portable pumping sampler, daily sampling using pump samplers located on the bank, sampling at tide peaks, intensive observations such as hourly sampling for a complete tidal cycle, 24 3/4 hours, or for a period of several days, etc. Some of these items were done on a trial basis and were discontinued as improved methods and equipment were made available. The methods and equipment and their duration of use are described in Appendix C.

Intensive observations or sampling were required to determine the variation or pattern of sediment discharge on the Fraser River at Port Mann. A number of these were done in 1966 and continued in the later years. An example of the pattern of suspended sediment discharge as determined from a sampling for June 17 and 18, 1966, June 15 and 16, 1967, and June 13 and 14, 1968 is illustrated in figures 3.2, 3.3, and 3.4 respectively. The details of other intensive sampling are given in Appendix C.

3.3 Bed Load Measurement

The other component of total load, bed load, is more difficult to determine. The methods or techniques of bed load measurement are largely in

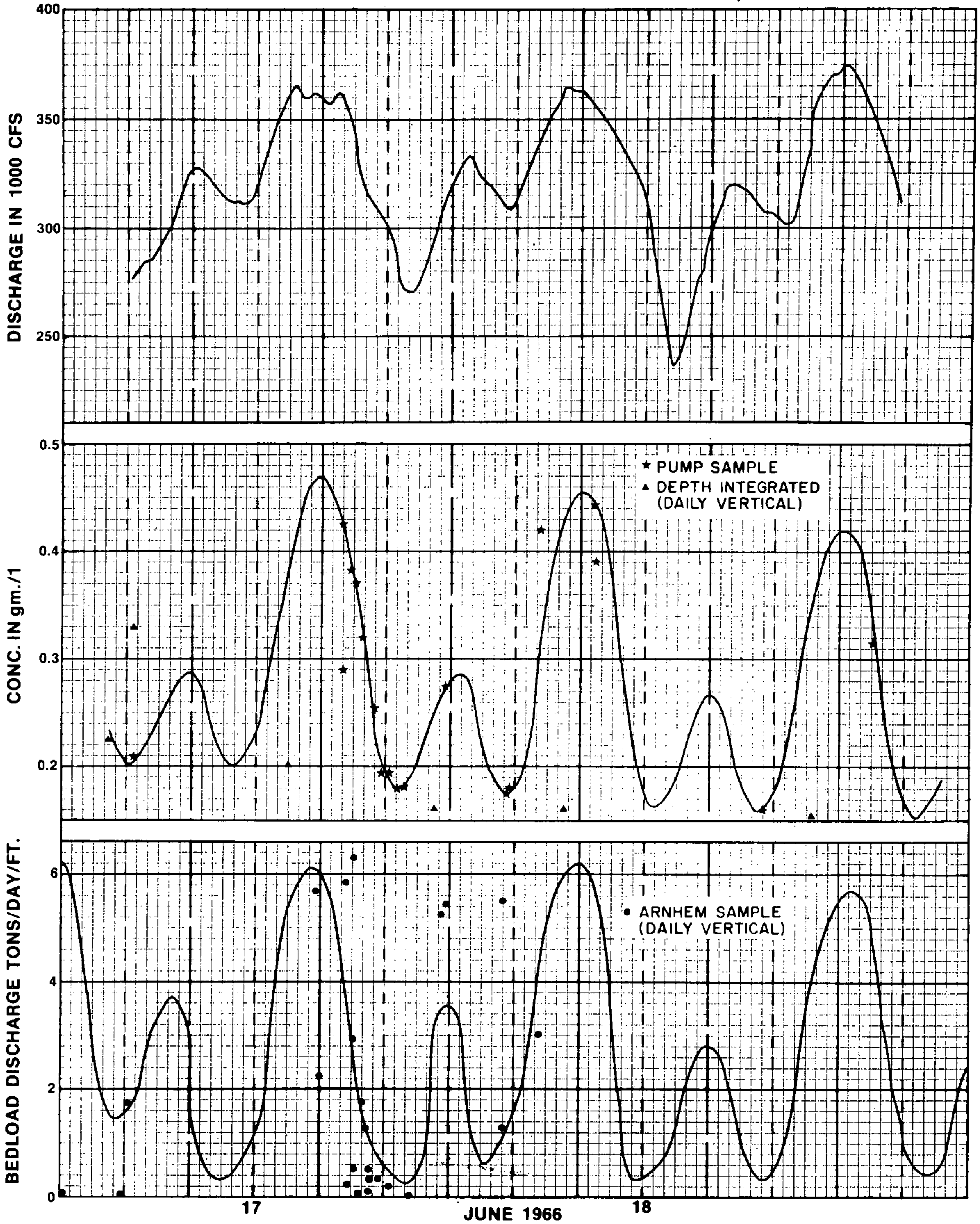


FIGURE 3·2—PATTERNS OF FLOW, CONCENTRATION AND BEDLOAD DISCHARGE.

FRASER RIVER AT PORT MANN

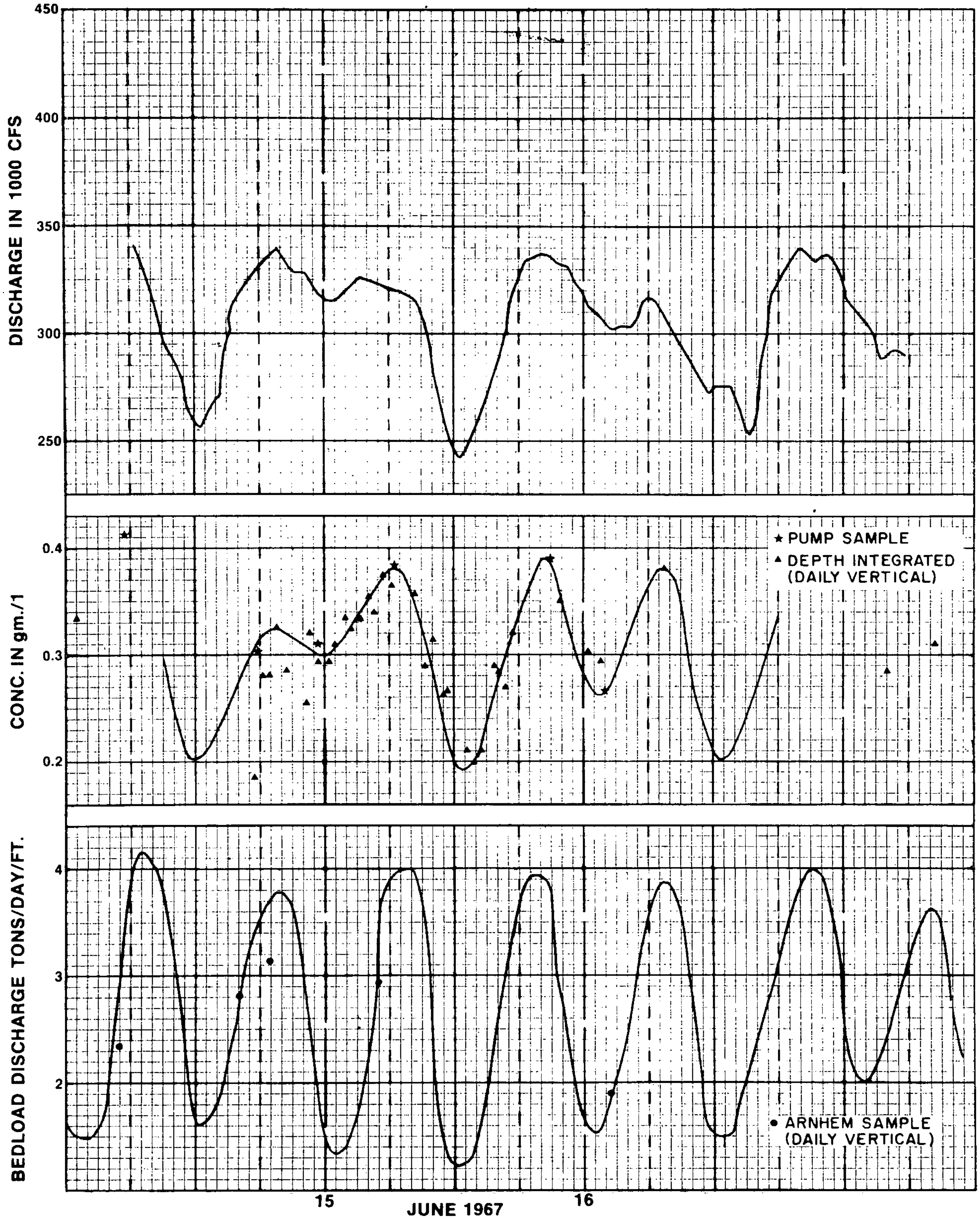


FIGURE 3·3—PATTERNS OF FLOW, CONCENTRATION AND BEDLOAD DISCHARGE.

FRASER RIVER AT PORT MANN

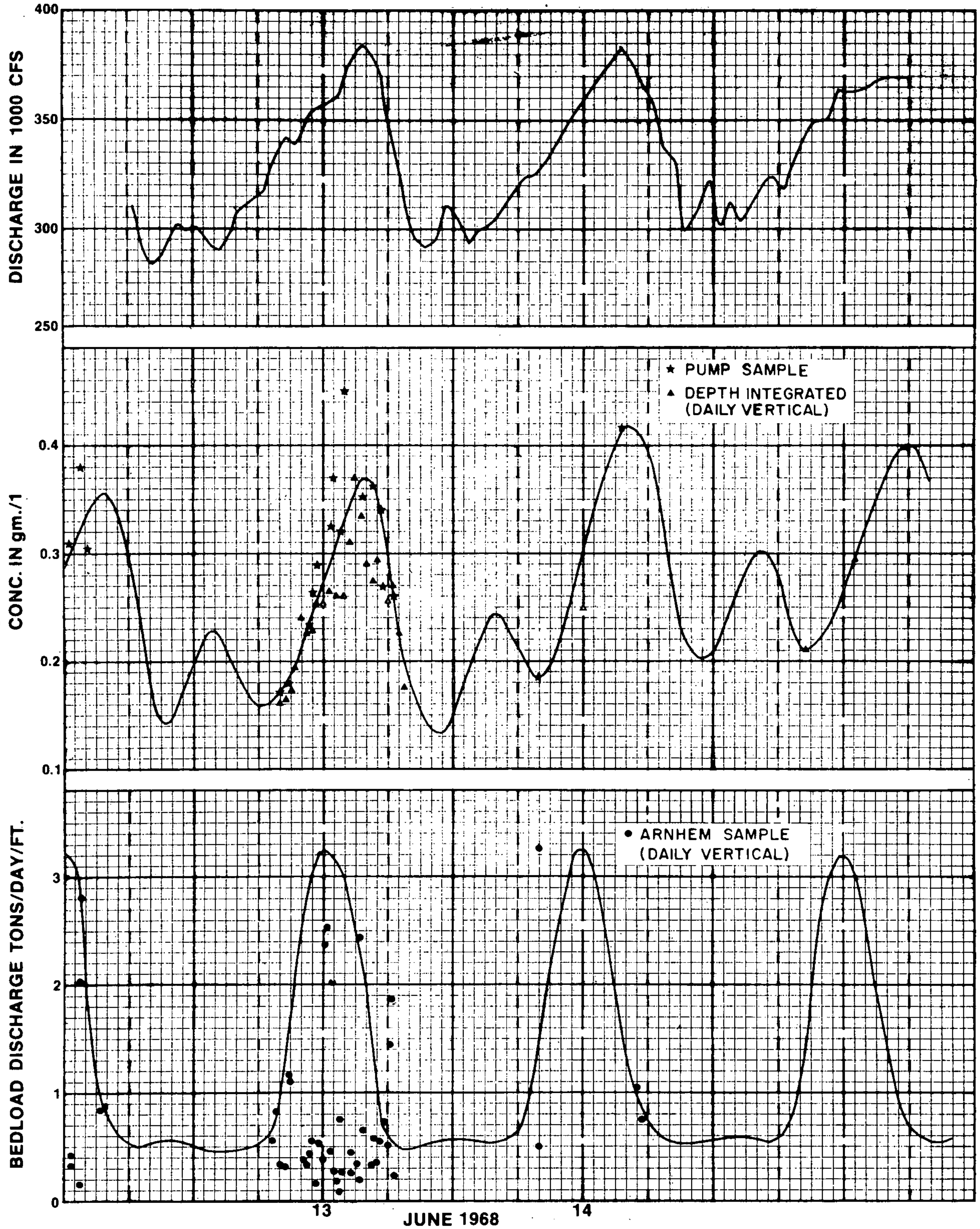


FIGURE 3·4 – PATTERNS OF FLOW, CONCENTRATION AND BEDLOAD DISCHARGE.

FRASER RIVER AT PORT MANN

the development stages. The methods commonly used include direct sampling, volumetric and acoustic measurements, and the use of tracers. The method used and its reliability depends largely on the river conditions. The bed load component is sometimes very significant in certain river engineering problems since channel behavior, dredging requirements, etc. may depend largely on bed load and very little on suspended sediment.

A number of empirical equations are often used to compute, or estimate, the bed load discharge on the basis of measured channel hydraulics parameters, water temperature, and particle size of bed material and suspended solids. These equations, such as Einstein, Kalinski, Shields, Meyer-Peter, etc., provide only an estimate. No two equations give the same result, just as no two measurement methods give the same result. Where possible a number of measurement methods and empirical equations should be used in determining the bed load transport. These results must then be combined with experience and knowledge of the entire physical system to produce a final practical and usable result.

A relatively intensive direct sampling program was carried out at the Fraser River stations Port Mann and Mission City and later at Agassiz. VUV, Sphinx, Arnhem and Basket type samplers were used. It was the Water Survey of Canada's first attempt to measure bed load by means of samplers. Some of the factors which have made bed load measurement extremely difficult are the following (Stichling, 1969):

(1) Any instrument placed on the bed of a stream disturbs the natural conditions, upsetting the patterns of flow and bed load movement in the immediate vicinity.

(2) The position taken up by the measuring instrument on the uneven bed of a channel can adversely affect the accuracy of the measurement.

(3) The extreme irregularity of bed load movement in both time and space, even under steady flow conditions, can cause very large variations between consecutive and adjacent samples.

(4) The necessity of calibrating bed load samplers for hydraulic efficiency of sampling can create additional problems.

In addition to problems concerning the mechanics of actual sampling were problems of equipment design, establishing a suitable and practical sampling frequency and of data analysis and interpretation. All of these problems are not yet solved, and in particular the ones of sampler calibration.

The bed load discharges were computed from the direct measurements in much the same way as suspended sediment discharges were. From the weight and duration of the samples and the width of the bed sampled, the unit bed load discharges are computed (tons/day/foot). The unit bed load time series graphs for the Fraser River at Port Mann and the Fraser River at Mission City which are shown in Appendix D show the average unadjusted unit bed load discharges for these two stations for the period 1966 to 1968 inclusive. By multiplying the unit discharges by the width of cross-section which the sample represents (an average width of 1800 feet can be reasonably used for each station), the bed load discharges in tons/day can be obtained. These discharges should be further multiplied by a factor, $K_b = 3.5$, to adjust the data for sampling inefficiency of the Arnhem bed load sampler and for that portion of bed load not readily measured with this type of sampler. An arbitrarily minimum bed load discharge of 0.2 tons/day/foot was assumed to exist during low flow periods.

At this low value of discharge the bed load samplers were found to be relatively ineffective.

It is anticipated that further studies and analysis of laboratory and field projects will in the future result in relatively more reliable methods of computing and interpreting the data. At the present time it is possible only to present our preliminary interpretation of the sampled data and to compare it with empirical estimates and with results of volumetric measurement methods.

Estimates of bed load transport for the Fraser River at Mission City were made by use of five different empirical equations. These equations were as follows (Morris, 1963; Rand Rivi, 1957):

1. Shields:

$$q_s = \left[\frac{10\ \gamma^2}{d(\gamma s-\gamma)}\right]\left(\frac{n}{1.5}\right)^{3/5} S^{1.7}\ q^{1.6} \quad \ldots\ 3.4$$

2. Einstein Bed-load Function:

$$q_s = \frac{40\ \gamma^4\ D^3\ S^3\ F}{\rho^{1/2}\ \sqrt{(\gamma s-\gamma)^5 d^3}} \quad \ldots\ 3.5$$

in which

$$F = \sqrt{2/3 + \frac{36\ u^2 g}{d^3\gamma(\gamma s-\gamma)}} - \sqrt{\frac{36\ u^2 g}{d^3\gamma(\gamma s-\gamma)}} \quad \ldots\ 3.6$$

3. Kalinski:

$$q_s = \gamma s\sqrt{g}\ \ 10\ \frac{\gamma^2}{d}\left[\frac{(DS)^{5/2}}{(\gamma s-\gamma)^2}\right] \quad \ldots\ 3.7$$

4. Meyer-Peter (1948):

$$q_s^{2/3} = 39.25\ q^{2/3}S - 9.95\ d \quad \ldots\ 3.8$$

5. Equation developed by regression analysis of 1968 bed load measurement data:

$$q_s = 2.3972 \times 10^{-20}\ Q^{3.377} \quad \ldots\ 3.9$$

An adjustment factor, K_b=3.0, is inherent in equation 3.9.

In these formulae the symbols, and their dimensions in terms of length, time and force, are defined as follows:

d	mean particle size of sediment (L)
D	depth of flow (L)
F	factor defined by equation 3.6
g	gravitational acceleration (L^2/T)
n	Manning's resistance coefficient ($L^{1/6}$)
q	fluid discharge per unit width (L^2/T)
q_s	bed load discharge per unit width (L^2/T)
Q	fluid discharge (L^3/T)
S	slope (general)
γ	specific weight of fluid (F/L^3)
γ^s	specific weight of solids (F/L^3)
u	dynamic viscosity of fluid (FT/L^2)
ρ	mass density of fluid (FT^2/L^4)

q_s for these equations will have the unit lb/sec/ft, when the foot-pound system of units is used. For illustration purposes, the results were multiplied by 43.2 to convert to tons/day/foot. Thus the bed load discharge as a function of discharge is illustrated graphically in figure 3.5.

From these results it becomes evident that the empirical equations alone do not give a reliable estimate of bed load discharge.

Further estimates of bed load transport for both Mission City and Port Mann were made using volumetric methods. The average dune velocities and heights were determined using an echo sounder at a number of verticals in each cross-section. The bed load discharge was computed using the differential equation of bed load transport for the ripples and dune bed configuration (Simons *et al.*, 1965):

$$\frac{\partial y}{\partial t} + \frac{1}{(1-\lambda)} \frac{\partial qb}{\partial x} = 0 \quad \text{.........................} \quad 3.10$$

in which qb is the bed load transport by volume, t is time, λ the porosity of the sand bed, and the other variables are as defined in figure 3.6. Equation 3.10 can be solved for qb such that

$$qb = (1-\lambda)\ Vs\ y + C_1 \quad \text{.........................} \quad 3.11$$

in which Vs is the average velocity of the ripples and dunes in the direction of flow, and C_1 is a constant of integration which may be interpreted as that

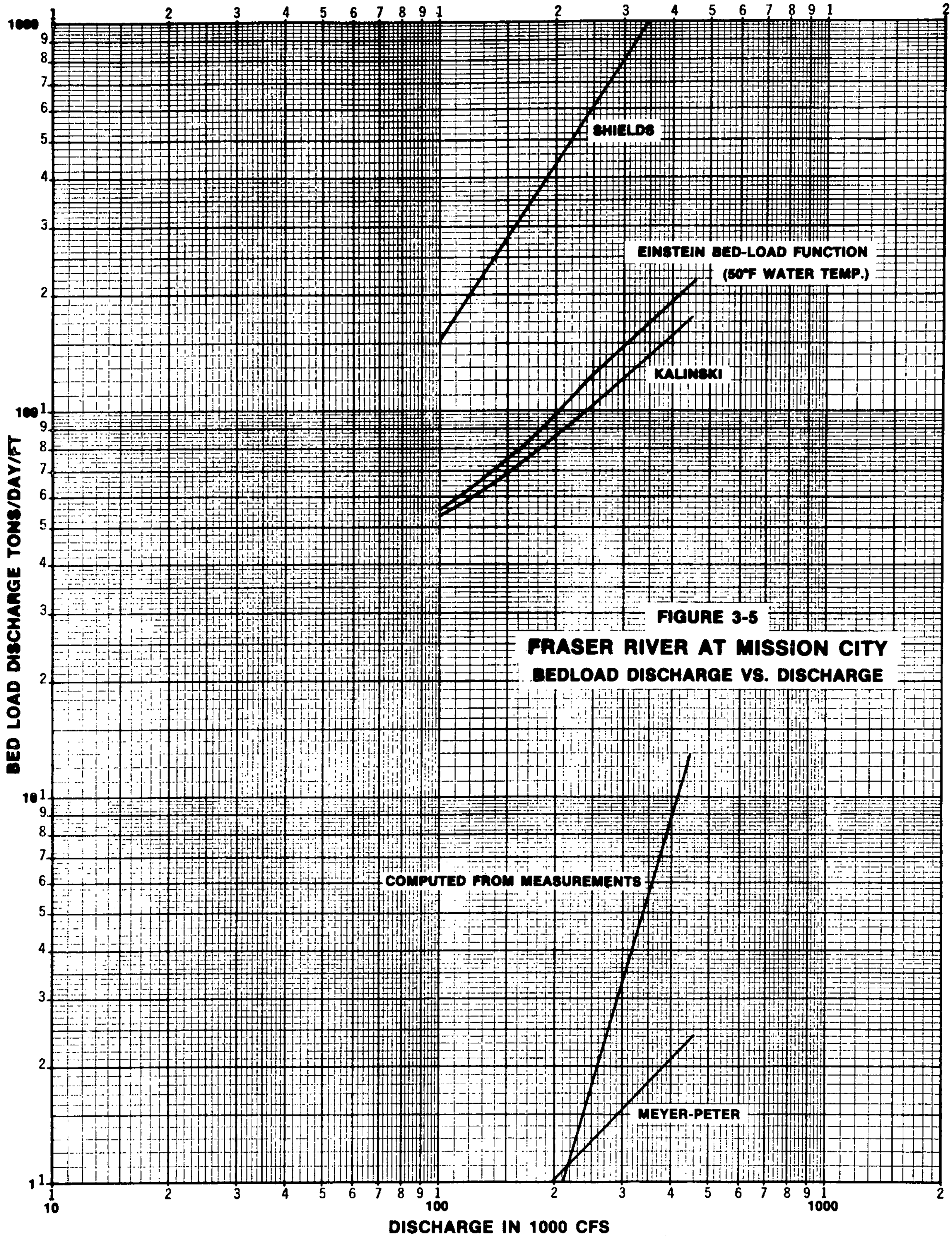


FIGURE 3-5
FRASER RIVER AT MISSION CITY
BEDLOAD DISCHARGE VS. DISCHARGE

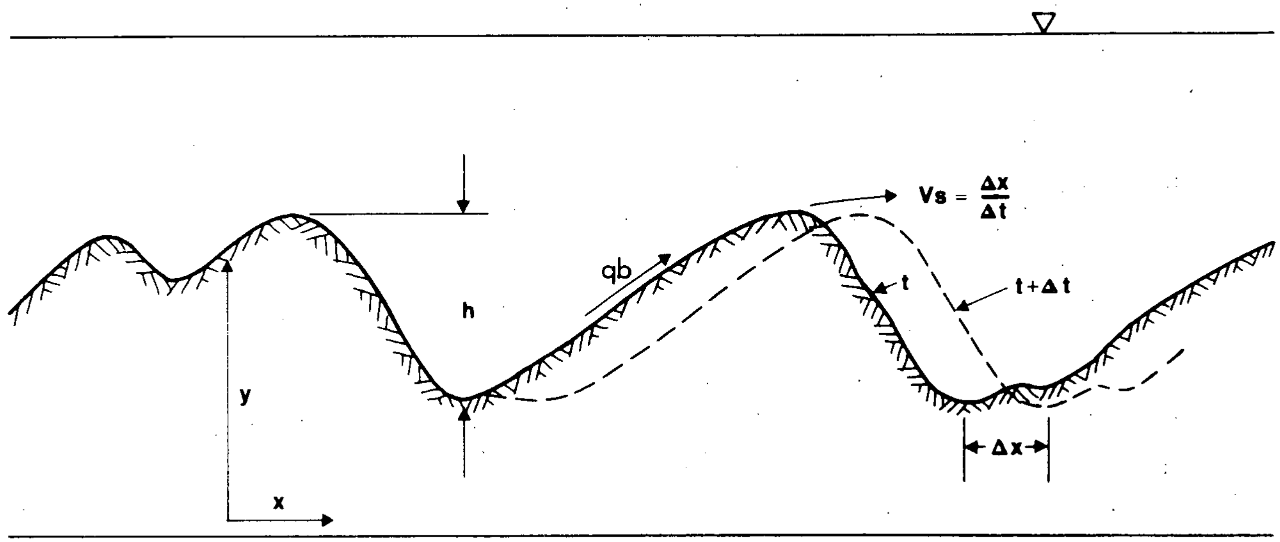


FIGURE 3-6 - DEFINITION SKETCH OF DUNES (not to scale) part of bed load which does not enter into the propagation of dunes and ripples. C_1 may be considered to be equal to zero so long as the bed is entirely covered with ripples and dunes. Thus, by setting $C_1 = 0$, assuming that the dunes and ripples are triangular in shape, and by multiplying by γ, the unit weight of sediment, the equation for bed load discharge is simplified to

$$qb = (1-\lambda)\ \gamma Vs\ (h/2) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ 3.12$$

In the Fraser River computations, equation 3.12 was used assuming that $(1-\lambda)\gamma = 93\ lb/ft^3$.

Some of the results for the Fraser River at Mission City for 1968 are shown in tables 3.2 and 3.3. Sounding data for the Fraser River at Port Mann are also available for 1967 and 1968. They are not shown in this report since analysis of these data is not yet completed.

3.4 Bed Material Sampling

Bed material samples were taken periodically at the Fraser River stations at Port Mann and Mission City as shown on table 3.1. A BM-54 type bed material sampler was used. Samples were usually obtained at five verticals and analysed for particle size for use in equations for estimating bed load discharge and for channel design.

Although bed material sampling was programmed for the Fraser River near Agassiz for 1968, it was found that the bed material sizes were too large for suitable sampling with a BM-54 sampler. A large Lane type sampler was designed and constructed for future years sampling at this station.

Results of particle-size analysis for the Fraser River stations at Port Mann and Mission City for the years 1965 to 1968 inclusive are shown in Appendix D. Only the average monthly particle-size distributions are shown. The results of individual measurements are published in the Sediment Data publications.

3.5 Summary of Results

The following basic computed data have been summarized in the form of graphs and tables: the total annual streamflow, suspended sediment, bed load and total load discharge; the daily water temperature, streamflow suspended sediment, and bed load time series graphs; suspended sediment, bed load and bed material particle-size distribution graphs; and a number of additional graphs showing the relationships of some of these variables.

The total annual streamflow, suspended sediment, bed load and total load discharges are summarized in tables 3.4 and 3.5 for the period 1965 to 1968 inclusive.

In these tables, the bed load discharges shown are the adjusted values. That is, these figures are the product of the total annual unit bed load discharge in tons/day/foot, the average width (1800 feet) and the coefficient, $K = 3.5$, as described in section 3.3. The row indicated as 'tributaries' shows the sums of the total annual figures of those five tributaries for which sediment survey programs are operational.

The discharge and sediment discharge hydrographs for the four Fraser River stations for the period 1965 to 1968 inclusive are shown in

TABLE 3.2

Comparison of Volumetric and Sampling Methods of
Bed Load Discharge Measurement
Vertical 900, Fraser River at Mission City

Date/Time (PST)	Volumetric* (T/day/ft)	Sampling** (T/day/ft)	Ratio=$\frac{\text{Volumetric}}{\text{Sampling}}$
May 30/68 9:00-13:30	5.596	0.905	6.2
June 7/68 10:00-13:30	5.904	1.727	3.4
June 21/68 11:30-13:30	6.115	1.771	3.5
		Average	4.4

* All values are averages over time period indicated.
**Arnhem bed load sampler used.

TABLE 3.3

Comparison of Bed Load Discharge in 5 Verticals to
Bed Load Discharge at the Daily Vertical (vertical 900)
Fraser River at Mission City (Volumetric method of measurement)

Date/Time (PST)	Average in 5 Verticals (T/day)	Average in Daily Vertical (T/day)	Ratio=$\frac{\text{5 Verticals}}{\text{Daily}}$
May 30/68 9:00-13:30	8,462	10,073	0.84
June 21/68 11:30-13:30	6,752	11,000	0.61
		Average	0.72

On the basis of these volumetric measurements, the multiplication coefficient, K, to obtain the average bed-load discharge at the cross-section from bed-load discharge sampled at the daily vertical with the Arnhem sampler is as follows:

$$K = 4.4 \times 0.72 = 3.2$$

in which 4.4 is the average volumetric/sampling ratio shown in table 3.2.

TABLE 3.4

Total Annual Water, Suspended Sediment, Bed Load and Total Load Discharges

Stations	1965*					1966				
	Discharge (a)	Suspended Sediment Discharge (b)	Bed Load Discharge (b)**	Total Sediment Discharge (b)	Suspended Sediment Concent-ration (c)	Discharge (a)	Suspended Sediment Discharge (b)	Bed Load Discharge (b)**	Total Sediment Discharge (b)	Suspended Sediment Concent-ration (c)
Fraser River at Hope	50,716	13,942	--	--	0.200	75,331	21,794	--	--	0.215
Fraser River near Agassiz	--	--	--	--	--	46,734*	9,839*	--	--	0.155*
Fraser River at Mission City	62,516	13,952	--	--	0.165	94,150	22,191	1,375	23,566	0.175
Fraser River at Port Mann	64,194	12,128	1,688	13,816	0.140	97,795	19,626	1,949	21,575	0.150
Tributaries										

* partial year only
**adjusted, $K_b = 3.5$

a discharge in 1000 acre-feet
b discharge in 1000 tons
c average suspended sediment concentration, grams/litre = (suspended sediment discharge in tons/discharge in acre-feet) x 0.7355

TABLE 3.5

Total Annual Water, Suspended Sediment,

Bed Load and Total Load Discharges

Stations	1967					1968				
	Discharge (a)	Suspended Sediment Discharge (b)	Bed Load Discharge (b)**	Total Sediment Discharge (b)	Suspended Sediment Concentration (c)	Discharge (a)	Suspended Sediment Discharge (b)	Bed Load Discharge (b)**	Total Sediment Discharge (b)	Suspended Sediment Concentration (c)
Fraser River at Hope	80,763	25,815	--	--	0.235	85,060	27,789	--	--	0.240
Fraser River near Agassiz	86,530	29,952	--	--	0.235	86,894	23,480	--	--	0.200
Fraser River at Mission City	99,643	32,128	1,385	33,513	0.235	102,960	26,441	945	27,386	0.190
Fraser River at Port Mann	103,380	26,645	1,715	28,360	0.190	107,070	22,697	898	23,595	0.155
Tributaries										

* partial year only
**adjusted, $K_b = 3.5$

a discharge in 1000 acre-feet
b discharge in 1000 tons
c average suspended sediment concentration, grams/litre = (suspended sediment discharge in tons/discharge in acre-feet) x 0.7355

Appendix D-1. Similarly, the discharge and unit bed load discharge hydrographs for the period April 1 to September 15 for 1966 to 1968 inclusive, are shown in Appendix D-2. Each set of graphs has common ordinate and abscissa scales so that the adjacent years data could be readily compared. The discharge hydrograph is also shown together with the other time series graphs so that this parameter could be readily compared with the others.

The water temperature time series graphs for the four Fraser River stations for the period 1965 to 1968 inclusive are shown in Appendix D-3. These temperatures are in degrees Centigrade. Some temperature data are also available for the tributary stations; however, they are not continuous and are therefore not shown in Appendix D-3. These data are published in the Water Survey of Canada's Sediment Data publications.

Particle-size distribution curves of suspended sediment for the Fraser River stations for the month of June for 1965 to 1968 inclusive are shown in Appendix D-4. These curves are intended to illustrate the variation in particle size of suspended sediment with location or distance from the mouth of the river. Only the average distribution as determined for the month of June is shown in each of these graphs. Further details of individual and additional particle-size analysis are published in the Sediment Data publications.

Particle-size distribution curves of bed material are shown for the Fraser River stations at Port Mann and Mission City for 1965 to 1968 inclusive in Appendix D-5. In cases where more than one measurement was made each month, the analysis results were averaged for that month and these average monthly distributions were summarized in the Appendix. The particle-size distributions for the individual measurements are published in the Sediment Data publications.

Particle-size distribution curves of bed load, the material obtained with the bed load samplers, are shown in Appendix D-6. An attempt was made to summarize that data which appeared to be most representative of the cross-section for the month for which the particle size data were available. Thus selected days of available data for the Fraser River stations at Port Mann, Mission City and near Agassiz are summarized in this Appendix.

The results can be illustrated in a number of other ways. It is interesting to summarize the net deposition of sediment in the river reaches between the stations where sediment data are obtained. Thus the net depositions (shown as negative deposition for those reaches where a net erosion resulted) for the Lower Fraser River are shown in table 3.6.

The results presented in this table should not be interpreted as exact or absolute quantities of depositions since they are dependent on the sampling and computational accuracy. The table is intended to illustrate the erosion-deposition trend or if such a trend actually exists.

The suspended sediment discharge can also be illustrated graphically as a function of discharge. Such relationships are shown in figures 3.7 to 3.10 inclusive for the four Fraser River stations. In each figure the available monthly mean data were used and the best fit line was fitted by the least squares method. The equations of the lines are shown. In these equations, y refers to the ordinate variable (suspended sediment discharge) and x refers to the abscissa variable (discharge). The degree of association between these variables is described by the correlation coefficient

TABLE 3.6

Net Sediment Deposition* in the Lower Fraser River

River Reach	1965** in 1000 tons	1966 in 1000 tons	1967 in 1000 tons	1968 in 1000 tons
Fraser River at Hope to Fraser River at Mission City	-10	-397	-6,313	1,348
Fraser River at Hope to Fraser River near Agassiz	-----	-----	-4,137	4,309
Fraser River near Agassiz to Fraser River near Mission City	-----	-----	-2,167	-2,961
Fraser River at Mission City to Fraser River at Port Mann	1,824	2,565	5,483	3,744

* Suspended sediment figures shown in tables 3.4 and 3.5 were used in computing the net sediment deposition.

**Partial year only.

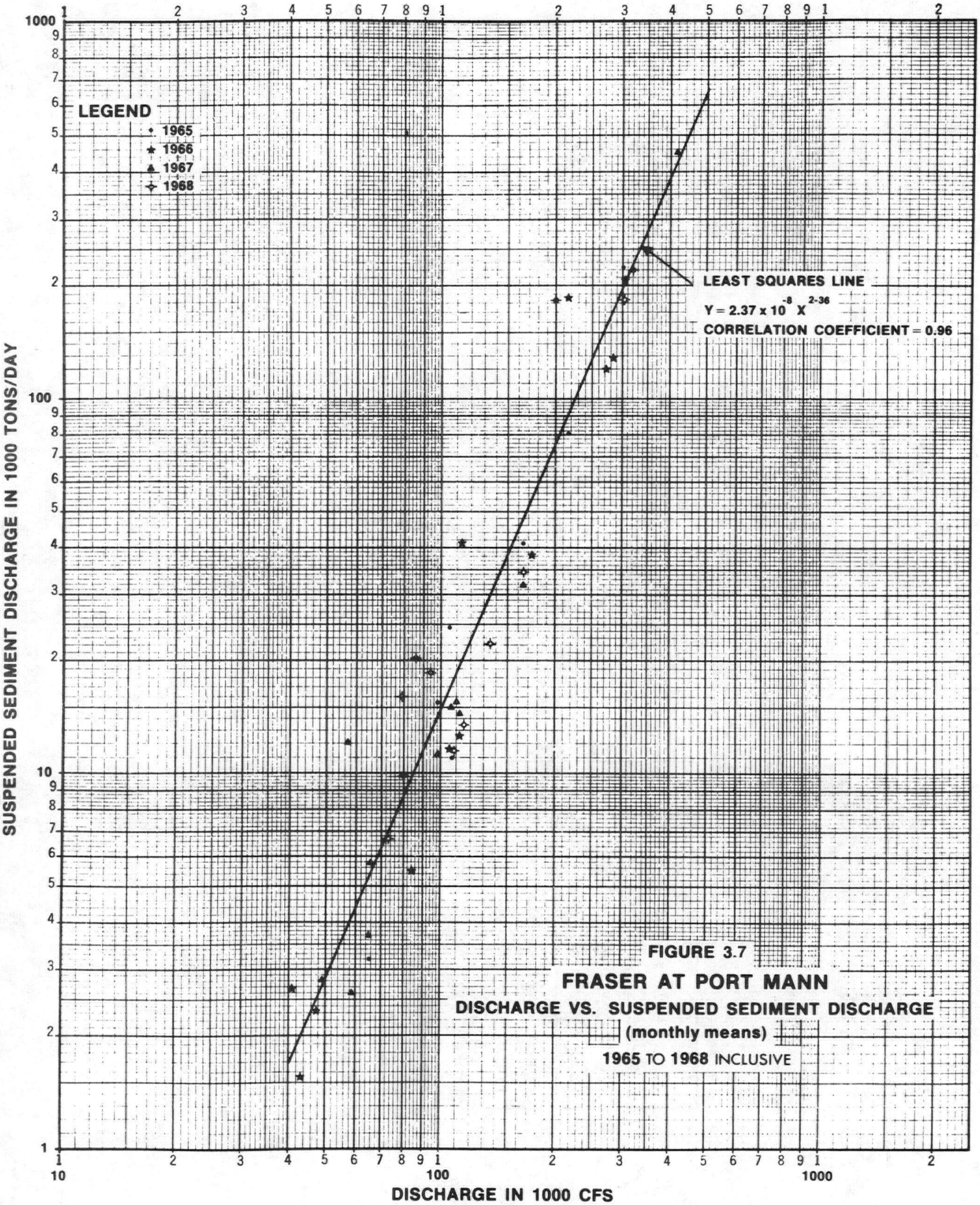


FIGURE 3.7

FRASER AT PORT MANN

DISCHARGE VS. SUSPENDED SEDIMENT DISCHARGE

(monthly means)

1965 TO **1968** INCLUSIVE

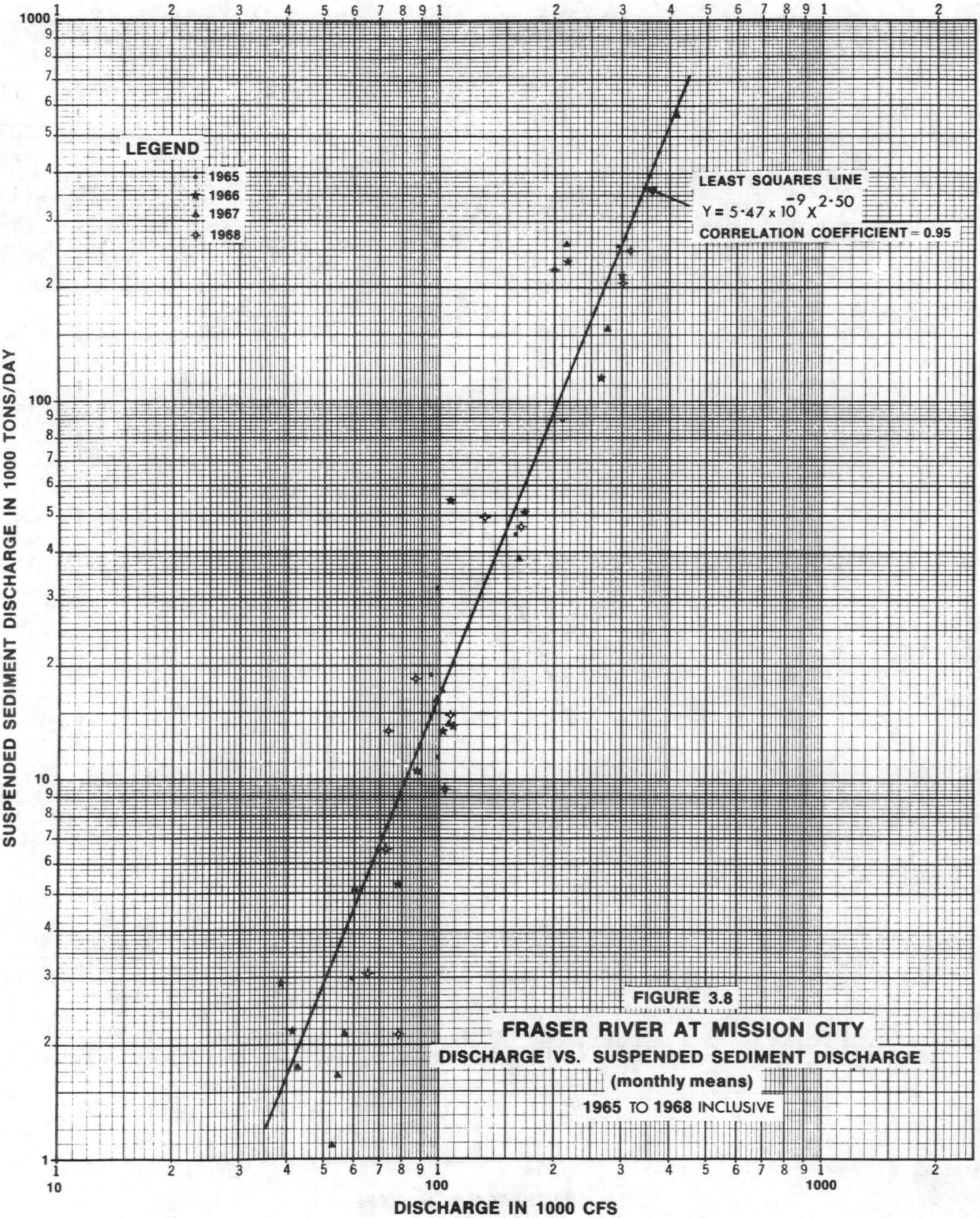


FIGURE 3.8

FRASER RIVER AT MISSION CITY

DISCHARGE VS. SUSPENDED SEDIMENT DISCHARGE

(monthly means)

1965 TO 1968 INCLUSIVE

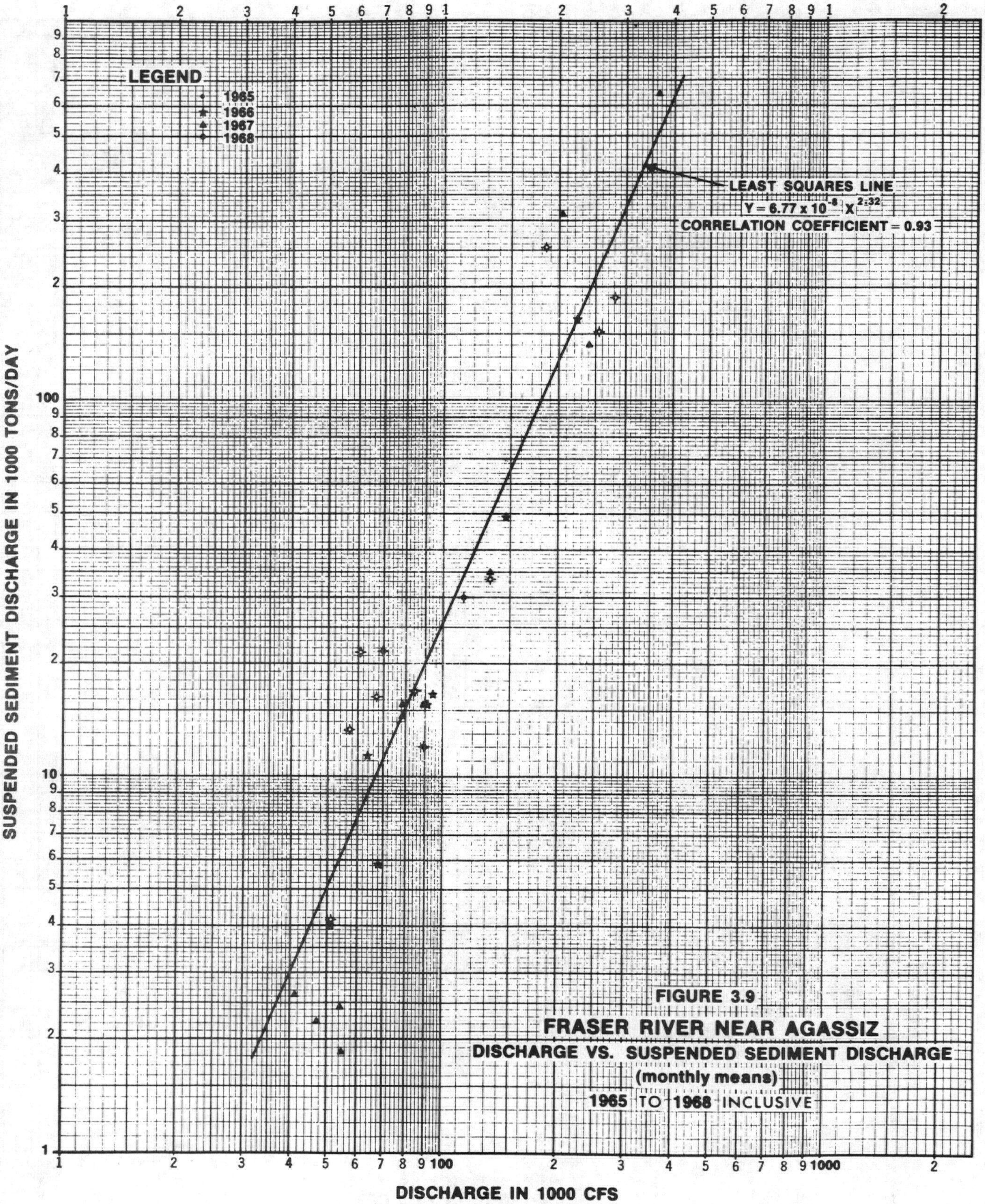


FIGURE 3.9
FRASER RIVER NEAR AGASSIZ
DISCHARGE VS. SUSPENDED SEDIMENT DISCHARGE
(monthly means)
1965 TO 1968 INCLUSIVE

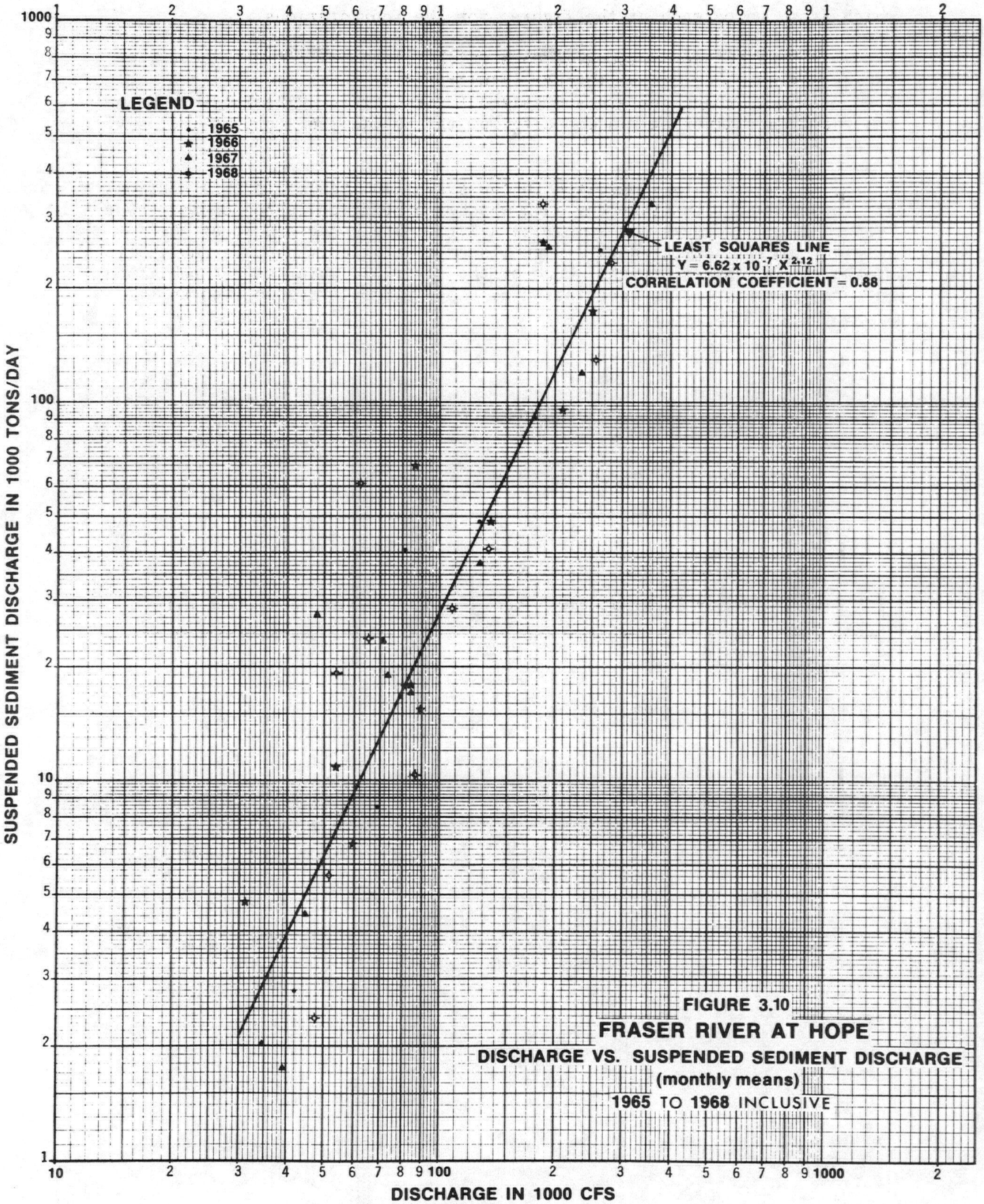


FIGURE 3.10
FRASER RIVER AT HOPE
DISCHARGE VS. SUSPENDED SEDIMENT DISCHARGE
(monthly means)
1965 TO 1968 INCLUSIVE

which is shown on each of the figures for the four stations.

The bed load discharge data which are shown in tons per year in tables 3.4 and 3.5, can be further illustrated in terms of percent of total load. These percentages are summarized for the Fraser River at Port Mann and the Fraser River at Mission City for the period 1965 to 1968 inclusive in table 3.7.

The results summarized in the graphs and tables in this section are intended to illustrate the data which are being collected on the Lower Fraser River. It does not summarize all the data because most of the relevant details of the data are published in the Sediment Data publications of the Inland Waters Branch. Much of the raw field data are not published but are used instead in computation of those parameters described and presented in this report.

TABLE 3.7

Bed Load Discharge as Percent of Total Load

Year	Fraser River at Port Mann	Fraser River at Mission City
1965*	12%	--
1966	9%	6%
1967	6%	4%
1968	4%	3%

*partial year only

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

4.1 General Conclusions

A number of general conclusions with respect to the hydrometric and sediment survey on the Lower Fraser River can be made.

The progress of the surveys, and the data and results obtained for the Lower Fraser River for the period 1965 to 1968 inclusive are only very briefly, not completely, summarized in this report. Some of the data used in the analysis, particularly the 1968 data, were provisional. The final and detailed data can be found in the Sediment Data publications. The methods of the surveys and data analysis and the reliability of the results have also been described briefly.

The network of stations and the programs at the stations were designed to provide data which would enable computation of continuous flow, suspended sediment and bed load discharge and the computation of bed load discharges using empirical equations at a number of Fraser River stations. The determination of net erosion or deposition between the stations and the contribution to the sediment discharge of the river of a number of tributaries was also made possible. Extension of the network to the delta region is recommended in the next section.

Improvement and automation of equipment and improvement of survey techniques has enabled collection of data of higher quality and greater reliability than would have been possible by conventional equipment and techniques. Similarly, automation and computerization of routine office analysis have made possible the efficient and accurate data computation and processing.

Bed load measurement has been, and still is, the major problem in the survey. Although considerable progress has been made in improvement of sampling equipment and techniques, many of the basic problems are not solved. It is anticipated that further improvement in sampling techniques and use of more sophisticated analysis will result in more reliable bed load discharge data.

4.2 Recommendations

Based on the survey operations and the results which have been obtained from the analysis and compilation of the data, a number of recommendations can be made.

The first item, which should perhaps be emphasized, is that the present hydrometric and sediment survey provide useful data only for the river reach between Hope and Port Mann. Extension of the survey to the delta reaches downstream from Port Mann, also a source of navigational and channel stability problems, should be given forceful consideration.

Several recommendations with respect to the hydrometric and sediment survey program and operations have already been put into effect. For example, the bed load measurement program is being improved by more intensive sampling; continuous recording of suspended sediment is in the process of being made operational at two Fraser River stations; an intensive hydrometric program has been planned for the Fraser River at Port Mann to obtain flow data for calibration and checking of the mathematical flow model; etc. These improvements of equipment and survey techniques have upgraded the quality of the data and have made the data collection more efficient.

The results of empirical computation of bed load discharges presented in section 3.3 of this report should be treated as preliminary. A more detailed analysis which would take into consideration a greater variety of variables and conditions is required. It is anticipated that such an analysis will be made in the near future and that the Modified Einstein method, a comparatively more lengthy analysis, will be used to further study the applicability of empirical computation of bed load discharge for the Fraser River stations.

With respect to the future of the hydrometric and sediment survey, it should perhaps be pointed out that at least 15 years data are required to perform appropriate statistical analysis of hydrologic and geomorphologic data. On this basis the following recommendations can be made:

(1) all aspects of the present survey should be continued for at least ten years,

(2) serious and immediate consideration should be given to extending the survey network to the delta region,

(3) the survey of the delta region should be complemented by simulation of water and sediment discharges and other hydrodynamic processes by mathematical modelling techniques, and

(4) the overall Lower Fraser survey should be complemented by mathematical modelling techniques, similar to item 3 above but for the entire Lower Fraser River.

The Lower Fraser River valley and delta are one of Canada's most densely populated and industrialized regions, yet virtually no reliable flow and sediment discharge data are available for this region. This alone is adequate justification for immediate consideration and action of the recommendations proposed in this report. Further justification stems from the need for reliable and continuous data for design of harbour facilities, improvement and maintenance of the navigation channel, assessment and abatement of water pollution, design of flood control works, and for other related purposes.

APPENDIX A

HYDROMETRIC STATION HISTORY

LOWER FRASER RIVER

APPENDIX A. HYDROMETRIC STATION HISTORY, LOWER FRASER RIVER

Station Number	Station*	Drainage Area Sq. Mi.	Gauge	Period of Record**	Mean Discharge cfs	Extremes Recorded***		Remarks
						Maximum	Minimum	
08MF005	Fraser River at Hope	78,300	recording	March 1912 - Sept. 1966	95,200 (54 yrs.)	536,000 cfs(d) May 31, 1948	12,000 cfs(d) January 8, 1916	Mean daily discharge published. Flow affected by storage and diversion.
08MF035	Fraser River near Agassiz		recording	April - July 1949 (elev. only) April 1950 - Sept. 1966 (elev. only), Oct. 1965 - Sept. 1966 (discharges)		57.13' (elev.)(d) June 16, 1964	34.50' (elev.)(I) March 22, 1952	Records prior to 1957 published under "Fraser River near Rosedale".
08MF056	Fraser River at Chilliwack Mountain		recording	July 1962 - Sept. 1966 (elev. only)		29.01' (elev.)(I) June 19, 1964	not determined	Tidal except for high water. Daily maximum and minimum elevations only, periods of varying length.
08MH024	Fraser River at Mission City		recording and telemetering	Elevations only, maximum yearly, 1876, 1882 and 1894 to 1935, daily max. and min. Oct. 1935 to Sept. 1966 Discharges, May 1965 - Sept. 1966		25.75' (elev.)(d) June 5, 1894 333,000 cfs (I) June 2, 1966	-1.00' (elev.)(d) usually reaches this low 33,100 cfs (d) March 4, 1966	Tidal except at high water. Daily mean discharges less than 190,000 cfs computed by cubature method.
08MH044	Fraser River at Whonock		recording	Elevations only, daily max. and min. May 1954 - Sept. 1966 Discharges, May 1965 - Sept. 1966, not published		27.25' (elev.)(I) June 19, 1964	7.16' (elev.)(I) March 20, 1955	Tidal except at high water. Discharges computed by cubature method.
08MH043	Fraser River at Port Hammond		recording	Elevations only, daily max. and min. May 1954 - Sept. 1966 Discharges, May 1965 - Sept. 1966 not published		22.87' (elev.)(I) June 19, 1964	6.45' (elev.)(I) January 24, 1962	Tidal at all stages. Discharges computed by cubature method.
08MH054	Fraser River at Port Mann		recording	Misc. measurements only, 1935, 1948 and 1954. Daily max. and min. elevations only, May 1956 - Sept. 1966 Discharges May 1965 - Sept. 1965 not published		19.49' (elev.)(I) June 10, 1956 339,000 cfs (d) June 7, 1965	5.86' (elev.) March 30, 1962 68,500 cfs (d) September 25, 1965	Tidal at all stages. Discharges computed by cubature method for May 1965 to September 1965.
08MH025	Fraser River at New Westminster		recording	Misc. measurements, 1919 and 1920 Max. elevations only, for most years from 1882 to 1935 Max. and min. daily elevations Oct. 1935 - Sept. 1966		19.20' (elev.)(I) June 10, 1948	5.22' (elev.)(I) Feb. 22, 1964	Tidal at all stages.
08MH053	Fraser River at Deas Island Tunnel		recording	Misc. measurements, 1949 to 1951 Max. and min. daily elevations, April 1956 to November 1960 and Oct. 1961 to Sept. 1966		15.96' (elev.)(I) Dec. 24, 1957	3.43' (elev.)(I) Feb. 24, 1964	Tidal at all stages. Records prior to Nov. 1960 were published under "Fraser River at Woodwards Landing near Steveston".
08MH028	Fraser River at Steveston		recording	Misc. measurements, 1934 Max. and min. daily elevations April 1933 - Sept. 1966		16.67' (elev.)(I) Dec. 19, 1933	1.04' (elev.)(I) Jan. 6, 1947	Tidal at all stages.
08MH032	North Arm Fraser River at Vancouver		recording	Misc. measurements, 1934, 1948, and 1950 Max. and min. daily elevations Dec. 1945 - Sept. 1966		16.31' (elev.)(I) Dec. 24, 1957	2.70' (elev.)(I) Feb. 24, 1964	Tidal at all stages.
08MF009	Silverhope Creek near Hope	80	Manual	Misc. measurement only, 1948 Continuous Dec. 1911 to Dec. 1913, and Nov. 1964 to Sept. 1966		4,500 cfs (d) Sept. 2 and 7, 1948	106 cfs (d) Sept. 28, 1965	
08MF034	Wahleach Creek near Laidlaw	44	Manual	April 1950 - Sept. 1966	112 (13 yrs.)	1830 cfs (d) Dec. 25, 1950	0.0 at (d) various times	Flow affected by diversion from Wahleach (Jones) Lake to power plant.
08MF048	Elk Creek at Prairie Central Road near Rosedale		Manual	Mainly Sept. to April, from March 1960 to April 1964, and continuous Sept. 1964 - Sept. 1966		158 cfs (d) Jan. 7, 1962	0.0 at (d) various times	

Station Number	Station*	Drainage Area Sq. Mi.	Gauge	Period of Record**	Mean Discharge cfs	Extremes Recorded*** Maximum	Extremes Recorded*** Minimum	Remarks
08MG013	Harrison River near Harrison Hot Springs	3,220	none (use gauge for Sta. No. 08MG012)	Misc. measurements, 1923 and 1924 continuous May 1951 - Sept. 1966	15,600 (15 yrs.)	56,300 cfs (d) June 12, 1956	2,220 cfs (I) Feb. 29, 1956	Flow affected by backwater from Fraser River during high water at which time discharges are computed by fall stage-discharge relationship method using Harrison Lake and Harrison River at Harrison Mills gauges.
08MG014	Harrison River at Harrison Mills		recording	Elevations only, Feb. 1938 - Sept. 1966		40.84' (elev.)(d) June 1, 1948	16.24' (elev.)(d) Jan. 24, 1952	Elevations affected by backwater from Fraser River at all stages.
08MG012	Harrison Lake near Harrison Hot Springs		recording	Elevations only, April 1933 - Sept. 1966		43.58' (elev.)(d) June 11, 1948	27.50' (elev.)(d) Feb. 6, 1949	Elevations are affected by backwater from Fraser River during high water.
08MH029	Sumas River near Huntingdon	57.6	recording	Gauge heights only, periods of varying length, Oct. 1935 to June 1949, and continuous Oct. 1952 to Sept. 1966 Discharges: Oct. 1952 - Sept. 1966	107 (14 yrs.)	1,130 cfs (I) Feb. 6, 1965	1.1 cfs (I) Aug. 28, 1958	
08MH039	Sumas River near Sardis		recording	Daily max. and min. elevations, Oct. 1951 - Sept. 1966		26.88' (elev.)(I) June 19, 1964	1.00' (elev.)(I) Nov. 30, 1952	Elevations affected by backwater from Fraser River at all stages.
08MH047	Vedder River near Yarrow		Manual	Elevations only, June 1952 - Sept. 1966		31.59' (elev.)(d) Nov. 3, 1955	24.93' (elev.)(d) Sept. 26, 1961	Records prior to 1959 were published under "Chilliwack River near Yarrow".
08MH016	Chilliwack River at Outlet of Chilliwack Lake	131	recording	Manily continuous, May 1923 to June 1951 and May 1957 to Sept. 1966	653 (34 yrs.)	3,550 cfs (I) May 24, 1951	104 cfs (d) at various times	
08MH103	Chilliwack River above Slesse Creek	254	recording	Sept. 1963 - Sept. 1966		5,240 cfs (I) Nov. 26, 1963	304 cfs (I) Sept. 30, 1965	
08MH001	Chilliwack River at Vedder Crossing	484	Manual	Gauge heights only, April 1943 to May 1951 Discharges, Nov. 1911 to May 1931 and May 1951 to Sept. 1966	2,350 (31 yrs.)	27,000 cfs (d) Dec. 29, 1917	280 cfs (d) Nov. 30, 1952	
08MH056	Slesse Creek near Vedder Crossing	62.7	recording	March 1957 - Sept. 1966	331 (5 yrs.)	3,860 cfs (I) Oct. 21, 1963	19.8 cfs (I) Oct. 5, 1960	
08MH058	Norrish Creek near Dewdney	44.1	recording	Aug. 1959 - Sept. 1966	426 (5 yrs.)	14,100 cfs (I) Nov. 26, 1963	28.0 cfs (I) Aug. 13, 1960	
08MH091	Silverdale Creek near Mission City		recording	March 1960 - Sept. 1966	28.4 (6 yrs.)	768 cfs (I) Nov. 26, 1963	1.2 cfs (I) Aug. 6, 1966	
08MH040	Stave River at Stave Falls	440		April 19 to Dec. 21, 1901, and May 1905 - Sept. 1966	3,710 (61 yrs.)			Flows are regulated. Discharge data are computed and supplied by the B.C. Hydro and Power Authority.
08MH098	West Creek near Fort Langley		Manual	Mainly Sept. to April, Jan., 1960 to April 1964 and c..tinuous Sept. 1964 - Sept. 1966		452 cfs (d) Dec. 23, 1963	0.2 cfs (d) Aug. 19, 20, 1966	
08MH076	Kanaka Creek near Websters Corners		recording	March 1960 - Sept. 1966	88.1 (5 yrs.)	3,660 cfs (I) Dec. 23, 1963	2.3 cfs (d) Aug. 28, 29, 1961	
08MH097	Yorkson Creek near Walnut Grove		Manual	Sept. to April 1960 to 1964, and continuous Sept. 1964 - Sept. 1966		180 cfs (d) Jan. 30, 1965	0.4 cfs (d) at various times	
08MH017	Pitt River near Alvin	196	recording	Mainly continuous, Oct. 1952 to Oct. 6, 1965 (discontinued)	1,890 (9 yrs.)	26,500 cfs (I) Oct. 6, 1965	24.0 cfs (I) March 9, 1957	Gauging installation was destroyed by a flood on October 6, 1965.

Station Number	Station*	Drainage Area Sq. Mi.	Gauge	Period of Record**	Mean Discharge cfs	Extremes Recorded***		Remarks
						Maximum	Minimum	
08MH052	Pitt Lake near Alvin		recording	Daily max. and min. gauge heights, periods of varying lengths, 1956 - 1966		16.28' (g. ht.)(I) June 10, 1956	2.89' (g. ht.)(I) April 7, 1964	This lake is tidal at all stages.
08MH062	Pitt Lake near Outlet		recording	July 1962 - Sept. 1966 (elev.)		20.41' (elev.)(I) June 19, 1964	7.44' (elev.)(I) April 6, 1964	This lake is tidal at all stages.
08MH035	Pitt River near Port Coquitlam		recording	Daily max. and min. elevations only, mainly continuous, June 1948 - September 1966		21.70' (elev.)(I) June 12, 1948	6.67' (elev.)(I) March 19, 1955	The river at this station is tidal at all stages.
08MH0?8	Alouette River near Haney	79		November 1911 - September 1966	803 (41 yrs.)			Computed discharge data are supplied by the B.C. Hydro and Power Authority. The published records consist of the combined discharge: (a) through the Alouette power plant, (b) through Alouette Lake to Stave Lake past the Alouette plant, (c) through the automatic weir on the Alouette Lake outlet dam, (d) change in storage in Alouette Lake.
08MH006	North Alouette River near Haney		Manual	Oct. 1911 to Dec. 1913 and March 1960 to September 1966	104 (7 yrs.)	2,690 cfs (d) Dec. 23, 1963	2.5 cfs (d) Aug. 30, 1961	
08MH108	Unnamed Creek above Jacobs Lake near Haney		recording	May 1965 - September 1966		392 cfs (I) Jan. 13, 1966	0.6 cfs Aug. 1, 2, 1965	In 1966 station name was Jacobs Creek above Jacobs Lake near Haney.
08MH041	Coquitlam - Buntzen Rivers near Port Coquitlam	77		October 1913 - September 1966	831 (53 yrs.)			Published flow figures represent the monthly mean inflow to Coquitlam and Buntzen Lakes. The data are supplied by B.C. Hydro and Power Authority. These figures do not include the Greater Vancouver Water District consumption which averages 12 cfs throughout the year.
08MH026	Brunette River at Sapperton	26.5	recording	Misc. measurements only, 1931 and 1963; mainly Oct. to April 1934 to 1958 and mainly continuous Aug. 1958 to Sept. 1962 and Oct. 1963 - Sept. 1966.		3,280 cfs (I) Jan. 25, 1935	0.1 cfs (I) July 23, 1965	Flow regulated at dam at outlet of Burnaby Lake.
08MH046	Burnaby Lake at Piper Avenue		recording	Mainly Sept. to April, Dec. 1960 to September 1966.		41.15' (elev.)(I) Dec. 23, 1963	36.80' (elev.)(d) Dec. 1, 1961	Elevations affected by operation of control dam at outlet of Lake.
08MH112	Deer Lake Brook at Burnaby		Manual	June 1965 to September 1965		3.6 cfs (d) July 25 to 27, 1965	1.5 cfs (d) June 29, 1965	
08MH061	Still Creek at Burnaby		recording	Misc. measurement only, 1935. Continuous April 1958 - Sept. 1966		1,900 cfs (I) Dec. 14, 1959	0.4 cfs (I) Aug. 16, 1964	Flow may be affected by discharge from industrial plants.
08MH117	Stoney Creek near Burnaby		Manual	July 1965 - Sept. 1965		1.7 cfs (d) Aug. 4 and 23, 1965	0.4 cfs (d) Aug. 30 and Sept. 1, 6 and 7, 1965	

* Based on stations operating September 1965 (1966 operation also shown in column marked 'Period of Record').

** Published record available to end of September 1966 except where station was discontinued in 1965.

*** Instantaneous if indicated (I), and mean daily if indicated (d).

APPENDIX B

HYDROMETRIC SURVEY AND DATA ANALYSIS DETAILS

LOWER FRASER RIVER

GENERAL DETAILS

Because emphasis is placed on those hydrometric stations whose operation is essential to complement the sediment survey, the operational details of only these stations is described. Table B-1-1 describes the type of hydrometric data available for the stations.

Operational problems related to equipment operation and maintenance, obtaining of a complete and continuous record, weather and other physical measurement hazards, etc. are too numerous to describe in detail. These types of problems are commonplace to most operational units and may or may not critically affect the end product. In the case of hydrometric data, the Surface Water Data publications either indicate the reliability of the records or refrain from publishing data of doubtful reliability.

Some of the data details shown in table B-1-1 require further explanation. The cubature and unsteady flow mathematical model methods are explained in detail in the next two sections. Some other field measurement and computational problems are summarized as follows:

Fraser River at Hope

Until 1966, the discharge measurements at this station were made by use of a motorized crane from the highway bridge. Some difficulty was experienced in obtaining high flow discharge measurements because of high velocities and a considerable amount of drift material. In many high flow measurements it was possible to measure surface velocity only and therefore to compute the measurement on the basis of low or medium flow bottom soundings and by application of the generally accepted multiplier, 0.88, to determine mean velocities from the surface measured ones. In 1966 and in following years, discharge (and sediment) measurements were made from the lower deck of the bridge by use of a truck mounted crane. This reduced some of the measurement problems as better control of the equipment was possible.

The stage-discharge relationship for this station is relatively well defined. Some shifting of the channel control, however, does appear to occur from year to year. Discharge measurements are made periodically (8 to 12 measurements per year) to ensure that a suitable definition of the stage-discharge relationship is maintained for the computations.

The stage data are recorded with an A35 recorder. Telemetering equipment is also located at this station.

Fraser River at Agassiz

Table B-1-1 indicates that a non-standard method of computation was used for 1966 and 1967 for this station. Although a continuous stage record was available for this period, regular discharge measurements were not begun at this station until March of 1968. The stage-discharge relationship developed on the basis of the 1968 and 1969 measurements was therefore used to compute the required mean daily discharges for the

1966 and 1967 water years. To date there is not enough data to evaluate the degree of shifting of the control but it is anticipated that the reliability of the 1966 and 1967 flow data is fair.

An A35 recorder installed in 1965 is used to record the stage data.

Fraser River at Mission City

The discharge at this station is affected by tides during low flow periods; that is, when the stage is 10 feet or less and flows less than approximately 200,000 cfs. A relatively good stage-discharge relationship prevails only for stages in excess of 10 feet. It was necessary, therefore, to use the cubature method of computation for the low flow period and the standard method for the remaining period.

An A35 recorder is used to record the stage data at this station. A telemeter is also located at this site. In the latter part of 1968, arrangements were made to install a pair of digital recorders (one at Mission City and one 25,435 feet upstream at Cox Landing) to be used to supply stage data for the unsteady flow mathematical model.

Fraser River at Port Mann

The discharge is tidal at all stages. Measurement of discharge has been made with varying degrees of reliability by use of standard velocity-area measurement, traversing and multiple hydrograph methods. Computation of hourly and mean daily discharges for the period 1965 to 1968 inclusive was done by the cubature method.

An A35 recorder at Port Mann is used to record the stage data. A pair of digital recorders, one at Port Mann and one 22,860 feet downstream, at New Westminster, were installed in September 1967 to provide synchronized stage data for the unsteady flow mathematical model. Some progress was made in calibration of the mathematical model, that is, in the assessment of boundary and other coefficients. Trial computations appear to be encouraging but a relatively large amount of additional work must be done in evaluating the required boundary data, resistance coefficients, etc.

Other Stations

Some additional explanation is required to further clarify table B-1-1. Only those stations described as having other than standard computational methods need be described.

The Harrison River flows, computed for the station Harrison River near Harrison Hot Springs, are affected by backwater from the Fraser River during high water periods. For the high water period, therefore, the discharges are computed by the fall-stage-discharge relationship method using Harrison Lake and Harrison River at Harrison Mills gauges.

For the stations Stave River at Stave Falls and Coquitlam-Buntzen Rivers near Port Coquitlam, the discharge data were supplied by the British Columbia Hydro and Power Authority.

Mean daily discharges for the Upper Pitt River near Alvin were also required in the cubature calculations. This station was operated on a regular basis up to October 6, 1965, at which time the gauging station was destroyed by a flood. Stage, and therefore discharge, records are available up to September 14, 1965. (Some stage record was lost when the station was destroyed). The daily discharges for the period September 14 to September 30, 1965 were estimated on the basis of a correlation with the Squamish River near Brackendale. For the period October 1, 1965 to December 31, 1968, a value of 0.001 cfs was used in the cubature calculations instead of the regular daily discharges. It was found that, in the computation of Port Mann discharges, the contribution of the Upper Pitt River discharge was negligible in comparison to the contribution of Fraser River discharge at Whonock.

TABLE B-1-1.

SUMMARY OF HYDROMETRIC DATA,

JUNE 1965 TO DECEMBER 1968 INCLUSIVE

Station No.	Station Name	Data Details
08MF005	Fraser River at Hope*	D**
08MF035	Fraser River near Agassiz*	D(1968), O(1966 and 1967)
08MH024	Fraser River at Mission City*	D, S***, C****, M
08MH044	Fraser River at Whonock	S, C
08MH043	Fraser River at Port Hammond	S, C
08MH054	Fraser River at Port Mann*	S, C, M
08MF009	Silverhope Creek near Hope*	D
08MG013	Harrison River near Harrison Hot Springs*	O
08MH001	Chilliwack River at Vedder Crossing*	D
08MH040	Stave River at Stave Falls*	O
08MH035	Pitt River near Port Coquitlam*	S, C
08MH039	Sumas River near Sardis	S
08MH041	Coquitlam-Buntzen Rivers near Port Coquitlam	O
08MH017	Upper Pitt River near Alvin	O
08MH052	Pitt Lake at Little Goose Island	S
08MH062	Pitt Lake at Outlet	S

* Sediment Survey Stations.

** Legend:
- C Hourly and mean daily discharges computed by cubature method. For the Fraser River at Mission City, the cubature calculations are used for low flow periods only.
- D Mean daily discharges obtained by standard hydrometric methods, that is, on the basis of a stage record and a stage-discharge curve developed by regular field measurements.
- M Hourly and mean daily discharges computed by unsteady flow mathematical model, proposed for 1969.
- O Other computational methods used.
- S Only stage data available.

*** Stage data only available for the period January 1 to April 30, 1965, for this station.

**** Cubature calculations for the 1965 water year were done only for the period May 1 to December 31 inclusive.

B-2.

CUBATURE CALCULATIONS

B-2-1 Theory (Keane, 1957; Water Survey of Canada, 1968b, 1966a,1966b)

The method of cubature is based on the law of continuity which can be analytically described for a river reach by the following equation:

outflow = base inflow + tributary inflow + change in storage.

The base and tributary inflows are readily determined by measurement or computation. The channel storage, the gain or loss of water in the reach, is computed from the rate of rise or fall of the water surface for a finite time duration and known water surface area. The basic assumptions which must be made are:

(1) water surfaces are planes
(2) channel sides are vertical
(3) effects of curvature are negligible.

The use of the continuity equation for tidal computation is illustrated by figure B-2-1. Water surface elevation (stage) is recorded at stations 1, 2 and 3. It is assumed that the upstream limit of tidal influence is at station 1. The longitudinal profile sketch shows the water surface profiles for the two times, t_1 to t_2, and the changes in stage Δ_2 and Δ_3 at stations 2 and 3 respectively which occurred during the time interval $t_2 - t_1$. The water surface areas of the two reaches are $A_{s_{1,2}}$ and $A_{s_{2,3}}$ as shown in the plan sketch of figure B-2-1. The tributary inflows are designated as Q' and the discharges of the main reach are Q_1, Q_2 and Q_3 at stations 1, 2 and 3 respectively. Q_1 and the tributary inflows are assumed to be known. Using this nomenclature, therefore, and the geometry of the channel between stations 1 and 2, the volume of water changed during the time interval $t_2 - t_1$ by an amount equal to $\frac{\Delta_2}{2} A_{s_{1,2}}$ or $V_{1,2}$ in which $V_{1,2}$ represents the volumetric change in storage.

This volume represents the decrease in tidal storage that must have taken place by outflow past station 2. The average discharge required to produce this change in storage during the time interval is simply $V_{1,2}/(t_2-t_1)$ which can be assumed to have occurred at time $\frac{t_1 + t_2}{2}$.

The total outflow at station 2 will have the average value given by $Q_2 = Q_1 + Q'_{1,2} - V_{1,2}/(t_2-t_1)$. When Q_2 is determined, the inflow to the second reach is known and, from the law of continuity, the outflow past station 3 is given by:

$$Q_3 = Q_2 + Q'_{2,3} - \frac{-(\Delta_2 + \Delta_3)\, A_{s_{2,3}}}{2(t_2 - t_1)} \quad \text{..............(B-2-1)}$$

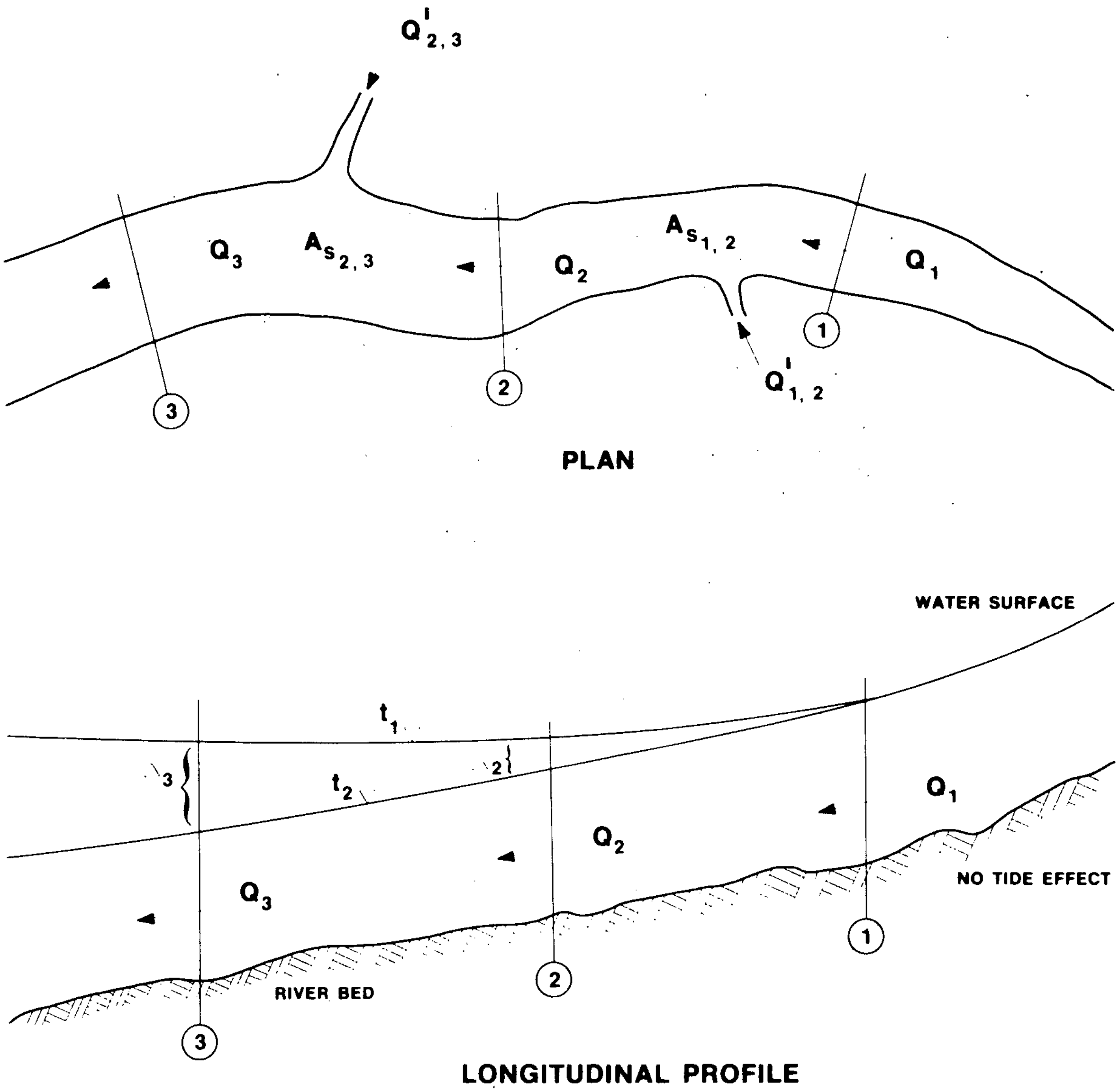


FIGURE B-2-1 **PLAN AND LONGITUDINAL PROFILE SKETCHES ILLUSTRATING TIDAL DISCHARGE.**

(Note that flood-tides give positive values of Δ and ebb-tides give negative values. The discharges produced by change in storage must therefore be subtracted from the inflow and tributary discharges in the computation of the discharge of the downstream station).

Examination of the equations for Q_2 and Q_3 shows that only the changes in the water surface elevations at these stations need to be known. The absolute value of the water surface elevation is not required except if the water surface area changes appreciably with change of water level.

B-2-2 Application

Study of the application of the cubature method to the Lower Fraser River was first done by the National Research Council in 1952. Subsequent measurements and simultaneous cubature calculations were carried out on May 15 and 16, June 19 and 20, and August 7 and 8, 1954 under the general co-ordination of the Fraser River Board (Keane, 1957). The Water Survey of Canada applied the cubature method on a continuous basis for the period June 1965 to December 1968 as described below.

Data from a total of 13 stations were used in the cubature calculations. The stations for which hourly gauge heights were required are as follows:

08MH054	Fraser River at Port Mann
08MH035	Pitt River near Port Coquitlam
08MH062	Pitt Lake near Outlet
08MH052	Pitt Lake at Little Goose Island
08MH043	Fraser River at Port Hammond
08MH044	Fraser River at Whonock
08MH024	Fraser River at Mission City
08MH039	Sumas River near Sardis

The station for which mean daily discharges were required are as follows:

08MH017	Upper Pitt River near Alvin
08MH040	Stave River at Stave Falls
08MH041	Coquitlam-Buntzen Rivers near Port Coquitlam
08MG013	Harrison River near Harrison Hot Springs
08MF005	Fraser River at Hope.

The cubature computations also require stage-area tables, that is, the area of the water surface as a function of river stage. These stage-area relationships are shown in figure B-2-2 for the five reaches involved: Mission City to Whonock, Whonock to Port Hammond, Port Hammond to Port Mann, Pitt River near Outlet, Port Coquitlam to Pitt Lake near Outlet, and Pitt Lake near Outlet to Pitt Lake at Little Goose Island. These relationships were obtained by planimetering the surface areas for various water levels from maps drawn to a scale of one inch equals 1000 feet (Water Survey of Canada, 1966a).

Use of the stage-area tables requires a mean geodetic elevation of the water surface between the stations at the ends of a reach. It was necessary, therefore, to adjust the gauge datum of the stations by an amount which would result in the elevation referred to G.S.C. datum. These adjustments are summarized in table B-2-1.

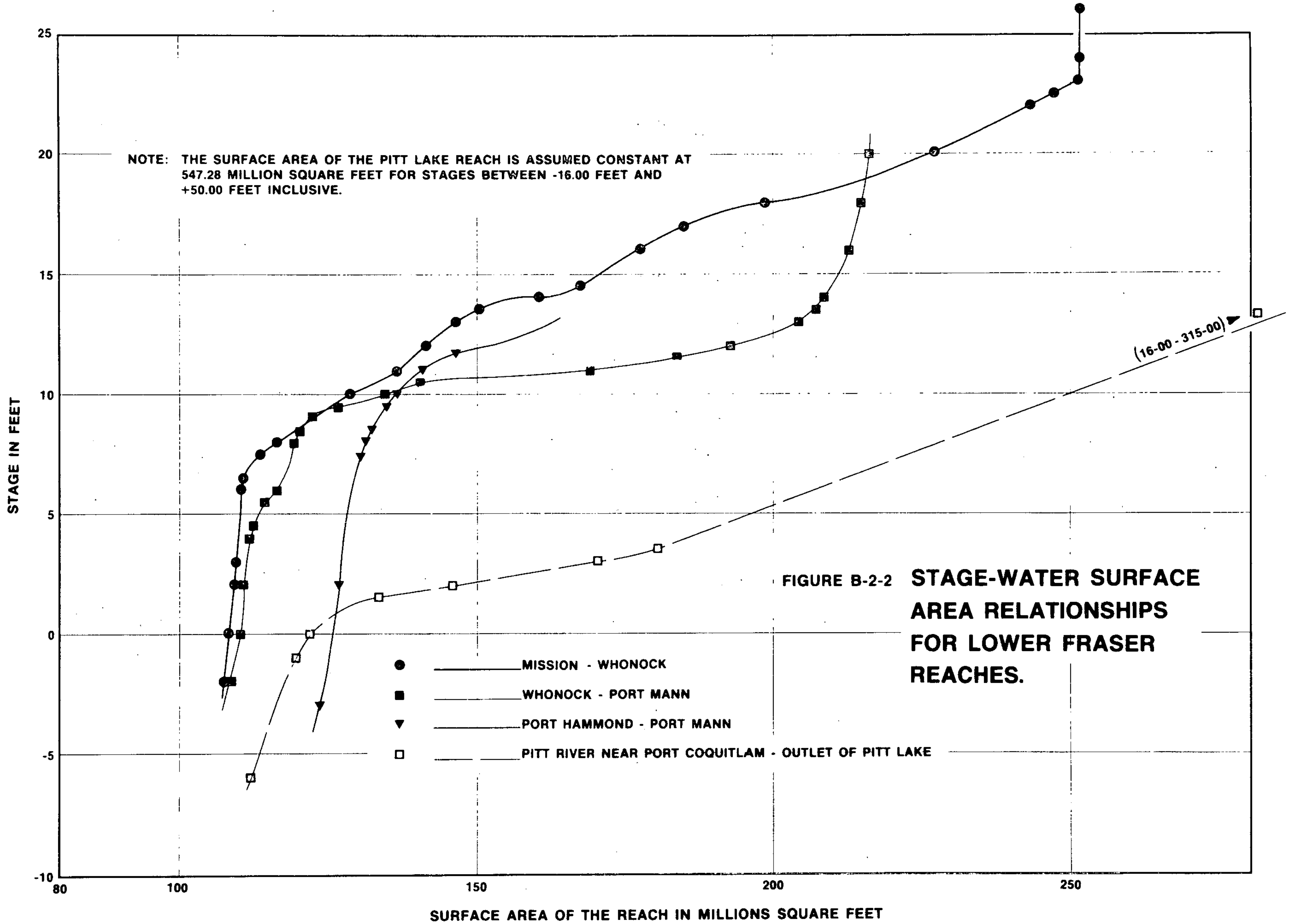


FIGURE B-2-2 **STAGE-WATER SURFACE AREA RELATIONSHIPS FOR LOWER FRASER REACHES.**

TABLE B-2-1

GAUGE DATUM ADJUSTMENTS

	Station	Adjustment*
08MH054	Fraser River at Port Mann	- 8.54
08MH043	Fraser River at Port Hammond	- 8.54
08MH044	Fraser River at Whonock	- 8.54
08MH024	Fraser River at Mission City	+ 0.24
08MH035	Pitt River near Port Coquitlam	- 8.54
08MH062	Pitt Lake near Outlet	- 5.11
08MH052	Pitt Lake at Little Goose Island	a**
08MH039	Sumas River near Sardis	+ 0.37

* Gauge datum + adjustment = elevation referred to G.S.C. datum (adjustment in feet).
** Datum of gauge is arbitrary.

A stage-discharge table was also required for the Fraser River at Mission City for the cubature calculations as described in the next few paragraphs. The stage-discharge relationships are illustrated by figure B-2-3. Curve No. 2 was used throughout for the 1965 water year computations (that is, for the period May 1 to September 30, 1965). Curve No. 3 was used throughout for the 1966 water year. For the 1967 water year, curve No. 3 was used for the period June 23 to September 30, 1967 inclusive. For the period October 1, 1967 to December 31, 1968 inclusive, curve No. 2 was used throughout.

The computations of hourly and mean daily discharges for the Fraser River stations were achieved as follows:

1. Mission City:

   (a) for gauge heights greater than 10.00 feet (discharge greater than approximately 190,000 cfs): discharges were computed from the stage record and the stage-discharge relationship as described above.

   (b) for gauge heights less than or equal to 10.00 feet: discharges were computed from the summation of the discharge at Hope (using a 12-hour time lag), 146 percent of the flow of the Harrison River near Harrison Hot Springs, and the tidal flow (or change in channel storage in the tidal reach) in the river channel upstream from Mission City. The 146 percent of Harrison River flows was an adjustment to account for all tributary flows between Mission City and Hope which was determined from correlation of past record. Hourly discharges were obtained by interpolation between daily means for those stations for which only mean daily flows were known. The tidal flow component was determined from the mathematical expression:

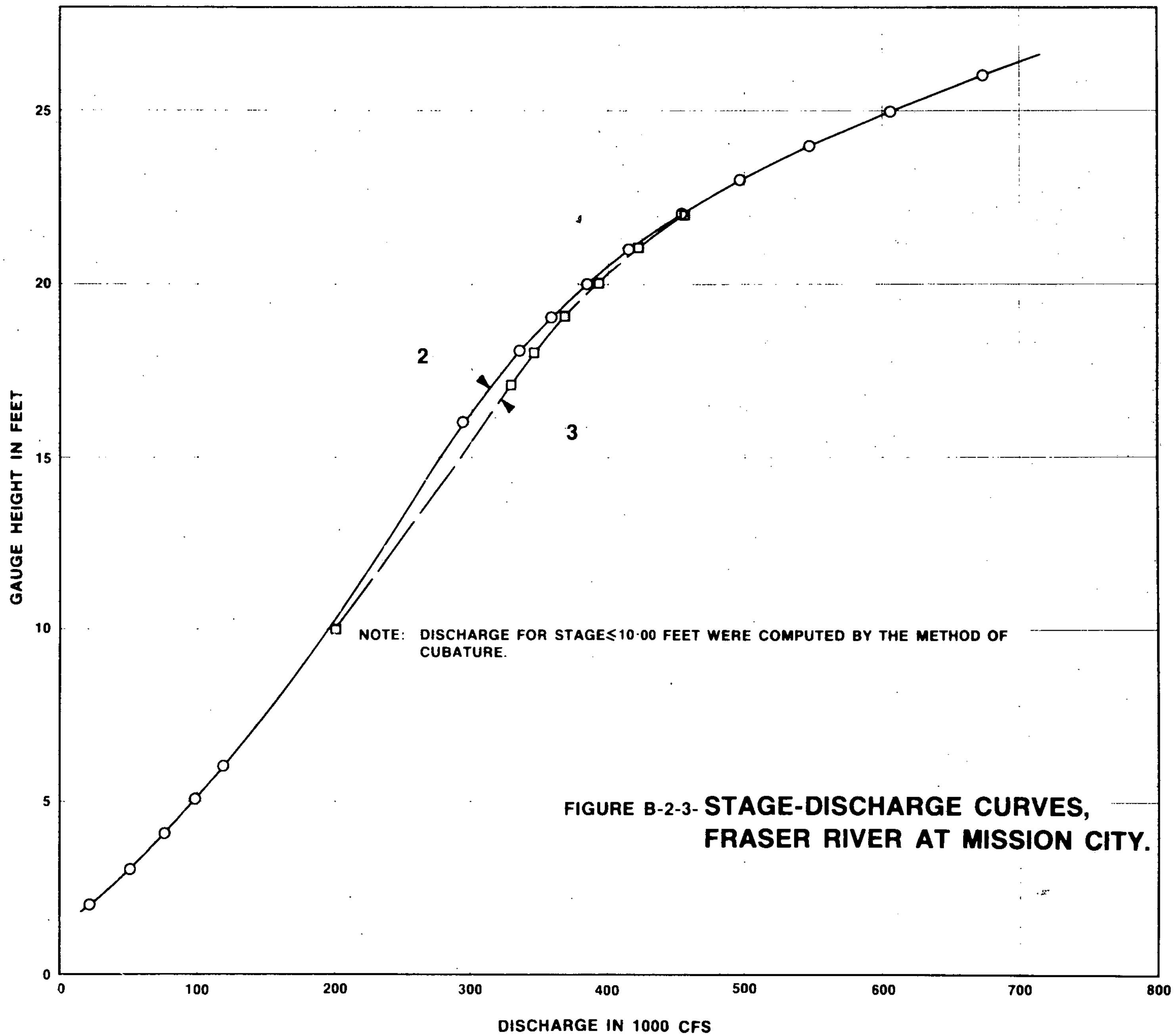


FIGURE B-2-3- **STAGE-DISCHARGE CURVES, FRASER RIVER AT MISSION CITY.**

$$\Delta Q = 12.46\ (\Delta S_m) + 22.18\ (\Delta S_s) \quad \ldots\ldots\ldots\ldots\ldots (B\text{-}2\text{-}2)$$

in which

ΔQ = change in channel storage of the tidal reach upstream of Mission City in 1000 cfs.

ΔS_m = rate of change of stage at the Mission City gauge in feet per hour.

ΔS_s = rate of change of stage at the Sumas River near Sardis gauge in feet per hour.

12.46 and 22.18 are constants based on the water surface area for the reaches Mission City to Sumas River and Sumas River to end of tidal effect. (They are not the water surface area).

2. Whonock:
   discharges were computed by summing the Mission City discharge, the Stave River discharge and the discharge resulting from the change in storage between Whonock and Mission City.

3. Port Hammond:
   discharges were computed by summing the Whonock discharge and the discharge resulting from the change in storage between Port Hammond and Whonock.

4. Port Mann:
   discharges were computed by summing the Port Hammond discharge, the discharge at the Pitt River near Port Coquitlam station (which itself was determined from the summation of the Upper Pitt River discharge and the discharge resulting from the change in storage in Pitt Lake and the Lower Pitt River), the Coquitlam River discharge and the change in channel storage between Port Mann and Port Hammond.

In addition to these four stations, hourly and mean daily discharges were computed for the outlet of Pitt Lake and for the Lower Pitt River, that is for the Pitt River at Port Coquitlam station. An example of the output is illustrated in figure 2.1.

The computational procedure is summarized in section 2.2. In summary, therefore, the hourly and mean daily discharges were computed for the following stations:

Fraser River at Mission City	Fraser River at Port Mann
Fraser River at Whonock	Outlet of Pitt Lake
Fraser River at Port Hammond	Pitt River near Port Coquitlam

B-2-3 Verification

Field verification of the cubature calculations was not emphasized by the Water Survey of Canada because it appeared that the method was adequately verified during its development stages prior to 1965. Comparison of measured and computed discharges are illustrated in figures B-2-4 and B-2-5 for February 15 and 25, 1967 respectively. It is anticipated that the tidal flow computations using the cubature method are within ± 10 percent of the actual values. Considering that unsteady flows are involved this can be considered as relatively good. It is further anticipated that the accuracy will be increased to ± 5% of the true discharges with the use of the unsteady flow mathematical model methods as subsequently described.

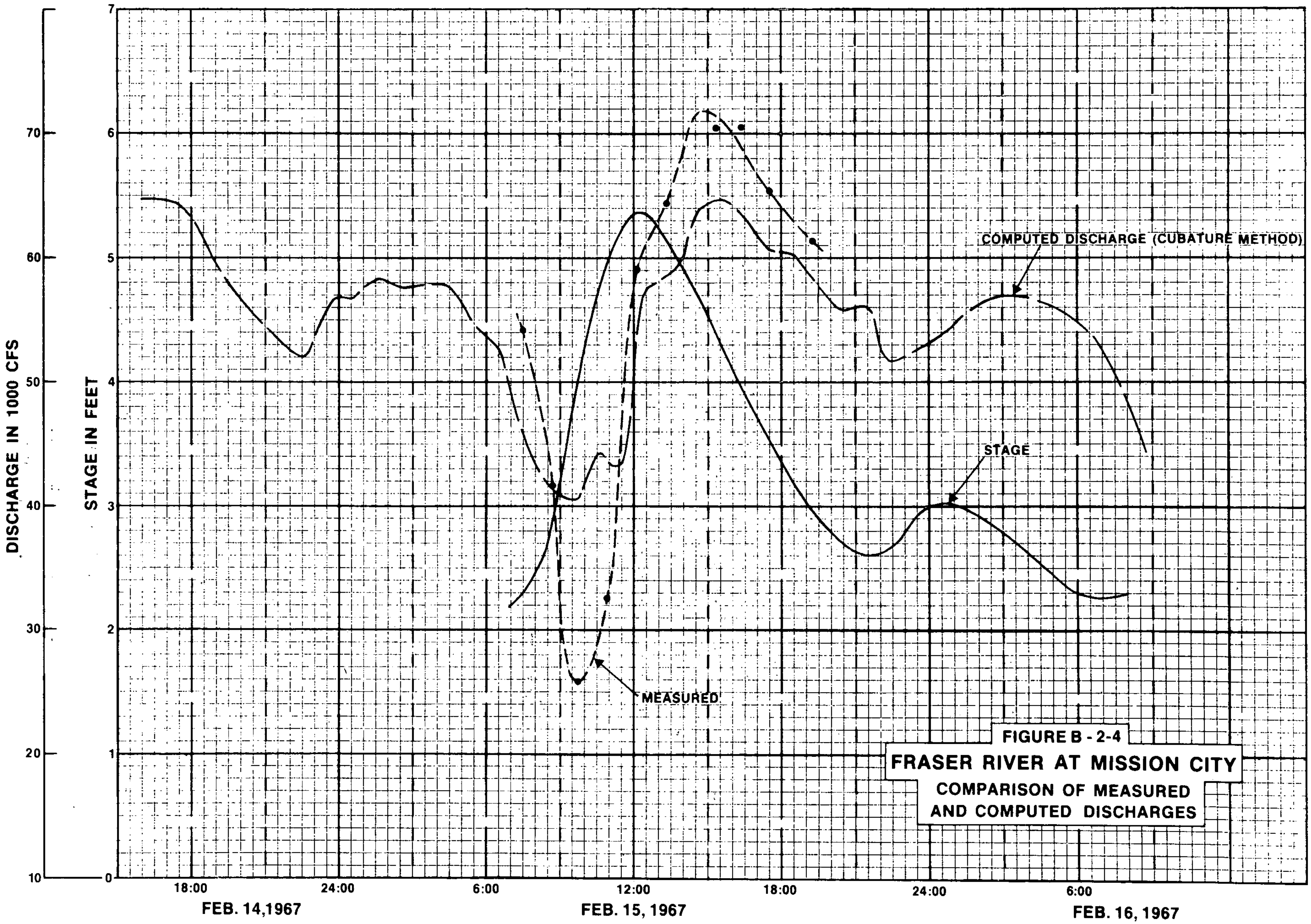


FIGURE B - 2-4
FRASER RIVER AT MISSION CITY
COMPARISON OF MEASURED AND COMPUTED DISCHARGES

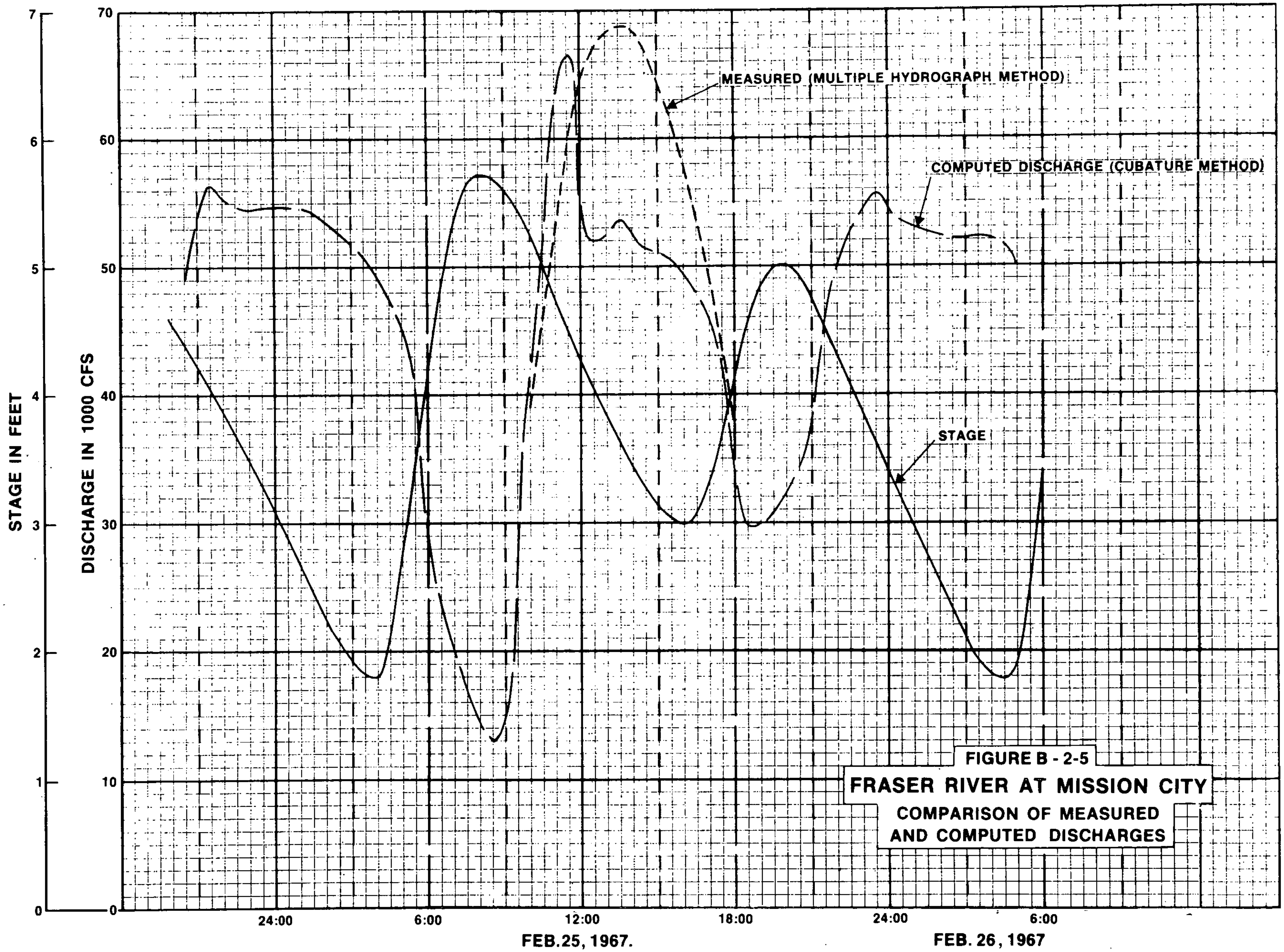


FIGURE B - 2-5
FRASER RIVER AT MISSION CITY
COMPARISON OF MEASURED AND COMPUTED DISCHARGES

UNSTEADY FLOW MATHEMATICAL MODEL

B-3-1 Theory

Tidal flow generally refers to the variable, quasi-periodic, unsteady flow that is observed in the lower reaches (tidal reaches) of rivers and other waterways connecting with the sea. Tide alone, however, is not the only causative factor contributing to the unsteady flow phenomenon. In the use of the term "tidal flow" in the Fraser River estuary, the term refers to the unsteady flow resulting from the tide as well as from all other forms of long, gravity-type, wave motion (including flood waves, storm surges and tsunamis, if such are present).

A system of unsteady flow equations is used to describe, analytically, the characteristics of tidal flow. Figure B-3-1 illustrates the cross-section and longitudinal profile of a tidal reach. In the analysis, however, an idealized reach as illustrated in figure B-3-2 is used, and the flow is treated as one-dimensional. A number of assumptions are made in the derivation of the equations:

1. the flow is moderately unsteady,
2. the density of the liquid is homogeneous,
3. the channel is prismatic, and
4. the water surface profile is continuous.

The system of equations representing unsteady, open-channel flow, and, therefore, tidal flow is composed of the equation of continuity and the equation of motion (Baltzer and Shen, 1961; Chow, 1964). This system of equations is:

$$A \frac{\partial u}{\partial x} + u \frac{\partial A}{\partial x} + b' \frac{\partial z}{\partial t} + q = 0 \qquad \text{.............(B-3-1)}$$

$$\frac{\partial z}{\partial x} + \lambda \left(\frac{A}{k}\right)^2 u^2 + \frac{1}{g} \frac{\partial u}{\partial t} + \frac{u}{g} \frac{\partial u}{\partial x} = 0 \qquad \text{............(B-3-2)}$$

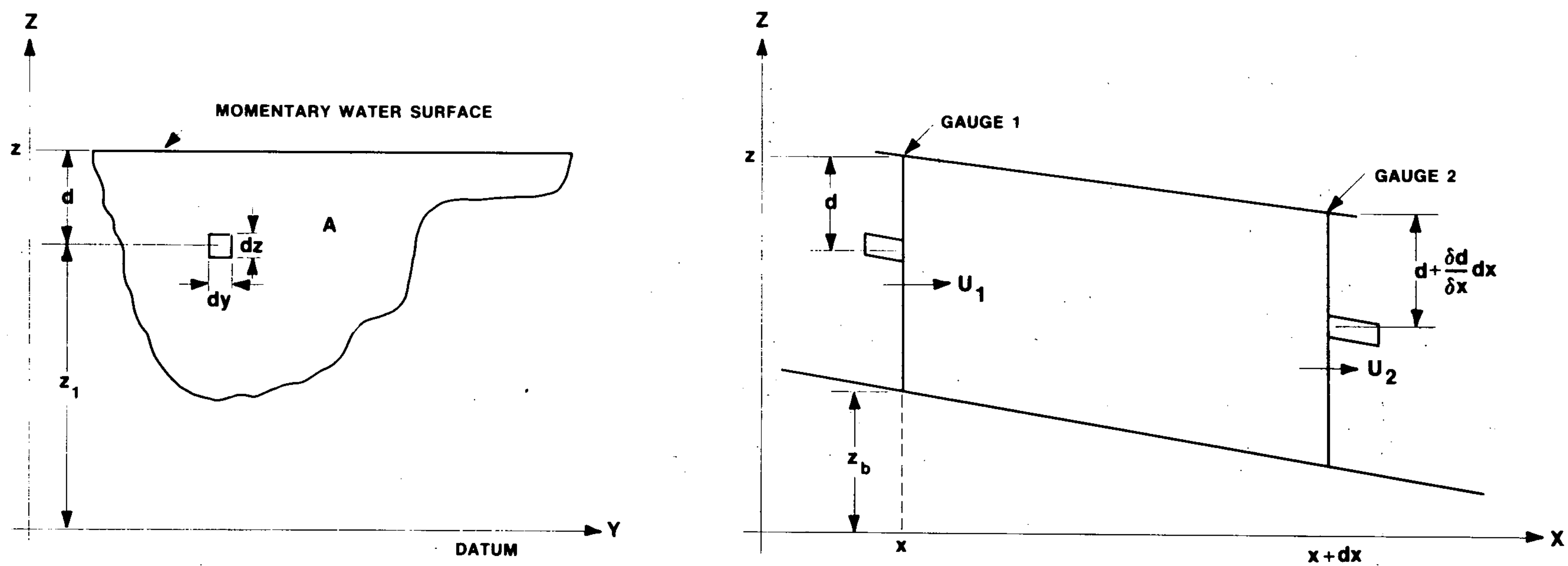
in which the symbols are defined as follows:

A	conveyance cross-sectional area of channel; ft.^{2}
b'	total channel width; ft.
g	acceleration due to gravity; ft./sec.^{2}
k	channel conveyance; ft.^{3}/sec.
q	lateral inflow throughout reach; ft.^{2}/sec.
t	time; sec.
u	bulk velocity in the X direction; ft./sec.
x	distance along with X-axis; ft.
z	distance in z direction; ft.
λ	algebraic sign operator.

This system of equations is a set of first order, quasi-linear, hyperbolic partial differential equations for functions of two independent variables and two dependent variables. In general terms, these equations are in the form

$$\Gamma_1 = A_1 \frac{\partial z}{\partial t} + B_1 \frac{\partial z}{\partial x} + C_1 \frac{\partial u}{\partial t} + D_1 \frac{\partial u}{\partial x} + E_1 = 0 \qquad \text{..........(B-3-3)}$$

$$\Gamma_2 = A_2 \frac{\partial z}{\partial t} + B_2 \frac{\partial z}{\partial x} + C_2 \frac{\partial u}{\partial t} + D_2 \frac{\partial u}{\partial x} + E_2 = 0 \qquad \text{..........(B-3-4)}$$



(a) CROSS-SECTION

(b) LONGITUDINAL PROFILE

FIGURE B-3-1 CROSS-SECTION AND LONGITUDINAL PROFILE VIEWS OF A LAMINA OF TIDAL REACH

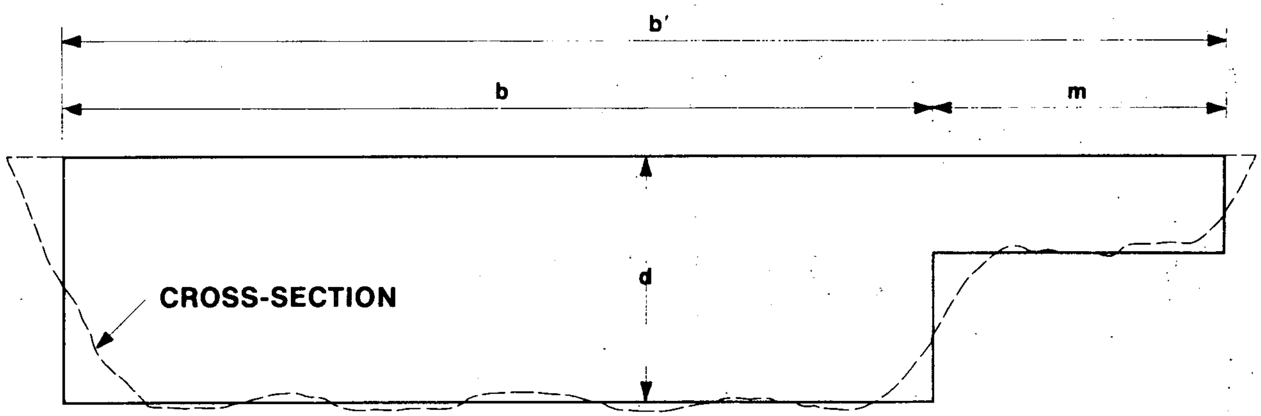


FIGURE B-3-2 **SCHEMATIC LAMINA OF A RECTANGULARIZED CROSS-SECTION** where Γ_1 and Γ_2 denote the respective partial differential expressions. The independent variables are t and x, the dependent variables are u and z. The quantities A_1, A_2, B_1 ..., E_2 are commonly variable coefficients and generally functions of x, t, u and z.

The partial differential equations can be solved by mathematical methods utilizing techniques such as Fourier series, power series, and the method of characteristics. Regardless of the evaluation technique used, an explicit solution of the equation system depends upon the boundary and initial conditions. The boundary conditions consist of the dimensional characteristics describing the selected reach of open channel and the wave characteristics evidenced by a continuous record to water stages within the reach. The initial conditions reference the flow conditions within the reach with respect to some starting time.

The power series technique, specifically, a Taylor series expansion, is used in the evaluation of tidal discharges for the Lower Fraser River stations. Mathematically a power series is defined as the sum of a sequence of successive powers of a particular variable. The power series for the general independent variable term, $(x - x_1)$, is

$$C_o + C_1(x - x_1) + C_2(x - x_1)^2 + \ldots C_n(x - x_1)^n + \ldots = \sum_{n=o}^{\infty} C_n(x - x_1)^n \quad \text{.......... (B-3-5)}$$

for which C_o, C_1,... C_n are constant coefficients and x is an arbitrarily selected point. The power series must have a non zero radius of convergence about the point x, in its use for evaluating unsteady flow.

The Taylor series for some function, F(x), having a convergence radius, δ, such that $(x_1 - \delta) < x < (x_1 + \delta)$, is defined as

$$f(x) = \sum_{n=o}^{\infty} C_n(x - x_1)^n = C_o + C_1(x - x_1)^1 + \ldots + C_n(x - x_1)^n + \quad \text{....... (B-3-6)}$$

where the coefficients are in the form

$$C_o = f(x_1) \quad \text{.......... (B-3-7)}$$

$$C_1 = \frac{f'(x_1)}{1!} \quad \text{.......... (B-3-8)}$$

$$C_2 = \frac{f''(x_1)}{2!} \quad \text{.......... (B-3-9)}$$

.

.

.

$$C_n = \frac{f^n(x_1)}{n!} \quad \text{.......... (B-3-10)}$$

It is evident, therefore, that every power series with a non zero radius of convergence is the Taylor series of its sum. In practice a finite number of terms of the series may be used to represent f(x); the exact number depends upon the particular nature of the series, the desired accuracy of representation, and the amount of computational labour which one is willing to tolerate. The general form of the Taylor series consisting of n + 1 terms is

$$f(x) = f(x_1) + \frac{f'(x_1)}{1!}(x - x_1) + \frac{f''(x_1)}{2!}(x - x_1)^2 + \dots + \frac{f^n(x_1)}{n!}(x - x_1)^n \quad \dots\dots\dots\dots (B\text{-}3\text{-}11)$$

Unlike Fourier series, Taylor series can be used to represent differential equations. All that is required is that f(x) be an analytic function within the indicated domain of convergence. For convenience, the above equation may be rewritten in the form indicating the number of terms used to represent f(x),

$$f(x)_I = f(x_1) + \frac{f'(x_1)}{1!}(x - x_1) \quad \dots\dots\dots\dots (B\text{-}3\text{-}12)$$

$$f(x)_{II} = f(x)_I + \frac{f''(x_1)}{2!}(x - x_1)^2 \quad \dots\dots\dots\dots (B\text{-}3\text{-}13)$$

$$\vdots \qquad \vdots$$

$$f(x)_n = f(x)_{n-1} + \frac{f^n(x_1)}{n!}(x - x_1)^n \quad \dots\dots\dots\dots (B\text{-}3\text{-}14)$$

$$\vdots \qquad \vdots$$

Because of the temporal nature of translatory-wave propagation in tidal reaches, both the stage, z, and the longitudinal flow velocity, u, are dependent upon time and relative location in the reach. This dependence is given by the functional notation

$$z = z(x,t) \quad \dots\dots\dots\dots (B\text{-}3\text{-}15)$$

$$u = u(x,t) \quad \dots\dots\dots\dots (B\text{-}3\text{-}16)$$

where x and t are independent variables. Since a technique utilizing power series (a Taylor series expansion) is sought for determining the continuous volume rate of flow at a particular location in a tidal reach, the task is to represent z as a series expansion of the function $f(x_1)$ at a moment of time. In this case, x_1 is any arbitrarily selected point along the X-axis. The Taylor series expansion may then be transformed to an incremental (finite difference) expression with regard to the time variable. A systematic step-by-step computation of discharge can then be made with respect to time using known boundary conditions and prescribed initial conditions.

In the development of the difference equations, the unsteady flow equations 1 and 2 are first reduced or simplified by elimination of secondary terms which are negligible in magnitude with respect to the other terms in the equations. Consequently, equations 1 and 2 reduce to

$$A \frac{\partial u}{\partial x} + u \frac{\partial A}{\partial x} + b' \frac{\partial z}{\partial t} + q = 0 \quad \dots\dots\dots\dots (B\text{-}3\text{-}17)$$

$$\frac{\partial z}{\partial x} + \lambda \left(\frac{A}{k}\right)^2 u^2 + \frac{1}{g}\frac{\partial u}{\partial t} = 0 \quad \dots\dots\dots\dots (B\text{-}3\text{-}18)$$

To form the Taylor series expansion for z (refer to figure B-3-1), a reference point within the reach must be first selected, x_1, about which the expansion is to be made and at which the discharge is to be determined. For convenience, x_1 is selected equal to zero, and the Taylor series is then reduced to the special case of a Maclaurin series. By computing the first three terms of the expansion as illustrated by equation 14, and by eliminating all insignificant terms, the resulting differential expression becomes:

$$z_{III} = z_1 - \lambda \frac{Q^2 x}{k^2} + \frac{\lambda Q x^2}{k^2} \left(b' \frac{dz}{dt} + q\right) + \frac{b' x^2}{2gA} \frac{d^2 z}{dt^2}$$

$$- \frac{x}{gA} \frac{dQ}{dt} \left(1 + \frac{\lambda b' x^2}{3k^2} \frac{dQ}{dt} + \frac{2}{3} \frac{b' x^2 Q^2 gA}{k^4}\right) - \frac{\lambda (b')^2 x^3}{3k^2} \left(\frac{dz}{dt}\right)^2 \quad \text{.......... (B-3-19)}$$

The following has been accomplished by the Taylor series expansion: the elevation of the water surface z_{III}, at <u>any</u> other point <u>within</u> the domain of convergence about x_I has been determined from the first few terms of the expansion. Moreover, z_{III} is expressed entirely in terms of z_1, the water surface at x_1, and several additional modifying terms including the discharge, the rate-of-change of discharge, the first and second rates-of-change of stage all at x_1, and other channel boundary conditions at a particular moment of time. The distance, x, in equation B-3-19 is the finite distance from x_1 to the point in the x-domain at which z_{III} is determined.

In order to solve equation 19 for discharge throughout time it is necessary to rewrite this expression in revised form and to transform it into a difference equation with respect to time. For clarity, z_{III} is redesignated as z_2, the stage at any other point within the domain of convergence about x_1. The point at which z_2 is located is henceforth designated x_2. Thus, the revised expression in difference form is

$$\Delta Q_{(1,t)} = \left[\frac{gA_t (z_1 - z_2)_t}{x} - \frac{\lambda g A_t Q^2(1,t)}{k_t^2} + \frac{\lambda g A_t Q_{(1,t)} x}{k_t^2} \left(b'_t \frac{\Delta z_{(1,t)}}{\Delta t} + q\right)\right.$$

$$\left. + \frac{b'_t x}{2} \frac{\Delta^2 z_{(1,t)}}{\Delta t^2} - \frac{\lambda g A_t (b'_t)^2 x^2}{3k_t^2} \left(\frac{\Delta z_{(1,t)}}{\Delta t}\right)^2\right]$$

$$\left\{\frac{\Delta t}{1 + \frac{2}{3} \frac{b'_t x^2 Q^2_{(1,t)} g A_t}{k_t^4} + \frac{\lambda b' x^2}{3k_t^2} \frac{\Delta Q_{(1,t)}}{\Delta t}}\right\} \quad \text{.......... (B-3-20)}$$

The discharge $\Delta Q_{(1,t)}$ occurring throughout an increment of time is derived. If the discharge, $Q_{(1,t)}$, at the beginning of the time increment is known, together with the required boundary conditions, then a subsequent discharge at a time increment, Δt, later may be computed from

$$Q_{(1,t+1)} = Q_{(1,t)} + \Delta Q_{(1,t)} \quad \text{.......... (B-3-21)}$$

As long as the boundary conditions are continuously known with time, continuous discharges may be determined by repeated solution of equations B-3-20 and B-3-21.

B-3-2 Application

A unique solution of equation 20 depends upon the boundary values such as the channel width, depth and cross-sectional area, recorded stages at the ends of the reach, the reach length and time increment. Some of these boundary values vary with respect to time and must be so defined for the computations.

The channel geometry which naturally contains irregularities due to bands, islands, shoals, etc., must be reduced to a simplified representative model for the computations. Actual on site field surveys and discharge measurements are used as a basis for the required schematization.

The natural reach must first be schematized to a prismatic channel representative of the mean cross-section. A constant bottom slope is used. In practise, the cross-section is rectangularized as illustrated in figure B-3-2. Because the depth and width are both functions of stage, the schematized cross-section must vary accordingly. Theoretically, b, d and A should vary with z, the stage at x_1. To more closely represent the overall reach, however, b and d are treated as functions of the arithmetic average of the water surface elevations at the ends of the reach, z_m, ($z_m = \frac{1}{2}(z_1 + z_2)$). Provision is made in the solution process to set $z_m = z_1$ if this is found to be desirable for a particular reach.

Figure B-3-2 illustrates the method of rectangularizing the cross-section. An overflow width, m, is used together with the width of the conveyance channel, b, provided the rectangularized section truly represents the conveyance characteristics of the natural reach.

Simultaneous recording of the water surface elevations at the end points of the reach is absolutely essential in the evaluation of tidal flow. The gauges must be accurately set to the same datum and their operation must be synchronized with respect to time.

In the development of the unsteady flow equations, the channel conveyance, k, was adopted as an implicit measure of the resistance to the tidal flow. In terms of Manning's equation, conveyance is represented by the expression:

$$k = \frac{1.49}{n} b\, d^{5/3} \qquad \text{(B-3-22)}$$

in which n is an empirical flow resistance coefficient (sec./ft.$^{1/3}$). Little factual information is known about the character of boundary resistance under conditions of unsteady or tidal flows. It is possible that the acceleration and deceleration of the water particles appreciably alters the shear stress pattern, the formation of turbulence, and thus the dissipation of energy in unsteady flow. By utilizing periods of continuous, field measured discharges, the value of n can be determined from an iterative solution of the inverted form of equations B-3-20 and B-3-22 as follows:

$$k_t^2 = \frac{\{ \lambda [Q^2 \Delta x - Qb' (\Delta x)^2 \Delta z/\Delta t - Qq(\Delta x)^2 + \frac{1}{3} (b')^2 (\Delta x)^3 (\Delta z/\Delta t)^2 + \frac{1}{3} b'(\Delta x)^3 /gA (\Delta Q/\Delta t)^2] + \frac{2}{3} (Q^2 b' (\Delta x)^3 / k_t^2) \Delta Q/\Delta t \}}{[(z_1 - z_2) + \frac{1}{2} b' (\Delta x)^2/gA (\Delta^2 z/\Delta t^2) - \Delta x/gA (\Delta Q/\Delta t)]} \quad \text{..... (B-3-23)}$$

The solution can be accomplished only by a trial and error method or by an iterative process since k cannot be eliminated from the right hand side of this expression. When k is known, the flow resistance coefficient, η, may be computed from

$$\eta_t = \frac{1.49\, b_t d_t^{5/3}}{K_t} \quad \text{...... (B-3-24)}$$

The length of selected tidal reach, Δx, and computational time increment, t, must not be so great as to exceed the domain of convergence of the Taylor series. On the other hand, the reach must be of sufficient length to permit accurate determination of the stage difference between the two end points, and similarly, the time increment must be sufficiently large to keep the computations at a minimum. In addition to the computational intervals, the series convergence depends largely upon the channel depth and upon the length and amplitude of the propagating wave, thus adding to the complexity of selection of appropriate intervals.

In general, a reach length of 3 to 7 miles and a time interval of 15 minutes is satisfactory. In the case of the Lower Fraser River, a time interval of 15 minutes is used and the reach lengths (determined along the centre line of the channel) are as follows:

Fraser River at Port Mann .... 22,860 feet.

Fraser River at Mission City .... 25,435 feet.

The initial conditions which must be prescribed to start the computation process are the initial discharge, $Q_{(1,0)}$, the preceding change in discharge, $\Delta Q_{(-1)}$, and the stage at the end point of the reach where the discharge is being computed for the two preceding time increments. It is possible, however, to start the computation process without knowing the initiating discharge and change of discharge. These discharges may be estimated; the effect of error in the initially assumed discharge values is quickly eliminated in the subsequent computations provided that convergence does occur. In other words, the prescribed boundary conditions applied to equations B-3-20 and B-3-21 define a unique solution of the discharge with time within the particular limits of conversion, and consequently the computed discharges converge to this unique solution.

Computation of tidal discharges utilizing equations B-3-20 and B-3-21 can at present be performed practicably only by high-speed digital computer. The program developed for the evaluation routine is very general and flexible to permit coverage of a wide variety of flow and boundary conditions which may occur. To make the computer operation as efficient as possible, a number of control points in the program are used to omit from the computation certain terms of equation B-3-20 whenever their contribution to the overall solution becomes insignificant. This is done by comparing those data which are chiefly responsible for the time variation of the particular terms with preselected limit values, whereas those lesser than the limit value are set to zero.

Two additional computer programs which complement the main discharge computation program are available. The first of these performs an editing operation upon the stage data recorded by the digital-type, water-level recorders located at either end of the tidal reach. The punched paper tapes are translated to a data format suitable for input to the digital computer. The data are then scanned for errors by the computer, the errors are corrected, and the data combined according to time into one data record. Thus, this program detects and eliminates errors in the stage data and combines the separate stage data records with respect to time. In the case of the Lower Fraser River, the tapes of the digital-type recorders are sent to the Department of Transport for interpretation.

The second complimentary program uses field measured discharges to define the particular characteristics relationship between the flow resistance coefficient, η, and Reynolds number for the reach. This is accomplished by solving equations B-3-23 and B-3-24 for η_t while also computing a corresponding Reynolds number. This set of discrete data are analysed by least squares methods to define the relationship which may then be used in the main discharge computation program.

B-3-3 Field verification

Field verification of the tidal flow computations for the two Lower Fraser River stations is not yet complete. A pair of digital recorders for the unsteady flow model for the Fraser River at Port Mann became operational in September 1967. Another pair of digital recorders for the Fraser River at Mission City station were scheduled for operation in 1969.

Field verification for the Fraser River at Port Mann station was started in 1968. The procedure is relatively involved: the discharges must be measured continuously throughout a 6 to 10 hour period. The multiple hydrograph technique of discharge measurement has been used. The channel geometry was determined from approximately a dozen cross-sections taken at equal intervals between the digital recorders, η was arbitrarily selected equal to 0.030 for the first verifications and it is realized that a more detailed evaluation of η would be desirable. The results of the first verifications have been encouraging. An example verification is shown in table B-3-1 and in figure B-3-3.

TABLE B-3-1

Example Verification of Mathematical Model,

May 29, 1968

(Refer also to figure B-3-3)

Inland Waters Branch, Vancouver, B.C.

Fraser River between Port Mann (Gauge 1) and New Westminster (Gauge 2)

Comparison of Discharges computed at the Base Gauge

by the Power Series Method with Discharges measured at the Base

Gauge over the same portion of a Tidal Cycle

Reach Parameters

Location of base gauge ISTA-	2
Reach length, X-	22860.0
Time increment, IDELI-	15
Base stage correction factor, ZC1-	-0.02
Auxiliary stage correction factor, ZC2	0.00
Distance between bottom elevation and gauge zero, H-	22.18
Flow resistance coefficient, EIA-	0.0295
Diversionary Flow, QS-	0.0
Computation Limit, EPS-	50.0

Initial Conditions

Stage at base gauge at time T-2,Z11-	14.77
Stage at base gauge at time T-1,Z12-	14.70
Stage at base gauge at time T, Z13-	14.62
Stage at auxiliary gauge at time T,Z23-	15.88
Discharge at base gauge at time T-1, PQ-	335000.0
Discharge at base gauge at time T,Q-	342000.0
Control for hour printing on plot, TP-	4
Control for starting time of plot, TREC-	3

DAY	HR.	MEASURED DISCHARGE 0	COMPUTED DISCHARGE
		342000	342000
		349000	356454
29	8	354000	364120
		360000	368088
		364000	372129
		369000	376507
	9	373500	379941
		377000	382252
		381000	385601
		384000	388183
	10	388000	390305
		391000	392377
		394000	394074
		397000	394444
	11	399000	393776
		402000	393998
		404500	395450
		407000	392722
	12	409500	392713
		410000	392910
		410500	390324
		410000	388278
	13	409000	388882
		407000	387657
		405000	386833
		403000	383273
	14	400000	381708
		397500	380799
		395000	378330
		392000	375375
	15	388500	377433
		385000	372700
		381000	370253
		377000	366454
MEAN		388705	381657

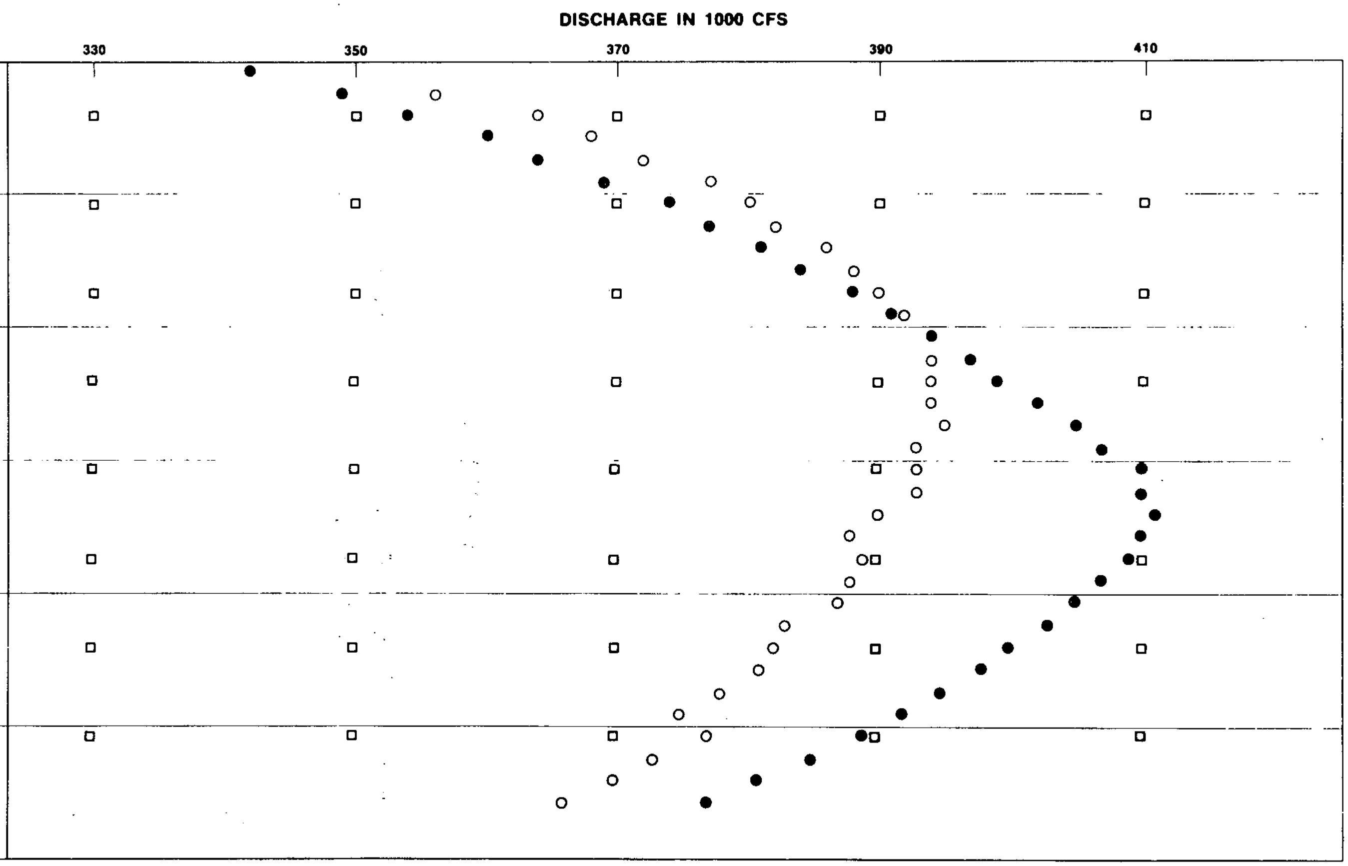


FIGURE B-3.3 **EXAMPLE VERIFICATION OF MATHEMATICAL MODEL. MAY 29, 1969** (REFER ALSO TO TABLE B-3-1)

APPENDIX C

DETAILS OF SEDIMENT SURVEY, LOWER FRASER RIVER
1965 TO 1968 INCLUSIVE

APPENDIX C

The details of the sediment survey at the Fraser River stations and the tributary stations are as follows:

Fraser River at Port Mann

1965 Suspended sediment sampling at this station began on June 6, 1965. The sampling was done from a catamaran designed for the survey. Positioning on the cross-section was made possible by means of markers placed on the river banks and on Port Mann bridge approximately one mile upstream of the cross-section. A P61 type sampler was used for the depth and point integrating samples. In addition to these samples which were analysed in the laboratory, numerous turbidity readings were made using a Secchi disk. Some intensive or frequent sampling was done to determine the concentration variation between the tide peaks but sampling over a complete tidal cycle was not done. Width integrating samples using a portable pumping sampler were obtained instead of the conventional depth-integrating measurements. Point integrating samples were taken concurrently to determine the variation of concentration with depth.

Sampling of bed load was also started on June 6, 1965. Sphinx, VUV and Arnhem type bed load samplers were used. Because of some difficulty in developing the samplers and sampling techniques, the bed load data obtained in 1965 are of doubtful reliability.

It became evident after several months sampling that the concentration variations were significantly affected by the tide. To sample effectively, therefore, the magnitude and time of the Port Mann tide peaks and crests was predicted in advance of sampling. These predictions were based on a correlation analysis using predicted Point Atkinson tide parameters and the corresponding parameters recorded at Port Mann. Thus, because Point Atkinson tide tables are prepared in advance by a year or more, it was useful to prepare the same type of table for the Port Mann station.

1966 The 1966 sampling was carried out in much the same way as in 1965. Width integrating measurements were made throughout the year instead of the standard depth integrating measurements.

A correlation analysis was made of Secchi disk readings and the 1965 and 1966 lateral daily sampling observations. The resulting curvilinear relationship was used to convert the Secchi disk readings into terms of equivalent daily concentration. In this way it was possible to use the Secchi disk data as an aid in the restoration of the concentration hydrograph.

A number of intensive surveys, sometimes referred to as 24 hour surveys since they are programmed for the duration of a complete tidal cycle, were carried out in 1966. These surveys, carried out on May 11, 12, 19 and 20, June 2, 3, 17 and 18 and July 5, 6, 20 and 21, were designed to obtain data which would be useful in determining the "pattern" of velocity, concentration and bed load movement and the range of variation of these throughout the tidal cycle. An example of the results is illustrated in section 3.2.

1967 In 1967, motorization of equipment enabled some changes and improvements of the survey program. Width integrating measurements were discontinued after January 12 and replaced by the standard depth integrating measurements. The P61 suspended sediment sampler normally used for the suspended sediment measurements was replaced on February 6 by the P63 which is a heavier and larger sampler more suited to the conditions.

A stationary pumping sampler became operational on April 20, 1967. This consisted of a pump located in a shelter on shore and a hose and intake nozzle placed to some point in the river. To take a sample, an observer simply placed a sample bottle at the pump outlet after the previous sample mixture was cleared out of the hose and pump. The pump samples were then related to samples taken at the daily vertical in the cross-section. On the basis of 120 lateral samples taken during the period April to September 1967, the relationship $C_d = 0.019 + 0.78\, C_p$ was developed for the range of concentrations 0 to 1.00 grams/litre with a coefficient of correlation of 0.97. C_p is the concentration of the sample taken with the pump sampler and C_d the concentration of the lateral sample taken at the daily vertical in the cross-section. Because the pump samples were intended to replace Secchi disk observations, the latter were discontinued on May 30.

As in 1966, the 1967 intensive surveys were carried out on May 1, 5 (pump sampler only), 23 and 31, June 15 and 16, July 13 and August 3.

1968 The sampling equipment and methods used throughout the year were much the same as during the latter part of 1967. Intensive observations were done on February 8 and 20, March 8, May 4 and 30, June 13 and July 4.

The bed load sampling program was perhaps the most difficult to develop because of equipment and sampling technique problems. The Sphinx, Arnhem and VUV samplers were used with emphasis on sampling with the Arnhem which appeared to be the most practical and reliable. Some parallel sampling, that is, using all three samplers, was done for relative comparison. Intensive bed load data were obtained for the following dates:

May 11, 12, 19 and 20; June 2, 3, 17, 18 and 29 and July 5, 6, 20 and 21, 1966; May 23 and 31, June 15, July 13, August 3 and September 5, 6, 7, 14, 18 and 19, 1967; and March 19 and 20, May 10, 14, 21, 28 and 30, June 11, 13 and 25 and July 2, 4 and 25, 1968. Periodic soundings of the river bottom were made to determine the configuration of the river bottom, to compute volumetrically the bed load movement, and to attain further knowledge of the physics of bed load transport. Such soundings were made on May 10, 21 and 28, June 11 and 25, and July 2 and 25, 1968. Some soundings were done in 1967 only to determine if a sounding program would provide useful data.

Bed material sampling was done periodically in the standard way using a BM-54 sampler. Some intensive sampling was done to determine if bed material sizes changed appreciably within the duration of tidal cycle but these were discontinued when it was found that no significant changes occurred.

Fraser River at Mission City

Sampling of suspended sediment began on May 29, 1965. A bridge installation was used for daily sampling. The regular cross-section was located approximately 1000 feet upstream of the bridge.

During high water the daily sampling was restricted to the top 20 feet of depth because of excessive velocities. Under these conditions point integrating sampling was done periodically to determine the concentration variation with depth and therefore to provide data for correcting or adjusting the daily samples taken in this way.

A full sediment survey program was operated at this station which, in addition to suspended sediment sampling, included sampling of bed load and bed material. A BM-54 sampler was used to sample bed material. Bed load samples were obtained with the Arnhem or VUV samplers. The Arnhem sampler was used most frequently. An echo sounding program similar to that at Port Mann was also made operational in 1967 and soundings of the river bottom were taken on the following dates: July 5 and 11, 1967, and May 7 and 30, June 7 and 21, July 8 and 23, and August 9, 1968.

Fraser River near Agassiz

Daily sampling of suspended sediment began on June 20, 1966 from a bridge installation. A detailed program which included bed load sampling became operational on April 9, 1968. Basket type samplers were used for the bed load surveys.

A detailed hydrometric survey program also became operational on April 9, 1968.

The 1967 suspended sediment computations were made on the basis of a K-factor determined for 1968. For the 1966 computations the K-factor was assumed equal to one for the entire period. It may be required to make further changes if additional years data indicate that such adjustments cannot be reliably made.

Fraser River at Hope

Daily sampling of suspended sediment started on May 30, 1965 from a bridge installation. Up to July 13, 1965 a D49 sampler was used and sampling was done through partial depth only. Following July 13, a P61 sampler was used for sampling the full depth. A comprehensive sediment survey program was started during the 1966 freshet. Bed load and bed material sampling was not included, however, because of excessive velocities and problems in handling the equipment.

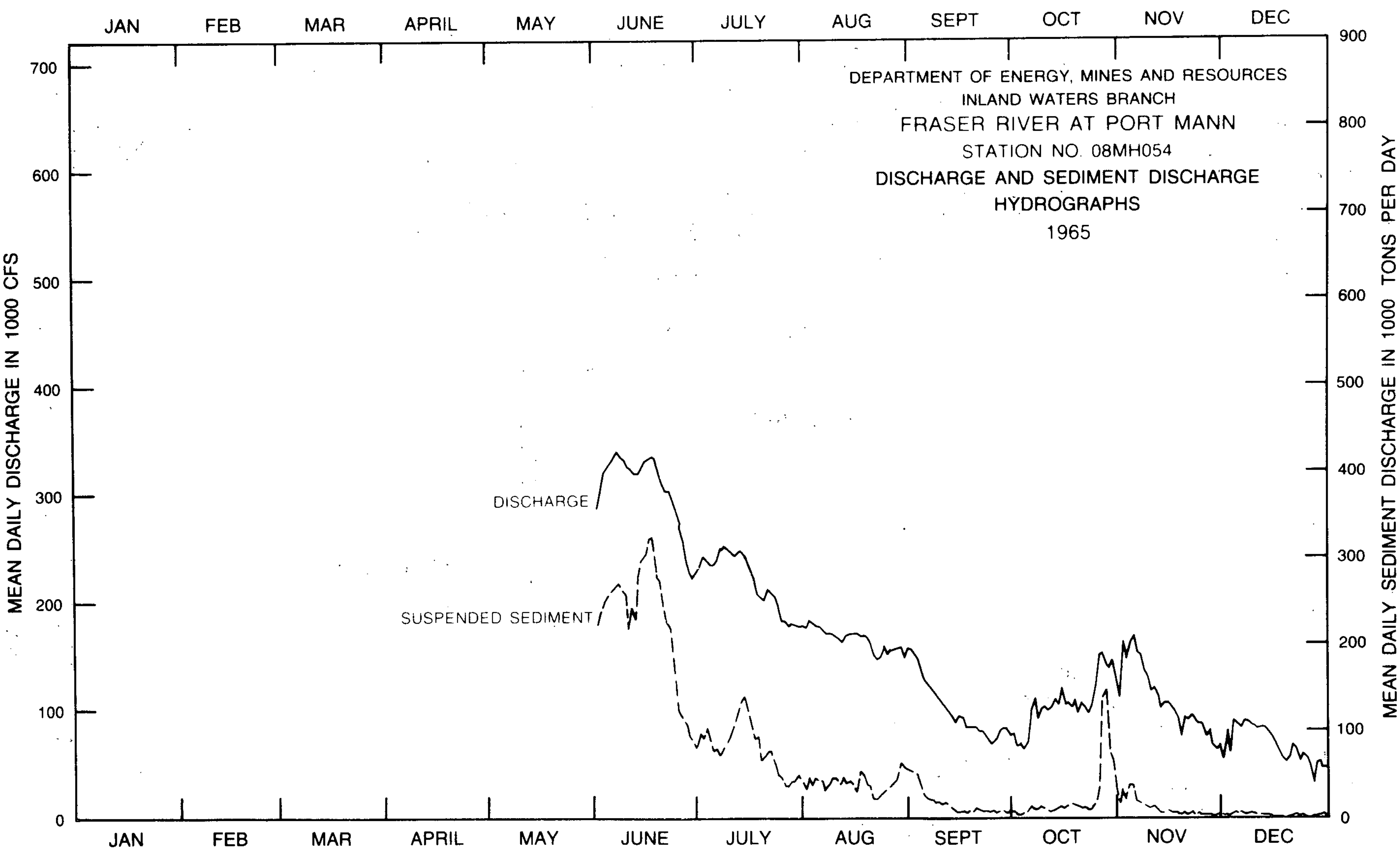
Tributary Stations

With the exception of the Pitt River near Port Coquitlam, the sampling of suspended sediment was limited to two or three samples per month at only one vertical. The tributary rivers in the Lower Fraser reach are generally relatively free of suspended sediment and the variation in concentration is not excessive. In the case of the Pitt River near Port Coquitlam, which is affected by tides, the limited program consisted of sampling suspended sediment daily at one vertical at the peaks and crests of the tide.

Bed load and bed material data were not obtained for the tributary stations.

APPENDIX D

SUMMARY OF RESULTS



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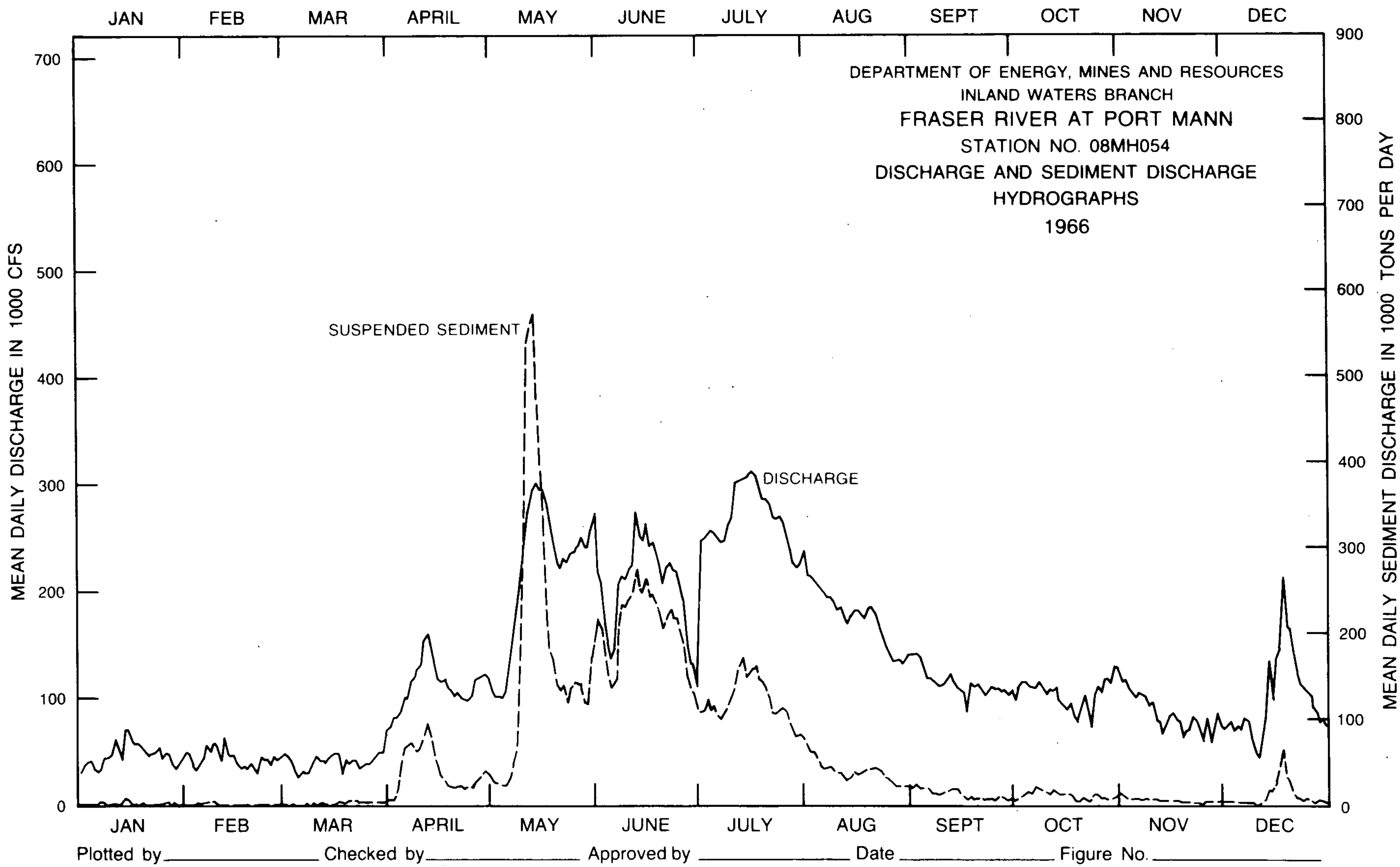
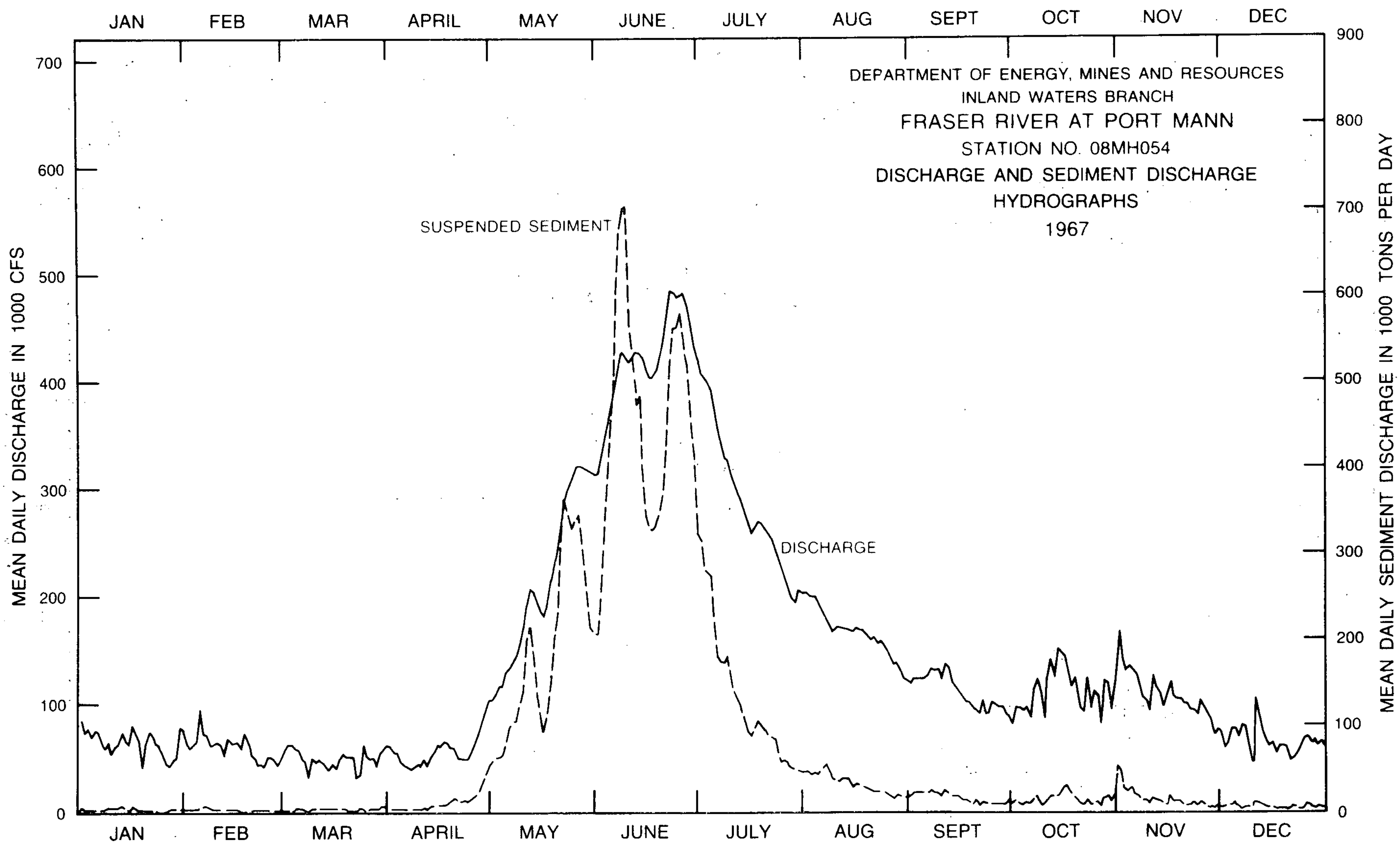

DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH
FRASER RIVER AT PORT MANN
STATION NO. 08MH054
DISCHARGE AND SEDIMENT DISCHARGE
HYDROGRAPHS
1966
JAN
FEB
MAR
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
MEAN DAILY DISCHARGE IN 1000 CFS
0
100
200
300
400
500
600
700
MEAN DAILY SEDIMENT DISCHARGE IN 1000 TONS PER DAY
0
100
200
300
400
500
600
700
800
900
SUSPENDED SEDIMENT
DISCHARGE
Plotted by
Checked by
Approved by
Date
Figure No.



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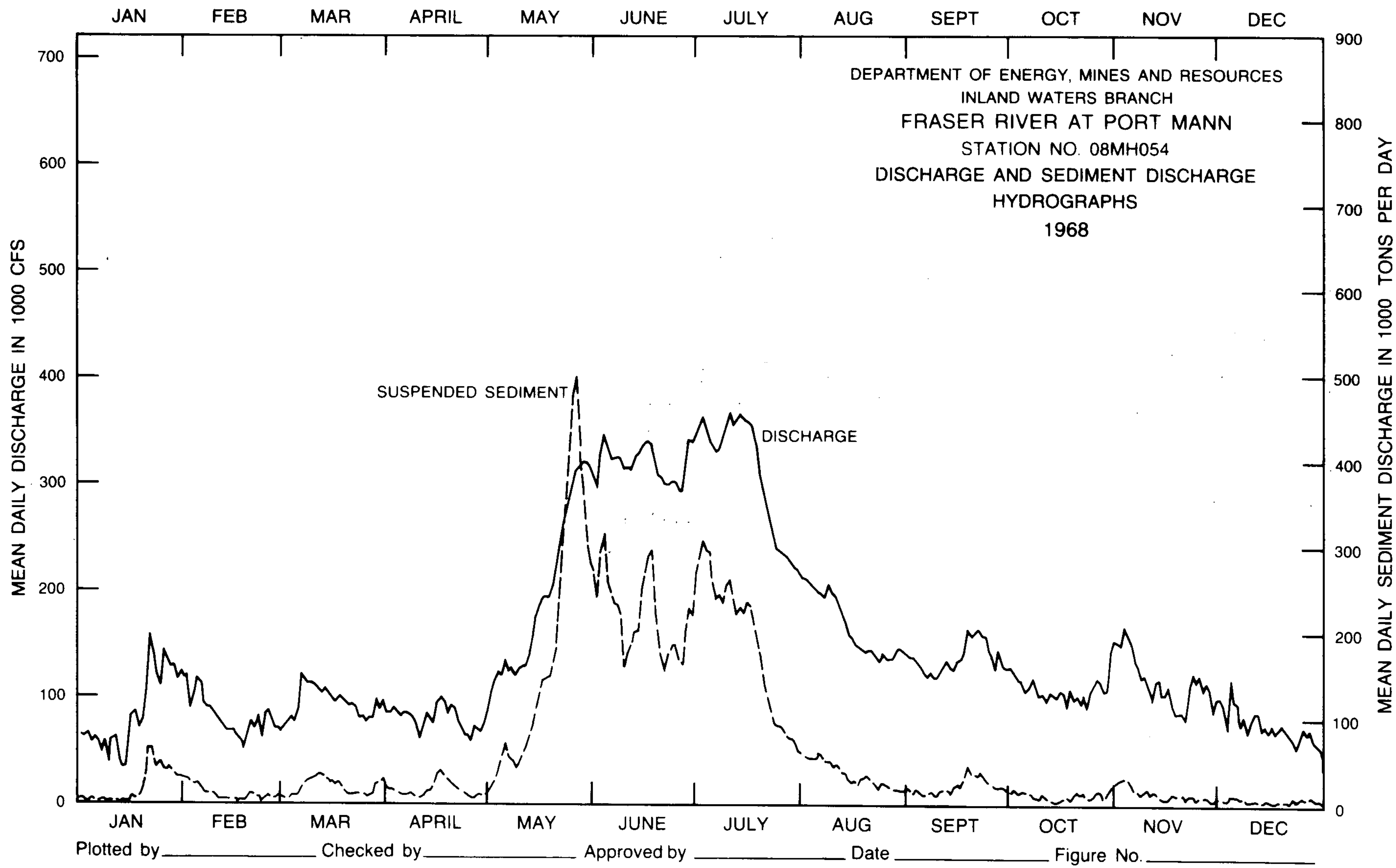
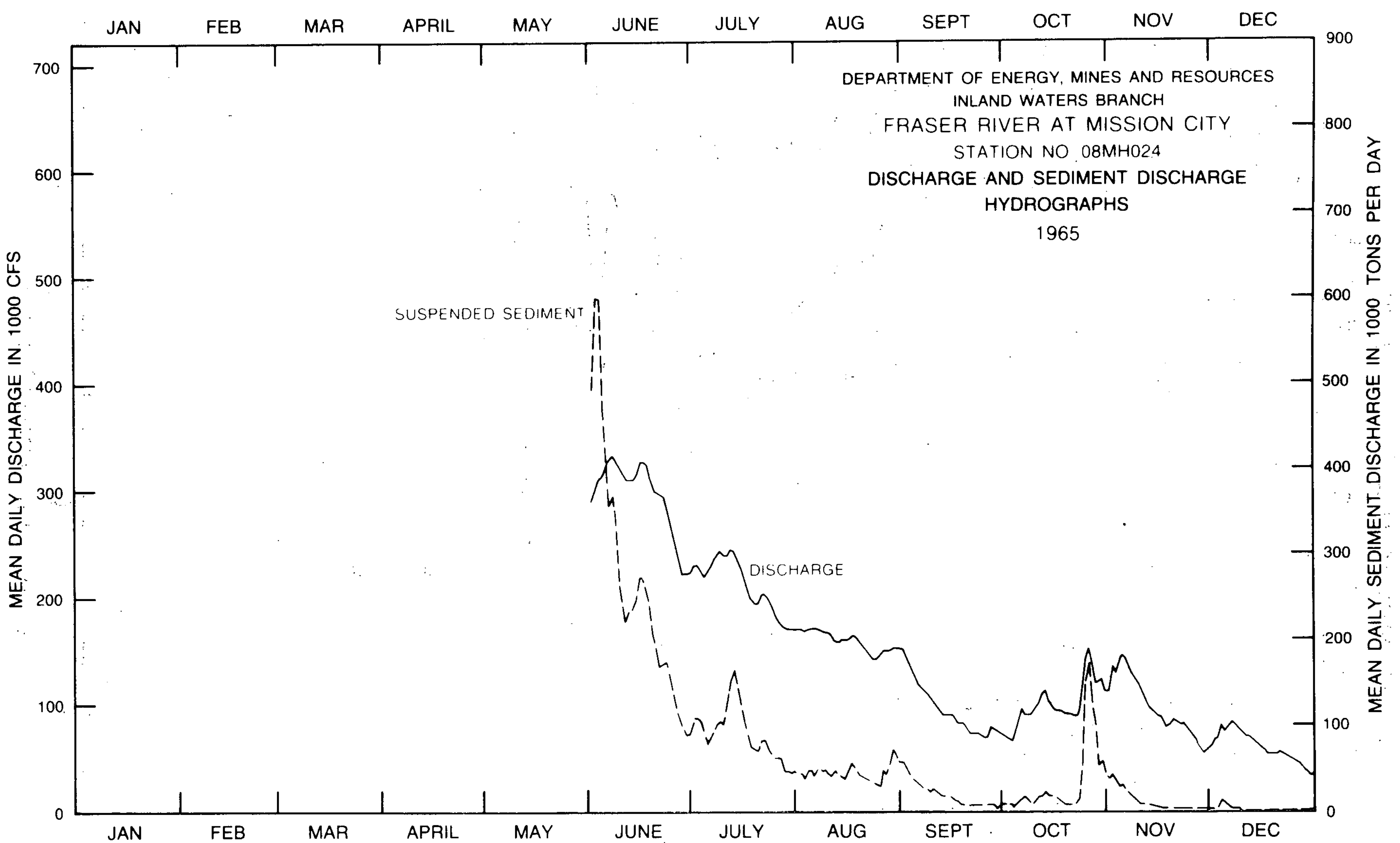

DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH
FRASER RIVER AT PORT MANN
STATION NO. 08MH054
DISCHARGE AND SEDIMENT DISCHARGE
HYDROGRAPHS
1968
JAN FEB MAR APRIL MAY JUNE JULY AUG SEPT OCT NOV DEC
MEAN DAILY DISCHARGE IN 1000 CFS
0 100 200 300 400 500 600 700
MEAN DAILY SEDIMENT DISCHARGE IN 1000 TONS PER DAY
0 100 200 300 400 500 600 700 800 900
SUSPENDED SEDIMENT
DISCHARGE
Plotted by Checked by Approved by Date Figure No.



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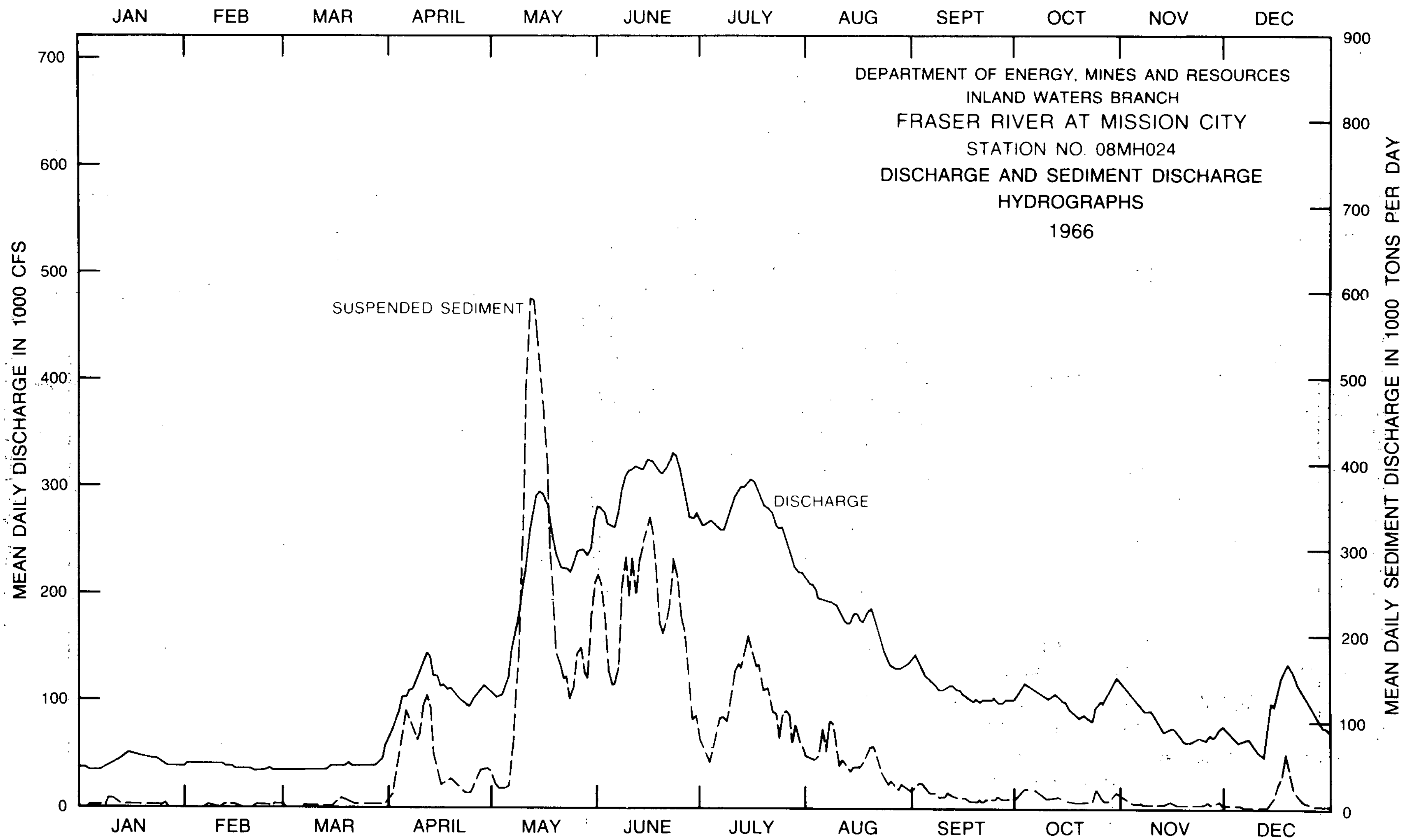

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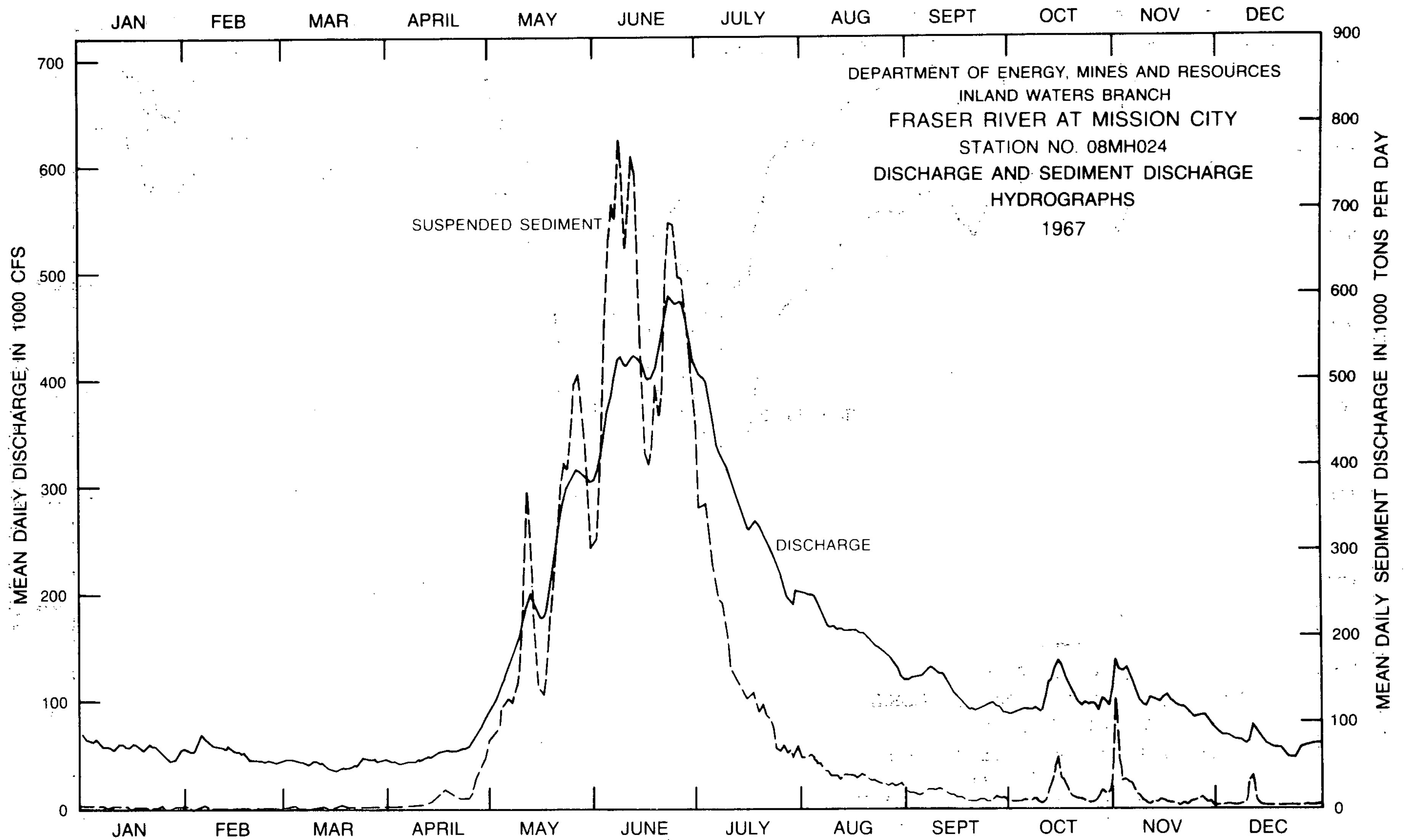

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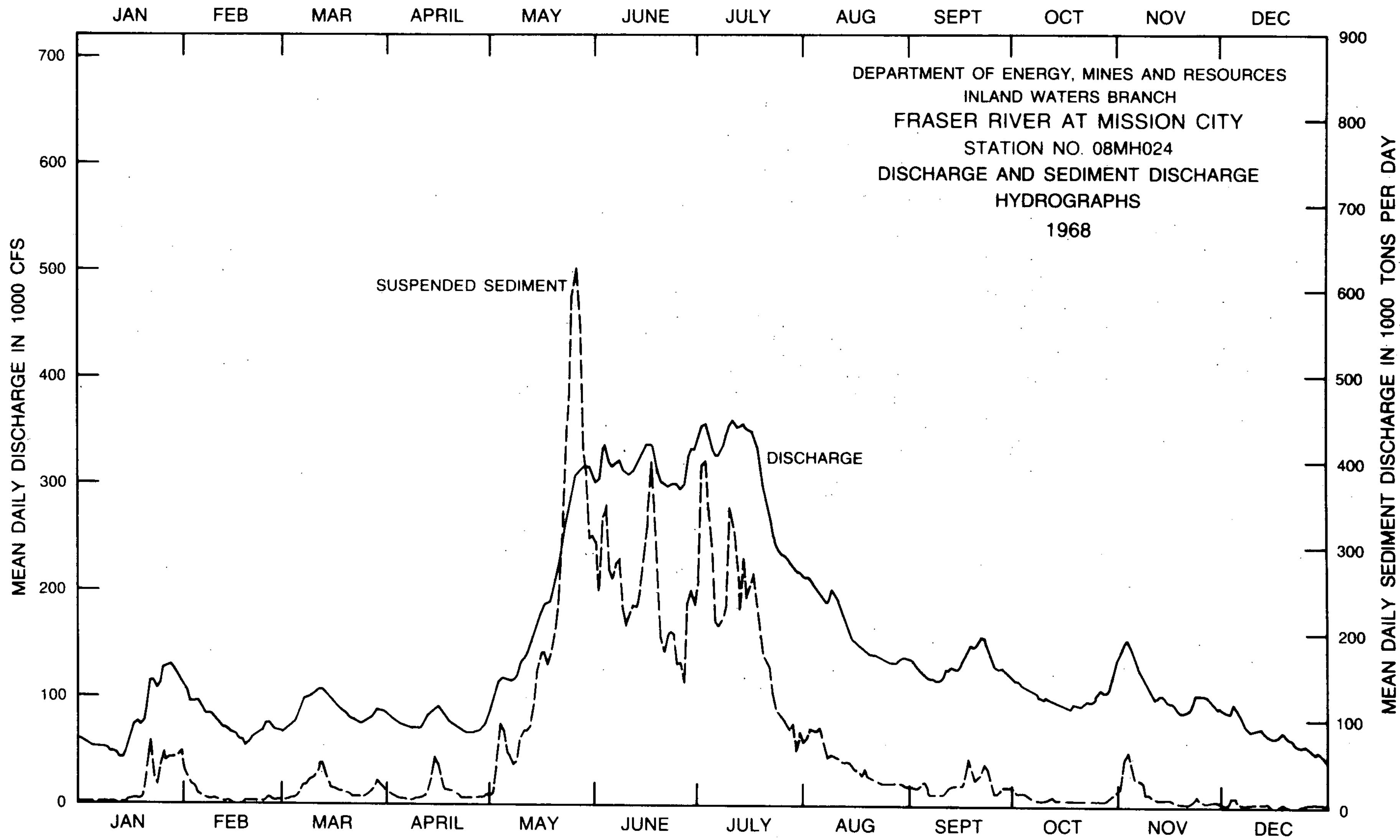

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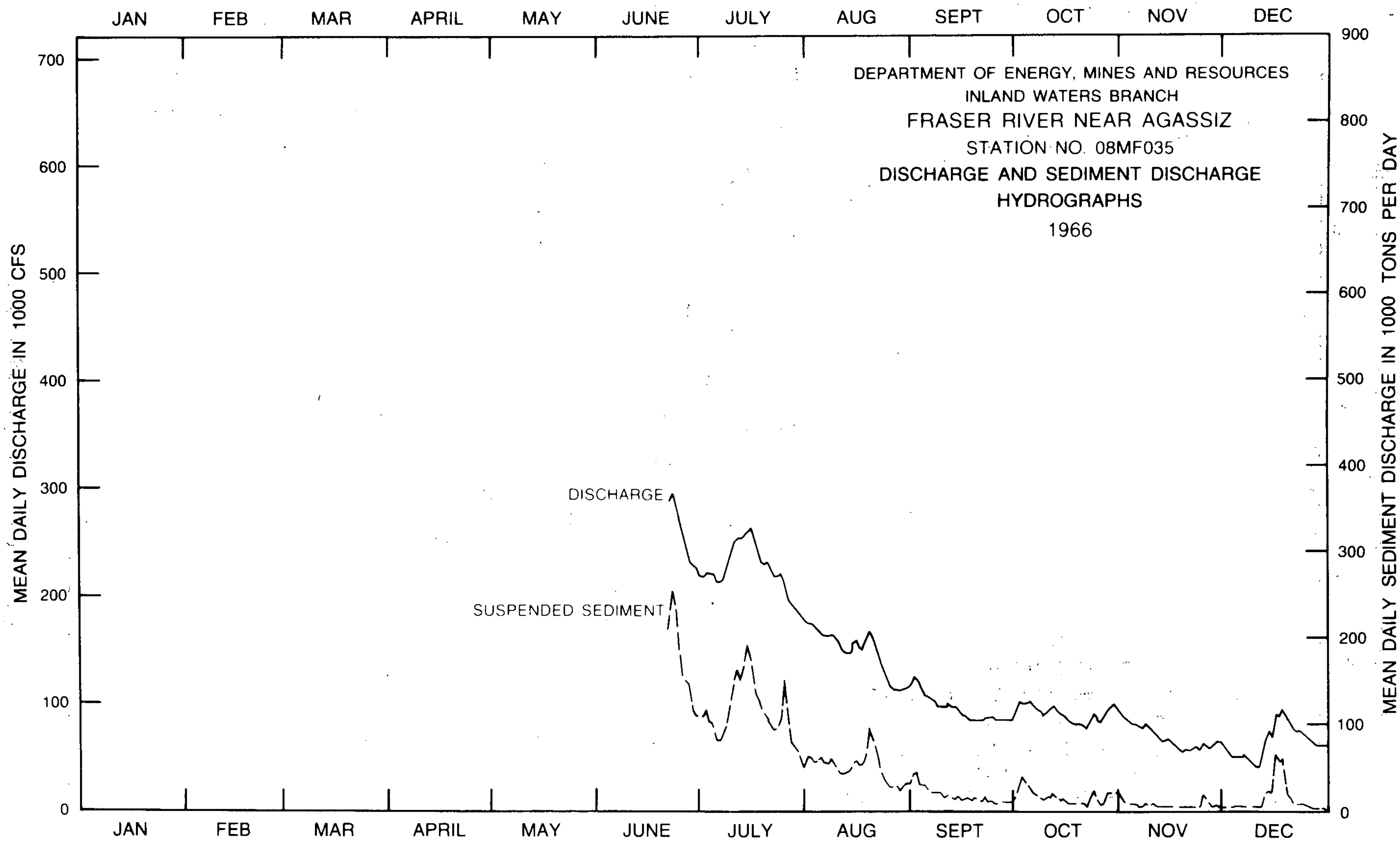

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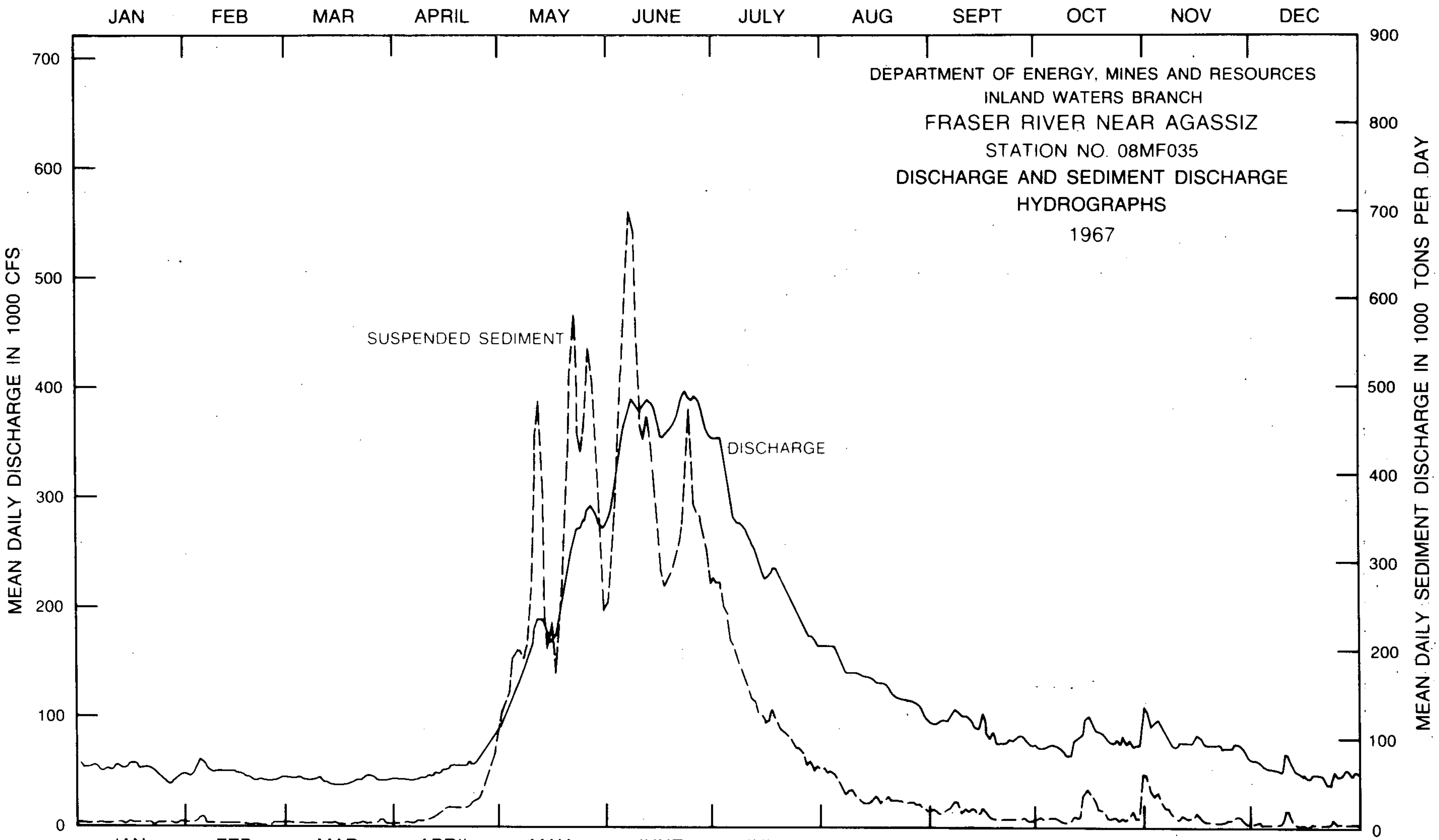

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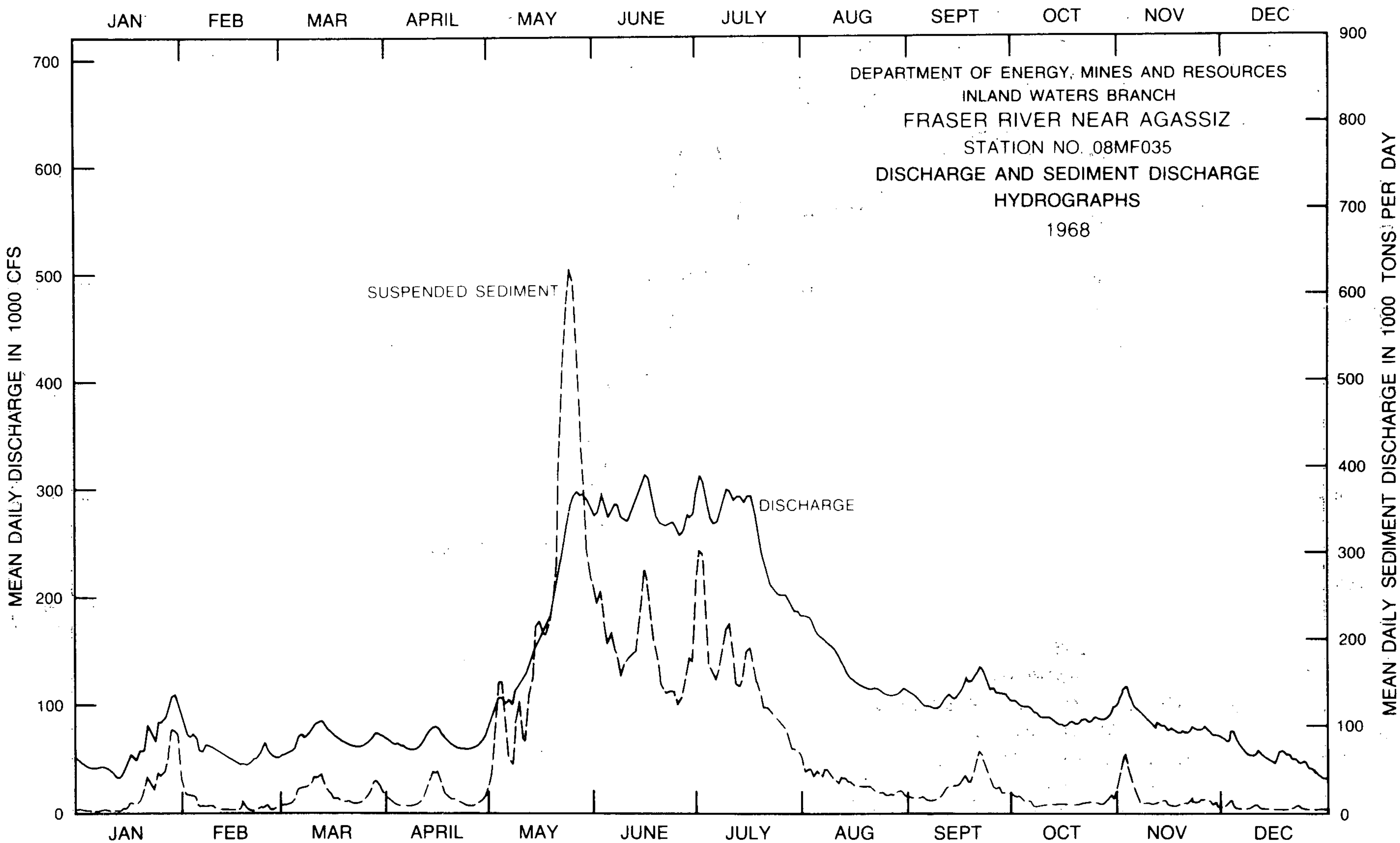

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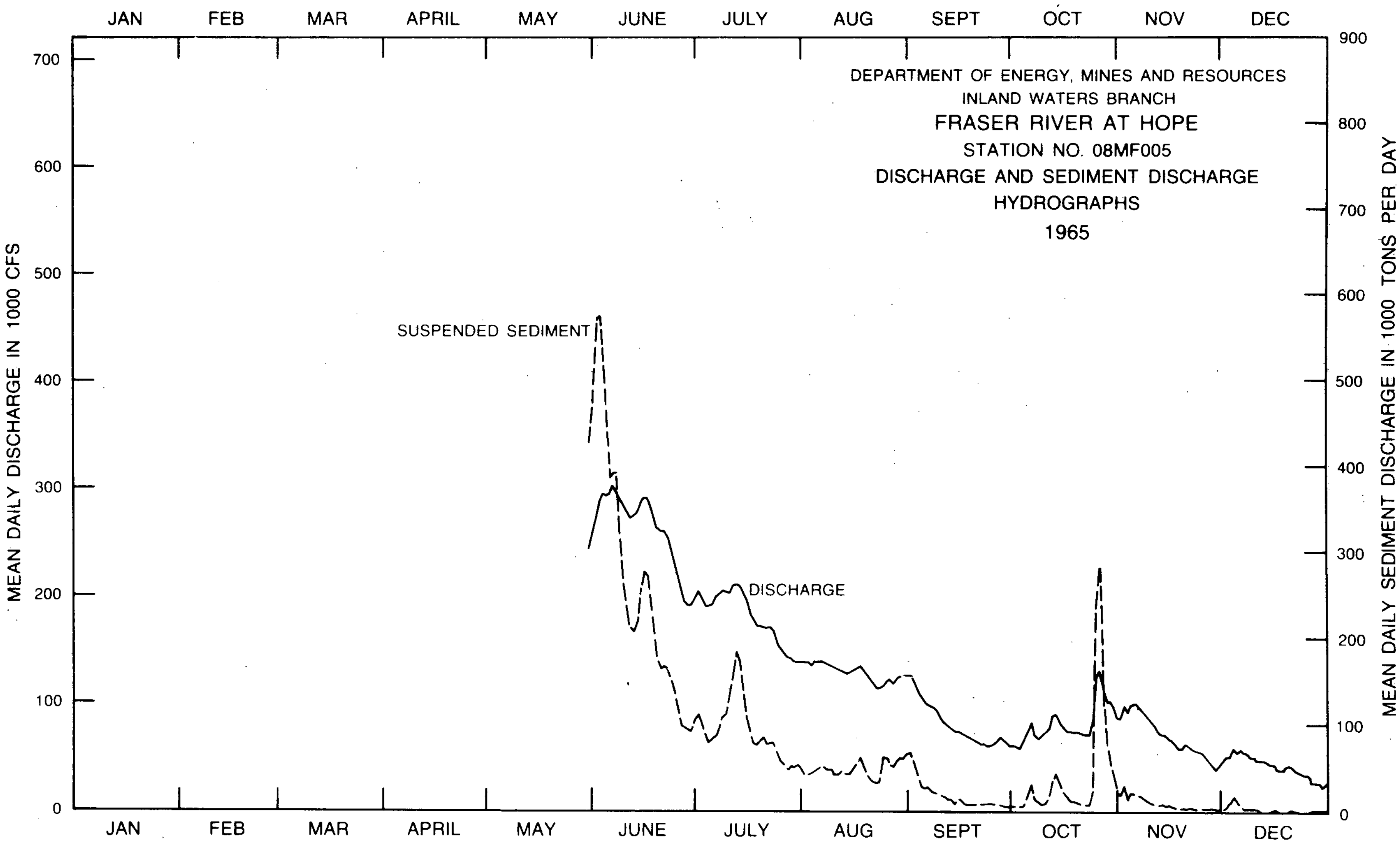

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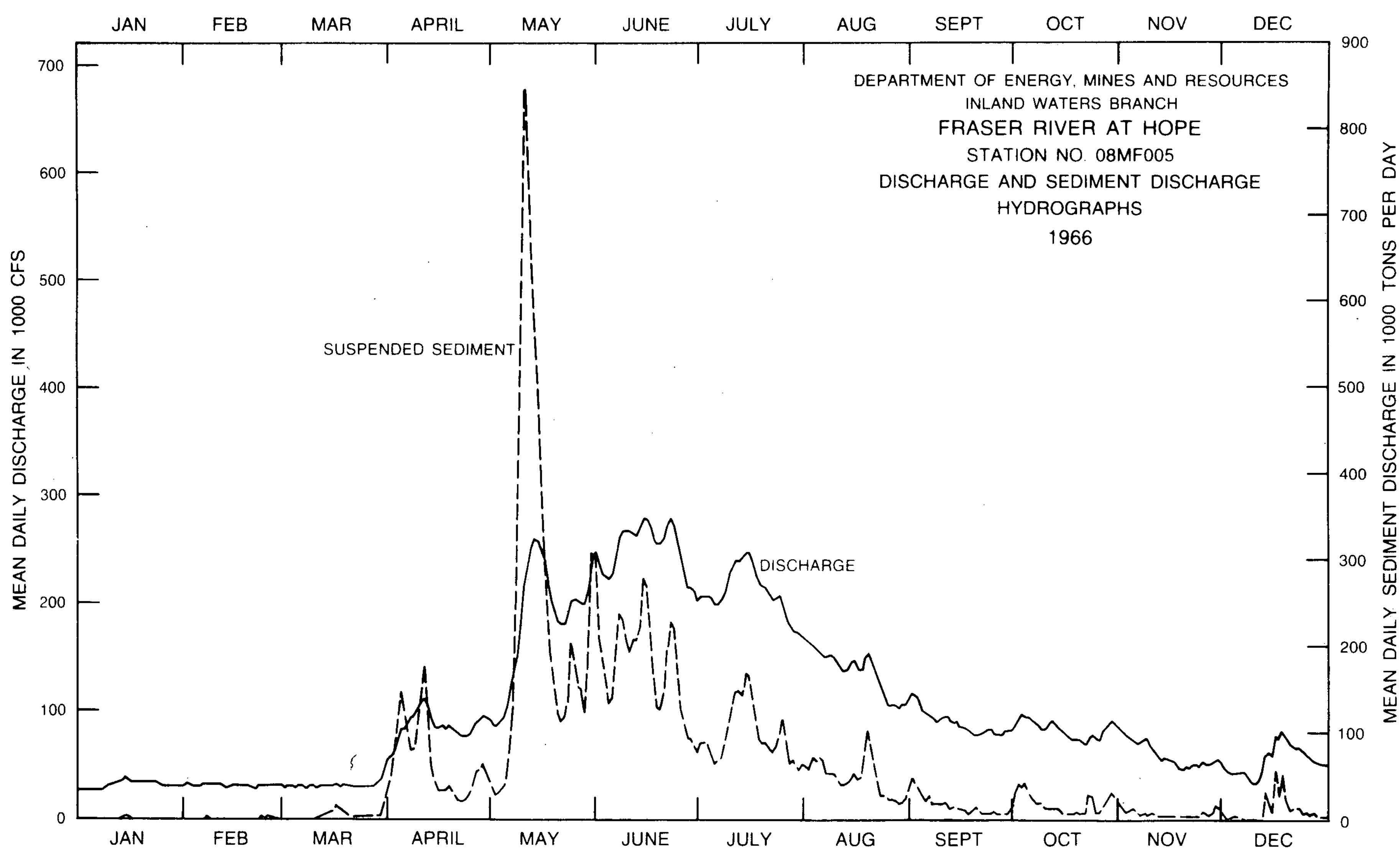

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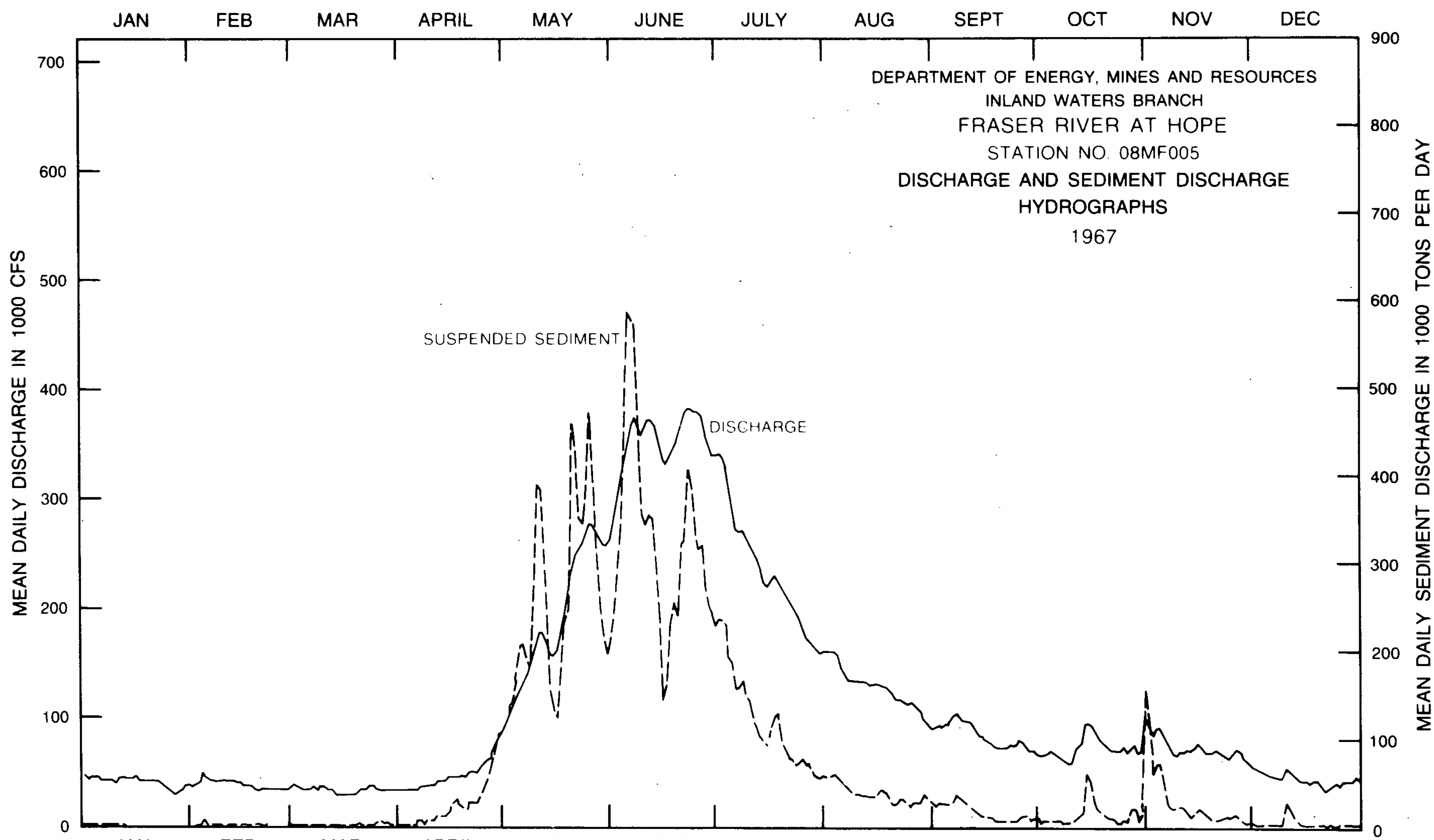

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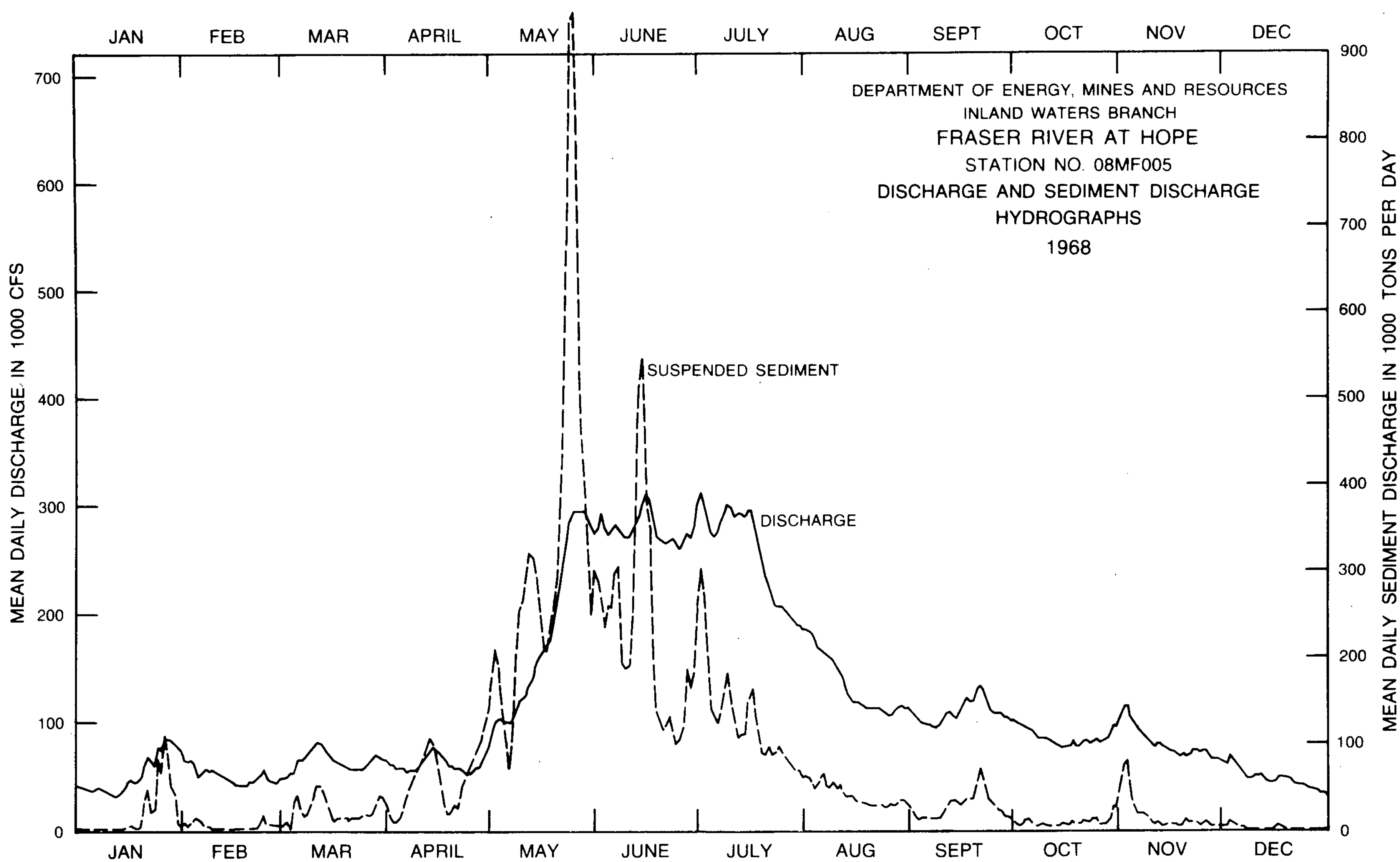

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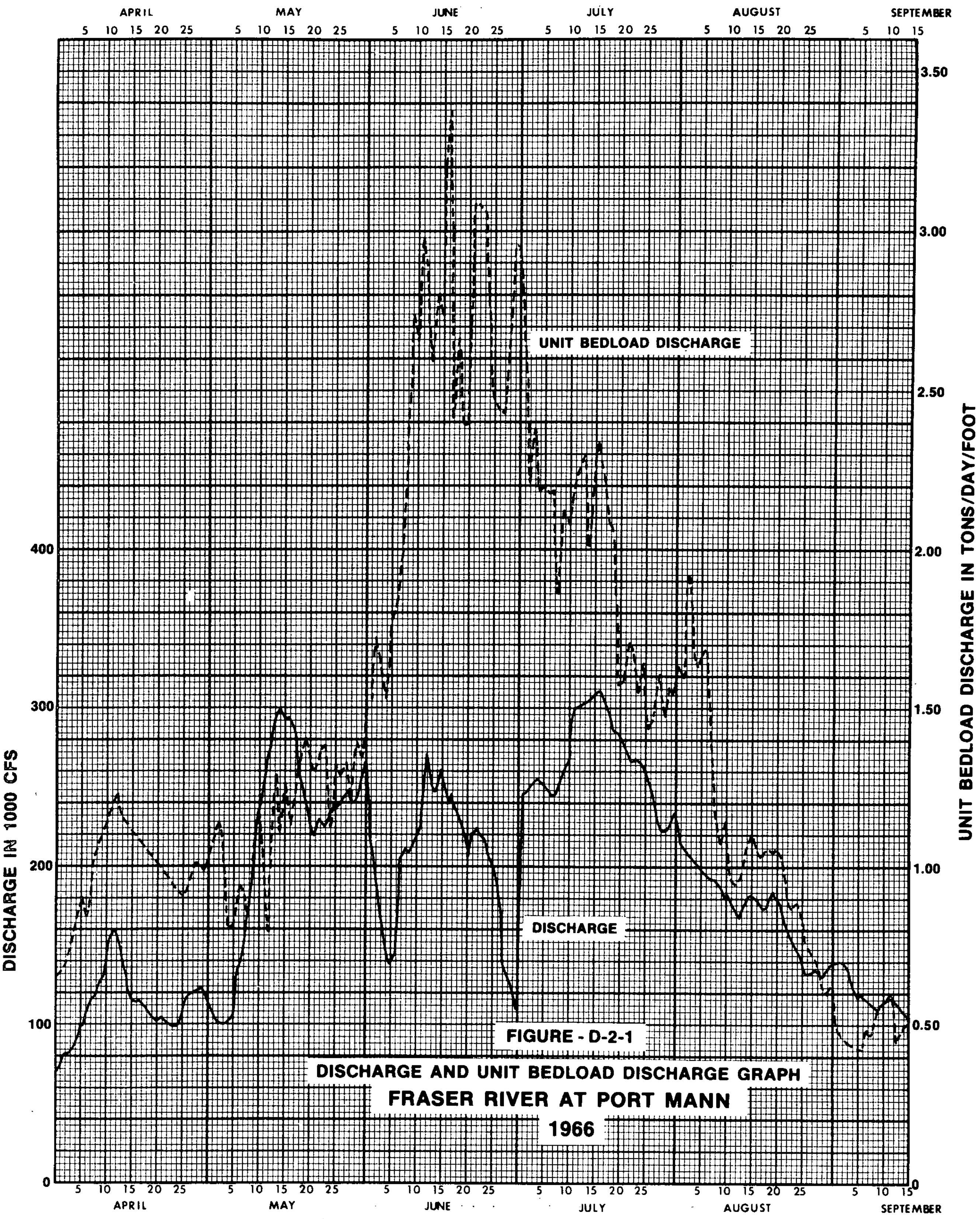


FIGURE - D-2-1

DISCHARGE AND UNIT BEDLOAD DISCHARGE GRAPH

FRASER RIVER AT PORT MANN

1966

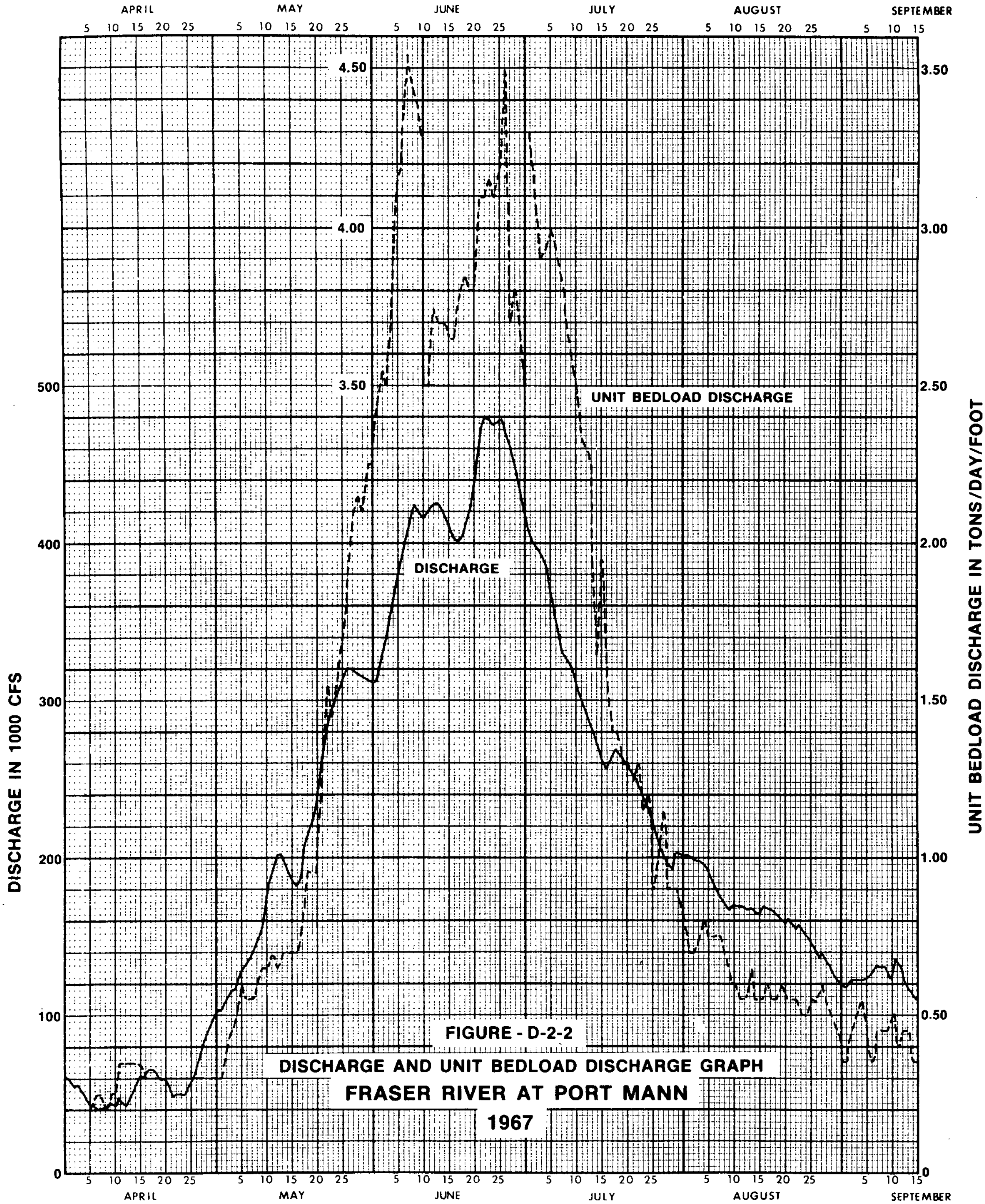


FIGURE - D-2-2

DISCHARGE AND UNIT BEDLOAD DISCHARGE GRAPH

FRASER RIVER AT PORT MANN

1967

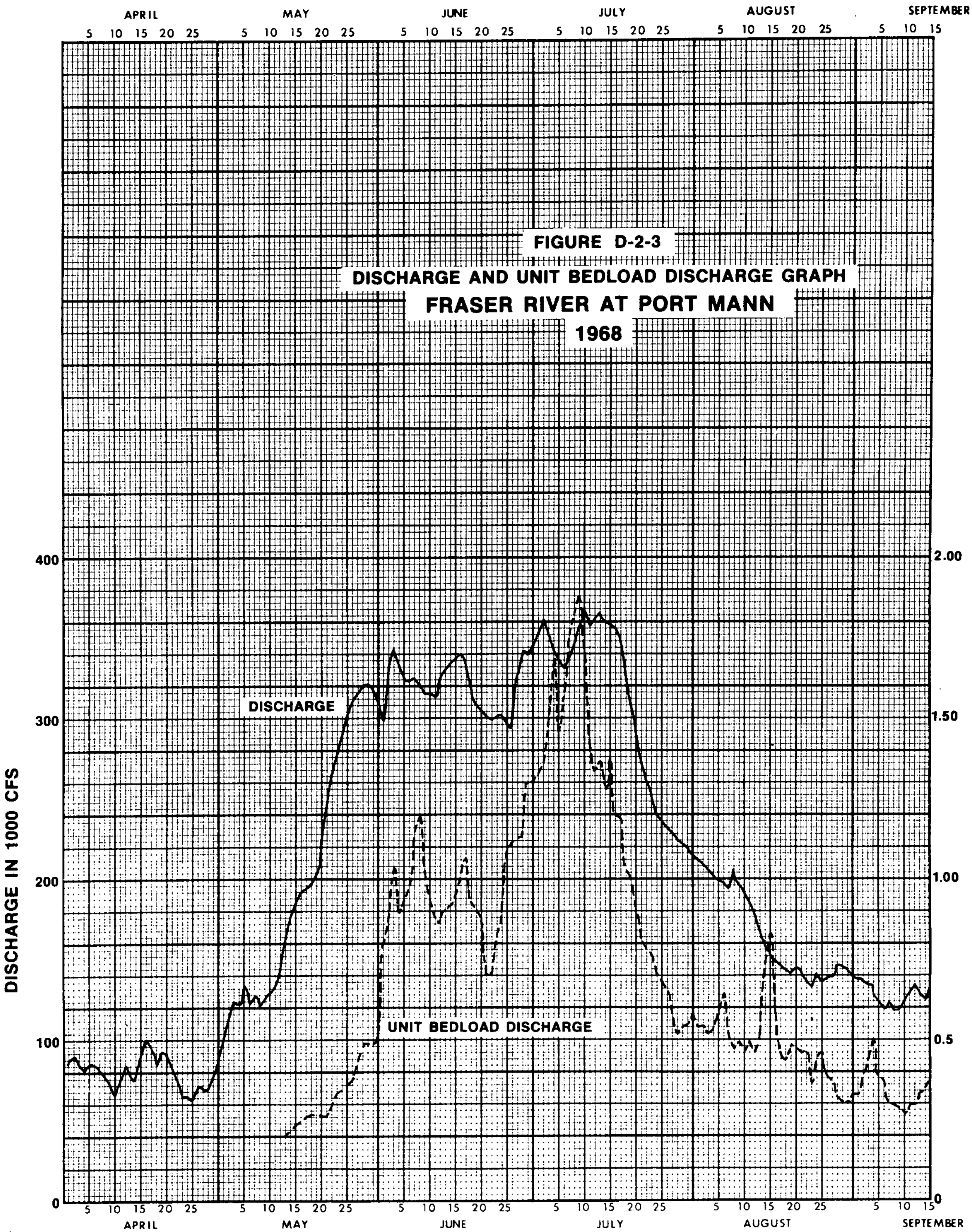


FIGURE D-2-3
DISCHARGE AND UNIT BEDLOAD DISCHARGE GRAPH
FRASER RIVER AT PORT MANN
1968
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
5 10 15 20 25
DISCHARGE
UNIT BEDLOAD DISCHARGE
DISCHARGE IN 1000 CFS
UNIT BEDLOAD DISCHARGE IN TONS/DAY/FOOT
0
100
200
300
400
0.5
1.00
1.50
2.00

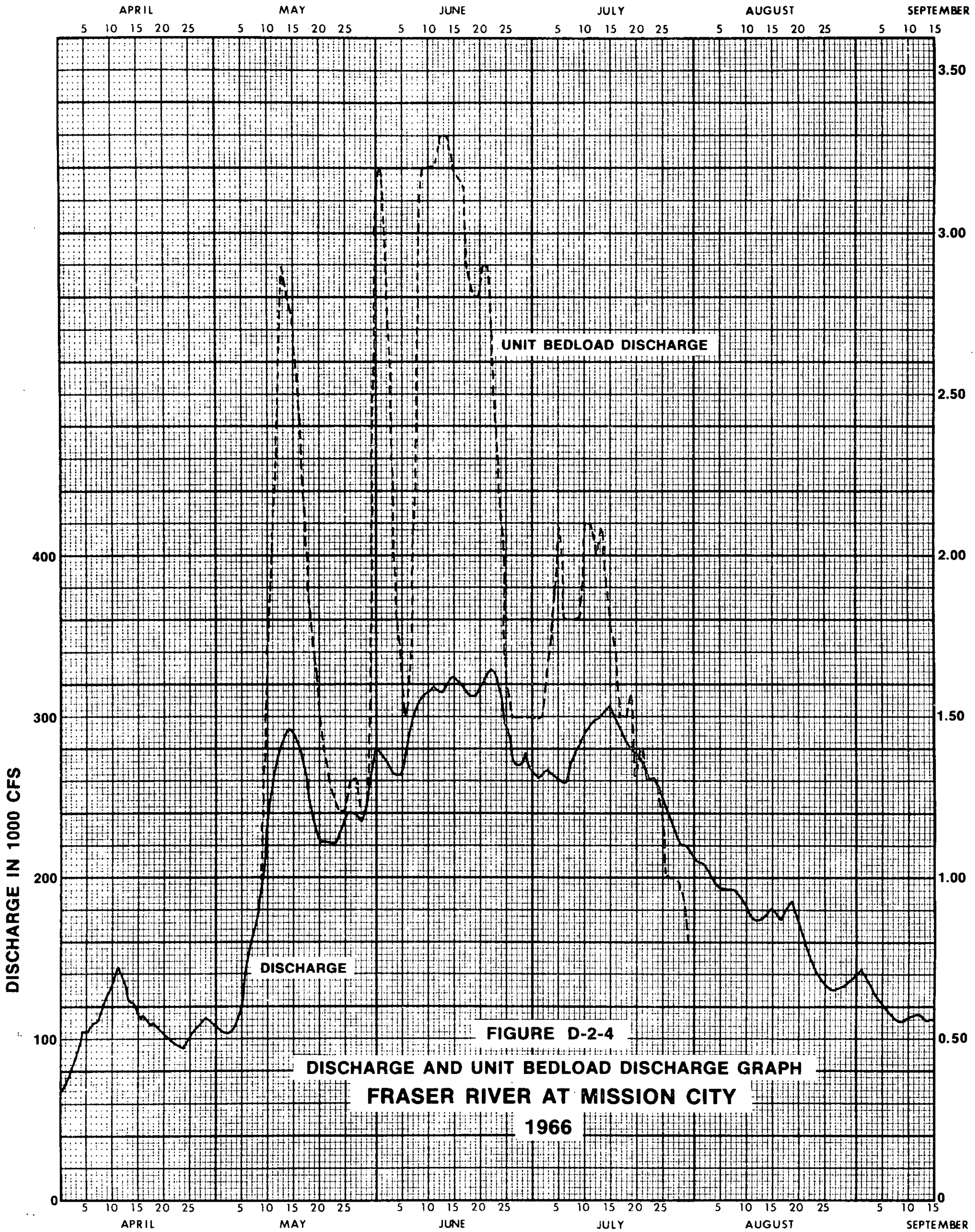


FIGURE D-2-4
DISCHARGE AND UNIT BEDLOAD DISCHARGE GRAPH
FRASER RIVER AT MISSION CITY
1966

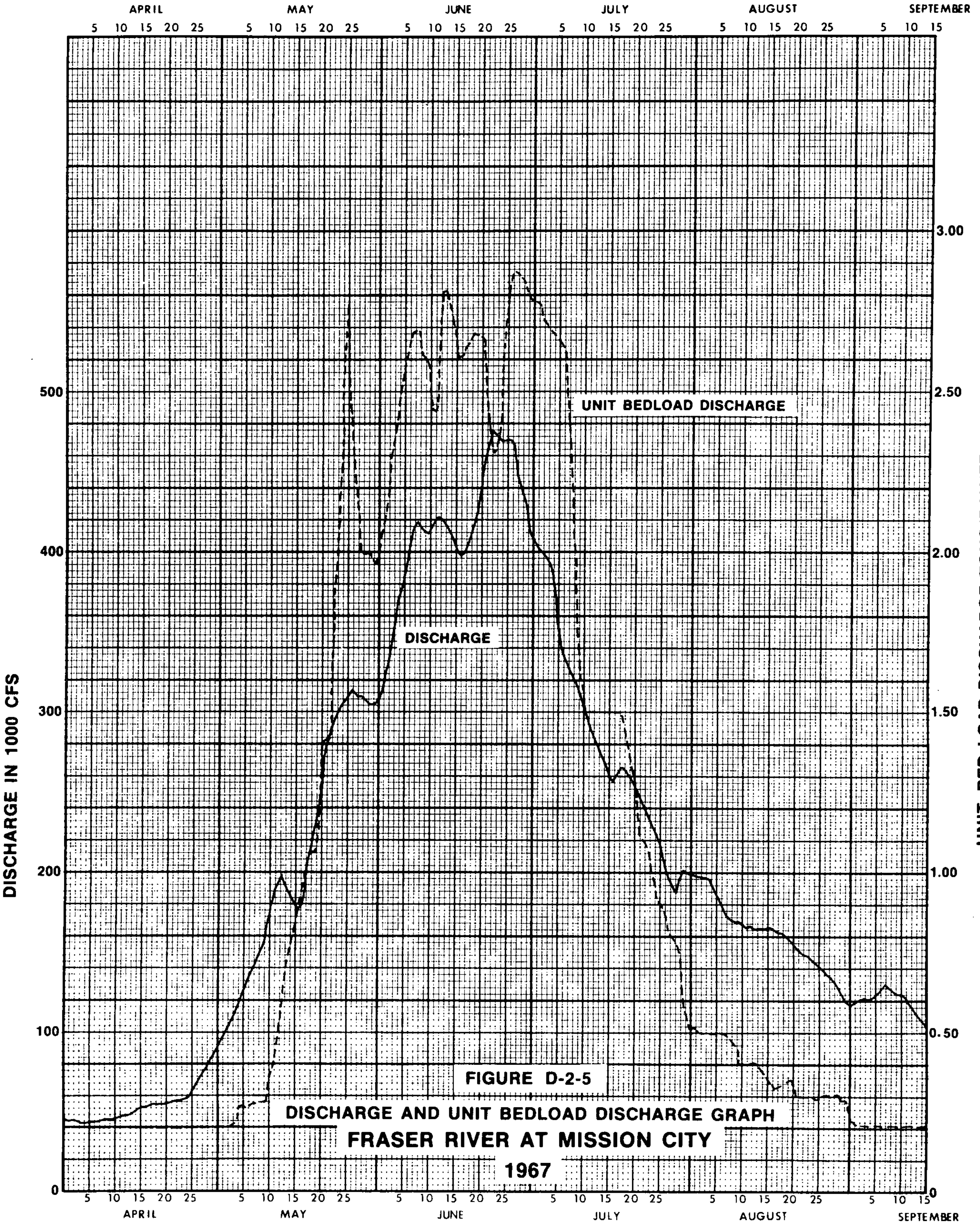


FIGURE D-2-5

DISCHARGE AND UNIT BEDLOAD DISCHARGE GRAPH

FRASER RIVER AT MISSION CITY

1967

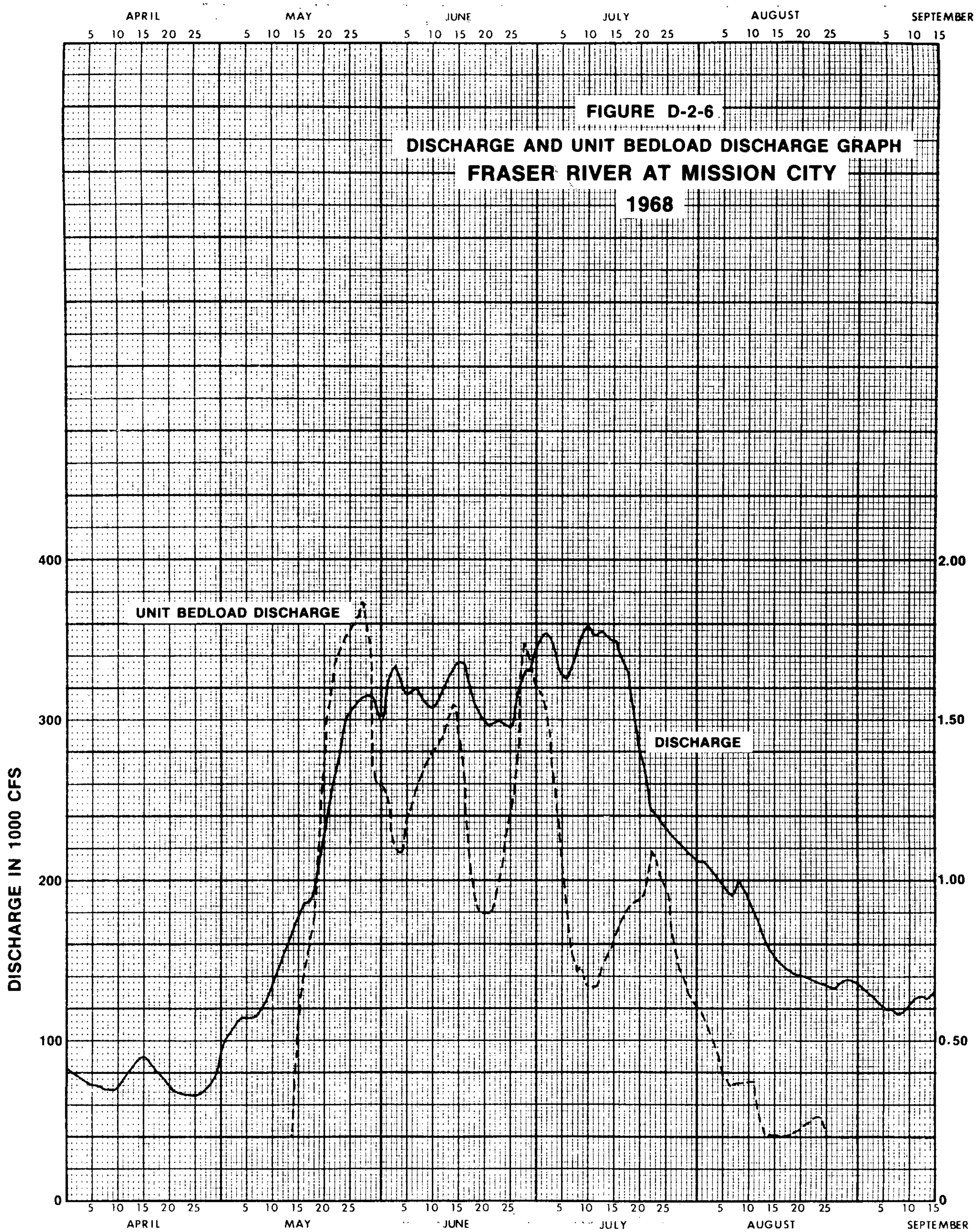
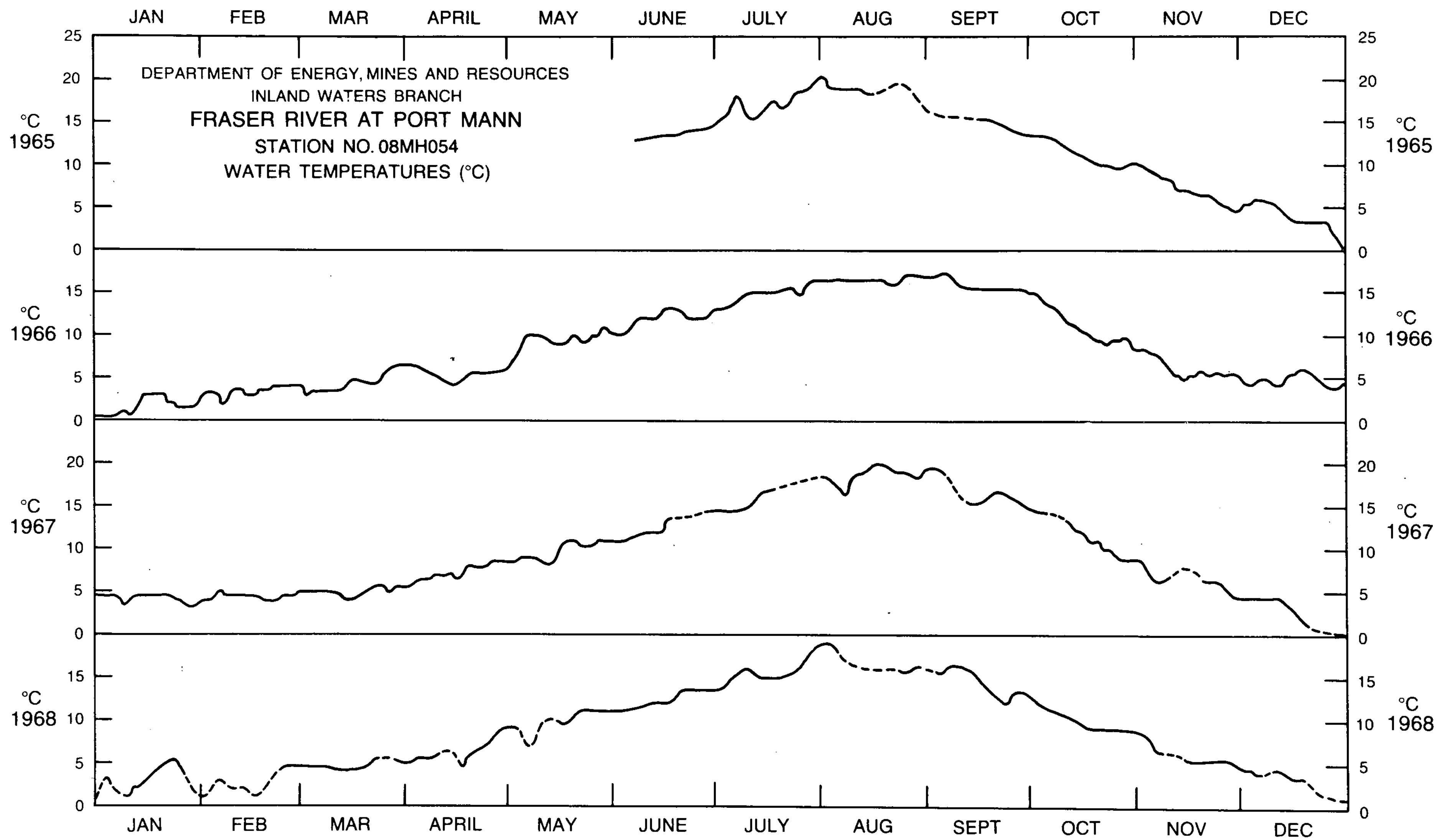


FIGURE D-2-6
DISCHARGE AND UNIT BEDLOAD DISCHARGE GRAPH
FRASER RIVER AT MISSION CITY
1968
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
5 10 15 20 25
UNIT BEDLOAD DISCHARGE
DISCHARGE
DISCHARGE IN 1000 CFS
UNIT BEDLOAD DISCHARGE IN TONS/DAY/FOOT
0
100
200
300
400
0.50
1.00
1.50
2.00



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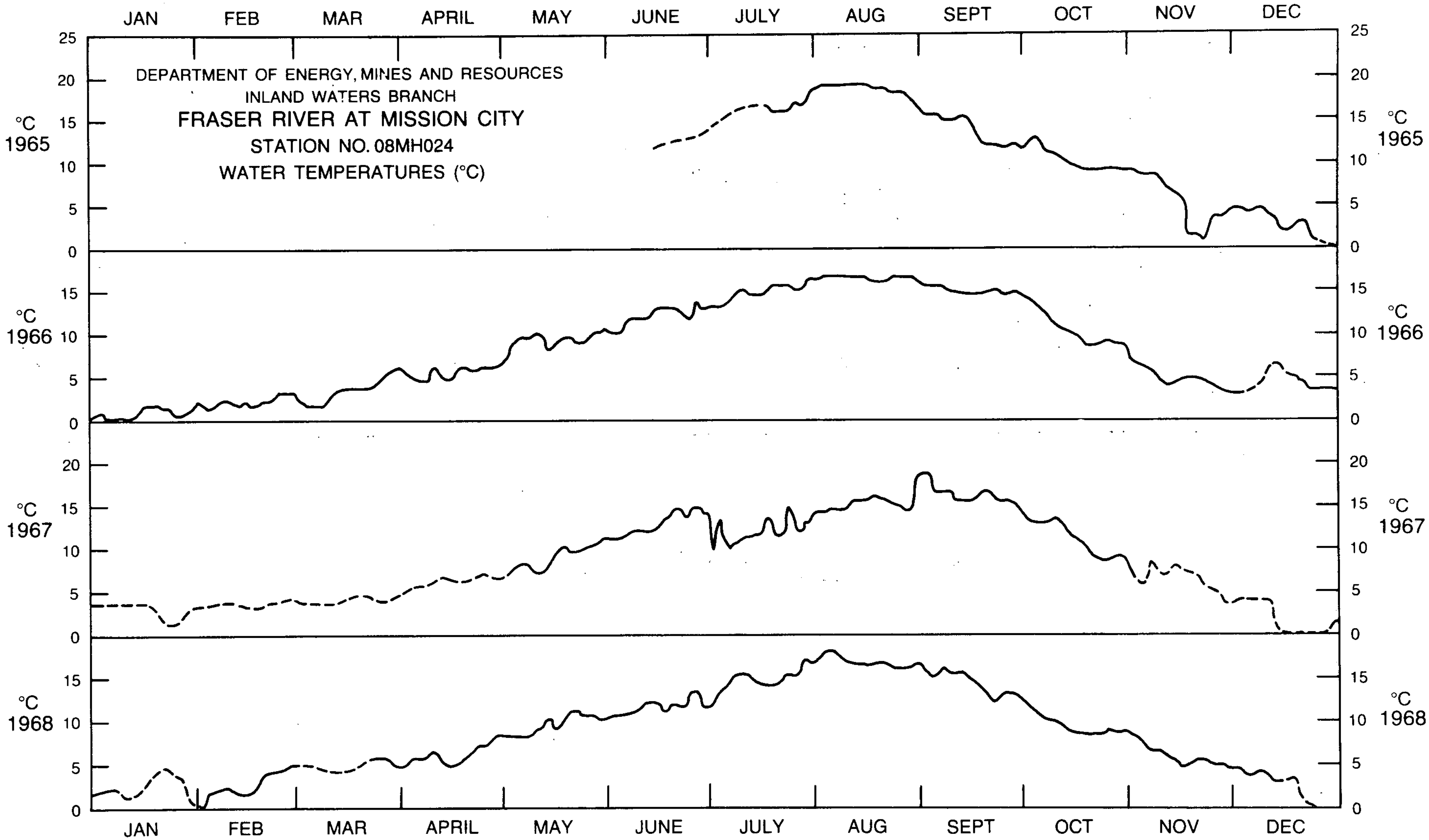

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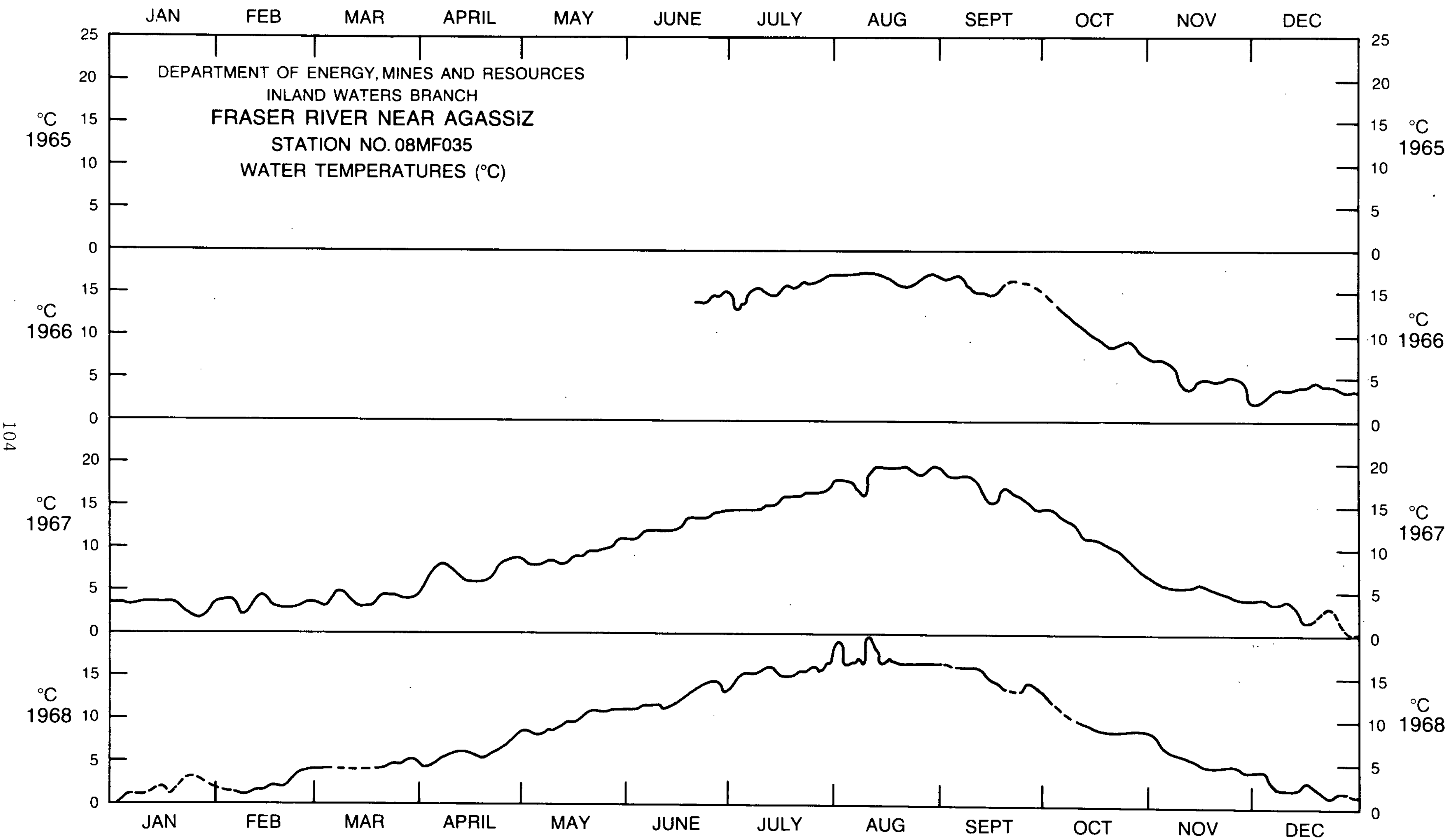
DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

FRASER RIVER NEAR AGASSIZ

STATION NO. 08MF035

WATER TEMPERATURES (°C)



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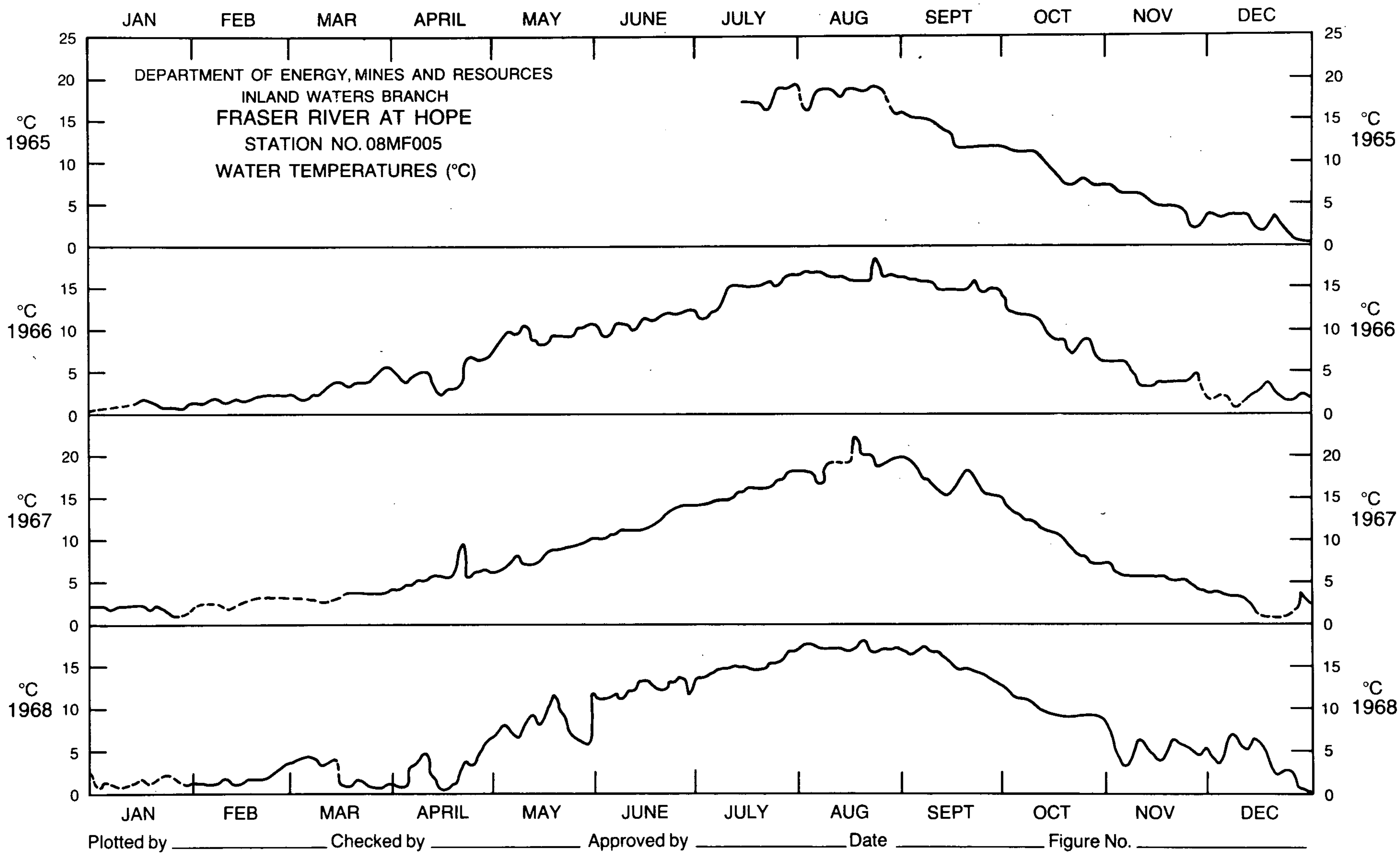
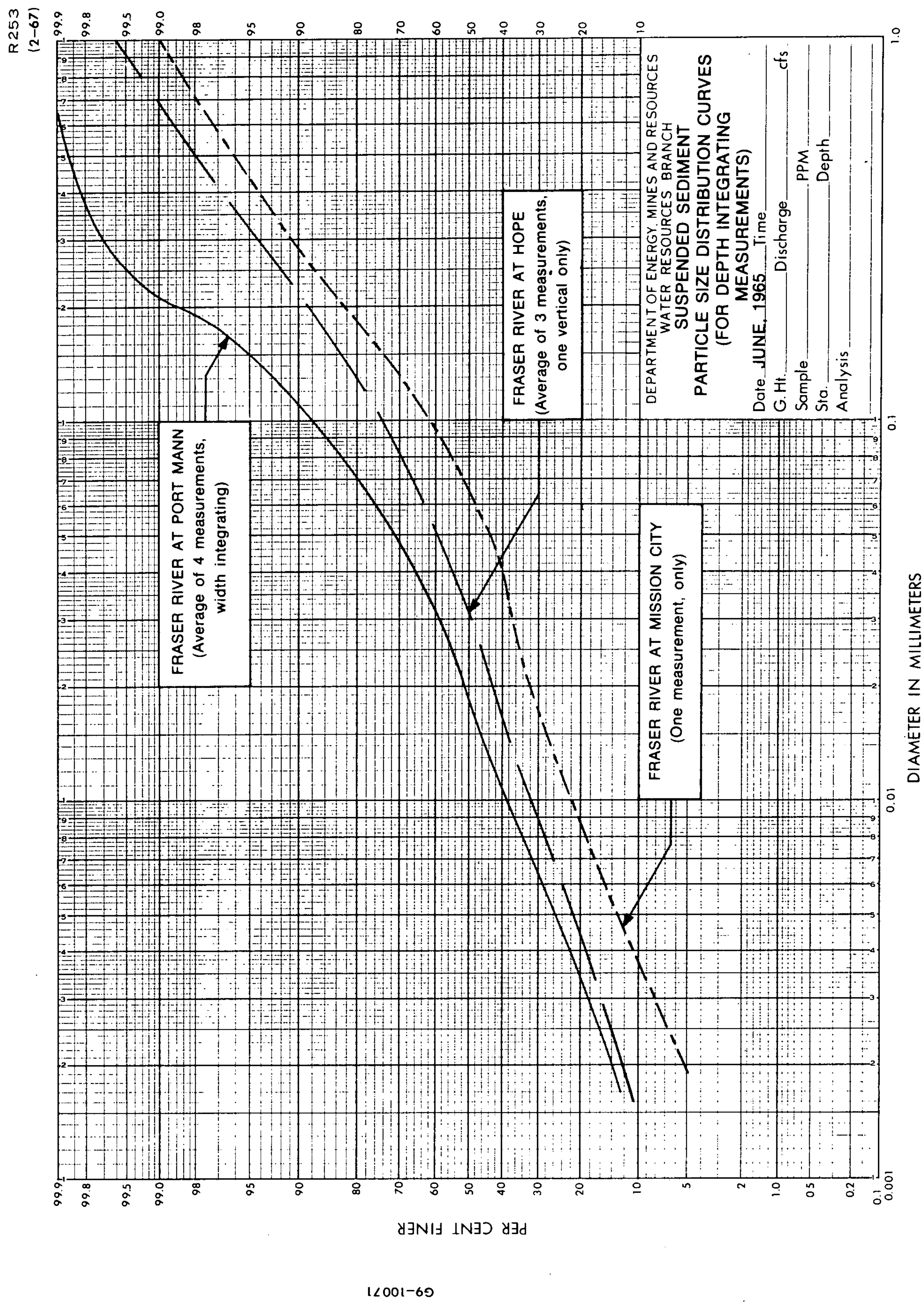
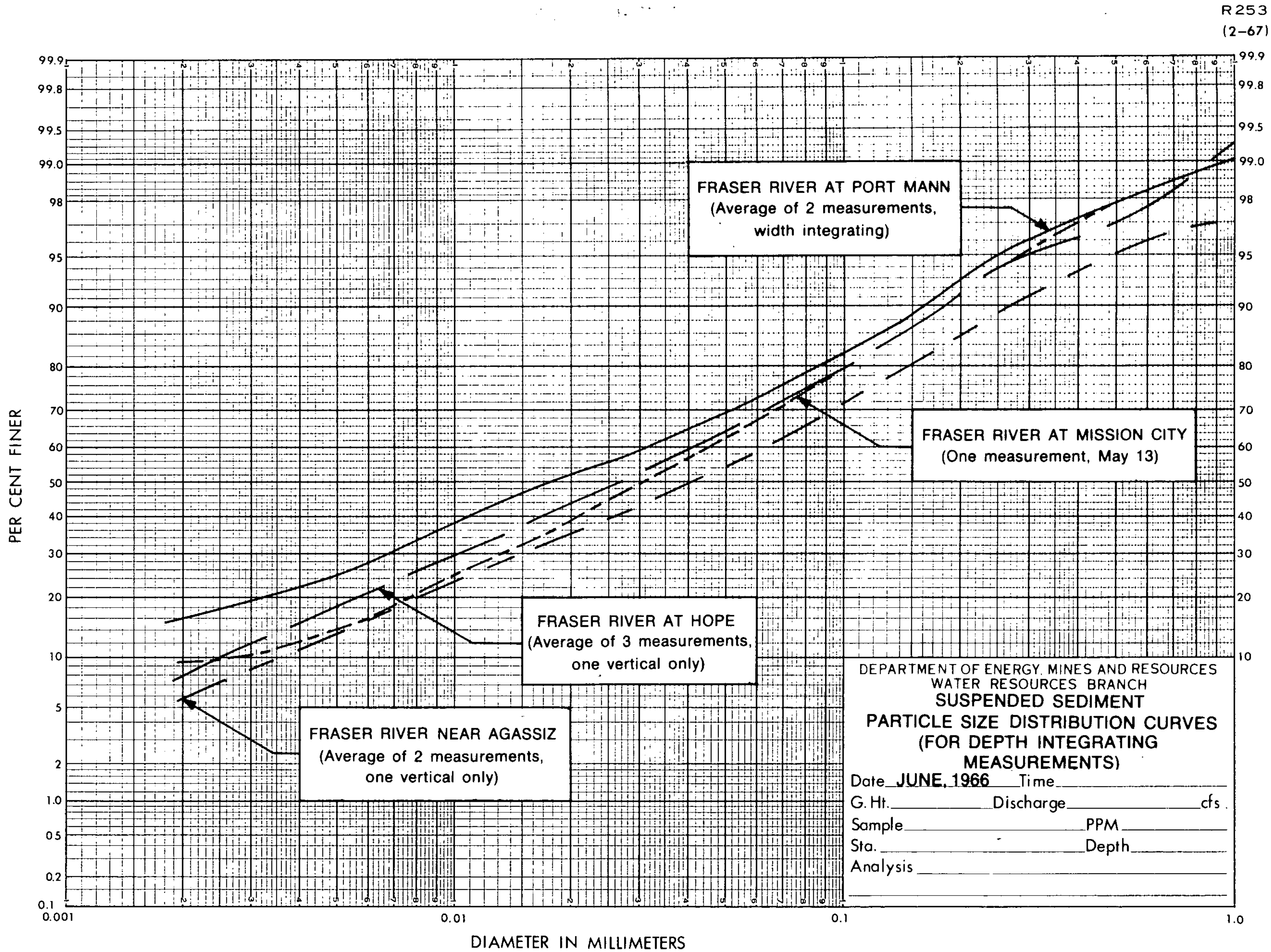

DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH
FRASER RIVER AT HOPE
STATION NO. 08MF005
WATER TEMPERATURES (°C)
JAN
FEB
MAR
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
°C 1965
°C 1966
°C 1967
°C 1968
0
5
10
15
20
25
Plotted by
Checked by
Approved by
Date
Figure No.

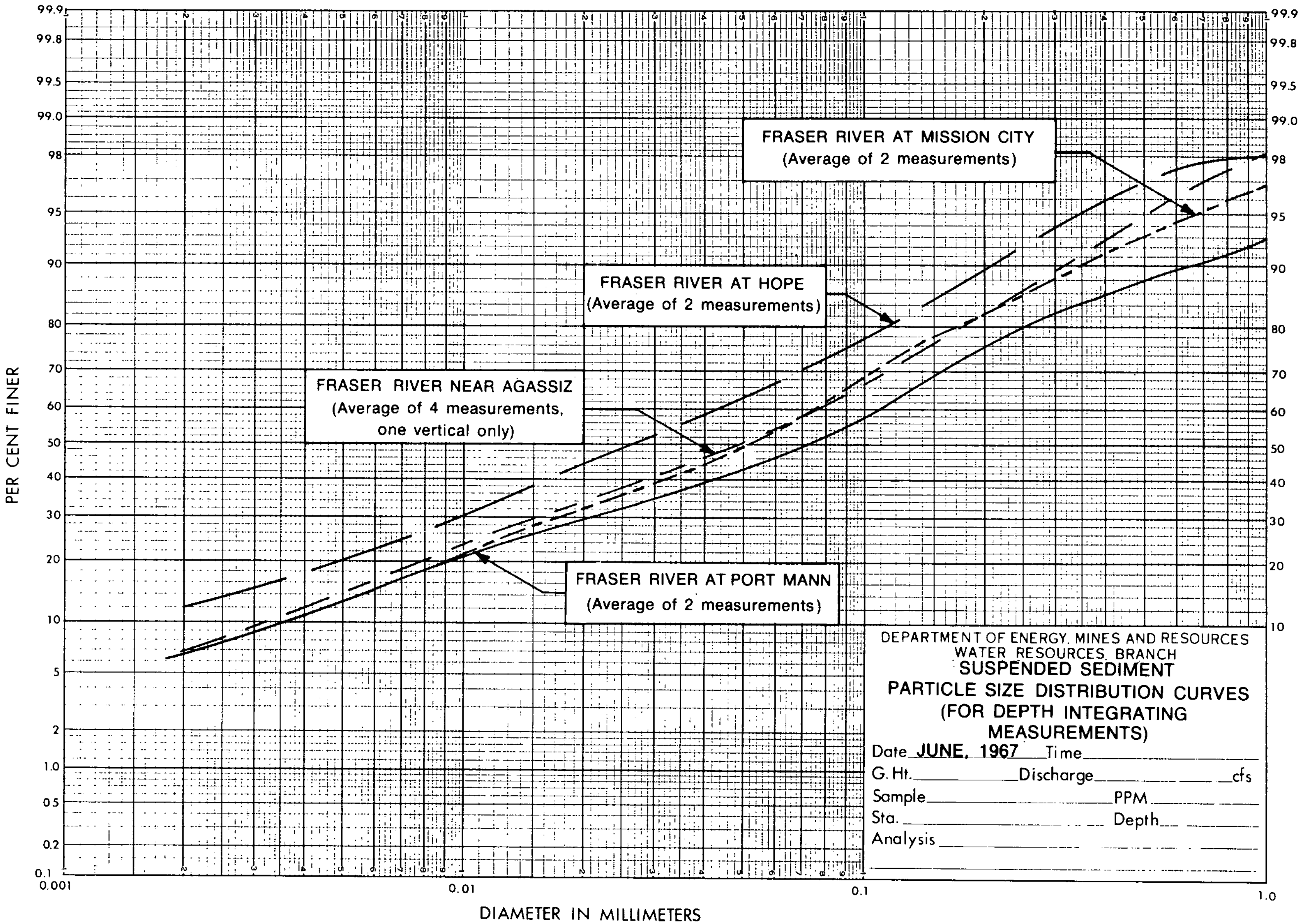


R253
(2-67)
FRASER RIVER AT PORT MANN
(Average of 4 measurements, width integrating)
FRASER RIVER AT HOPE
(Average of 3 measurements, one vertical only)
FRASER RIVER AT MISSION CITY
(One measurement, only)
DEPARTMENT OF ENERGY, MINES AND RESOURCES
WATER RESOURCES BRANCH
SUSPENDED SEDIMENT
PARTICLE SIZE DISTRIBUTION CURVES
(FOR DEPTH INTEGRATING
MEASUREMENTS)
Date JUNE, 1965 Time
G.Ht. Discharge cfs
Sample PPM
Sta. Depth
Analysis
0.001
0.01
0.1
1.0
DIAMETER IN MILLIMETERS
99.9 99.8 99.5 99.0 98 95 90 80 70 60 50 40 30 20 10 5 2 1.0 0.5 0.2 0.1
PER CENT FINER
G9-10071


R253
(2-67)
FRASER RIVER AT PORT MANN
(Average of 2 measurements, width integrating)
FRASER RIVER AT MISSION CITY
(One measurement, May 13)
FRASER RIVER AT HOPE
(Average of 3 measurements, one vertical only)
FRASER RIVER NEAR AGASSIZ
(Average of 2 measurements, one vertical only)
DEPARTMENT OF ENERGY, MINES AND RESOURCES
WATER RESOURCES BRANCH
SUSPENDED SEDIMENT
PARTICLE SIZE DISTRIBUTION CURVES
(FOR DEPTH INTEGRATING MEASUREMENTS)
Date JUNE, 1966 Time
G. Ht. Discharge cfs.
Sample PPM
Sta. Depth
Analysis
PER CENT FINER
DIAMETER IN MILLIMETERS
0.001
0.01
0.1
1.0
99.9
99.8
99.5
99.0
98
95
90
80
70
60
50
40
30
20
10
5
2
1.0
0.5
0.2
0.1

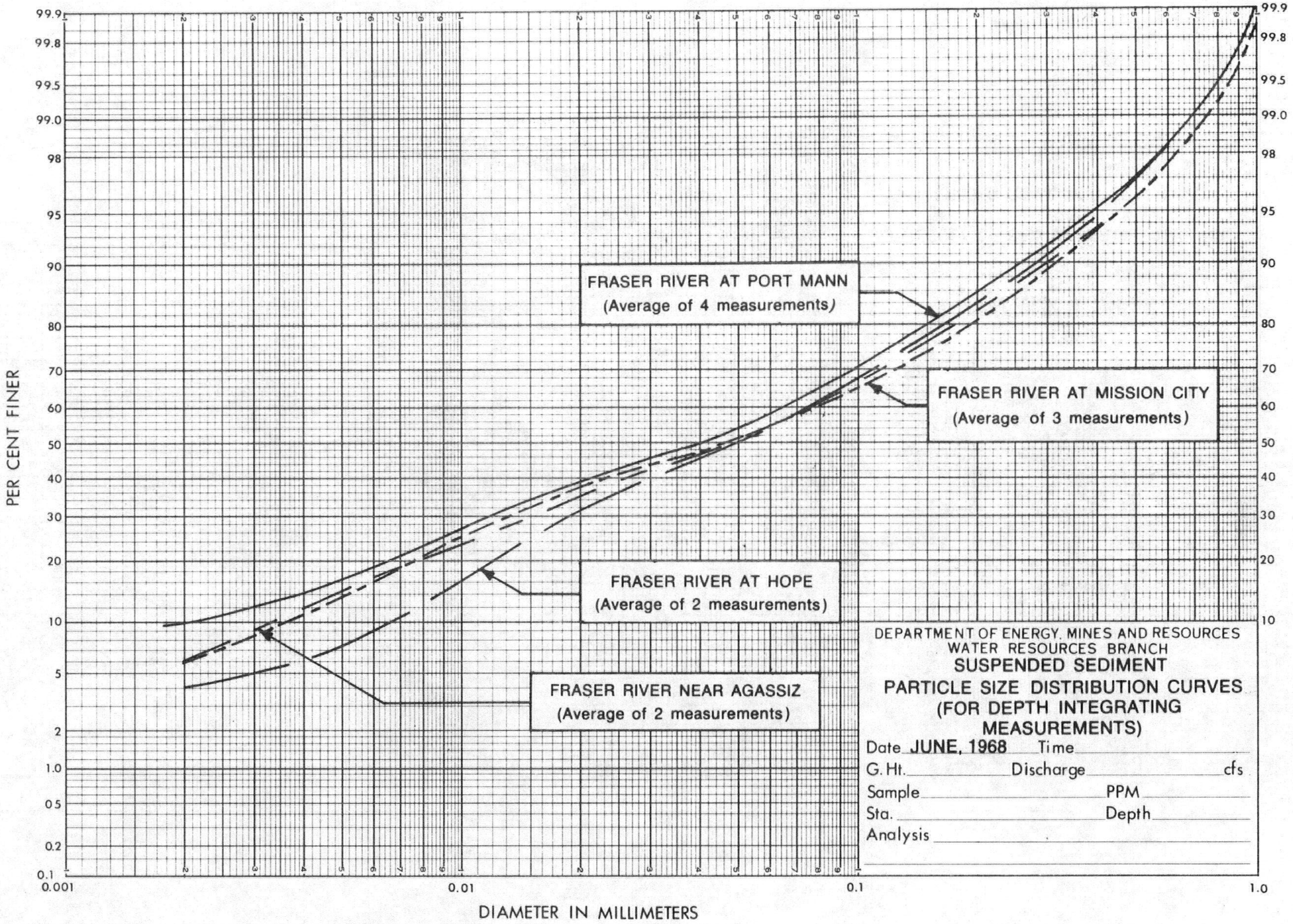
G9-10071

R253
(2-67)



G9-10071

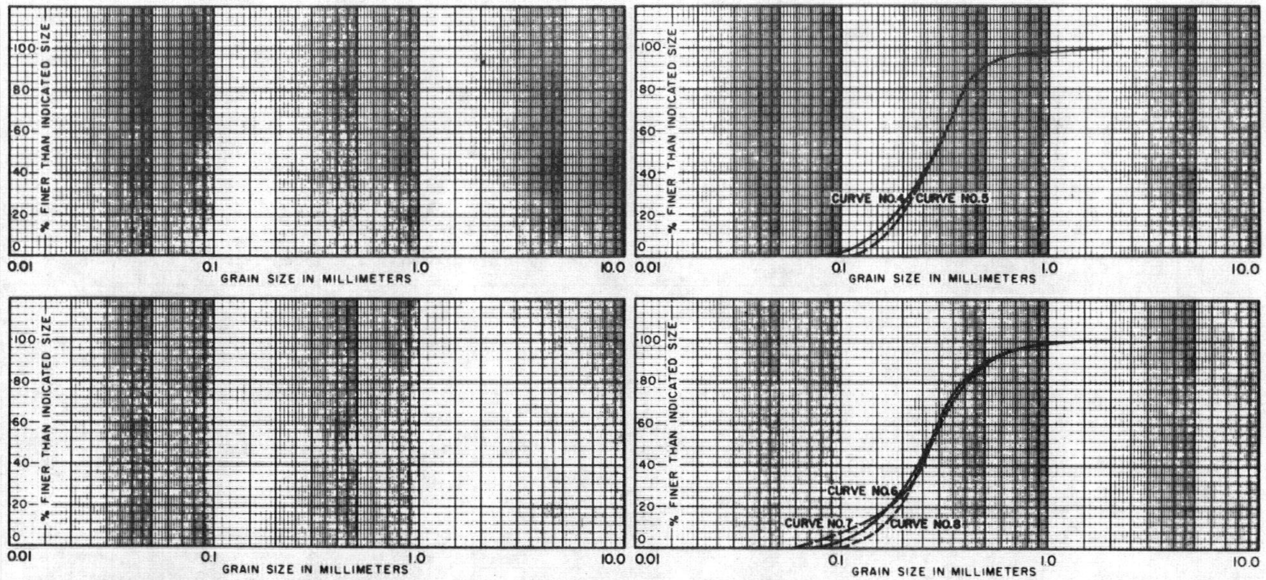
R253
(2-67)

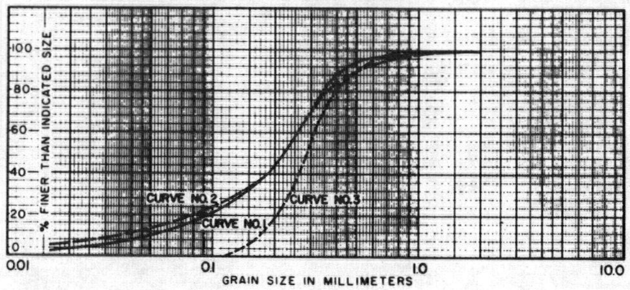


G9-10071

CURVE NO.	MONTH	NO. OF SAMPLES *	NO. OF SAMPLED POINTS IN X - SEC.	PERCENTAGE FINER THAN INDICATED SIZE								
				4.000	2.000	1.000	0.500	0.250	0.125	0.062	0.031	0.016
1	JUNE	7	7		100	99	94	58	26	12	6	3
2	JULY	7	7		100	98	90	58	29	16	9	6
3	JULY	6	3		100	99	92	36	2	0		
4	AUG	10	5		100	98	92	42	5	0		
5	SEPT	20	5		100	98	92	37	3	0		
6	OCT	10	5		100	99	93	44	8	1	0	
7	NOV	10	5		100	99	93	41	10	1	0	
8	DEC	15	5		100	99	95	45	4	0		

NOTE * AVERAGE PARTICLE SIZE USED





DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

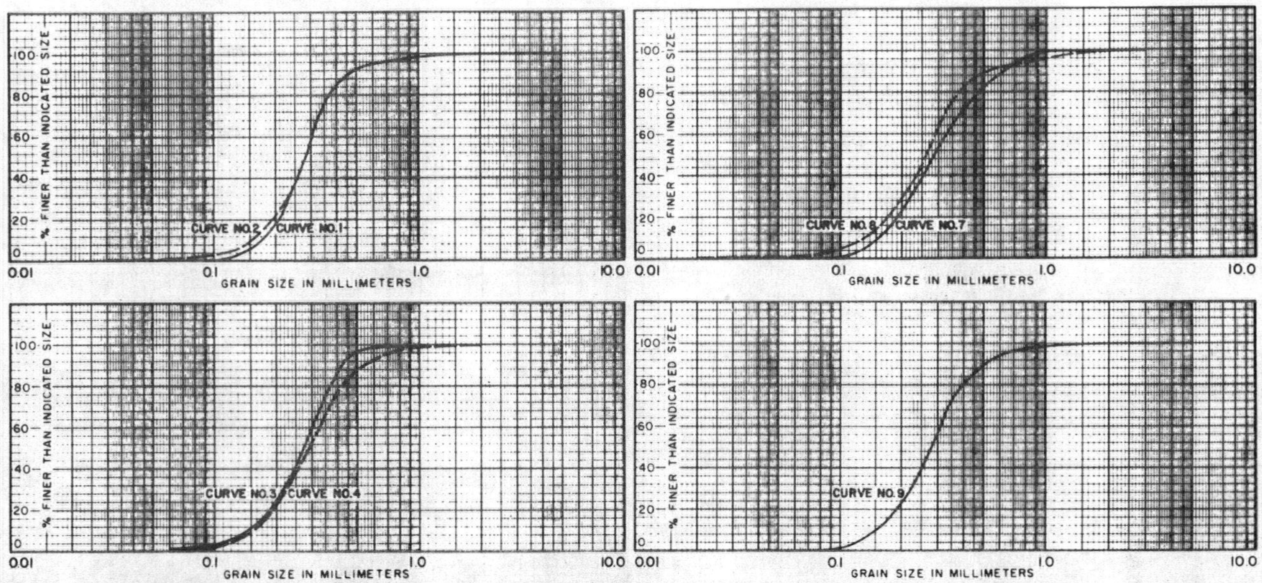
LOWER FRASER RIVER SEDIMENT SURVEY

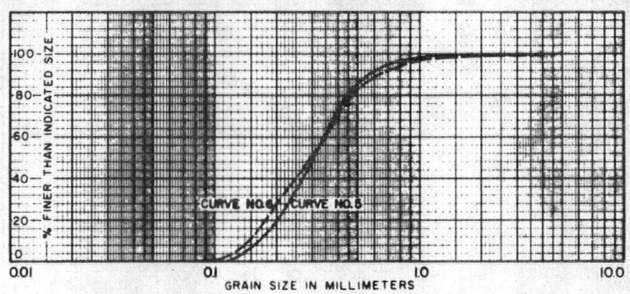
RESULT OF BED MATERIAL ANALYSIS 1965
FRASER RIVER AT PORT MANN

PREPARED BY:________ CKD. BY:________ FILE Nº:________
DATE:________ FIGURE Nº:________

CURVE NO	MONTH	NO. OF SAMPLES *	NO. OF SAMPLED POINTS IN X - SEC.	PERCENTAGE FINER THAN INDICATED SIZE								
				4.000	2.000	1.000	0.500	0.250	0.125	0.062	0.031	0.016
1	FEB	15	5		100	99	94	39	4	0	0	
2	MAR	20	5	100	100	98	92	39	6	0	0	
3	APR	10	5		100	99	92	37	5	1	0	
4	MAY	15	5		100	99	97	43	7	0	0	
5	JUNE	20	5	100	100	99	92	36	2	0		
6	JULY	5	5	100	99	98	91	42	3	0		
7	AUG	19	5	100	100	99	83	37	4	0	0	
8	SEPT	25	5	100	100	97	90	46	10	0	0	0
9	OCT	20	5	100	100	98	91	40	5	0	0	

NOTE * AVERAGE PARTICLE SIZE USED





DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

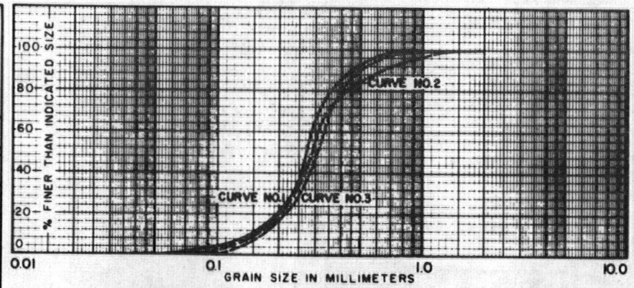
LOWER FRASER RIVER SEDIMENT SURVEY

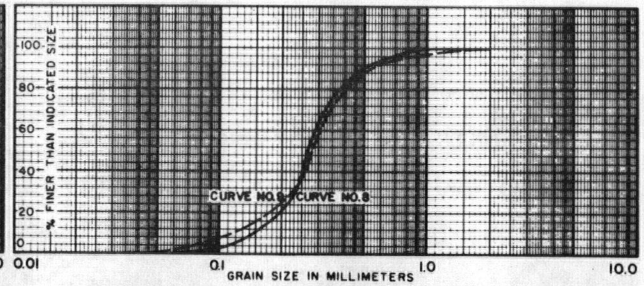
RESULT OF BED MATERIAL ANALYSIS
1966
FRASER RIVER AT PORT MANN

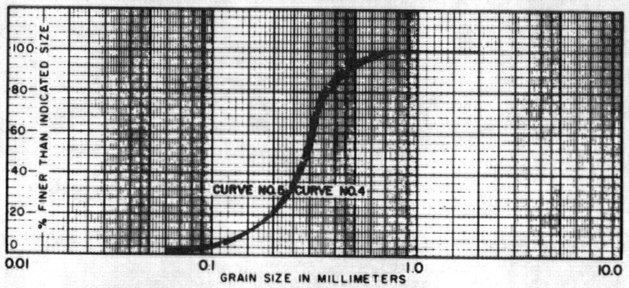
PREPARED BY: ___________ CKD BY __________ FILE Nº __________
DATE __________ FIGURE Nº __________

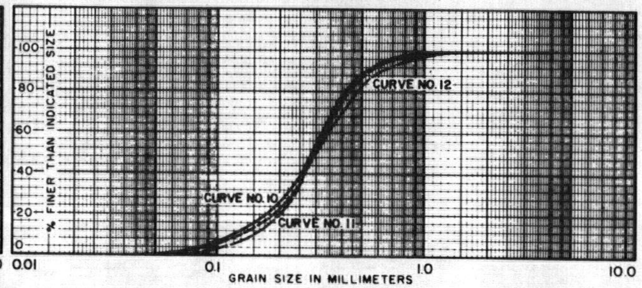
CURVE NO.	MONTH	NO. OF SAMPLES *	NO. OF SAMPLED POINTS IN X - SEC.	PERCENTAGE FINER THAN INDICATED SIZE								
				4.000	2.000	1.000	0.500	0.250	0.125	0.062	0.031	0.016
1	JAN	10	5	100	100	99	94	36	8	2	0	
2	FEB	10	5		100	98	87	35	6	0	0	
3	MAR	9	5	99	99	98	92	32	4	0	0	
4	APR	15	5		100	100	94	35	8	2	0	
5	MAY	19	5		100	100	95	36	6	0	0	
6	JUNE	20	5	100	100	100	97	47	11	2	0	
7	JULY	12	5	99	99	97	89	38	4	0		
8	AUG	10	5			100	89	40	6	0	0	
9	SEPT	15	5		100	98	88	38	12	3	0	
10	OCT	20	5		100	99	89	40	11	1	0	
11	NOV	20	5		100	99	88	36	6	0		
12	DEC	10	5	100	99	97	84	36	9	1	0	

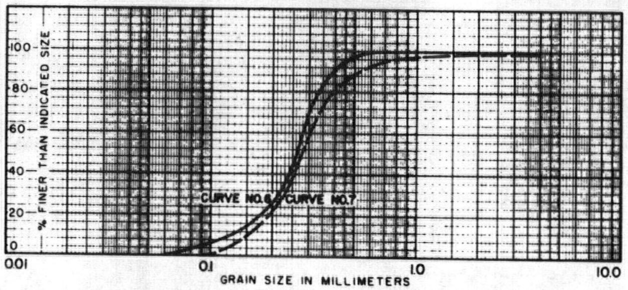
NOTE * AVERAGE PARTICLE SIZE USED











DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

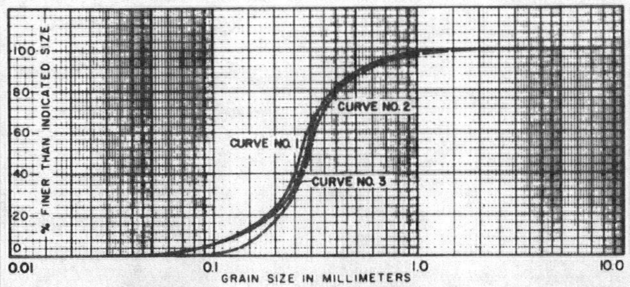
LOWER FRASER RIVER SEDIMENT SURVEY

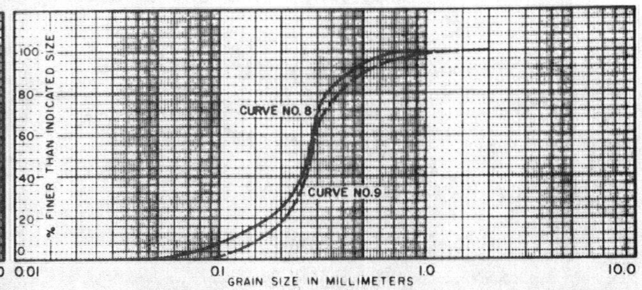
RESULT OF BED MATERIAL ANALYSIS
1967
FRASER RIVER AT PORT MANN

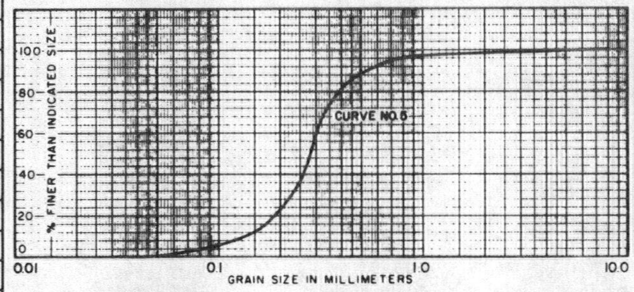
PREPARED BY:__________ CKD BY:__________ FILE No:__________
DATE:__________ FIGURE No:__________

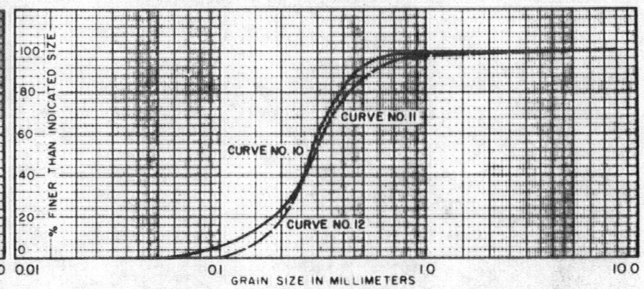
CURVE NO	MONTH	NO. OF SAMPLES *	NO OF SAMPLED POINTS IN X - SEC.	PERCENTAGE FINER THAN INDICATED SIZE								
				4000	2000	1000	0.500	0.250	0.125	0.062	0.031	0.016
1	JAN	10	5		100	99	89	39	9	1	0	
2	FEB	10	5	99	99	98	87	30	3	0		
3	MAR	20	5		100	98	89	34	9	1	0	
4	APR	0										
5	MAY	10	5	99	98	96	88	35	8	1	0	
6	JUNE	5	5	100	99	98	90	38	3	0		
7	JULY	5	5	99	98	96	85	37	6	0		
8	AUG	10	5		100	99	95	36	12	1	0	
9	SEPT	20	5		100	98	90	35	5	0		
10	OCT	10	5		100	98	93	38	9	1	0	
11	NOV	10	5	98	98	97	93	39	3	0		
12	DEC	10	5	100	98	97	89	35	3	0		

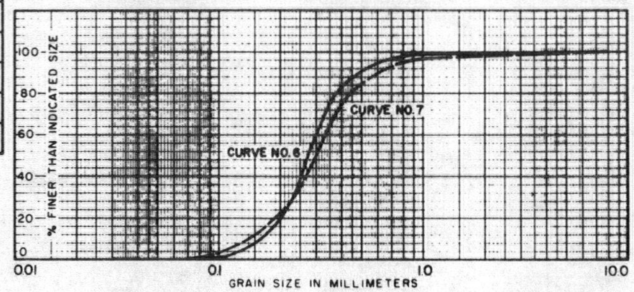
NOTE * AVERAGE PARTICLE SIZE USED











DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

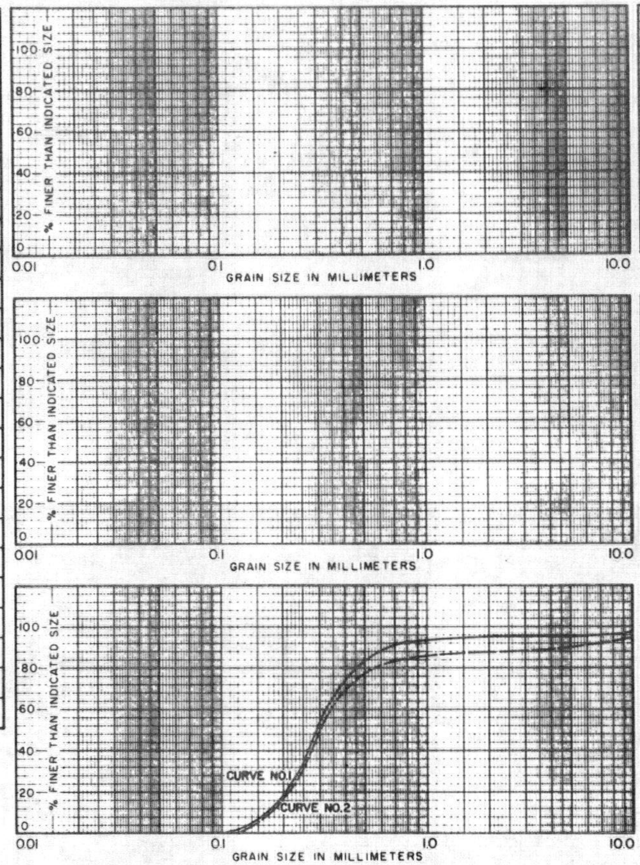
LOWER FRASER RIVER SEDIMENT SURVEY

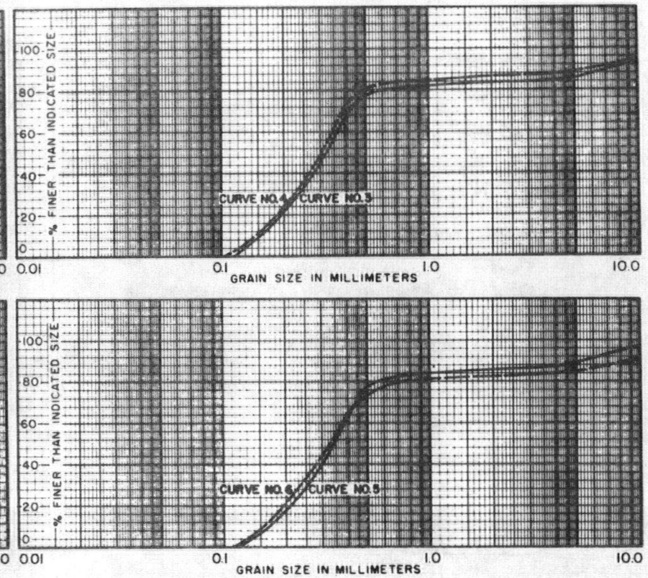
RESULT OF BED MATERIAL ANALYSIS
1968
FRASER RIVER AT PORT MANN

PREPARED BY: ____ CKD BY: ____ FILE No: ____
DATE ____ FIGURE No: ____

CURVE NO.	MONTH	NO. OF SAMPLES *	NO. OF SAMPLED POINTS IN X - SEC.	PERCENTAGE FINER THAN INDICATED SIZE								
				16.000	8.000	4.000	2.000	1.000	.500	.250	.125	.062
1	JUNE	14	14	100	96	95	94	93	84	30	2	0
2	JULY	20	5	100	92	89	87	86	79	29	1	0
3	AUG	15	5	100	92	87	85	84	79	33	3	0
4	SEPT	5	5	100	92	88	86	85	81	34	4	0
5	NOV	5	5	97	93	87	86	84	78	30	3	0
6	DEC	5	5	95	88	84	83	82	75	32	3	0

NOTE * AVERAGE PARTICLE SIZE USED





DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

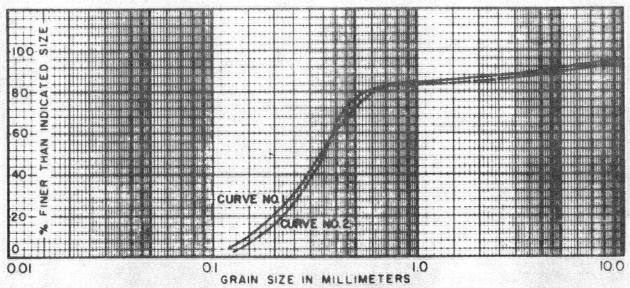
LOWER FRASER RIVER SEDIMENT SURVEY

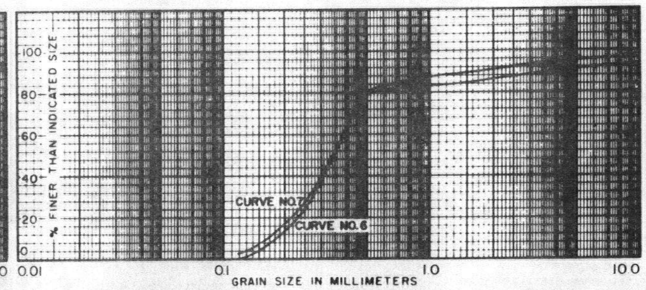
RESULT OF BED MATERIAL ANALYSIS 1965 FRASER RIVER AT MISSION CITY

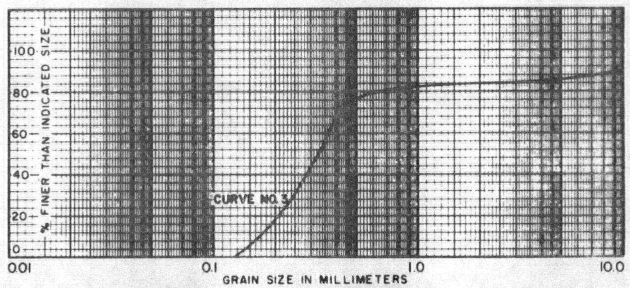
PREPARED BY:___________ CKD BY:__________ FILE NO:___________
DATE:__________ FIGURE NO:___________

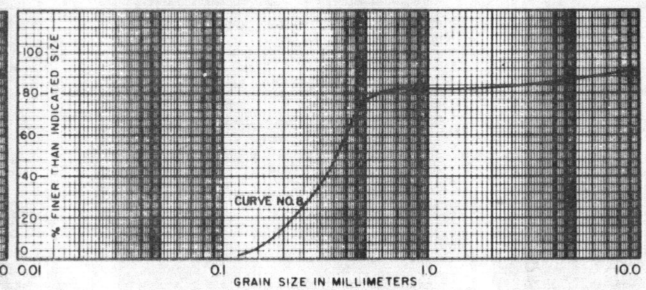
CURVE NO	MONTH	NO. OF SAMPLES *	NO. OF SAMPLED POINTS IN X - SEC.	PERCENTAGE FINER THAN INDICATED SIZE								
				16,000	8.000	4.000	2.000	1.000	.500	.250	.125	.062
1	JAN	5	5	96	93	89	86	84	73	30	5	2
2	MAR	5	5	95	90	86	85	84	78	25	4	1
3	MAY	10	5	93	88	85	84	83	77	31	1	0
4	JUNE	10	5	98	97	94	93	91	84	25	1	0
5	JULY	5	5	100	90	87	86	84	72	20	0	0
6	AUG	5	5	100	94	90	88	86	80	26	1	0
7	SEPT	10	5	95	92	88	85	83	80	27	4	0
8	OCT	10	5	100	89	85	83	81	76	25	3	0

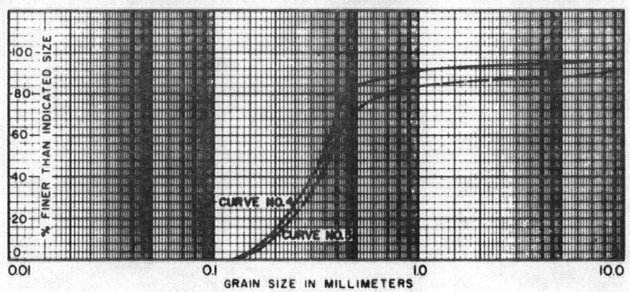
NOTE * AVERAGE PARTICLE SIZE USED











DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

LOWER FRASER RIVER SEDIMENT SURVEY

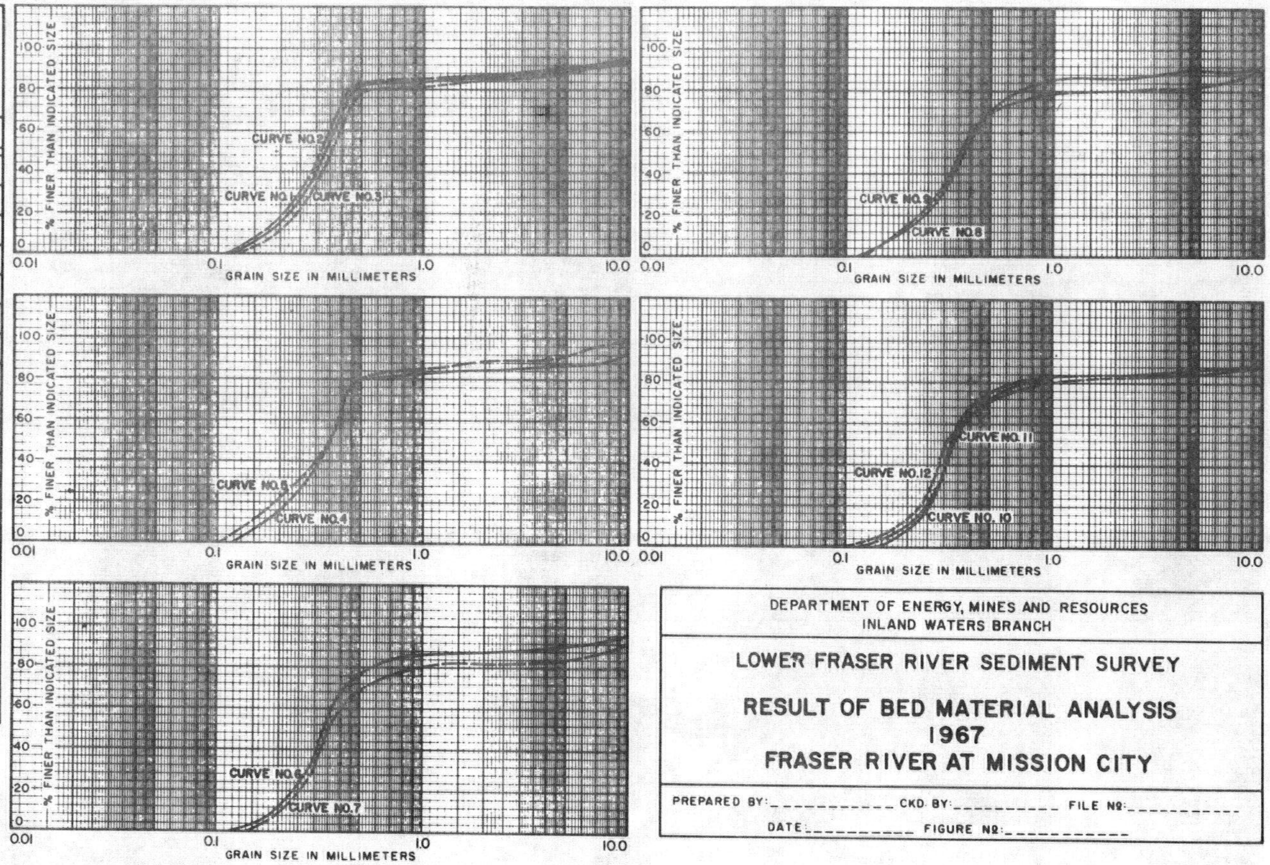
RESULT OF BED MATERIAL ANALYSIS
1966
FRASER RIVER AT MISSION CITY

PREPARED BY:__________ CKD BY:__________ FILE Nº:__________

DATE:__________ FIGURE Nº:__________

CURVE NO.	MONTH	NO. OF SAMPLES *	NO. OF SAMPLED POINTS IN X - SEC	PERCENTAGE FINER THAN INDICATED SIZE								
				16.000	8.000	4.000	2.000	1.000	.500	.250	.125	.062
1	JAN	5	5	100	91	88	86	84	82	27	3	0
2	FEB	10	5	100	93	89	87	85	82	30	4	0
3	MAR	5	5	100	90	86	85	83	79	23	2	0
4	APR	5	5	100	89	86	84	83	80	27	3	1
5	MAY	15	5	100	97	90	88	85	80	30	4	1
6	JUNE	15	5	100	93	91	87	86	77	23	1	0
7	JULY	10	5	100	88	82	81	80	69	18	1	0
8	AUG	5	5	100	90	87	86	86	71	22	2	0
9	SEPT	10	5	100	87	82	80	79	69	24	2	0
10	OCT	5	5	100	89	85	84	83	75	20	2	0
11	NOV	10	5	100	88	85	84	83	72	23	3	0
12	DEC	5	5	100	87	84	83	82	71	27	5	0

NOTE * AVERAGE PARTICLE SIZE USED



DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

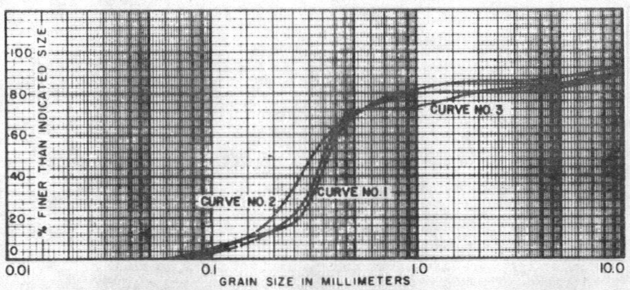
LOWER FRASER RIVER SEDIMENT SURVEY

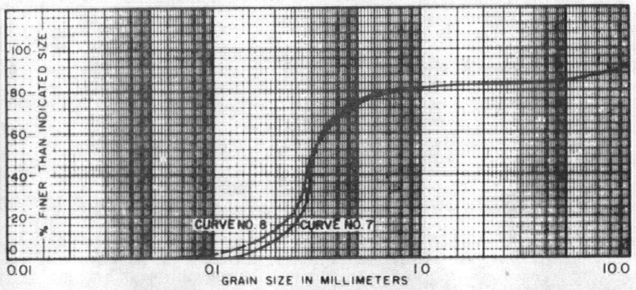
RESULT OF BED MATERIAL ANALYSIS
1967
FRASER RIVER AT MISSION CITY

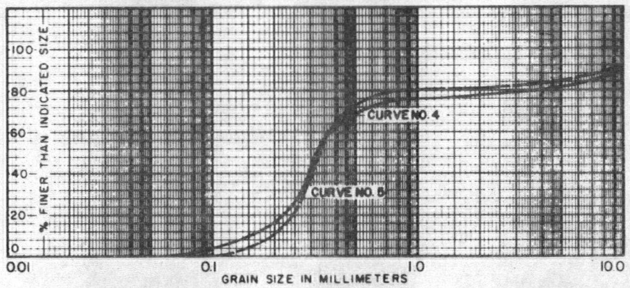
PREPARED BY:________ CKD. BY:________ FILE NO:________
DATE:________ FIGURE NO:________

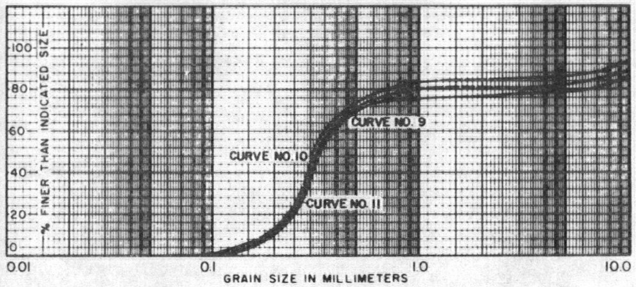
CURVE NO.	MONTH	NO. OF SAMPLES *	NO. OF SAMPLED POINTS IN X - SEC.	PERCENTAGE FINER THAN INDICATED SIZE								
				16,000	8,000	4,000	2,000	1,000	.500	.250	.125	.062
1	JAN	10	5	100	90	86	85	82	69	18	8	0
2	FEB	10	5	100	86	82	80	79	70	34	7	0
3	MAR	5	5	100	86	81	80	73	71	21	6	0
4	APR	10	5	99	84	79	78	76	69	26	6	0
5	MAY	5	5	97	86	82	82	81	74	21	2	0
6	JUN	5	5	100	89	84	83	82	77	26	0	0
7	AUG	5	5	100	87	83	82	81	76	17	0	0
8	SEPT	15	5	100	88	84	83	82	75	24	4	0
9	OCT	10	5	100	82	78	77	75	70	20	1	0
10	NOV	10	5	100	90	85	85	83	74	24	3	0
11	DEC	5	5	100	85	83	81	80	71	22	2	0

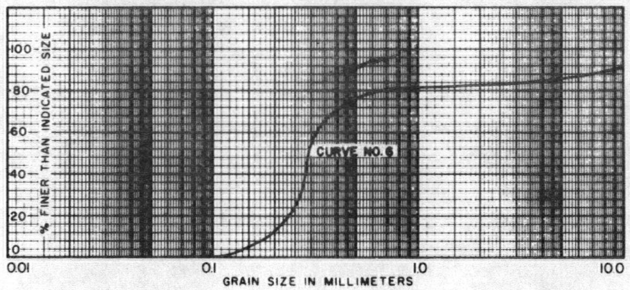
NOTE * AVERAGE PARTICLE SIZE USED











DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

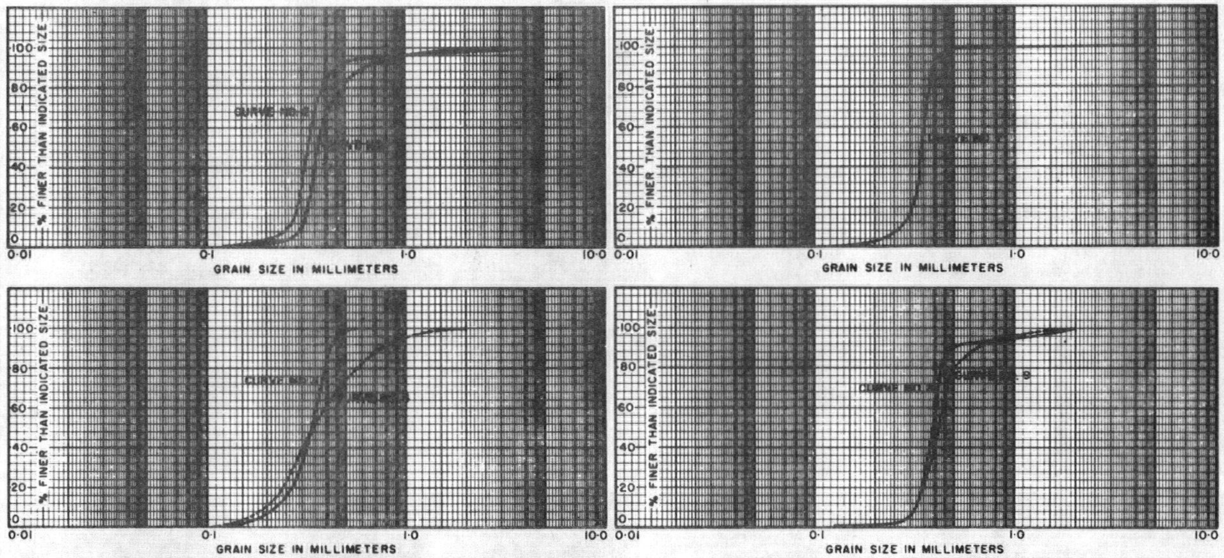
LOWER FRASER RIVER SEDIMENT SURVEY

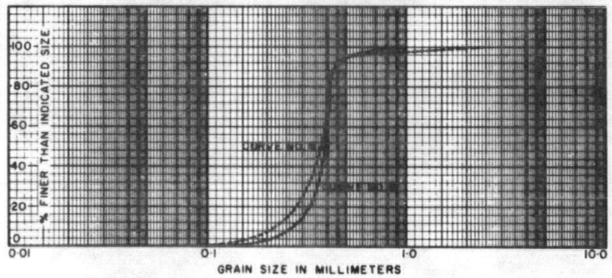
RESULT OF BED MATERIAL ANALYSIS 1968 FRASER RIVER AT MISSION CITY

PREPARED BY:__________ CKD BY:__________ FILE Nº:__________
DATE__________ FIGURE Nº:__________

CURVE NO	DATE	NO OF SAMPLES*	NO OF SAMPLED POINTS IN X - SEC.	PERCENTAGE FINER THAN INDICATED SIZE								
				16.000	8.000	4.000	2.000	1.000	.500	.250	.125	.062
1	JUNE 16	1	1		100	99	98	96	83	4	1	0
2	JULY 19	1	1		100	99	97	96	93	9	1	0
3	AUG. 16	1	1					100	99	16	0	0
4	AUG. 16	4	4				100	96	74	23	1	0
5	SEPT. 17	1	1					100	95	8	0	
6	OCT. 13	1	1			100	99	97	95	14	1	0
7	NOV. 15	1	1			100	99	99	98	7	0	0
8	DEC. 12	1	1				100	94	90	1	0	
9	DEC. 12	4	4				100	96	79	1	0	

NOTE • AVERAGE PARTICLE SIZE USED
ARNHEM TYPE SAMPLER USED





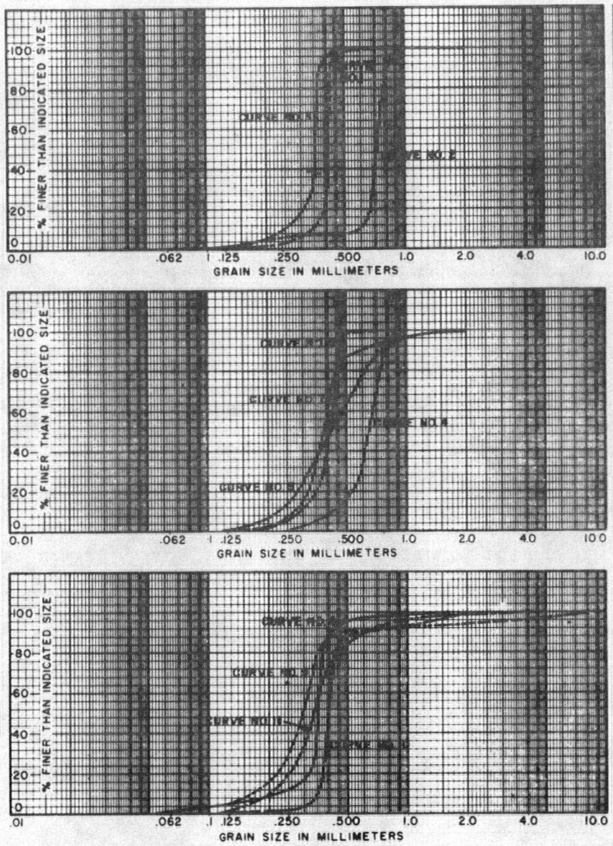
DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

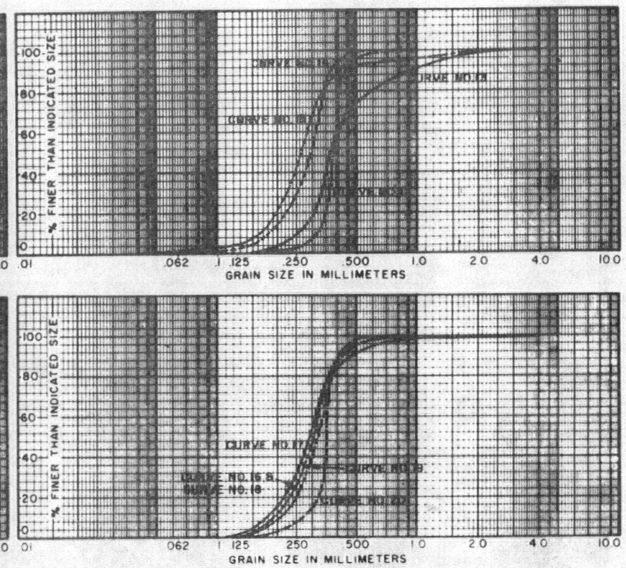
LOWER FRASER RIVER SEDIMENT SURVEY
BED LOAD PARTICLE SIZE DISTRIBUTION
1965
FRASER RIVER AT PORT MANN

PREPARED BY: ____________ CKD. BY: ____________ FILE Nº: ____________
DATE: ____________ FIGURE Nº: ____________

CURVE NO	DATE	NO OF SAMPLES*	NO OF SAMPLED POINTS IN X - SEC	PERCENTAGE FINER THAN INDICATED SIZE								
				16.000	8.000	4.000	2.000	1.000	.500	.250	.125	.062
1	JAN 12	1	1				100	99	98	3	0	0
2	JAN 12	4	4				100	99	8	6	0	0
3	FEB 9	2	1						100	10	0	0
4	MAR 11	1	1					100	17	1	0	0
5	MAR 11	5	5			100	99	97	64	14	0	0
6	ARR 12	1	1					100	99	6	0	0
7	APR 12	10	5				100	97	86	15	0	0
8	MAY 16	1	1				100	98	96	12	5	2
9	MAY 16	5	5				100	93	89	29	5	1
10	JUNE 14	1	1		100	98	96	93	87	2	0	0
11	JUNE 14	4	1			100	99	96	84	19	1	0
12	JULY 12	2	1				100	96	93	3	0	0
13	JULY 12	9	4			100	99	91	74	9	0	0
14	AUG 15	1	1					100	99	29	2	0
15	AUG 15	5	5				100	99	96	43	4	1
16	SEPT 15	1	1					100	99	26	0	0
17	SEPT 15	4	4			100	99	99	92	32	1	0
18	OCT 14	1	1					100	98	27	0	
19	NOV 15	1	1					100	99	20	0	
20	DEC 21							100	96	8	0	

NOTE * AVERAGE PARTICLE SIZE USED
ARNHEM TYPE SAMPLER USED





DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

LOWER FRASER RIVER SEDIMENT SURVEY

BED LOAD PARTICLE SIZE DISTRIBUTION

1966

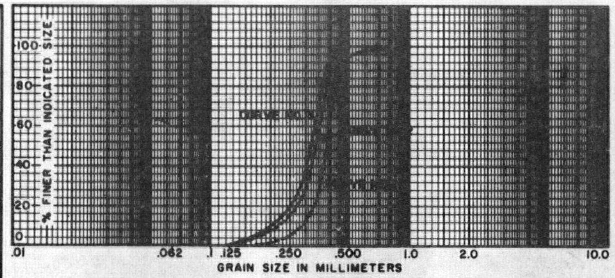
FRASER RIVER AT PORT MANN

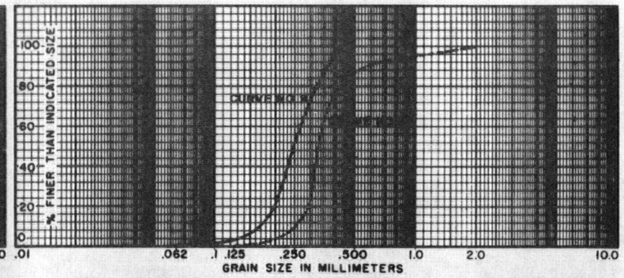
PREPARED BY: ___________ CKD BY: ___________ FILE Nº ___________

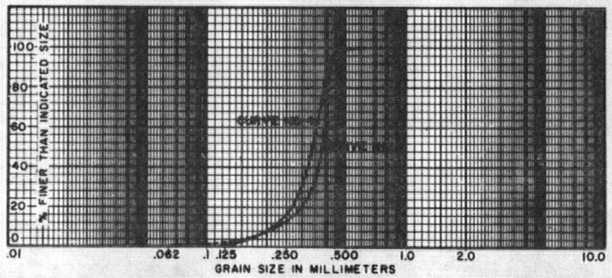
DATE ___________ FIGURE Nº ___________

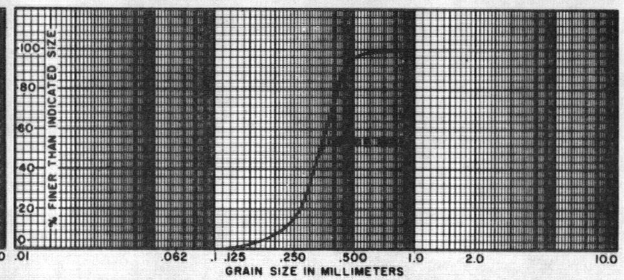
CURVE NO.	DATE	NO. OF SAMPLES*	NO. OF SAMPLED POINTS IN X-SEC.	PERCENTAGE FINER THAN INDICATED SIZE								
				16.000	8.000	4.000	2.000	1.000	.500	.250	.125	.062
1	JAN 13	1	1					100	95	6	0	
2	FEB 16	1	1					100	99	15	0	
3	MAR 16	1	1					100	99	20	0	
4	APR 14	1	1					100	99	16	0	0
5	MAY 15	1	1					100	99	13	1	0
6	JUNE 13	1	1					100	93	5	1	0
7	JUNE 13	4	4					100	93	20	2	0
8	JULY 14	1	1				100	95	86	9	0	0
9	AUG 14	1	1						100	51	3	0
10	SEPT 13	1	1					100	96	16	0	0

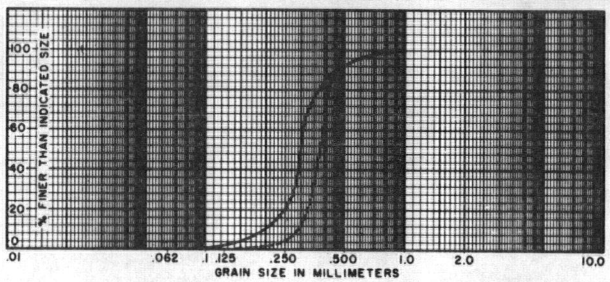
NOTE * AVERAGE PARTICLE SIZE USED
ARNHEM TYPE SAMPLER USED











DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

LOWER FRASER RIVER SEDIMENT SURVEY

BED LOAD PARTICLE SIZE DISTRIBUTION

1967

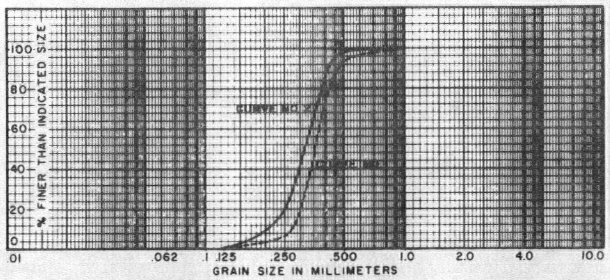
FRASER RIVER AT PORT MANN

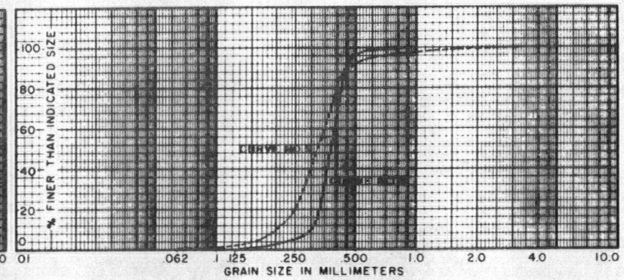
PREPARED BY:__________ CKD. BY:__________ FILE No:__________

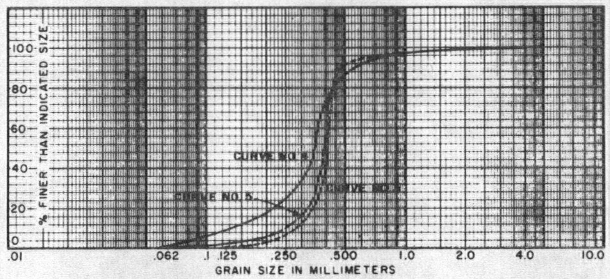
DATE:__________ FIGURE No:__________

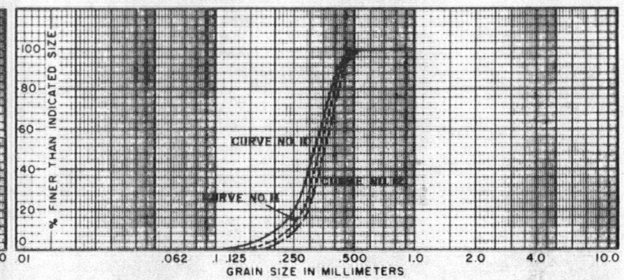
CURVE NO	DATE	NO OF SAMPLES*	NO OF SAMPLED POINTS IN X - SEC	PERCENTAGE FINER THAN INDICATED SIZE								
				16000	8000	4000	2000	1000	500	250	125	062
1	MAR 15	1	1					100	93	9	0	
2	APR 16	1	1					100	97	19	0	
3	MAY 24	1	1				100	99	90	6	1	0
4	MAY 24	5	5			100	99	98	86	24	9	1
5	JAN 13	10	1			100	99	97	91	10	2	0
6	JULY 18	2	1		100	99	99	99	97	12	1	0
7	JULY 18	8	4			100	99	98	91	19	1	0
8	AUG 15	1	1					100	96	5	0	0
9	AUG 15	4	4			100	99	98	92	20	1	0
10	SEPT 23	1	1					100	99	18	0	
11	OCT 24	1	1					100	98	12	0	
12	NOV 8	1	1					100	98	8	0	

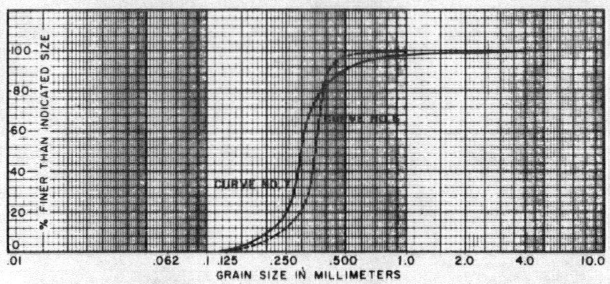
NOTE * AVERAGE PARTICLE SIZE USED
ARNHEM TYPE SAMPLER USED











DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

LOWER FRASER RIVER SEDIMENT SURVEY

BED LOAD PARTICLE SIZE DISTRIBUTION

1968

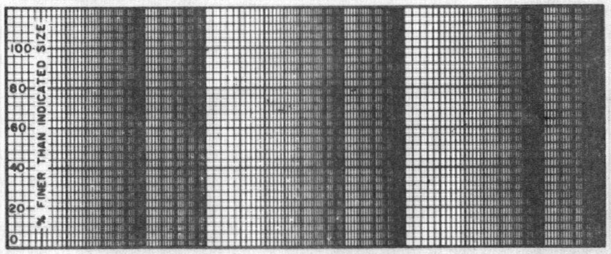
FRASER RIVER AT PORT MANN

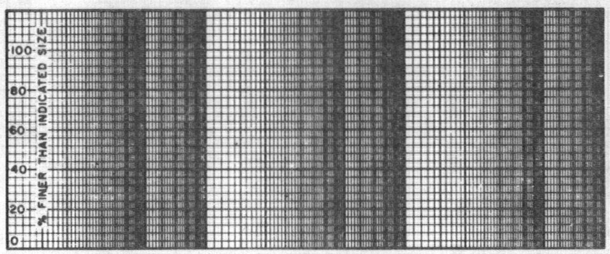
PREPARED BY:___________ CKD BY:__________ FILE NO:___________

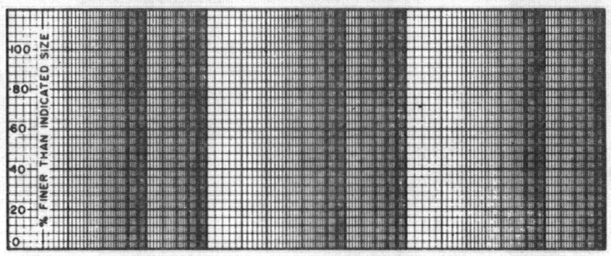
DATE:__________ FIGURE NO:___________

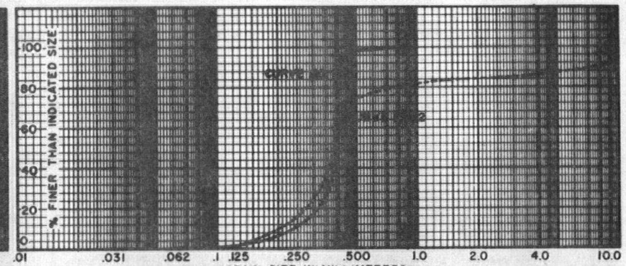
CURVE NO	DATE	NO. OF SAMPLES *	NO. OF SAMPLED POINTS IN X-SEC	PERCENTAGE FINER THAN INDICATED SIZE								
				16.000	8.000	4.000	2.000	1.000	.500	.250	.125	.062
1	JULY 28	1	1					100	98	11	1	0
2	JULY 28	5	5	100	91	86	84	82	75	16	1	0
3	SEPT 10	1	1				100	99	97	17	1	0

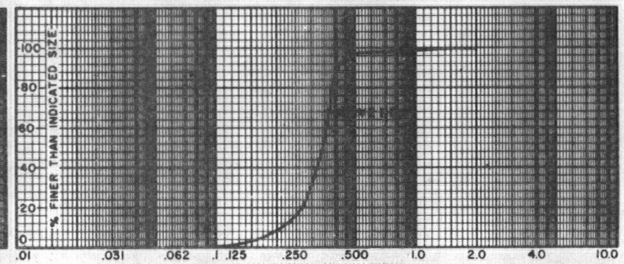
NOTE * AVERAGE PARTICLE SIZE USED
ARNHEM TYPE SAMPLER USED











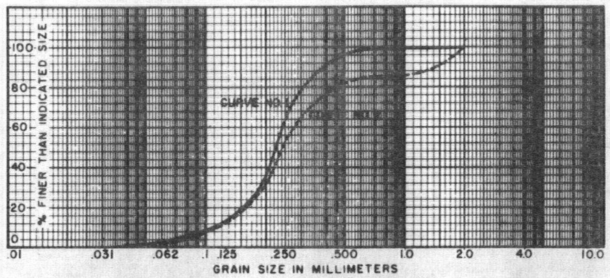
DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

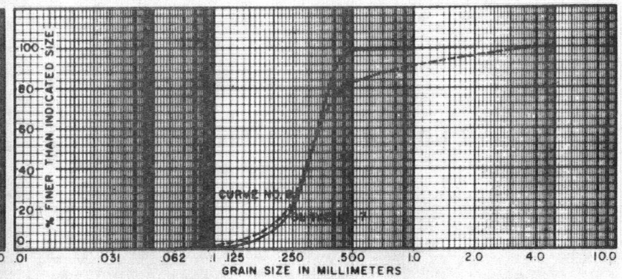
LOWER FRASER RIVER SEDIMENT SURVEY
BED LOAD PARTICLE SIZE DISTRIBUTION
1965
FRASER RIVER AT MISSION CITY

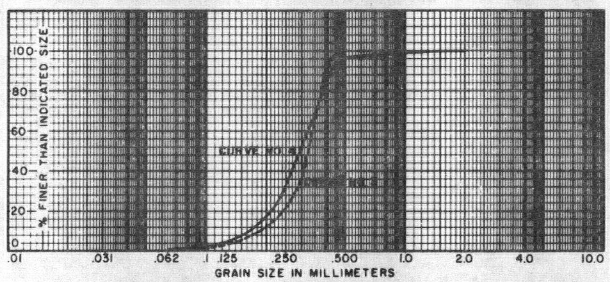
PREPARED BY:___________ CKD. BY:__________ FILE No:___________
DATE:__________ FIGURE No:___________

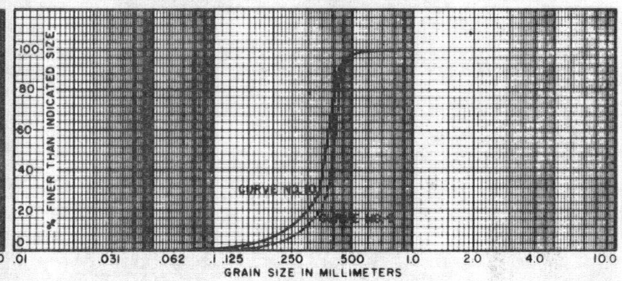
CURVE NO.	DATE	NO OF SAMPLES*	NO OF SAMPLED POINTS IN X-SEC	PERCENTAGE FINER THAN INDICATED SIZE								
				16.000	8.000	4.000	2.000	1.000	.500	.250	.125	.062
1	MAY 10	2	1				100	98	97	64	13	4
2	MAY 10	8	5				100	85	82	53	12	3
3	JUNE 14	1	1						100	22	2	0
4	JUNE 14	5	5				100	98	96	32	4	0
5	JULY 13	1	1					100	98	21	2	0
6	JULY 13	5	5	100	99	98	97	96	83	25	1	0
7	AUG 10	2	1				100	99	98	20	0	0
8	AUG 10	7	5			100	94	91	83	23	1	0
9	SEPT 20	2	1					100	99	7	0	0
10	OCT 6	1	1					100	98	12	0	0

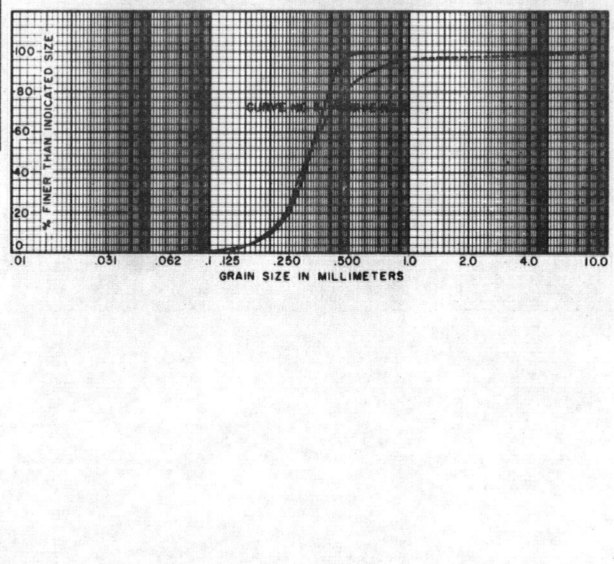
NOTE: * AVERAGE PARTICLE SIZE USED
ARNHEM TYPE SAMPLER USED











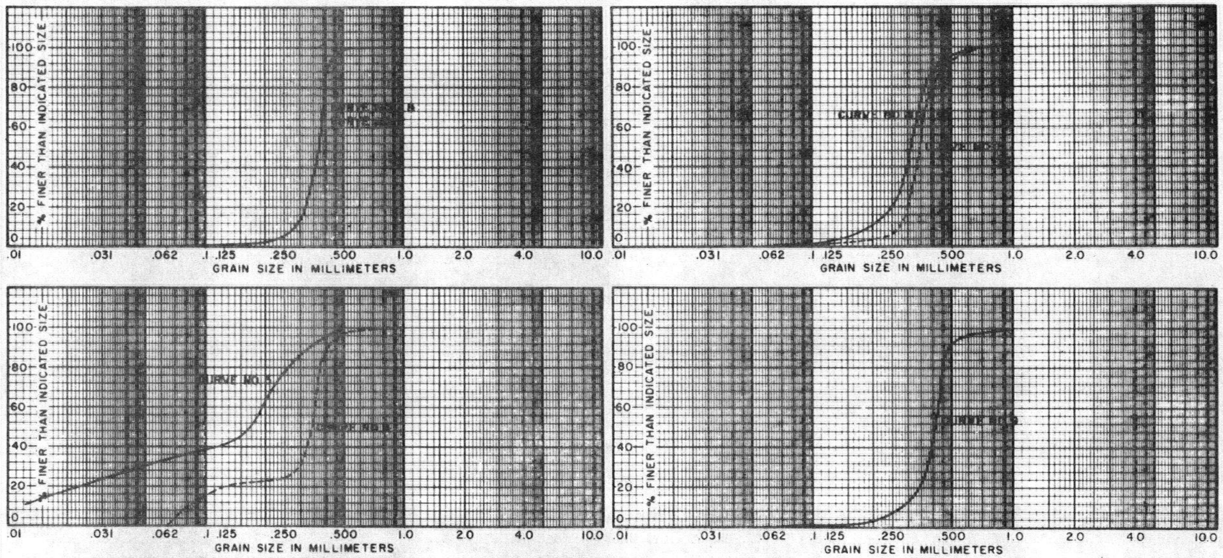
DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

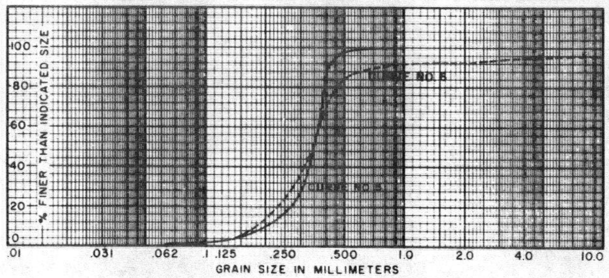
LOWER FRASER RIVER SEDIMENT SURVEY
BED LOAD PARTICLE SIZE DISTRIBUTION
1966
FRASER RIVER AT MISSION CITY

PREPARED BY:_________ CKD BY:_________ FILE No:_________
DATE:_________ FIGURE No:_________

CURVE NO	DATE	NO OF SAMPLES*	NO OF SAMPLED POINTS IN X-SEC	PERCENTAGE FINER THAN INDICATED SIZE								
				16.000	8.000	4.000	2.000	1.000	.500	.250	.125	.062
1	JAN 17	1	1					100	99	6	0	
2	FEB 14	1	1					100	99	5	0	
3	APR 27	3	1						100	78	42	35
4	MAY 16	1	1					100	98	25	20	0
5	JUNE 14	1	1					100	98	16	3	1
6	JUNE 14	5	5	97	95	94	93	92	84	24	3	0
7	JULY 14	1	1				100	99	93	7	0	0
8	AUG 18	1	1					100	96	20	1	0
9	SEPT 11	2	1					100	92	7	0	0

NOTE * AVERAGE PARTICLE SIZE USED
ARNHEM TYPE SAMPLER USED





DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

LOWER FRASER RIVER SEDIMENT SURVEY

BED LOAD PARTICLE SIZE DISTRIBUTION

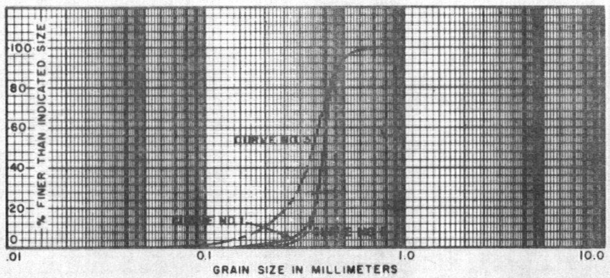
1967

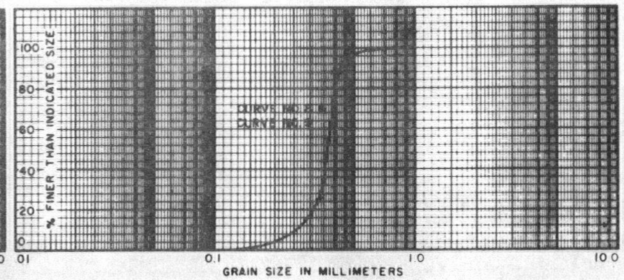
FRASER RIVER AT MISSION CITY

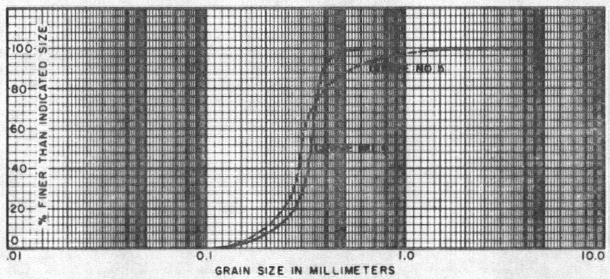
PREPARED BY: ____________ CKD BY: ____________ FILE No: ____________
DATE: ____________ FIGURE No: ____________

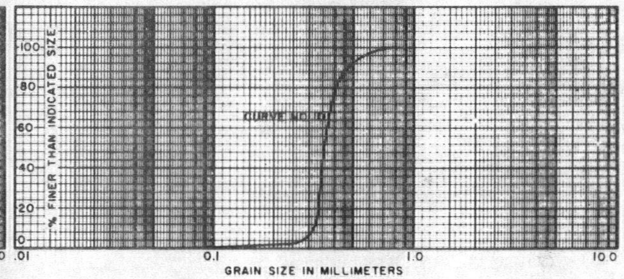
CURVE NO.	DATE	NO OF SAMPLES*	NO OF SAMPLED POINTS IN X-SEC	PERCENTAGE FINER THAN INDICATED SIZE 16.000	8.000	4.000	2.000	1.000	.500	.250	.125	.062
1	MAR 11	1	1					100	95	4	0	
2	APR 19	1	1					100	95	2	0	
3	MAY 14	1	1					100	95	19	3	0
4	JUNE 14	1	1					100	98	15	1	0
5	JUNE 14	5	5		100	99	99	97	88	22	1	0
6	JULY 12	1	1					100	99	22	1	0
7	JULY 12	5	1		100	96	95	94	86	17	0	0
8	AUG 13	1	1					100	96	10	1	0
9	SEPT 12	1	1					100	97	10	1	0
10	NOV 22	1	1					100	93	2	1	0

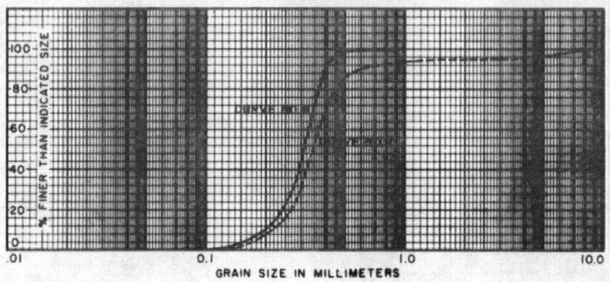
NOTE ● AVERAGE PARTICLE SIZE USED
ARNHEM TYPE SAMPLER USED











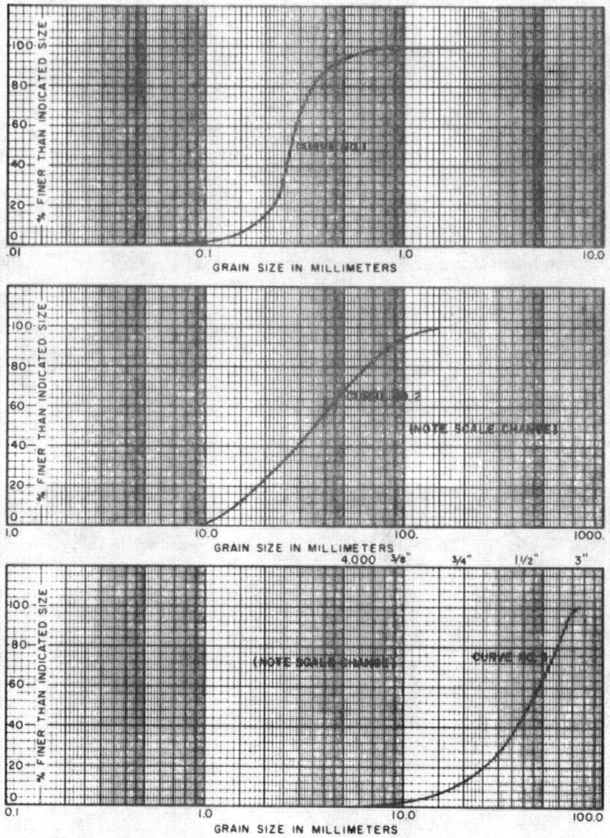
DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

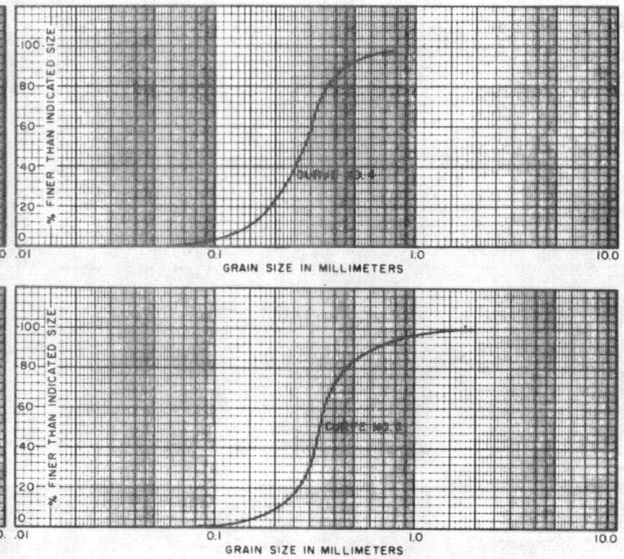
LOWER FRASER RIVER SEDIMENT SURVEY
BED LOAD PARTICLE SIZE DISTRIBUTION
1968
FRASER RIVER AT MISSION CITY

PREPARED BY:__________ CKD. BY:__________ FILE No:__________
DATE:__________ FIGURE No:__________

CURVE NO	DATE	NO OF SAMPLES*	NO OF SAMPLED POINTS IN X - SEC	PERCENTAGE FINER THAN INDICATED SIZE								
				16000	8000	4000	2000	1000	500	250	125	.062
1	APR 24	5◇	5			100	99	99	94	35	4	0
2	MAY 24											
3	JUNE 18											
4	OCT 7	5◇	5				100	99	93	39	6	0
5	NOV 8	6◇	6				100	97	84	31	2	0
						6"	3"	1½"	¾"	⅜"	4.000	2.000
2	MAY 24	5*	5			100	86	53	21	1	0	
3	JUNE 18	2*	2				100	41	12	1	0	

NOTE • AVERAGE PARTICLE SIZE USED
TYPE OF SAMPLER USED ◇ V.U.V.
* ¼" BASKET





DEPARTMENT OF ENERGY, MINES AND RESOURCES
INLAND WATERS BRANCH

LOWER FRASER RIVER SEDIMENT SURVEY

BED LOAD PARTICLE SIZE DISTRIBUTION

1968

FRASER RIVER NEAR AGASSIZ

PREPARED BY: ___________ CKD BY: ___________ FILE Nº ___________
DATE ___________ FIGURE Nº: ___________

APPENDIX E

DESCRIPTION OF HYDROMETRIC AND

SEDIMENT SAMPLING EQUIPMENT

APPENDIX E

The following is a brief summary describing the sediment sampling equipment and the specialized hydrometric equipment which has been or is being used on the Lower Fraser River survey.

A. Suspended Sediment Sampling Equipment

1. Portable Pumping Samplers: There are many types of portable pumping samplers in use. The simple portable pumping sampler consists of a small pump driven by a portable gasoline, electric or battery motor and a flexible plastic hose fitted with an intake nozzle. The nozzle is attached to a weight which may be lowered by cable from a boat, catamaran or bridge to a predetermined depth in a stream cross-section. Usually, the pumping samplers are calibrated in such a way that the intake velocity in the nozzle can be regulated to suit the natural velocity at the sampling point.

The pumping sampler may be used as a point-integrating or depth-integrating sampler. Samplers developed by the staff of the Water Survey of Canada yielded good results for streams with low and medium velocities. A pumping sampler was used at the Fraser River at Port Mann cross-section with reasonable success.

2. Point-Integrating Samplers: Point-integrating samplers for suspended sediment are similar to depth-integrating samplers. The main difference is that the point-integrating samplers are fitted with a control valve in the intake-exhaust passages and a pressure equalizing chamber in the sampler body to equalize the air pressure in the sampling container and the hydrostatic pressure at the intake. With the sampler open or closed at any depth in the cross-section, there will be no inrush of water. Because the intake and exhaust are controlled, point-integrating samplers may be used for depth-integrating sampling at partial depth if required.

Two types of point-integrating sampler have been used in the Lower Fraser River survey:

(a) US P61 point-integrating sampler consists of a streamlined cast bronze shell, 28 inches long and weighing about 100 lbs., in which the sample bottle (pint milk bottle) is enclosed. The sampler control valve is operated by a rotary solenoid, closing and opening the intake and air-exhaust passages; the solenoid is energized by 36 or 48 volt batteries. The sampler can be used at depths to 150 feet.

(b) US P63 point-integrating sampler is 34 inches long and weighs 200 lbs. The form, valve mechanism and operation of the US P63 sampler are identical to the US P61. Pint and quart size sample containers may be used. The sampler has the compression chamber volume adequate for operation to a depth of 180 feet.

3. Depth-Integrating Samplers: A sampler which takes samples over an extended period of time to average the momentary suspended sediment concentration at a point may be called a time-integrating sampler. If a time-integrating sampler is moved vertically in a stream to integrate the concentration on a sampling vertical, then it is called a depth-integrating sampler.

Usually depth-integrating samplers do not have the mechanism to control the opening of the nozzle and the process of sampling starts when a sampler is submerged and stops when the sampler is removed from the water. In general, there are many types of depth-integrating sampler, almost all of them based on the same principle.

The Inter-Agency Subcommittee on Sedimentation, in the U.S.A. has designed a series of depth-integrating samplers which are used on the continent and in some European countries. Most popular of these which have been used in the Lower Fraser River survey, mainly at the tributary stations, are:

(a) US DH-48, hand-operated and used in shallow streams. It is 13 inches long and weighs $4\frac{1}{2}$ pounds. A stream-gauging rod is used for lowering the sampler.

(b) US DH-59, used with a hand-line suspension, is 15 inches long and weighs 24 pounds.

(c) US D-49, used with a line suspension, is 24 inches in length and weighs 62 pounds.

Each of these depth-integrating samplers consists of a streamlined casting in which the sample bottle is enclosed. Each is supplied with three intake nozzles, 1/4, 3/16 and 1/8 inch diameter. An air exhaust outlet on the side of the sampler head allows air to escape from the sample bottle during the sampling. Depth-integrating samplers are not recommended for depth over 20 feet.

4. <u>Turbidity Meters</u>: Most turbidity meters currently in operation have been in use for some considerable time. They are simple and fast to operate but may not be very accurate. Turbidity meters operate on the dubious assumption that suspended sediment concentration is proportional to the turbidity in water samples, disregarding the particle-size distribution of the sediment, the colour of the water and other factors.

Of the several types of turbidity meter available, the Disk Secchi* meter has been used at the Fraser River at Port Mann station. This meter simply consists of a white disk, 10 inches in diameter, installed on a graduated rod or string. The depth of water is measured to the point beyond which the disk is no longer visible. The measured depth is used to determine the suspended sediment concentration with the use of a calibration curve. The unit has limited application and has limited accuracy.

5. <u>Continuous Concentration Recorders</u>: The Water Survey of Canada plans for installation and operation of two continuous suspended solids recorders: one at the Fraser River at Port Mann and one at the Fraser River at Mission City. The recorders selected are the Southern Analytical Suspended Solids Recorders, Type A.1690, built in England by Southern Analytical Limited and designed to measure suspended sediment concentration in the range of 1 - 1,000 p.p.m. The design is based on the principle of determining the ratio of scattered light to transmitted light, and the instrument will operate satisfactorily under a wide range of natural and industrial conditions.

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*Trade names used do not indicate preference of equipment over other types available.

The instrument consists of two parts, an optical unit and an electronic unit. The optical unit is housed in a cast metal box which is robust and waterproof; it contains the light-source rotating disc and auxiliary photodiodes. The electronic unit which is connected to the optical unit by a cable (maximum length, 200 yards), is fully transistorized and carries a meter which can be calibrated to read directly in p.p.m. or it can drive a recorder. The instrument can be calibrated for material of different sizes and for different optical density filters. Although installation of the instrument is relatively simple, proper positioning of the intake requires some care.

B. Bed Load Sampling and Measurement Equipment

1. Pressure-Difference Samplers: Pressure-difference samplers are designed so that the presence of the sampler on the river bottom will not change the stream velocity at the entrance. Equalization of velocity is achieved by creating a pressure drop inside the sampler by expanding the rear part of the unit.

The pressure-difference samplers used on the Lower Fraser River survey included the Sphinx, Arnhem and VUV types which are described below.

The Sphinx sampler was developed by the Research Department of the Rijkswaterstaat and the Hydraulic Laboratory at Delft, Netherlands. It has a design hydraulic efficiency of 1.09 (empty) and can measure grain sizes smaller than 0.4 mm. The intake of the sampler is rectangular and further inside gradually becomes circular. Sediment in the water entering the sampler is deposited in the settling chambers; water from which the sediment has been removed is discharged at the rear of the unit. Although there is no information available on the sampling efficiency, tests show that a small amount of very fine material passes through the sampler. Tested under natural conditions in Canada, it was found that this sampler does not give consistent results when used on irregularly-formed channel bottoms. The sampler was lowered to the river bottom by means of a heavy frame in which it was mounted.

The Arnhem sampler was designed by the Hydraulic Structures Bureau of the Government of Holland. The unit has a rigid rectangular entrance connected by a rubber section to an expanded basket of 0.2 - 0.3 mm. mesh. The expanded section reduces the pressure at the downstream end so that the entrance velocities approximate the undistributed condition. The sampler is installed in a streamlined framework by means of springs and cables, so designed that when the unit is lowered for sampling, it will make gentle contact with the stream bed.

The Arnhem sampler is probably the best of its kind in operation at the present time. It suffers however, from the disadvantage that the sampling efficiency is not constant, but varies with the amount of sediment in the bag and the clogging condition of the mesh. It was the most frequently used sampler at the Lower Fraser stations with sand beds.

The VUV sampler was developed in 1956 by P. Novak, Hydraulic Research Institute, Prague. The body of the sampler is partly streamlined and measures 50 inches long (with rudder, 94 inches). The height at the front is 8 inches and it is 18 inches wide. The rear part of the sampler is 16 inches high and is divided by a horizontal partition. The lower chamber so formed is for deposition of bed load and the upper for passing the flow. The instrument has a rear door which is closed by lowering or raising the sampler.

Designed for gravel grain size material, the sampler is better suited to shallow streams than to deep streams. It is difficult to operate in deep streams and has the added disadvantage of being difficult to rate for sampling efficiency coefficient.

2. Basket Samplers: A basket sampler consists of a large rectangular frame and tail section into which fits a basket with one open end. This sampler has been used at the Fraser River near Agassiz because of gravel size particles at this station.

The basket sampler is 24 inches wide, 10 inches deep and 30 inches long and weighs 240 pounds. The mesh sizes of the basket are as follows: top, 3/4 inch; sides and back, 1/2 inch; and bottom, 1/4 inch. The average sampling efficiency of the sampler is less than 50%.

3. Depth Recorders: Two types of depth recorders have been used on the Lower Fraser River survey: Kelvin Hughes, Type MS-36, and the Bludworth. Each unit is a complete echo depth sounder designed to provide detailed records of river bed topography in water depths of 200 feet or more. Each unit consists of a recorder chassis and a transducer connected by coaxial cable.

C. Bed Material Samplers

Only one type of bed material sampler was used in the Fraser River survey. It was the US BM-54 which weighs 100 pounds and is 22 inches long. This sampler is streamlined and equipped with a tail vane. The bucket, installed at the bottom of the sampler has a capacity of approximately 200 cubic centimeters. When the sampler is suspended on the line, the bucket may be locked in the open position. Resting the sampler on the river bed releases the tension on the cable which releases the bucket and causes it to scoop up and enclose a two inch deep sample of bed material. The sample cannot be washed out while the sampler is being raised to the surface.

D. Specialized Hydrometric Equipment

Only two types of specialized hydrometric equipment which have been used on the Lower Fraser River survey will be described: the Ott directional current meter and the VADA equipment.

VADA Equipment: The name VADA is the acronym formed from the first letters of Velocity-Azimuth-Depth-Assembly and is applied to a "package" of equipment designed by the United States Geological Survey to provide a means of determining the mean velocity in a vertical of a cross-section of a stream. This is done by integrating the velocity from near streambed to the water's surface. It is particularly useful in making discharge measurements in a river where the velocity distribution in the vertical is complex such as occurs in unsteady flow or under the influence of tides. In addition to velocity observations the equipment also provides indications of the direction of flow (azimuth) and the depth.

The instrument package, or assembly, consists essentially of:

1. a velocity meter rigidly mounted above a streamlined sounding weight weighing approximately 140 pounds. This weight houses a remote-reading magnetic compass, for determining the orientation of the weight and hence the meter, and a transducer for a sonic sounder for measuring the distance to the streambed;

2. a DC powered reel with 7-conductor armoured cable for suspending the above assembly from a crane and returning signals from the equipment;

3. analog chart readout of signals from the meter, compass and sonic sounder.

The current meter used is a modified Ott component type which registers velocity along its axis for flow impinging upon it at any angle up to 45°. One of the modifications is the introduction of a 24-pulse (per revolution of the rotor) signal which provides for all practical purposes an instantaneous and continuous readout of velocity.

When the measurement has been completed the analog charts can be analyzed and reduced to provide the information required for the normal computation of the river discharge.

Ott Directional Current Meter: The Ott directional current meter consists of an electric sounding weight, an assembly encompassing a floating compass and an Ott current meter, a multicore conducting suspension cable and an instrument panel. The current direction of water is detected by gradual measurements of the angle between the axis of the instrument and the magnetic meridian of the floating part of the fluid compass. A direction indicator of this type may be used in water depths of up to 330 feet.

The electric sounding weight and an Ott current meter may be used together with the direction indicator, the first to indicate when the river bottom has been reached and the latter to record the velocity. The instrument panel is equipped with a counter and a stopwatch (in addition to an angle indicator dial and other controls) to facilitate velocity measurement.

This brief description does not include all the equipment which has been used on the Lower Fraser River survey. The standard hydrometric equipment, reels, cranes, etc. are too numerous to describe in a progress report. For additional description and illustration of such equipment, reference should be made to the Proceedings of the Seventh Hydrology Symposium (October, 1969, Victoria, B.C.).

Copies of this report may be obtained from:

Director,

Inland Waters Branch,

Department of Energy Mines and Resources,

588 Booth Street,

Ottawa, Ontario.

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