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WATER INVESTIGATIONS ALONG THE ALASKA HIGHWAY PIPELINE ROUTE IN THE YUKON TERRITORY

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December 1978

Inland Waters Directorate
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APPENDIX A

STREAMFLOW AND SUSPENDED SEDIMENT AT SELECTED SITES ALONG THE ALASKA HIGHWAY PIPELINE ROUTE IN THE YUKON TERRITORY

by

P. W. Strilaeff

December 1978

Inland Waters Directorate
Pacific and Yukon Region
Vancouver, B.C.

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INTRODUCTION

A total of 16 crest-stage gauges were operated along the Alaska Highway pipeline route between May and September 1978. Ten were installed and operated by the Department of Indian and Northern Affairs, Whitehorse, Y.T. at the request of Environment Canada, Inland Waters Directorate, Vancouver, B.C., and six were operated by DINA as part of their ongoing crest-stage network. Five of the 16 stations were equipped with water-stage recorders. The network provides a representative runoff sample of the several types of drainage basins along the pipeline route.

Data are presented in graphic form and include: daily mean discharge for 5 sites, instantaneous discharge, miscellaneous measured discharge, bankfull discharge, and miscellaneous sampling of suspended and dissolved solids where such information was obtained.

A graphic format was selected as it facilitates comparisons to be made both in time and among gauge sites; it could thus serve as a tool for evaluating streamflow characteristics at ungauged streams.

Table 1 lists the 16 crest-stage gauges operated in 1978 and for which data are included in this report.

Table 2 lists miscellaneous discharge measurements obtained at other selected locations along the Alaska Highway.

Table 3 gives results of suspended sediment sampling in Yukon Territory and at a number of adjacent sites in British Columbia. For a few sites these data are presented also in graphic form in Figures 17 to 24.

There are approximately 19 Water Survey of Canada gauging stations in the vicinity of the pipeline route which may be useful in providing additional streamflow information along the pipeline route. These data are available from Water Survey of Canada data files. For data at DINA crest-stage gauges prior to 1978, application should be made to that Department's office in Whitehorse.

TABLE 1 - SMALL STREAM NETWORK - ALASKA HIGHWAY - 1978

Station	Purpose	Comments
1) Snag Creek at MP 1208.0 (drainage area 380 sq.mi.) Equipped with water stage recorder 2) Dry Creek at MP 1184.0 (drainage area 52 sq.mi.) DINA network station 3) Sanpete Creek at MP 1178.4 (drainage area 29 sq.mi.)	Between Alaska-Yukon Border and White River terrain is generally flat, comprising of muskeg, potholes and swamps. Pipeline trench could induce toxic waters into swamp-free basins such as Beaver Creek. These streams are expected to be representative of hydrology in the area.	Icing and frost heaving is expected to be severe because of terrain type. Permafrost is reported to be 4' below ground level.
4) Long's Creek at MP 1156.0 (drainage area 44 sq.mi.) DINA network station, equipped with water stage recorder	Lakes and swamps may be drained into the Koidern River from upstream during and/or after construction. Thawing of the slope which the pipeline must ascend (gradient about 500 ft./mile) will probably cause erosion and slumping during construction.	High velocities with considerable drift and ice in the spring.
5) Burwash Creek at MP 1103.9 (drainage area 65 sq.mi.) Equipped with water-stage recorder 6) Unnamed Creek at MP 1082.5 (drainage area 3.4 sq.mi.) 7) Silver Creek at MP 1053.6 (drainage area 18.6 sq. mi.)	High energy streams between MP 1060 and 1100 are expected to be a source of drainage and icing problems during and after construction. To arrive at hydrologic estimates for this area is difficult by conventional means. Highway experience and snow survey data from Burwash Landing can contribute to the estimate.	Burwash Creek is glacier fed. Runoff is intermittent.

TABLE 1 - SMALL STREAM NETWORK - ALASKA HIGHWAY - 1978 (Cont'd)

Station	Purpose	Comments
8) Bear Creek at MP 1022.3 (drainage area 30 sq.mi.) DINA network station 9) Marshall Creek at MP 1005.6 (drainage area 83 sq.mi.) DINA network station	Bank stability is a major problem in this area. Banks are high with evidence of seepage.	
10) Mendenhall River at MP 968.0 (drainage area 293 sq.mi.) DINA network station, equipped with water-stage recorder 11) Stoney Creek at MP 956.0 (drainage area 19 sq.mi.)	The potential instability problems in the Ibex River - Porter Creek area require an understanding of hydrologic variations.	Icing is expected to be intense some winters and runoff violent in the spring.
12) Deadmans Creek at MP 822.3 (drainage area 84 sq.mi.)	Lacustrine terraces are sharply incised by numerous small watercourses having extremely steep sidewalls; construction activity will be noteworthy for high sediment yields in presently clear water systems. Lacustrine deposits are known to be high in sodium and sulphate; could increase pH and specific conductivity.	

TABLE 1 - SMALL STREAM NETWORK - ALASKA HIGHWAY - 1978 (Cont'd)

Station	Purpose	Comments
13) Logjam Creek at MP 751.1 (drainage area 33 sq.mi.)	Swift River system is expected to suffer similar problems to those on the N.E. side of Teslin Lake.	
14) Partridge Creek at MP 736.4 (drainage area 24 sq.mi.) DINA network station, equipped with water stage recorder		
15) Spencer Creek at MP 695.3 (drainage area 62 sq.mi.)	Relic moraines in the Rancheria River system represent concentrations of fine materials subject to degradation with disturbance.	
16) Big Creek at MP 674.0 (drainage area 405 sq.mi.)		

TABLE 2 - MISCELLANEOUS DISCHARGE MEASUREMENTS AT SELECTED SITES ALONG THE ALASKA HIGHWAY

Stream	Date	Width (ft.)	Area (sq.ft.)	Velocity (ft./sec.)	Discharge (cfs)
Beaver	Aug. 7, 1978	128	304	4.38	1,330
White	Aug. 7	292	2,270	10.83	24,600
Koidern	May 18	52.0	69.9	1.19	83.4
Donjek	May 16, 1977	braided cross-section			826
	June 23				4,110
	July 14				8,810
	Aug. 10				13,900
	Sep. 29				1,310
	June 7, 1978				3,330
	June 26				5,000
	June 27				4,980
	June 28				5,180
	June 29				4,930
	June 30				5,380
	July 17				8,700
	July 18				8,840
	July 19				9,100
	July 20				11,900
	July 21				13,200
	Aug. 2				13,400
	Aug. 3				15,200
	Aug. 4				16,500
	Aug. 5				17,100
	Aug. 6				22,800
Swede Johnson	May 19	15.5	13.4	0.31	4.2
Quill	Aug. 8	22.5	10.7	1.87	20.0
Duke	May 20	34.0	31.5	1.46	45.9
	June 28	65.6	81.4	4.24	334
	July 19	64.0	104	5.13	539
	Aug. 9	braided cross-section			879

TABLE 2 - MISCELLANEOUS DISCHARGE MEASUREMENTS AT SELECTED SITES ALONG THE ALASKA HIGHWAY (Cont'd)

Stream	Date	Width (ft.)	Area (sq.ft.)	Velocity (ft./sec.)	Discharge (cfs)
Halfbreed	Aug. 9, 1978	13.5	8.9	3.19	28.5
Christmas	May 15	22.5	20.1	3.37	67.7
Jarvis	May 17	70.0	124	2.25	279
Cracker	May 16	20.0	9.2	2.72	24.9
	Aug. 10	15.5	6.2	1.62	10.1
McIntyre	May 22	25.5	12.9	2.79	36.0
Brook's	July 11, 1977	18.0	14.4	2.49	35.8
	Aug. 14, 1978	6.0	7.4	1.13	8.3
Ten Mile	July 11, 1977	17.5	8.9	1.86	16.6
	Aug. 13, 1978	8.0	3.2	1.82	5.8
Strawberry	Aug. 12	11.5	4.7	1.47	6.9
Morley	Aug. 12	75.0	224	1.12	251
Smart	Aug. 13	83.0	201	1.03	207
Screw	Aug. 13	23.0	18.3	1.38	25.2
Rancheria at M.P. 687	June 8, 1977	222	948	5.48	5,160
	July 13	202	687	3.32	2,280
	July 27	198	653	3.09	2,020
L. Rancheria	June 1	118	489	5.30	2,590
	July 12	114	368	4.38	1,610
	Aug. 12, 1978	100	196	2.05	1,630

TABLE 3 - SUSPENDED SEDIMENT AND DISCHARGE IN THE YUKON TERRITORY AND AT A NUMBER OF ADJACENT SITES IN BRITISH COLUMBIA

Stream	Date	Total Concentration (mg/L)	Discharge (cfs)
Aishihik River near Whitehorse	June 15, 1972	219	2,020
Alsek River above Bates River	July 16, 1974	408	19,600
	Sep. 4	1,586	23,700
	May 2, 1975	50	1,760
	June 2	270	10,100
	July 16	1,171	34,000
	Aug. 12	146	17,160
	Sep. 4	104	11,600
	Oct. 10	93	6,810
	June 8, 1976	116	9,560
	Aug. 13	772	25,000
	Aug. 25	233	16,600
	Oct. 20	89	3,690
	May 10, 1977	65	3,340
	June 22	95	17,000
	July 26	511	24,600
Big Creek at Alaska Hwy.	July 13	14	603
Brooks Brook at Alaska Hwy.	July 11	4	35.8
Burwash Creek at Alaska Hwy.	June 4, 1978	53	115
Deadmans Creek at Alaska Hwy.	July 28, 1977	3	87
*Donjek River at Alaska Hwy.	May 16	568	826
	June 23	1,690	4,110
	July 14	3,610	8,810
	Aug. 10	4,130	13,900
	Sep. 29	35	1,310
	June 27, 1978	1,960	4,980
	June 28	1,700	5,180
	June 29	1,530	4,930
	June 30	2,320	5,380

*Weighted average of several samples in the braided cross-section

TABLE 3 - SUSPENDED SEDIMENT AND DISCHARGE IN THE YUKON TERRITORY AND AT A NUMBER OF ADJACENT SITES IN BRITISH COLUMBIA (Cont'd)

Stream	Date	Total Concentration (mg/L)	Discharge (cfs)
*Donjek River at Alaska Hwy.	July 17, 1978	2,840	8,700
	July 18	3,150	8,840
	July 19	3,300	9,100
	July 20	6,850	11,900
	July 21	5,030	13,200
	Aug. 2	5,280	13,400
	Aug. 3	6,340	15,200
	Aug. 4	5,820	16,500
	Aug. 5	5,910	17,100
	Aug. 6	10,600	22,800
Duke River at Alaska Hwy.	June 28, 1978	75	334
	July 19	209	539
Hyland River near Lower Post	June 1, 1972	572	39,900
Kechika River	June 6	245	20,800
Liard River at Lower Crossing	June 15, 1968	163	
Liard River at Upper Crossing	May 31, 1972	291	84,300
Liard River at Lower Crossing	June 2	822	273,000
Liard River at Upper Crossing	Dec. 11, 1974	15	5,280
Liard River at Upper Crossing	June 24, 1975	53	45,300
Little Rancheria at Alaska Hwy.	July 12, 1977	10	1,610
Rancheria River at Alaska Hwy.	July 27	2	2,010
M'Clintock River near Whitehorse	July 12	33	-
Mendenhall River at Alaska Hwy.	June 8, 1978	399	126
Ogilvie River at Dempster Hwy.	June 18, 1974	3	2,530
	Dec. 7	7	87
Pelly River at Pelly Crossing	June 5, 1968	204	56,700
	June 10, 1970	350	79,700
	June 11	355	66,500
	June 28	166	30,300
	July 31	102	34,400

*Weighted average of several samples in the braided cross-section

TABLE 3 - SUSPENDED SEDIMENT AND DISCHARGE IN THE YUKON TERRITORY AND AT A NUMBER OF ADJACENT SITES IN BRITISH COLUMBIA (Cont'd)

Stream	Date	Total Concentration (mg/L)	Discharge (cfs)
Pelly River at Pelly Crossing	Nov. 25, 1970	11	4,160
	Jan. 20, 1971	5	2,210
	Feb. 16	3	1,610
	Mar. 17	6	1,580
	May 26	291	47,700
	May 27	260	47,200
	June 22	210	50,600
	July 22	61	20,500
	Aug. 1, 1972	309	29,500
	Sep. 6	17	12,500
	Oct. 5	11	9,450
	Mar. 29, 1973	1	1,570
	July 29	40	16,800
	June 19, 1974	158	42,400
	Oct. 16	9	8,250
	Nov. 2	4	6,270
	June 7, 1975	462	91,300
	Aug. 18	37	17,400
	Oct. 10	30	19,600
	June 3, 1976	243	40,200
	Aug. 17	28	15,500
	Oct. 5	15	11,500
	June 22, 1977	114	32,800
	Aug. 8	61	18,200
	Oct. 5	39	16,000
Silver Creek at Alaska Hwy.	June 13, 1978	3,394	80.2
Snag Creek at Alaska Hwy.	June 14	31.5	153
Stewart River at Mouth	June 8, 1968	207	71,800
	Apr. 7, 1975	3	2,180
	June 20	244	79,200

TABLE 3 - SUSPENDED SEDIMENT AND DISCHARGE IN THE YUKON TERRITORY AND AT A NUMBER OF ADJACENT SITES IN BRITISH COLUMBIA (Cont'd)

Stream	Date	Total Concentration (mg/L)	Discharge (cfs)
Stewart River at Mouth	Aug. 13, 1975	26	21,700
	Sept. 26	57	25,400
	Aug. 12, 1976	17	17,200
	Aug. 4, 1977	10	19,100
	Sep. 29	10	15,100
Stoney Creek at Alaska Hwy.	June 8, 1978	11	17.3
Takhini River near Whitehorse	(No date) 1972	36	-
Ten Mile Creek at Alaska Hwy.	July 11, 1977	2	16.6
White River at MP 1169.2	June 21, 1972	136 (at mouth)	-
	April 30, 1975	85	568
	May 11, 1977	332	1,430
	June 23	1,213	8,100
	July 13	3,593	13,400
	July 28	4,255	15,800
	Aug. 9	8,683	19,100
	Aug. 17	7,041	17,100
	Sep. 28	70	1,990
Yukon River at Dawson	June 5, 1968	229	223,000
	June 21, 1971	736	216,000
	Aug. 27	300	117,000
	June 12, 1974	177	156,000
	Dec. 4	13	26,500
	June 17, 1975	219	216,000
	Aug. 13	263	151,000
	Sep. 22	222	136,000
	June 11, 1976	1,166	228,000
	Oct. 1	53	72,500
	Aug. 4, 1977	612	147,000
	Sep. 30	108	90,900
	July 12	36	151,000

TABLE 3 - SUSPENDED SEDIMENT AND DISCHARGE IN THE YUKON TERRITORY AND AT A NUMBER OF ADJACENT SITES IN BRITISH COLUMBIA (Cont'd)

Stream	Date	Total Concentration (mg/L)	Discharge (cfs)
Yukon River at Dawson	Aug. 3, 1977	17	154,000
Yukon River at Whitehorse	May 4, 1970	9	5,200
	May 22	781	3,920
	June 8	686	6,500
	June 29	868	9,420
	July 20	900	10,200
	July 31	735	12,000
	Aug. 31	850	12,100
	Sep. 30	842	8,370
	Oct. 27	798	7,500
	Nov. 26	858	5,550
	Jan. 5, 1971	0.3	5,160
	Feb. 1	2	4,200
	Mar. 15	2	4,280

Figure 1 - SNAG CREEK AT MP 1208.0

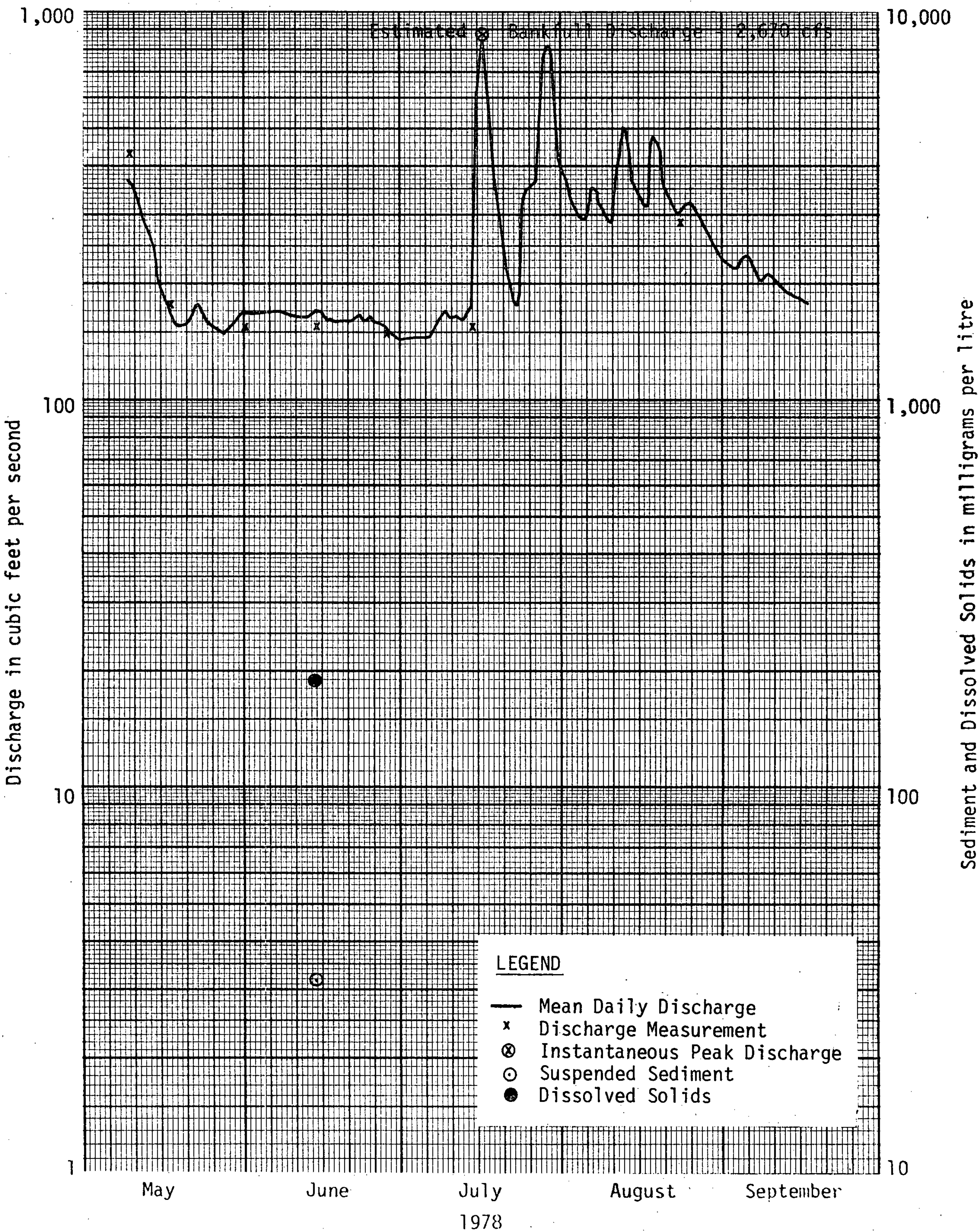


Figure 2 - DRY CREEK AT MP 1184.0

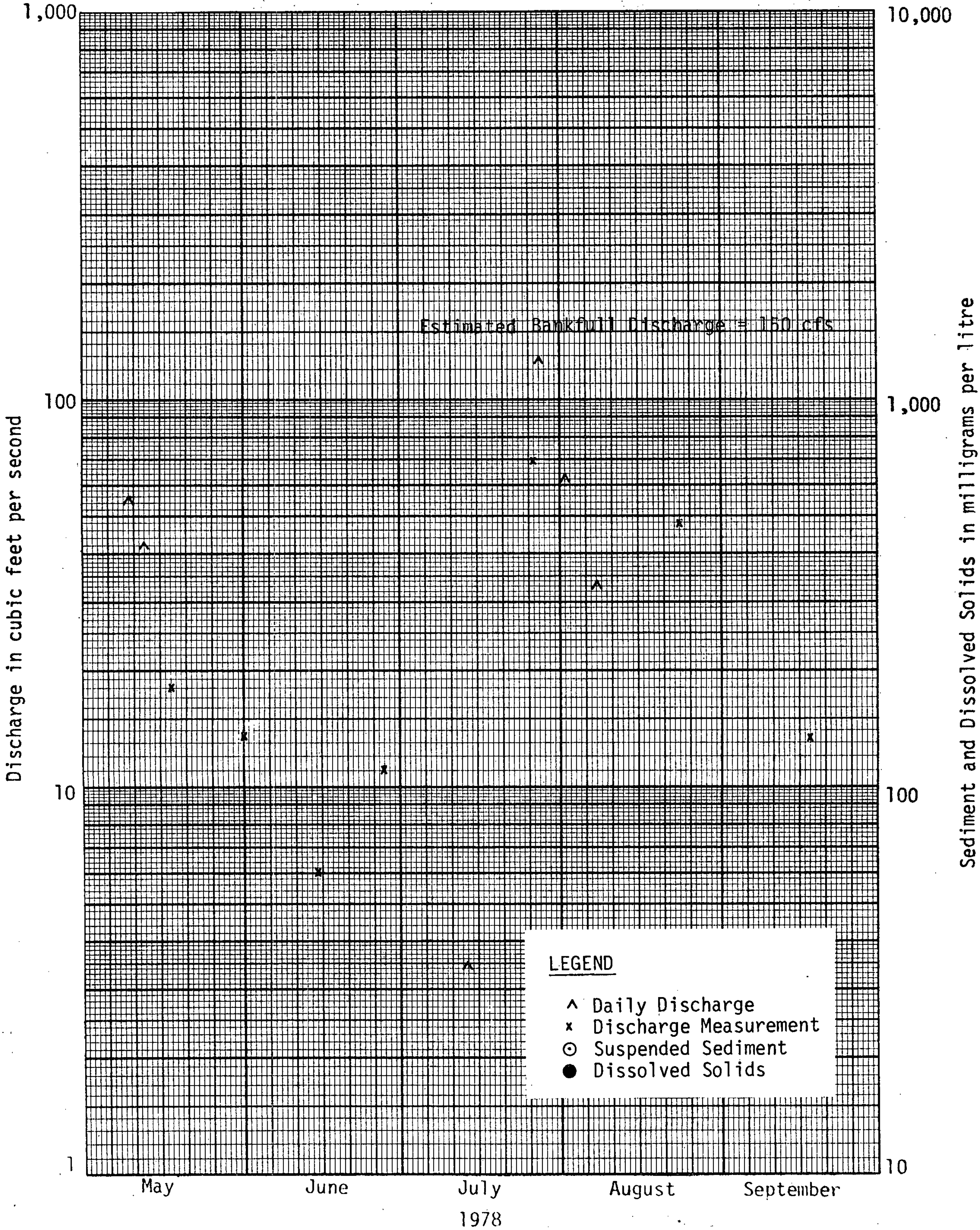


Figure 3 - SANPETE CREEK AT MP 1178.4

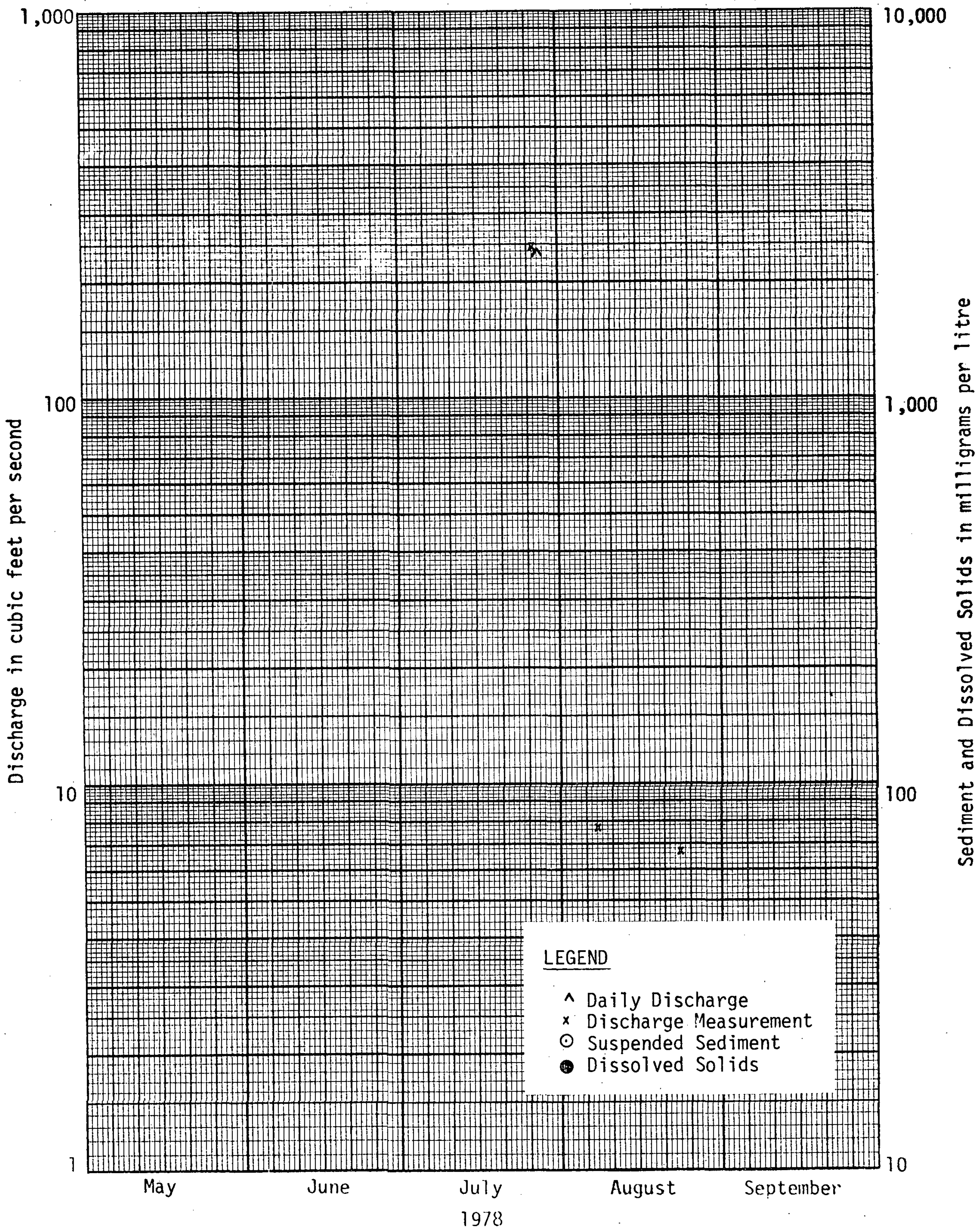


Figure 4 - LONG'S CREEK AT MP 1156.0

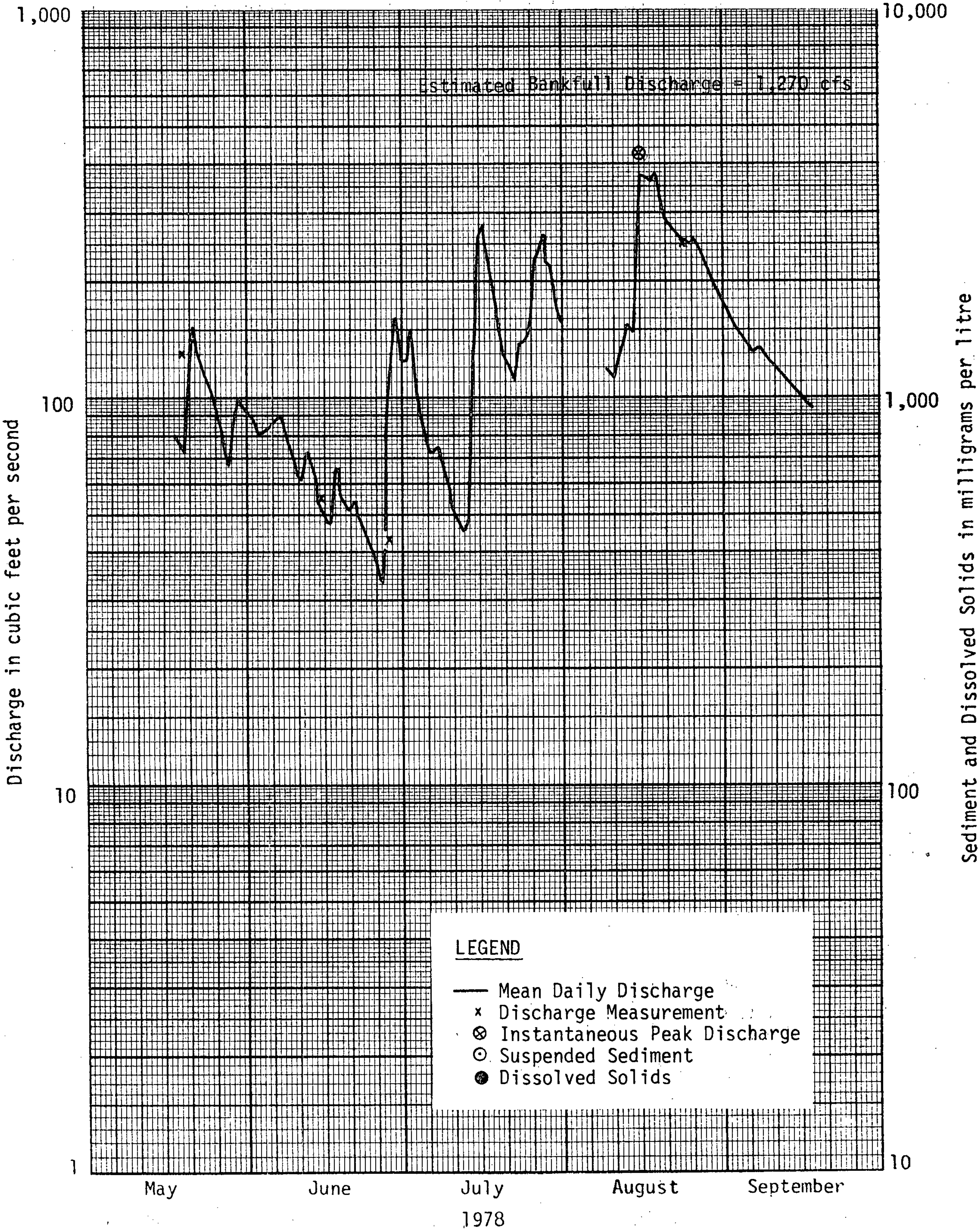


Figure 5 - BURWASH CREEK AT MP 1103.9

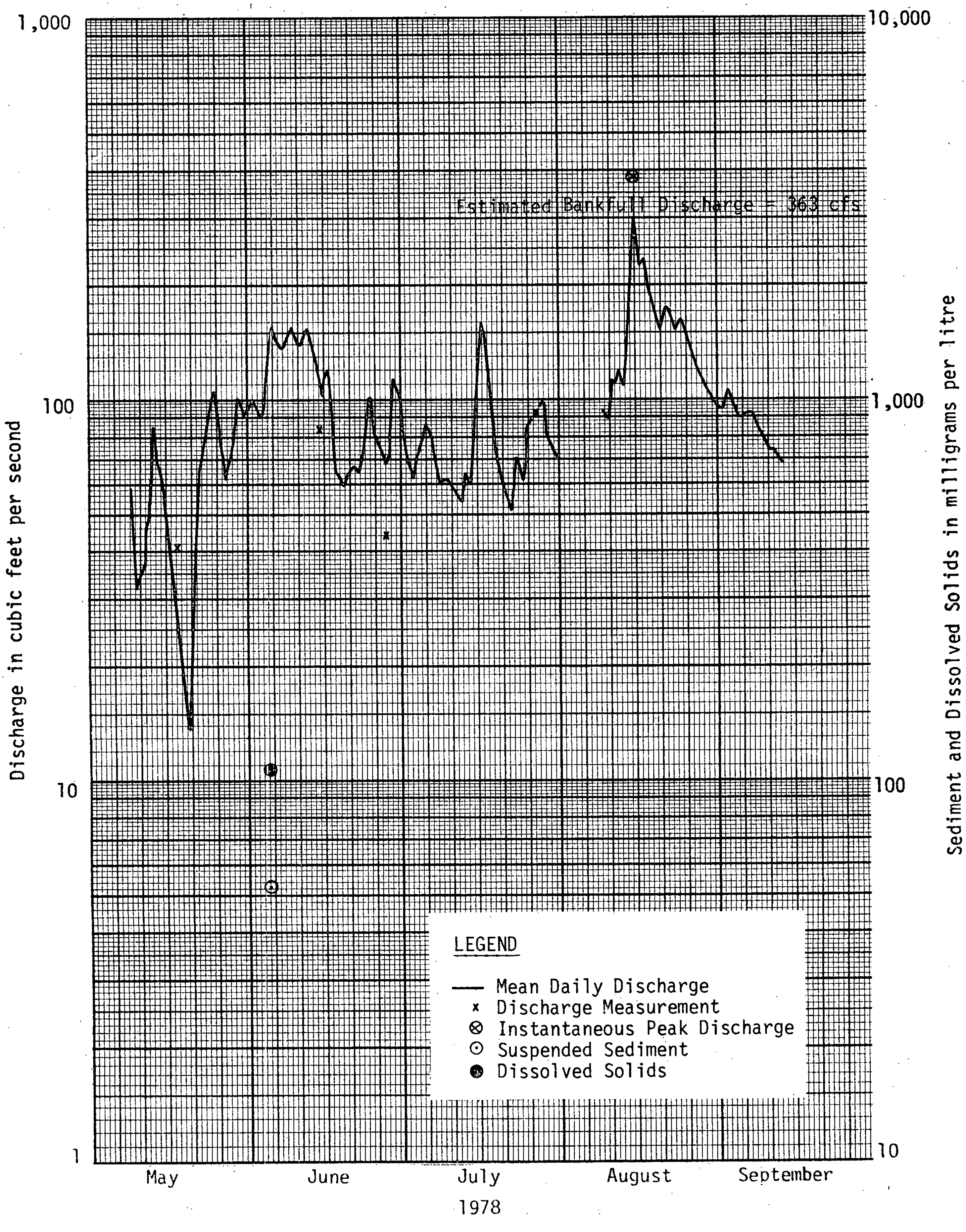


Figure 6 - UNNAMED CREEK AT MP 1082.5

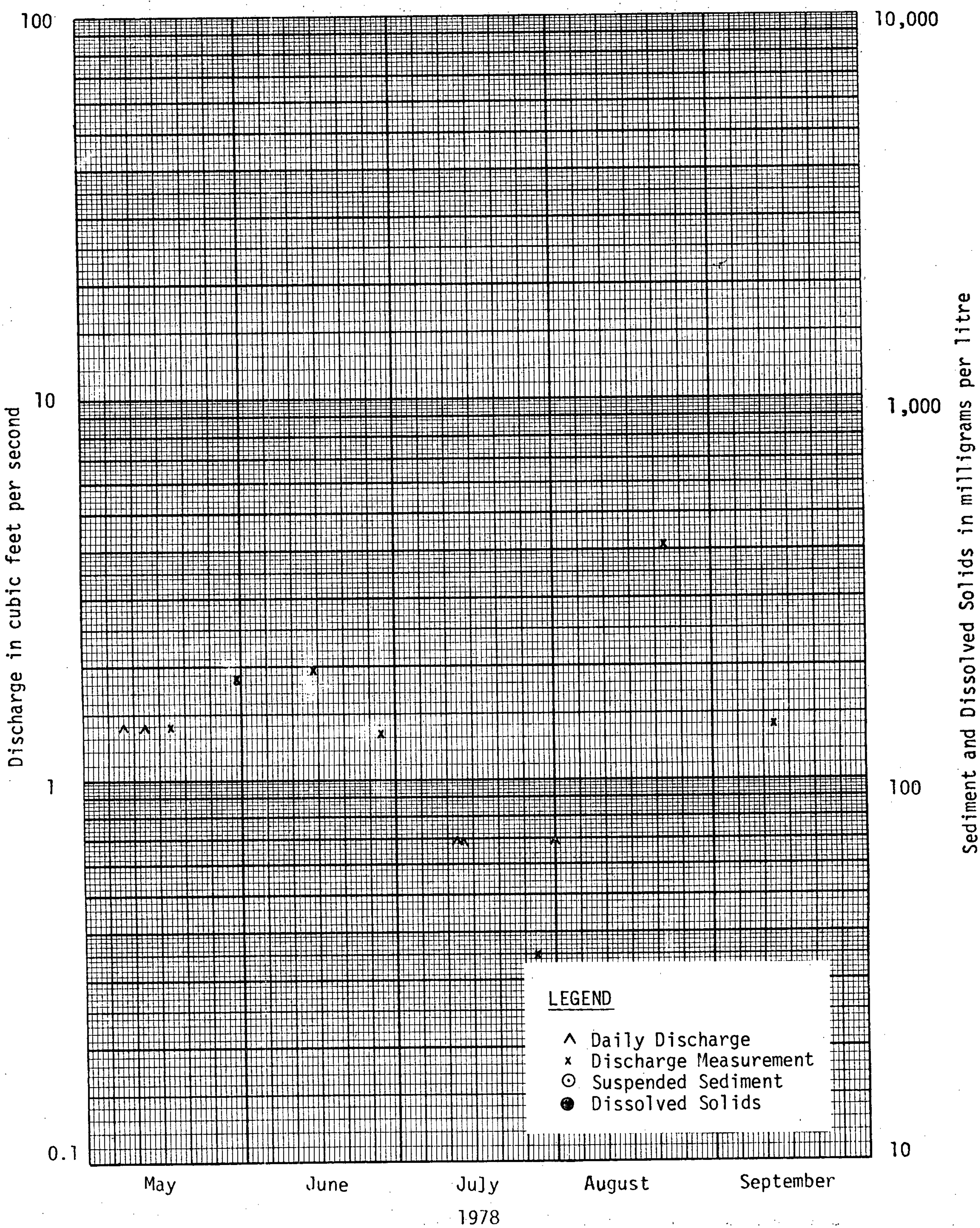


Figure 7 - SILVER CREEK AT MP 1053.6

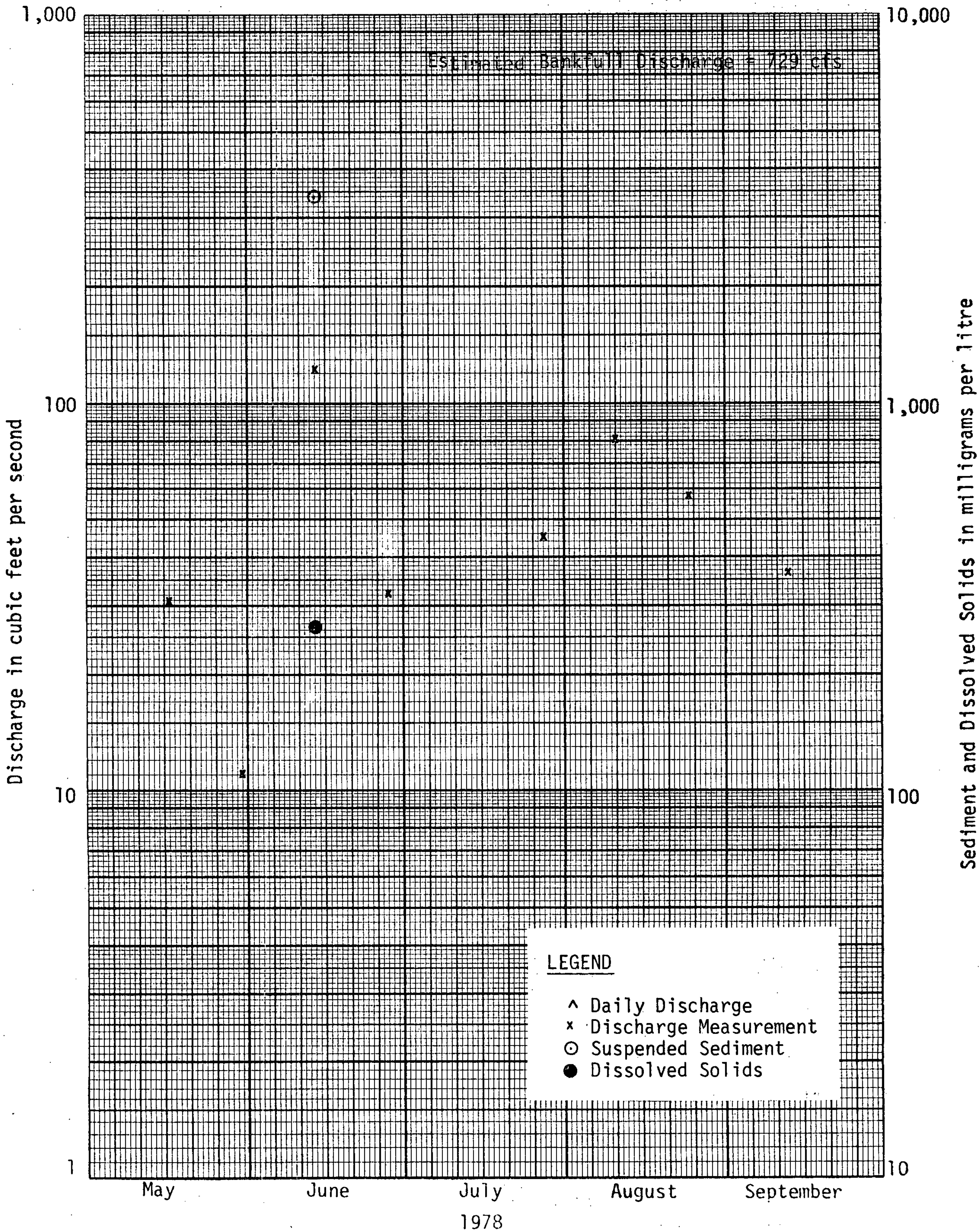


Figure 8 - BEAR CREEK AT MP 1022.3

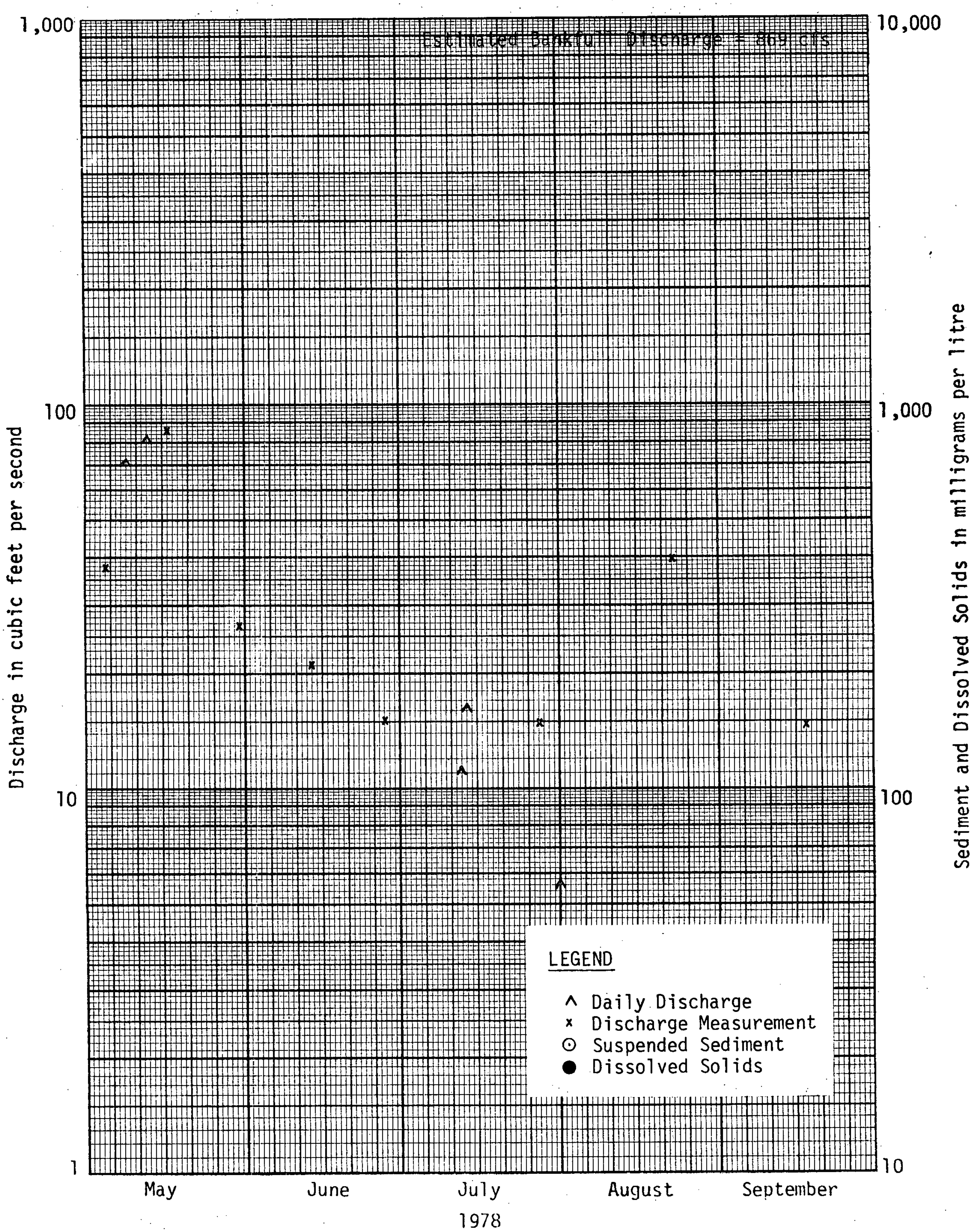


Figure 9 - MARSHALL CREEK AT MP 1005.6

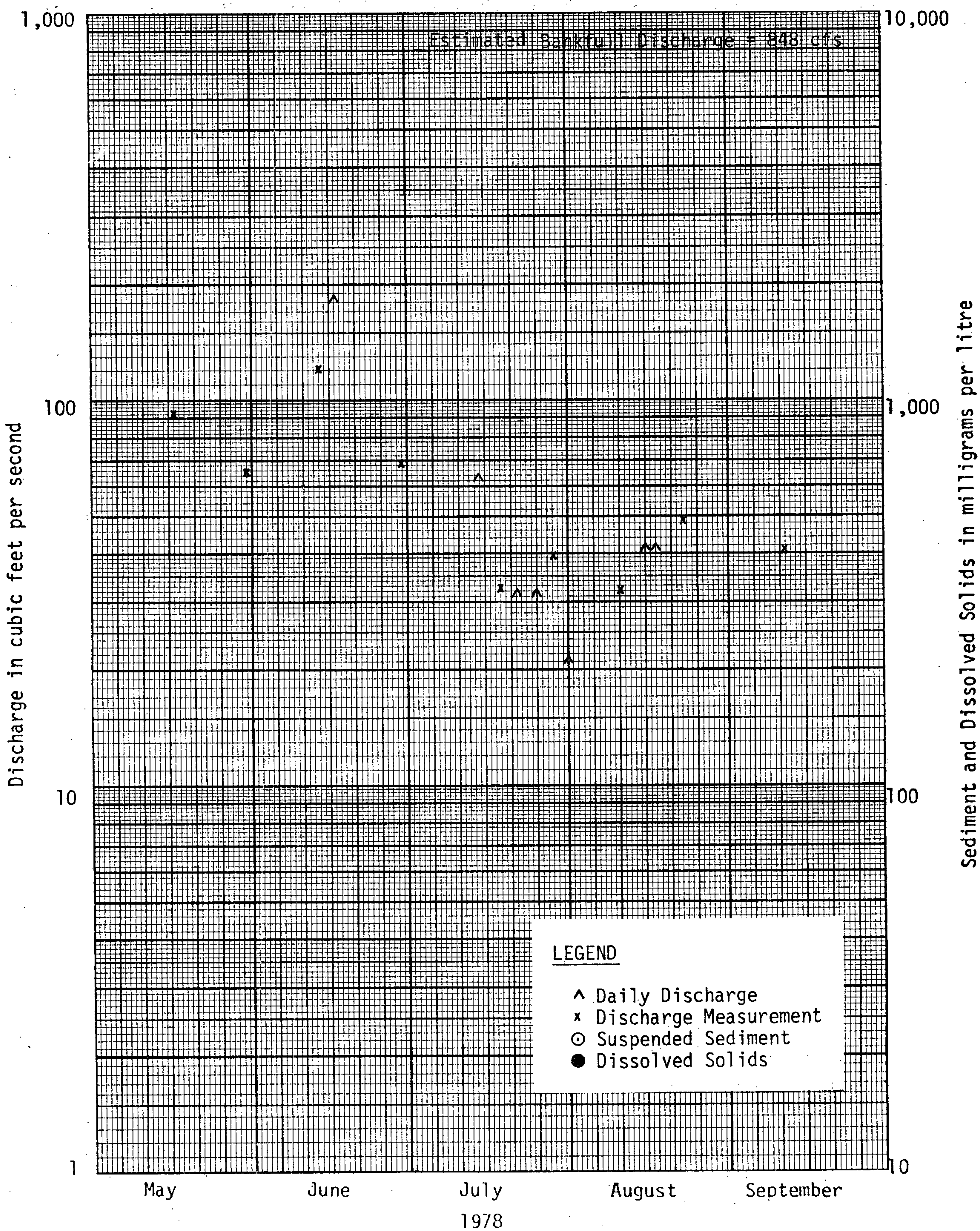


Figure 10 - MENDENHALL CREEK AT MP 968.0

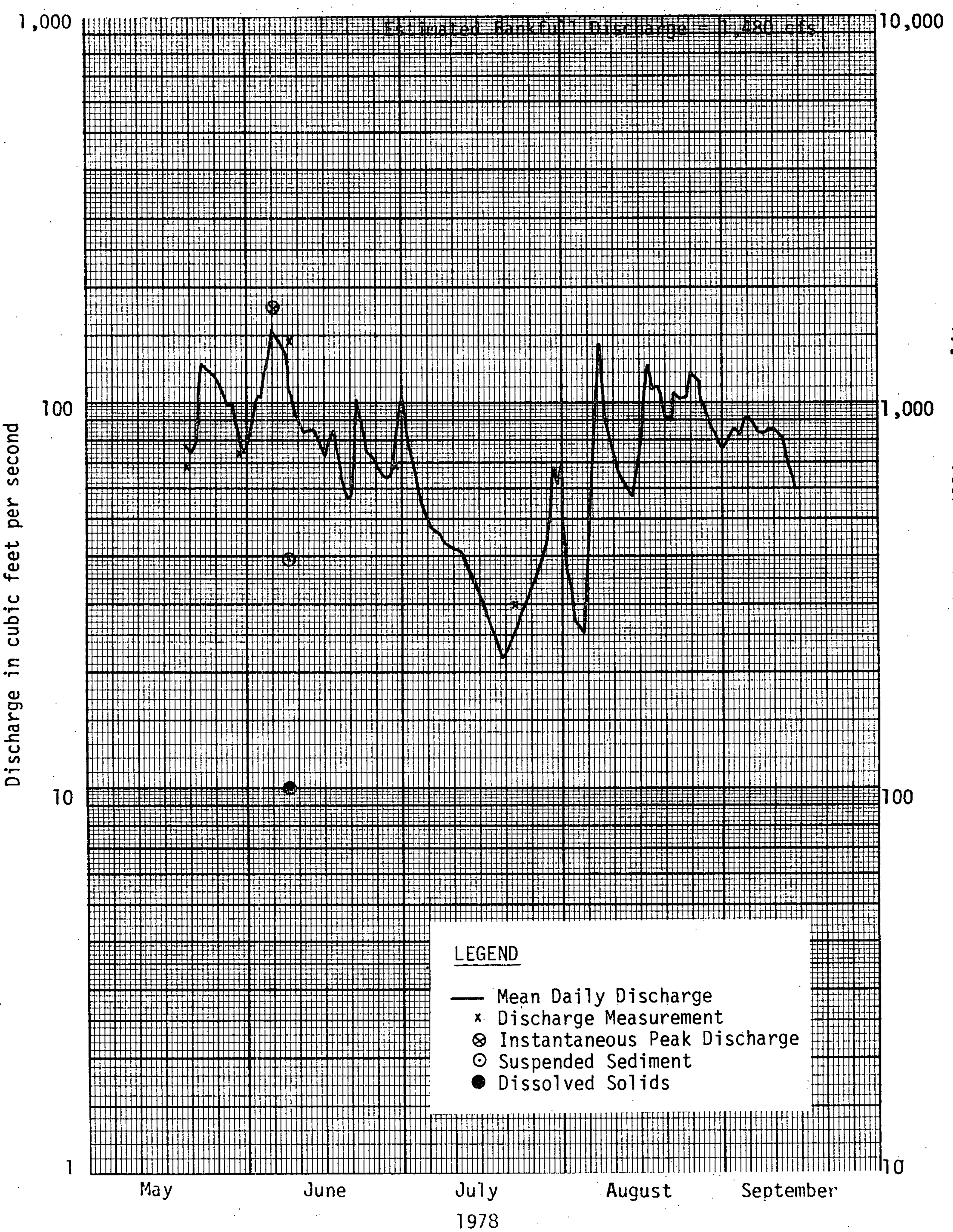


Figure 11 - STONEY CREEK AT MP 956.0

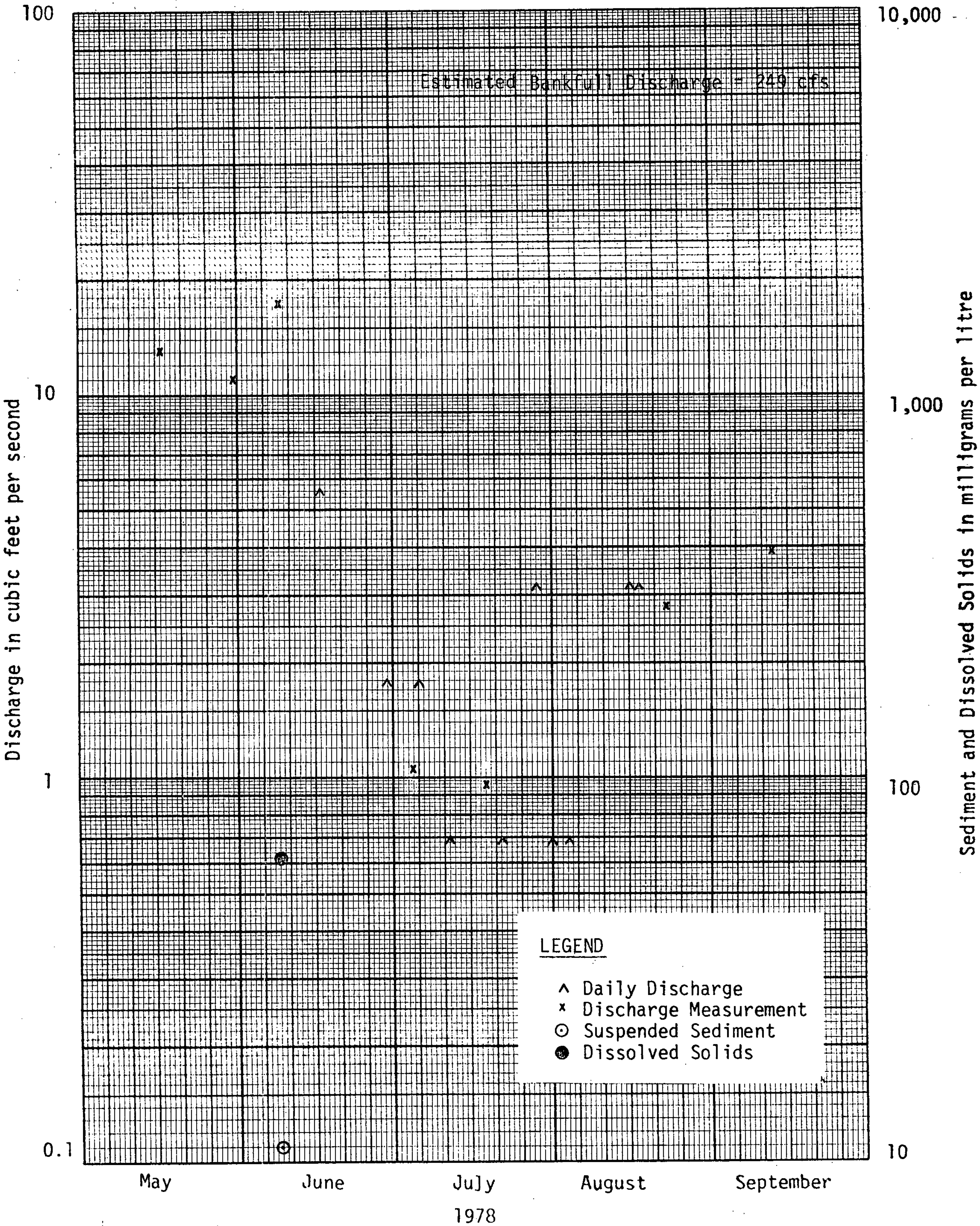


Figure 12 - DEADMANS CREEK AT MP 822.3

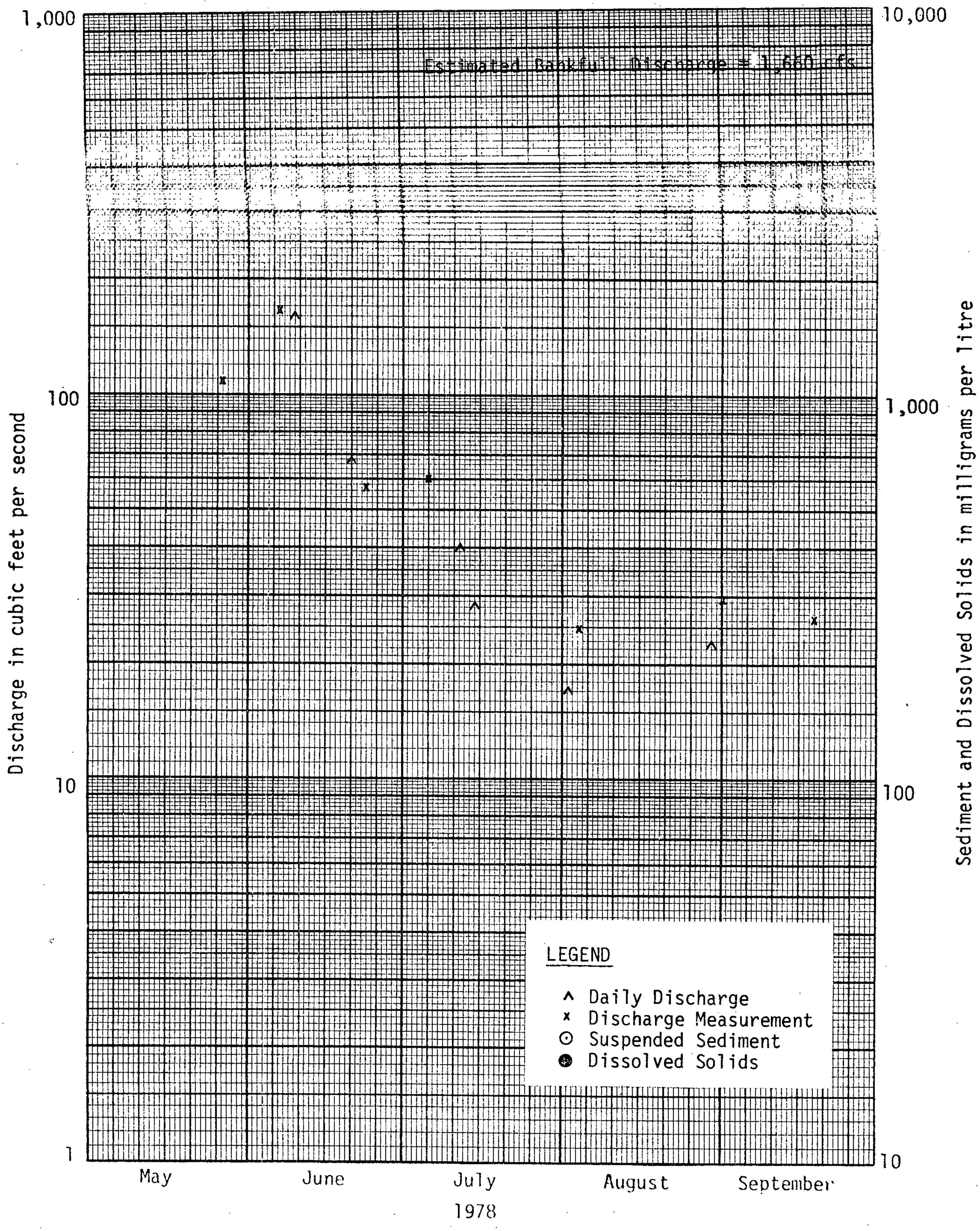


Figure 13 - LOGJAM CREEK AT MP 751.1

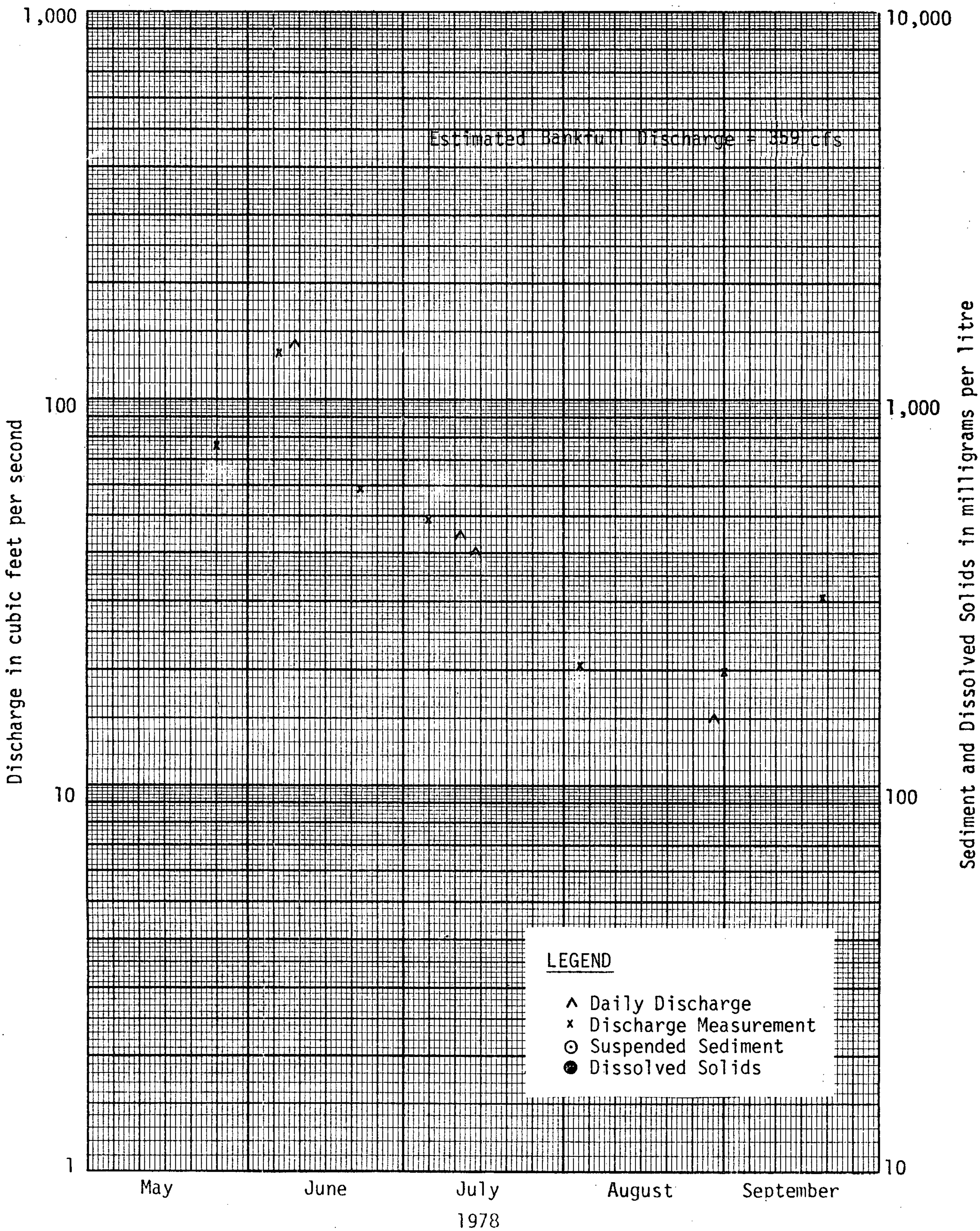


Figure 14 - PARTRIDGE CREEK AT MP 736.4

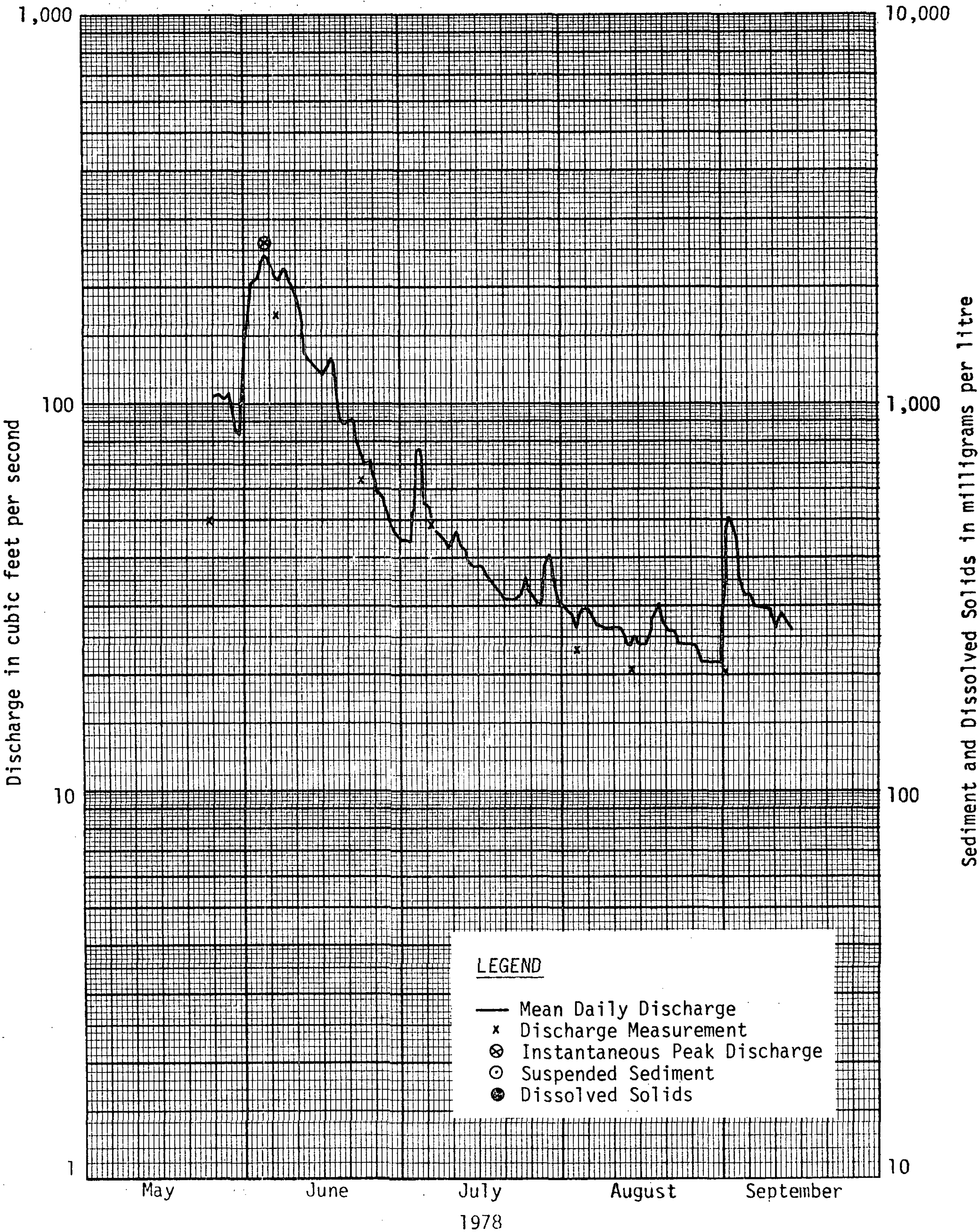


Figure 15 - SPENCER CREEK AT MP 695.3

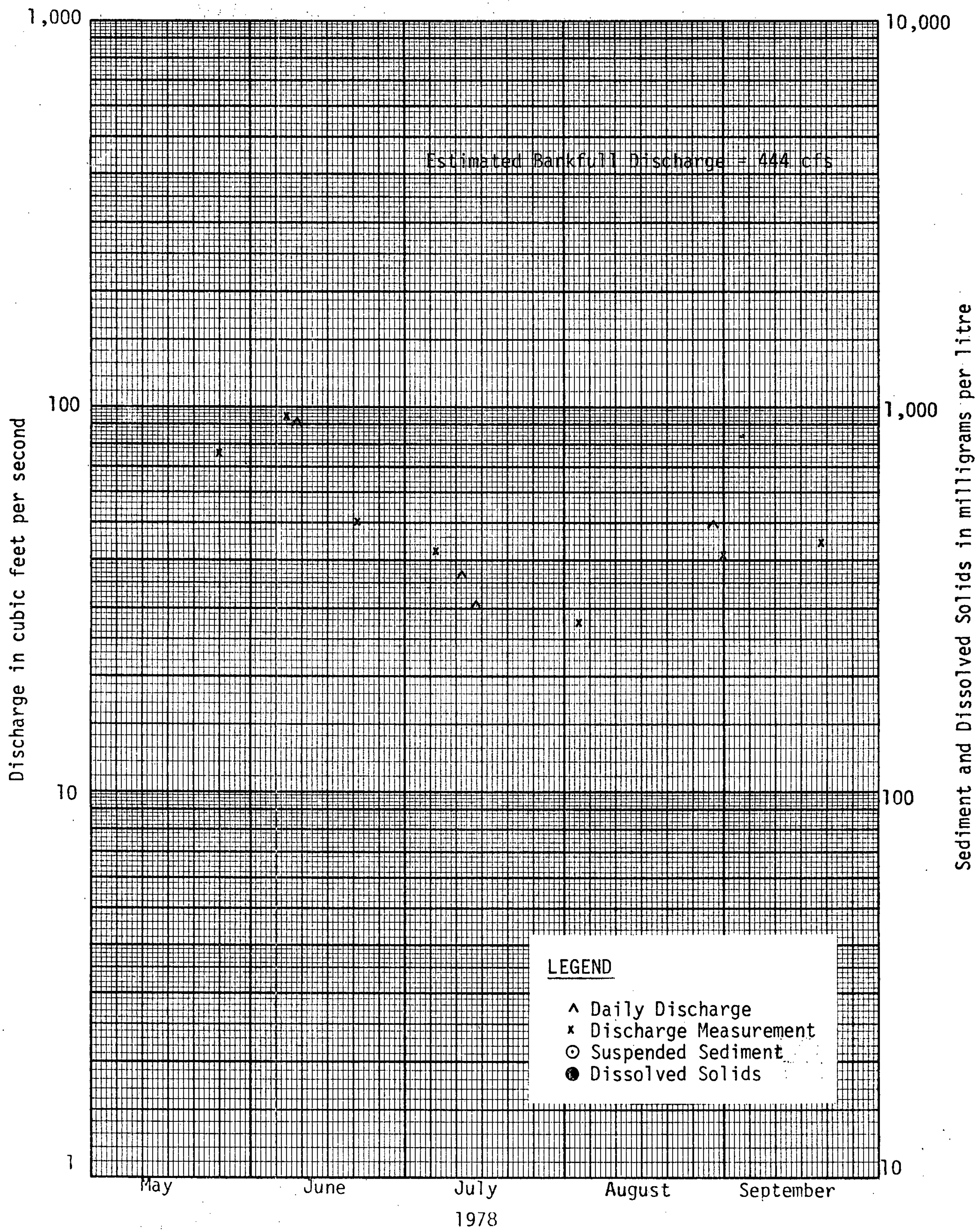


Figure 16 - BIG CREEK AT MP 674.1

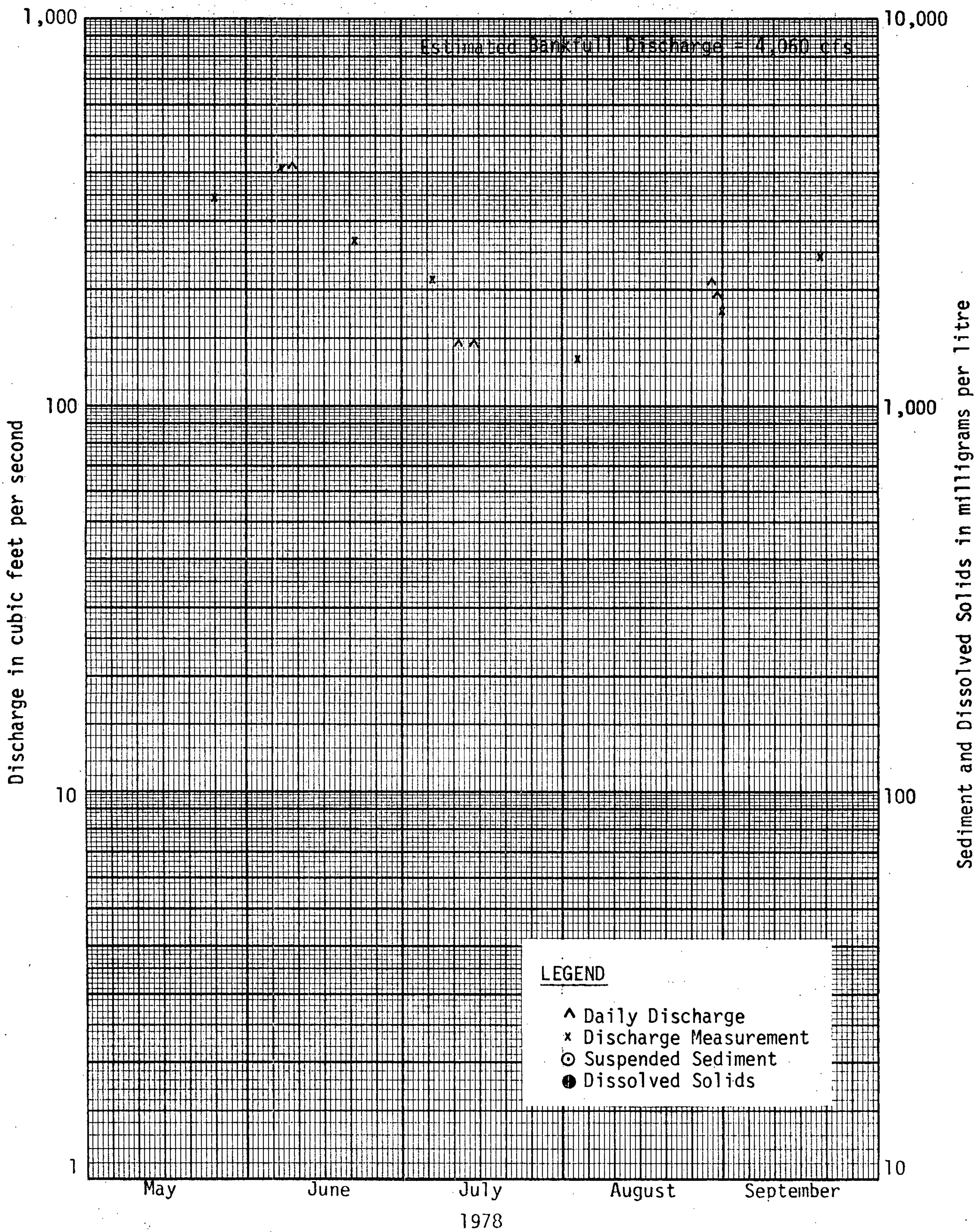


Figure 17 - WHITE AND DONJEK RIVERS - 1978

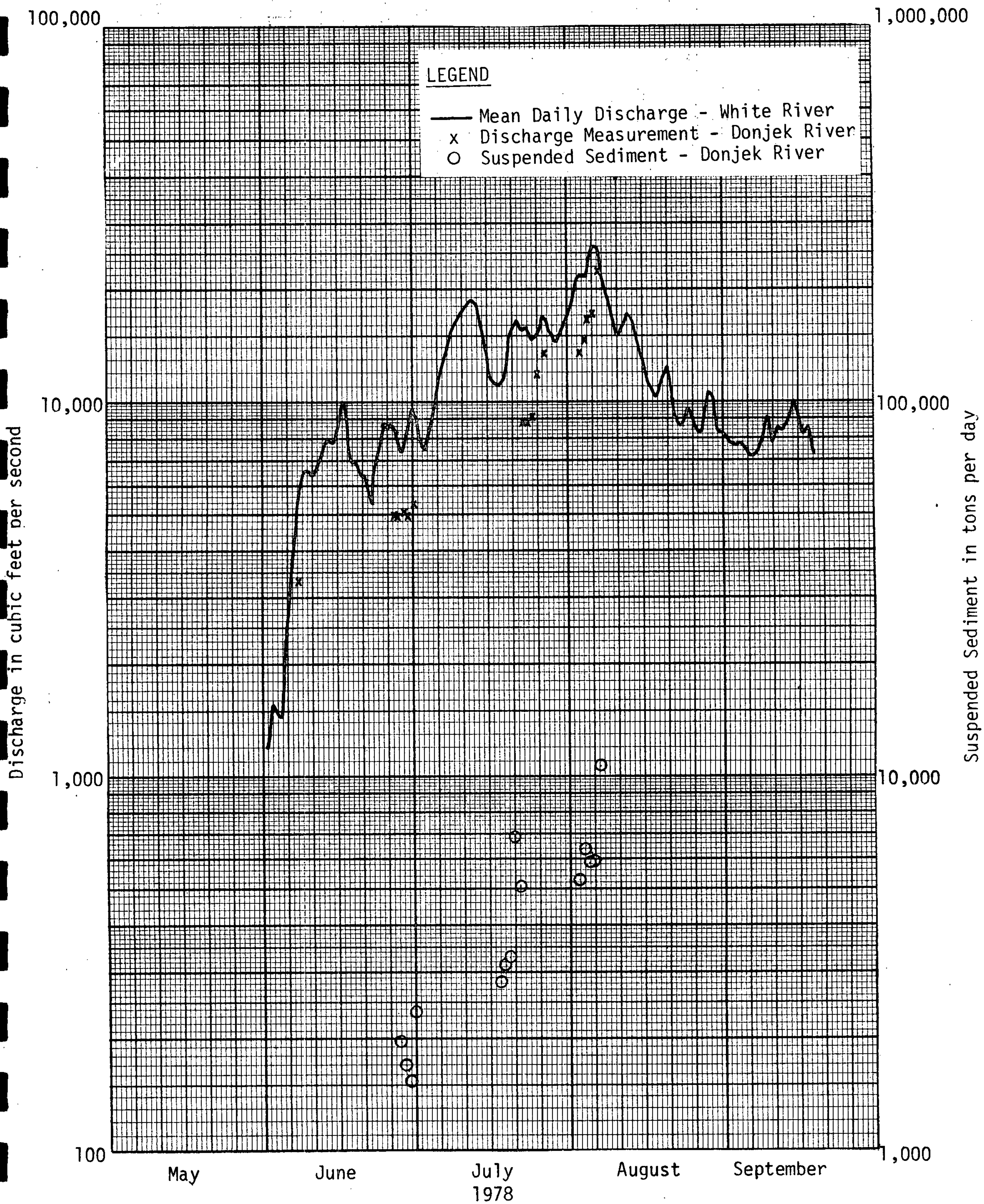


Figure 18 - DONJEK RIVER - Suspended Sediment Load, 1977 & 1978

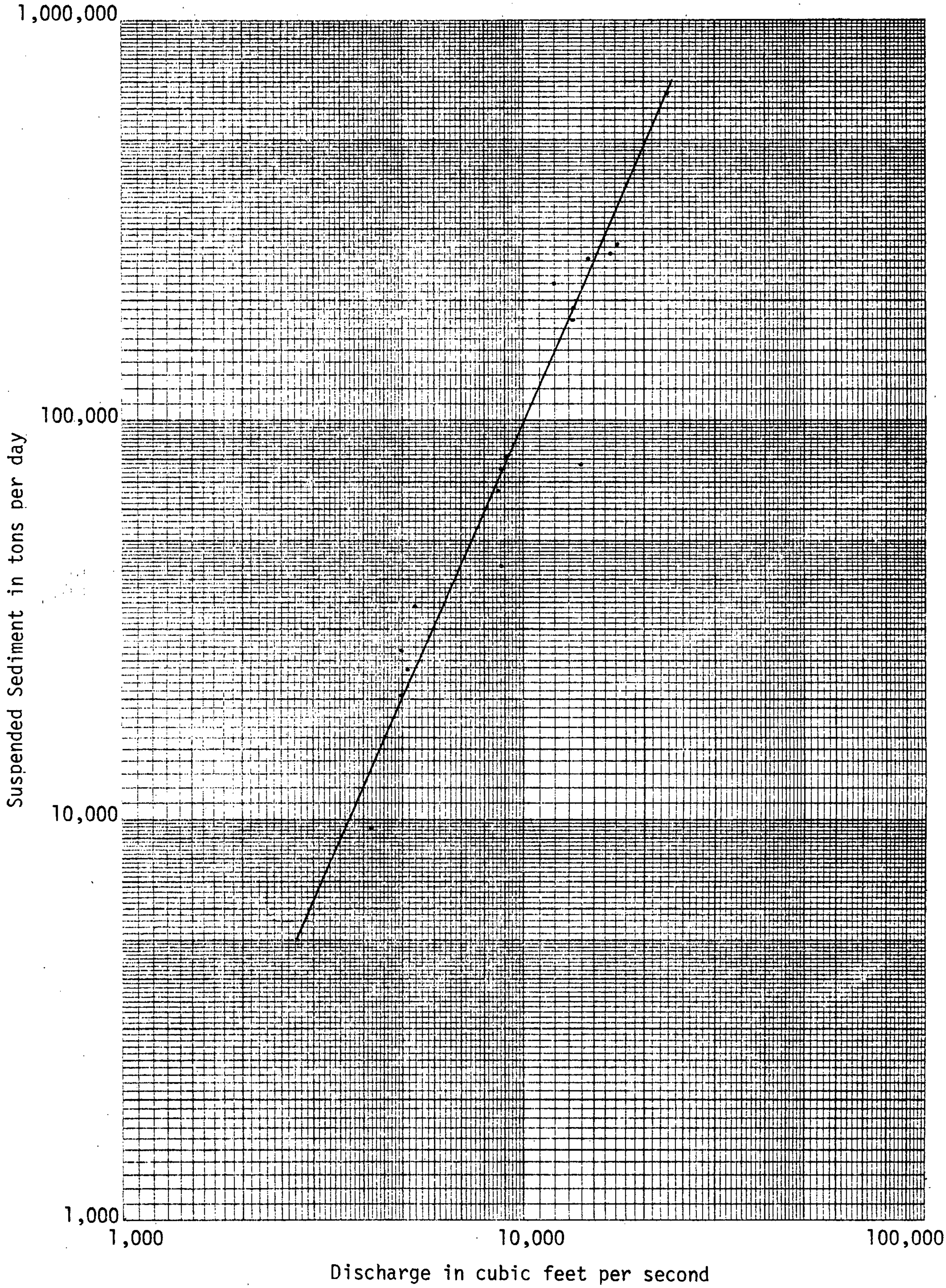


Figure 19 - ALSEK RIVER ABOVE BATES RIVER, 1974 - 1977

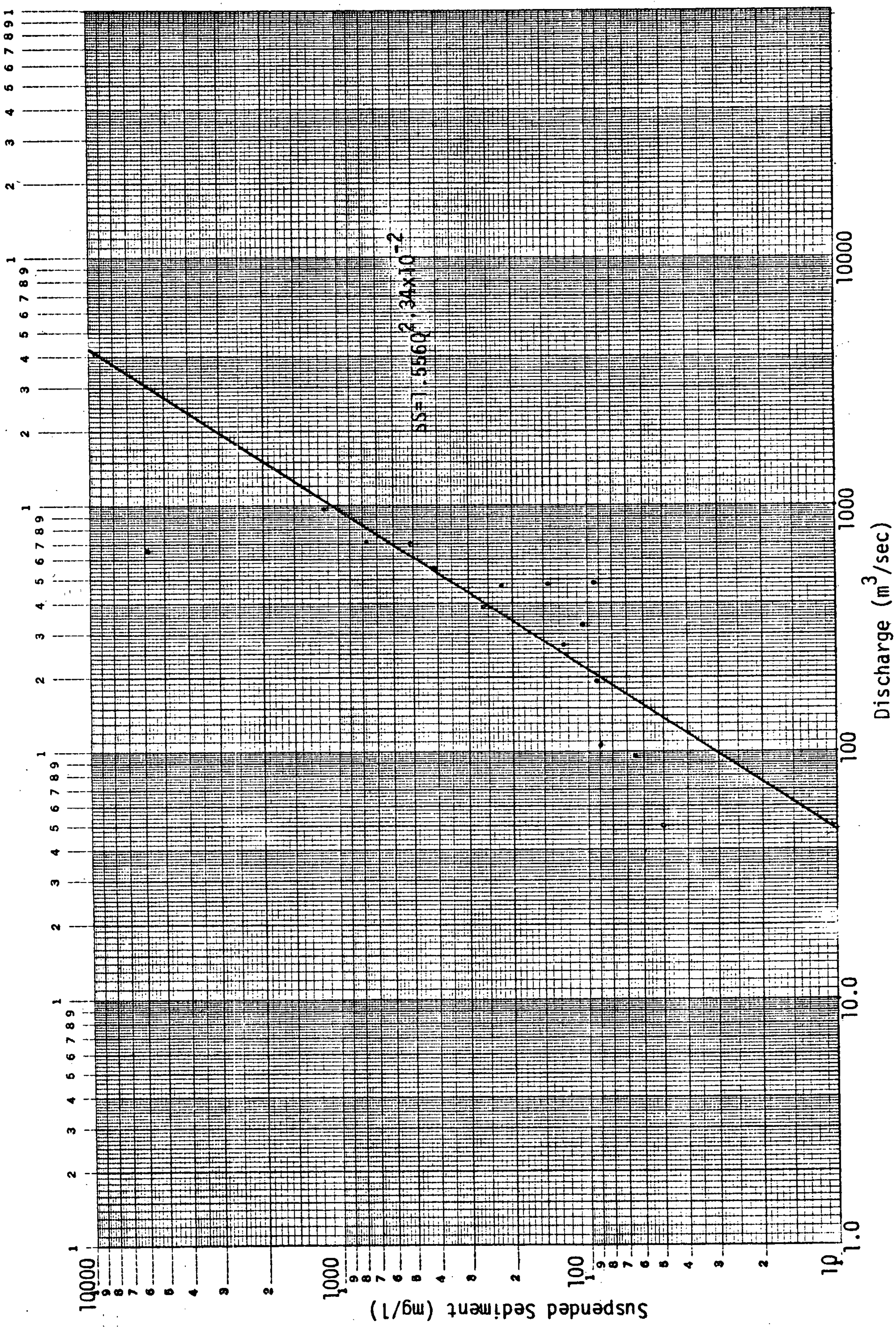


Figure 20 - DONJEK RIVER AT ALASKA HIGHWAY, 1977 - 1978

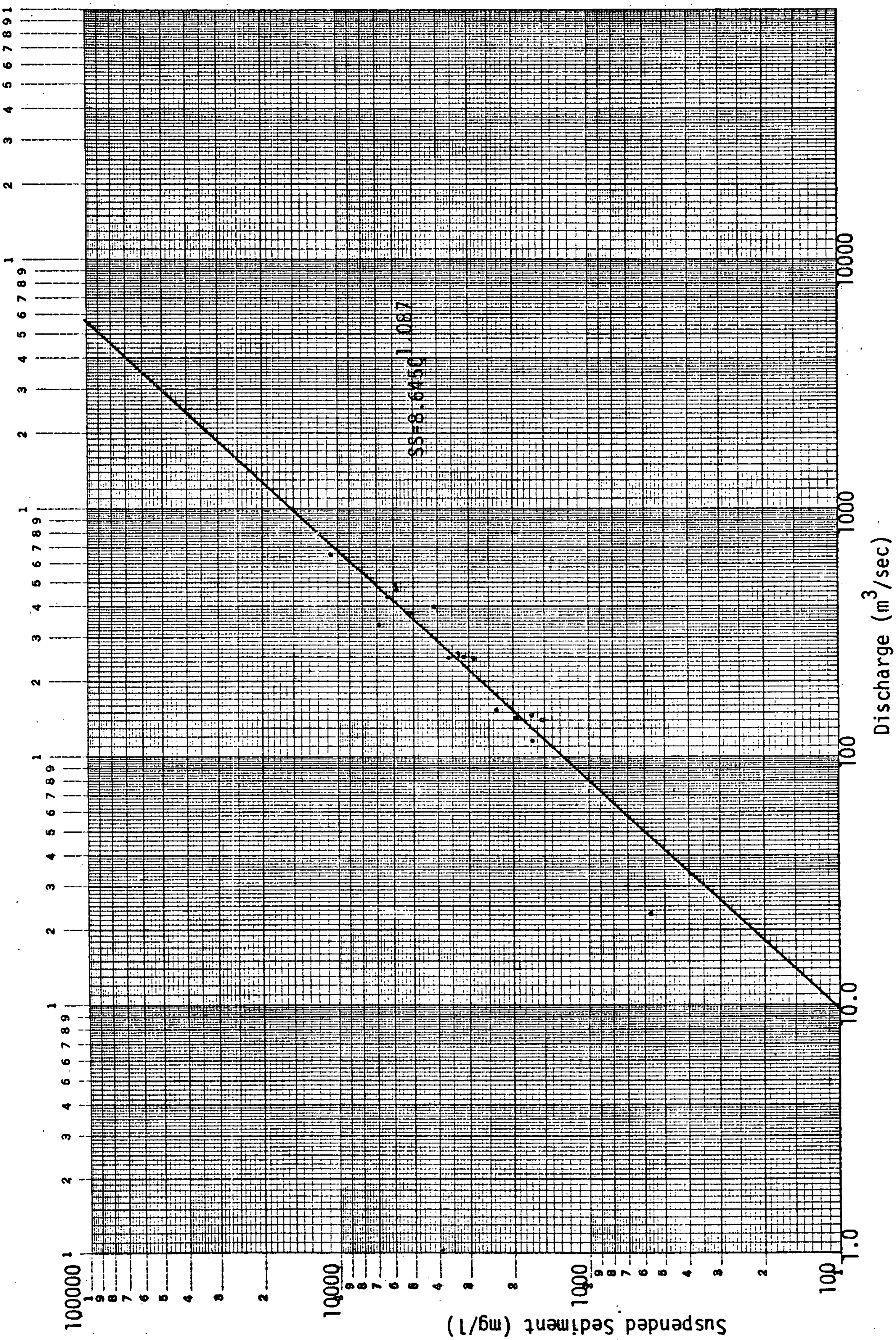


Figure 21 - PELLY RIVER AT PELLY CROSSING, 1968 & 1970 - 1977

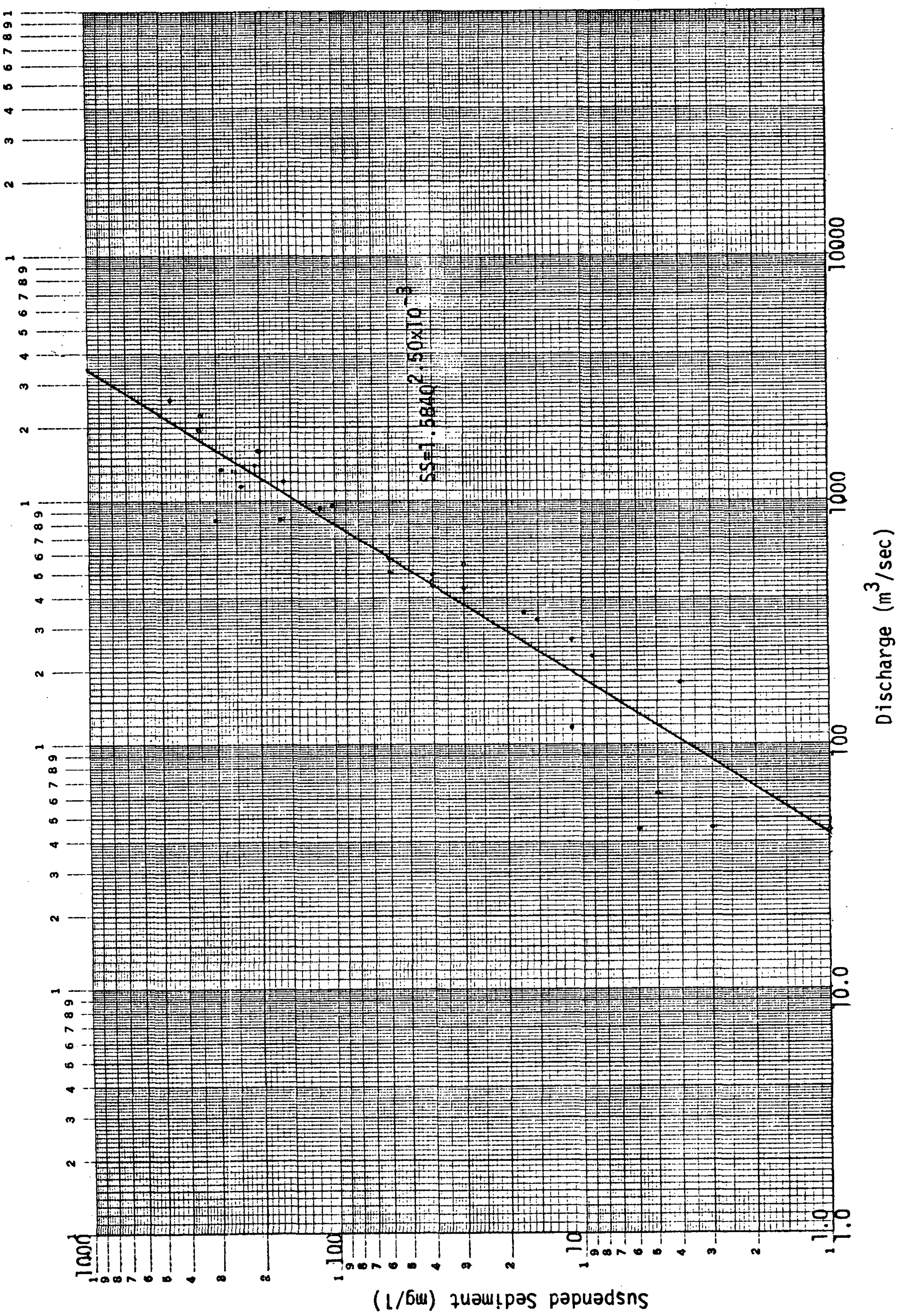


Figure 22 - STEWART RIVER AT MOUTH, 1968 & 1975 - 1977

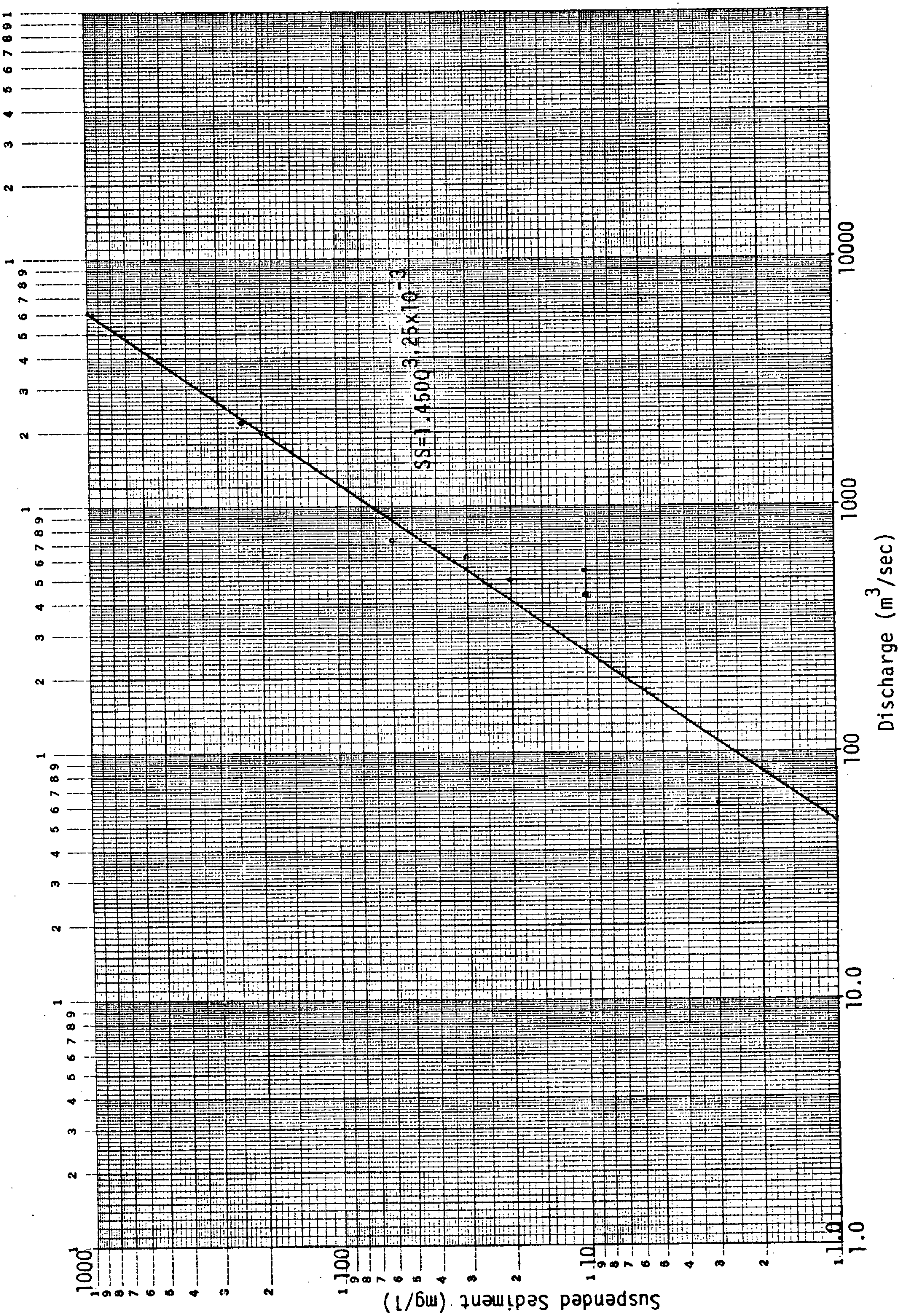


Figure 23 - WHITE RIVER AT MILE 1169.2 ALASKA HIGHWAY, 1972, 1975 & 1977

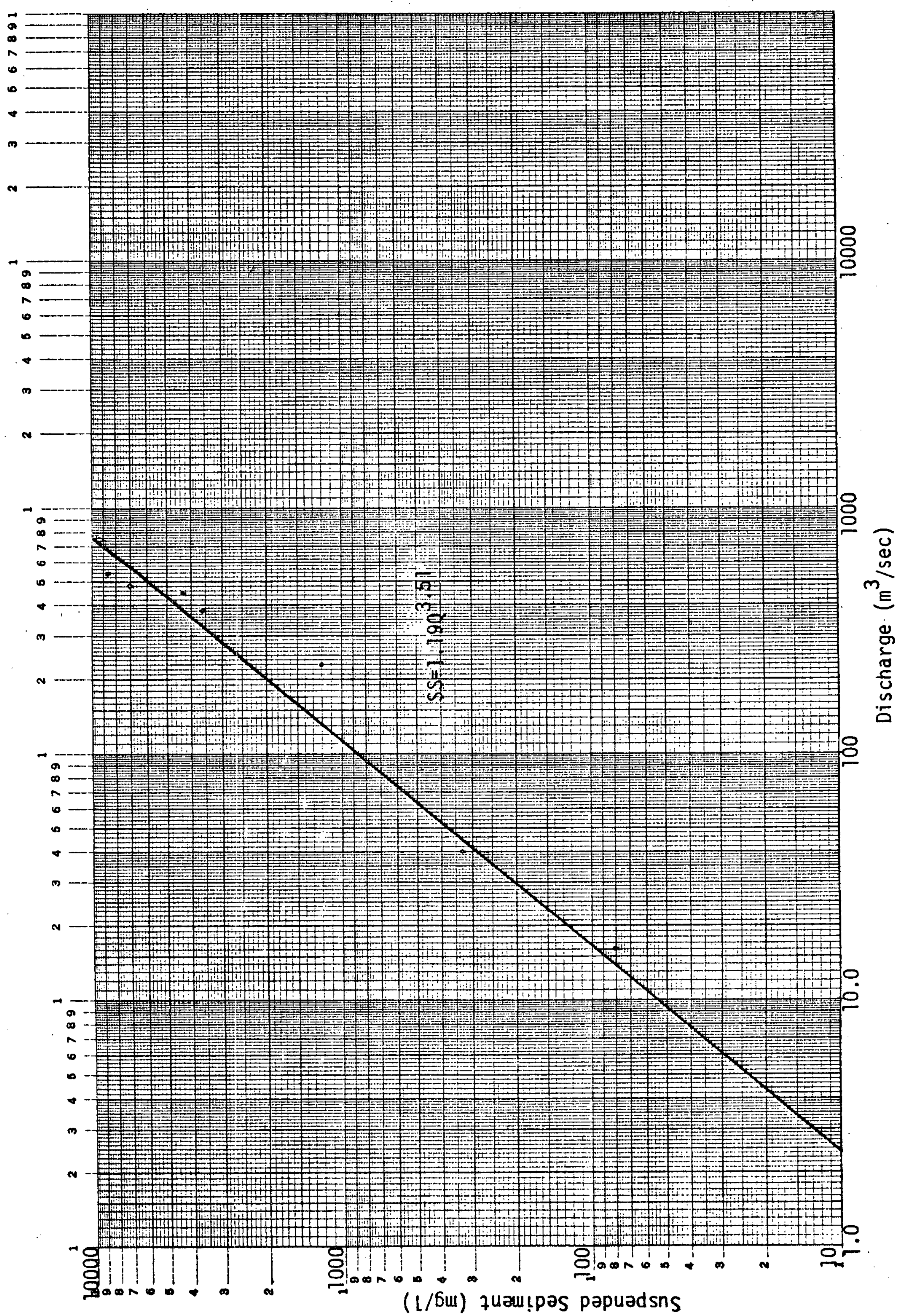
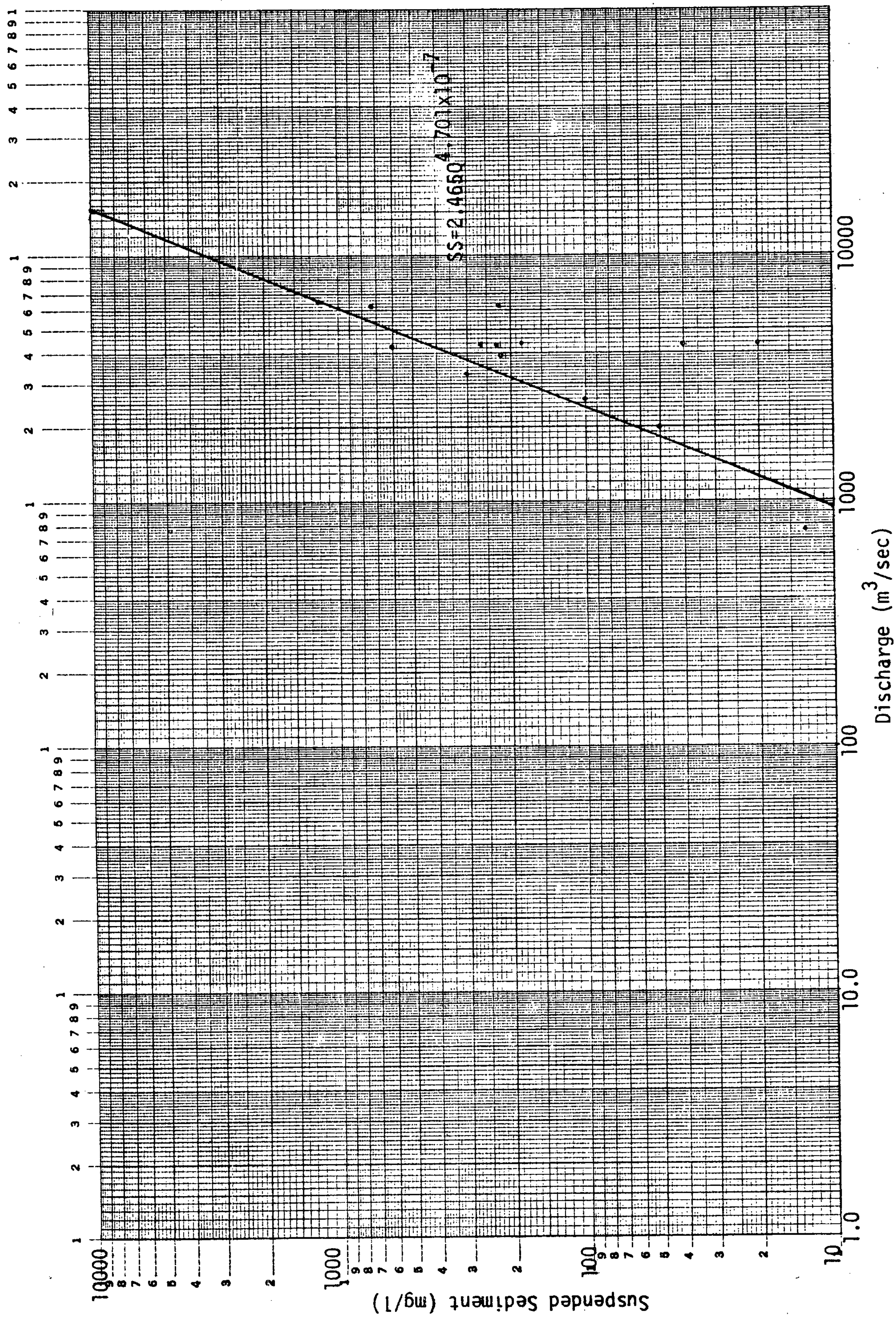


Figure 24 - YUKON RIVER AT DAWSON, 1968, 1971 & 1974 - 1977



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by

W.L. Kreuder and R.M. Leith

1 July 1977

Revised August 1978

Planning & Studies Section
Water Survey of Canada
Inland Waters Directorate
Pacific and Yukon Region
Vancouver, B.C.

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ABSTRACT

Several methods have been used to aid in estimating selected hydrologic quantities of the Yukon Territory for an examination and adequate assessment of the pipeline proposals. Regression on physiographic parameters was used to compute the mean annual flood, the 10-year flood, the 50-year flood and the 100-year flood. The ratio to mean annual flood technique was another method to derive the same values; and the envelope curve approach served as a back-up to estimating extreme values. Regression studies were also conducted for mean annual flow volumes and low flows, defined as the average flow over a seven-day period.

1. INTRODUCTION

Water level records were collected on the Yukon River at Whitehorse as early as 1902, but streamflow data was not gathered until the early 1940's when several stations were established on the Yukon River. Presently (1977) records are available from approximately 50 locations for periods of time varying from one year to 35 years. Nearly half of these stations were established around Whitehorse and along the stem of the Yukon River. One of the results of this lack of network development is that large areas exist where little or no streamflow information is available. The vast size of the Territory, its great ranges of physiography, and the lack of data precluded a comprehensive analysis of the hydrologic characteristics of the Territory and, indeed, of the major drainage basins to be crossed by the proposed pipeline routes.

Streamflow records at about 40 sites in the Yukon Territory and Northern British Columbia were used to study the hydrology of the area. Peak flows were analyzed for mean, 10-year, 50-year and 100-year recurrence intervals. An analysis of the flood characteristics by multiple regression methods gave a set of equations which relate floods to drainage basin characteristics. Another method of estimating peak flows is presented by the "dimensionless ratio to the mean" technique, a simple technique of multiplying the mean annual flood by a factor derived from the slope of the frequency curve. Also, maximum known floods at more than 60 gauging stations in the Yukon Territory, Northern British Columbia, and Eastern Alaska were related to drainage area size; the resultant envelope curve gave yet another technique of estimating peak flows along the proposed pipeline routes.

Similarly, several methods were used to estimate average annual runoff and low flow volumes.

2. MAGNITUDE AND FREQUENCY OF FLOODS

1. Ratio to Mean Annual Flood

The mean annual flood values (which have a recurrence interval of 2.33 years according to the extremal distribution) and the 50-year and 100-year floods were taken from a compilation of peak flow data published by the Water Survey of Canada in 1972 and 1978 (References 5 and 6) and shown in Table 1. The mean annual flood data were plotted against size of drainage area; since only about forty sampling points could be used no separation of homogeneous regions became evident. The following equation was developed for estimating mean annual flood (M.A.F.) values along the proposed pipeline routes using drainage area size as the only independent variable:

$$\text{Log}_{10}(\text{M.A.F.}) = 0.968 + 0.909\text{Log}_{10}(\text{Drainage Area}) \qquad (1)$$

Figure 1 depicts the mean line and the 90% confidence limits. The relationship is far from complete, but with the available data it gives another method of estimating floods along the pipeline routes.

Assuming some homogeneity the 50-year and 100-year floods expressed as ratios to mean annual floods for the 43 basins in Table 1 were averaged to obtain the following mean ratios for the area:

$$\text{mean 50-year ratio} = 2.01 \times \text{M.A.F.} \qquad (2)$$

$$\text{mean 100-year ratio} = 2.34 \times \text{M.A.F.} \qquad (3)$$

For 13 basins having drainage area less than 1000 square miles the mean ratios are:

$$\text{mean 50-year ratio} = 2.15 \times \text{M.A.F.}$$

$$\text{mean 100-year ratio} = 2.63 \times \text{M.A.F.}$$

The mean lines for the 43 and 13 basins are shown in Fig. 2.

2. Envelope Curve

Maximum known mean daily peak discharges for all gauging stations in the Yukon Territory and some in Northern

British Columbia are listed in Table 2 and were plotted in cubic feet per second per square mile in relation to drainage area size. The plot on Figure 3 shows one envelope curve for drainage basins originating in the Ogilvie-Selwyn Mountains, one curve for the Plateau Mountains on the northeastern side of the St. Elias Mountains and one curve for the Plateau areas generally along the Alaska Highway east of Kluane Lake. The following equations may be used for drainage areas ranging in size from about 50 square miles to 10,000 square miles:

$$q(\text{cfs/sq.mi.}) = 106 \text{ Area}^{-0.18} \quad \text{(Ogilvie-Selwyn Mountains)} \tag{4}$$

$$q = 46 \text{ Area}^{-0.18} \quad \text{(Plateau Mountains)} \tag{5}$$

$$q = 8.6 \text{ Area}^{-0.18} \quad \text{(Plateau)} \tag{6}$$

About halfway between curves (4) and (5), a curve may be drawn for drainage areas in the Northern British Columbia highlands (Dease Plateau).

3. Regression on Physiographic Parameters

The following notes outline a regression study of certain hydrologic quantities upon basin-averaged physiographic parameters. The basins under consideration were in the Yukon Territory or close to the Yukon Territory for which the physiographic characteristics and at least 5 years of streamflow record were available. The purpose of the study was to provide a means of estimating the hydrologic quantities for ungauged basins along the proposed pipeline routes in the Yukon. The hydrologic quantities under consideration were: the mean annual flow, the mean annual flood, the 10-year flood, the 50-year flood, the 100-year flood, the mean annual 7-day low flow, the 10-year 7-day low flow, and the 50-year 7-day low flow.

The regression study was conducted using UBC's TRIP package and the equations have been examined through tests on the residuals as discussed in Draper and Smith (Reference 9).

Tabulation and description of the physiographic parameters are given in Table 4, at the back of this report.

A. Mean Annual Flood (M.A.F.)

Considering basin drainage area only, a logarithmic transformation of data was undertaken to bring the variance to a more uniform band; two equations were produced, one with intercept, the other without.

With intercept:

$$\mathrm{Log}_{10}(\mathrm{M.A.F.}) = 0.9683 + 0.9089\,\mathrm{Log}_{10}(\mathrm{Drainage\ Area}) \qquad (7)$$

$R^2 = 0.8330$ S.E. = 23,055 cfs Skew = 0.859 Kurtosis = 6.25

For normal distribution of residuals skew = 0.0, kurtosis = 3.0. The normalcy of the residuals is a basic assumption of regression analysis; if the residuals are not normal then probably the equation will not be correct and tests on the residuals will not be conclusive. The mean for the sample was 10,700 cfs (mean of mean annual floods). This equation was used in Section 1, Ratio to Mean Annual Flood.

Without intercept:

$$\mathrm{Log}_{10}(\mathrm{M.A.F.}) = 1.181\,\mathrm{Log}_{10}(\mathrm{Drainage\ Area}) \qquad (8)$$

$R^2 = 0.9929$ S.E. = 53,000 cfs Skew = -3.94 Kurtosis = 19.5

This appears to be a considerably weaker equation in view of the higher standard error, larger magnitude of skew and kurtosis.

When the residuals for the equation with intercept are plotted against observed mean annual flood a non-uniform variance is obvious; largest residuals appear for largest mean annual floods. As well a sloped band of residuals gives indication of missing terms. There is a suggestion of regionality with a concentration of negative residuals, i.e. overprediction, occurring in the southwestern section of the Territory.

With the remaining 10km x 10km grid basin-averaged physiographic parameters added to the study, 37 stations were used in developing a 10-variable equation.

$$\text{Log}_{10}(\text{M.A.F.}) = 20.1529 + 0.9484\text{Log}_{10}(\text{AREA}) - 0.7732\text{Log}_{10}(\text{NPOS I}) - 4.3917\text{Log}_{10}(\text{NPOS J}) + 1.9478\text{Log}_{10}(\text{ELEV}) - 0.3026\text{Log}_{10}(\text{RA LKE}) + 0.2716\text{Log}_{10}(\text{RA GLC}) - 2.7439\text{Log}_{10}(\text{SE NW}) - 0.3339\text{Log}_{10}(\text{SE W}) + 0.0246\text{Log}_{10}(\text{SS E}) - 0.0263\text{Log}_{10}(\text{SS SE}) \quad (9)$$

FPROB critical was 0.05 so all the variables appear to be significant. The Standard Error was 10,200 cfs. Skew = -1.55 Kurtosis = 14.9

By a rule of thumb used in regression building there are too many predictor variables for 37 observations. Usually 5 observations are required per parameter or predictor variable used in an equation. Also, signed slopes are not properly admitted to equations that involve log transformation, as these variables take negative and zero values. In using log transformations, zero and negative values are translated to one's or some other value.

In view of the excessive number of variables, the signed slopes were removed and a shorter equation developed.

$$\text{Log}_{10}(\text{M.A.F.}) = 5.0702 + 0.9400\text{Log}_{10}(\text{AREA}) + 1,8651\text{Log}_{10}(\text{ELEV}) - 0.2853\text{Log}_{10}(\text{RA LKE}) + 0.3229\text{Log}_{10}(\text{RA GLC}) - 1.6721\text{Log}_{10}(\text{SE NW}) - 0.5111\text{Log}_{10}(\text{SE W}) \quad (10)$$

The Standard Error was 10,750 cfs. Skew = -0.207 Kurtosis = 6.87 Residuals are not normal but are more nearly so than for the previous equation. The largest residuals for the three equations are shown on the next page. Plots of Residuals vs Predicted Mean Annual Flood show largest residuals occurring with largest floods. i.e. non-uniform variance, but the 6-variable equation does move toward a more uniform variance band than the drainage area only equation can. (Figures 4 and 5)

Mean Annual Flood - Largest Residuals in Cfs

River & Station No.		Drainage Area Only with Intercept Equation (7)	6-variable Equation (10)	10-variable Equation (9)
Yukon	09AB001	- 12,400		
	09AB009	- 23,000		
	09AH001	- 50,300		
	09CD001 †	- 46,800		
	09EB002		- 20,700	15,300
Liard	10AA001 †		12,000	5,810
	10BE001		4,700	- 44,400
Pelly	09BC001 †		4,160	424
Stewart	09DC002 †	37,600		
	09DD002 †	39,300	- 30,600	- 3,040
	09DD003 †		- 23,800	1,990
Porcupine	09FD001 †	78,500	34,000	- 4,300
Peel	10MA001 †	60,100	11,500	15,400

† These also appeared as large residuals for the 50-year Flood Regression Study.

B. 10-year Flood (Q_{10})

Equations for the 10-year or 10 percent flood and the 50-year or 2 percent flood were handled in a similar manner i.e. logarithmic transformation of physiographic parameters (predictor variables). For the 10-year flood (Q_{10}) 6-variable equation:

$$\begin{aligned} \mathrm{Log}_{10}(Q_{10}) = {} & 4.3960 + 0.9246\mathrm{Log}_{10}(\mathrm{AREA}) + 1.7945\mathrm{Log}_{10}(\mathrm{ELEV}) \\ & - 0.5044\mathrm{Log}_{10}(\mathrm{DS\ W}) - 0.3354\mathrm{Log}_{10}(\mathrm{RA\ LKE}) + 0.2658\mathrm{Log}_{10}(\mathrm{RA\ GLC}) \\ & - 1.6271\mathrm{Log}_{10}(\mathrm{SE\ NW}) \end{aligned} \tag{11}$$

The Standard Error was 14,000 cfs. Skew = 0.796 Kurtosis = 6.55
No residual plots have been done.

10-year flood, 50-year flood and mean annual flood are closely related; there is very nearly a common ratio for $\frac{\text{10-year}}{\text{Mean Annual}}$ and $\frac{\text{50-year}}{\text{Mean Annual}}$ for the stations in the study. The largest residuals occurred for the following stations:

10-year Flood - Largest Residuals in Cfs

River & Station No.		6-variable Equation (11)
Yukon	09CD001	22,000
Stewart	09DC002	20,100
	09DD002	- 32,800
Porcupine	09FD001	44,400
Liard	10AA001	28,000
Pelly	09BC001	24,300
Peel	10MA001	24,200

These stations also show largest residuals for 50-year flood (the equations have the same variables and similar coefficients). The equation for 10-year flood was "tested" by applying it to ungauged basins near basins for which physiographic parameters are available.

C. 50-year & 100-year Floods (Q_{50} and Q_{100})

As a first step, equations were developed for the 50-year and 100-year floods in cfs for drainage areas in square miles.

$$\text{Log}_e(Q_{50}) = 3.08 + 0.887 \times \text{Log}_e(\text{D.A.}) \quad R^2 = 0.793 \qquad (12)$$

$$\text{or } Q_{50} = 21.8 \times (\text{D.A.})^{0.887}$$

$$\text{Log}_e(Q_{100} = 3.26 + 0.880 \times \text{Log}_e(\text{D.A.}) \quad R^2 = 0.775 \qquad (13)$$

$$\text{or } Q_{100} = 26.1 \times (\text{D.A.})^{0.880}$$

Notes:

(1) Residuals from these equations show a non-uniform distribution, with a large divergence for larger floods.

(2) Considering the standard errors for the coefficients there is no significant difference between the equations.

(3) The equations should not be used for drainage areas of less than one hundred square miles. They will be most reliable for streams with drainage areas of about 2500 square miles.

As an example of the use of the equations consider Station 09BA001:

Drainage area = 2800 square miles

$Q_{50} = 21.8 \times (2800)^{0.887} = 24893$ (24900) cfs

Q "observed" was 29200 cfs.

$Q_{100} = 26.1 \times (2800)^{0.880} = 28193$ (28200) cfs

Q "observed" was 32500 cfs.

The next step was utilization of additional information provided by the correlation with other physiographic parameters. Equations were developed by forward selection for Q_{50} and Q_{100}.

For Q_{50}:

RSQ = 0.9826

FPROB = 0.0

STD ERR Y = 0.2357

VAR	COEFF	STD ERR	F-RATIO	FPROB
CONST	30.0859	5.1163		
AREA	0.9491	0.0368	663.8878	0.0
ELEV	1.1510	0.4238	7.3755	0.0104
RA LKE	-0.3317	0.0735	20.3380	0.0001
RA FOR	-0.8821	0.1775	24.6849	0.0000
BH W	0.7887	0.3129	6.3533	0.0163
SE NW	-2.2147	0.2653	69.7068	0.0000
SE W	-1.2739	0.2216	33.0366	0.0000

where variables are logarithms to the base e

i.e.	ELEV	mean basin elevation
	RA LKE	relative area of lakes
	RA FOR	relative area of forests
	BH W	barrier height to the west
	SE NW	shield effect to the northwest
	SE W	shield effect to the west

$$\text{Log}_e(Q_{50}) = 30.1 + 0.9491 \times \text{Log}_e(\text{AREA}) + 1.1510 \times \text{Log}_e(\text{ELEV}) - 0.3317 \times \text{Log}_e(\text{RA LKE}) + \ldots.$$

For Q_{100}:

RSQ = 0.9746

FPROB = 0.0

STD ERR Y = 0.2817

VAR	COEFF	STD ERR	F-RATIO	FPROB
CONST	15.0187	3.0778		
AREA	0.9577	0.0444	464.5321	0.0
ELEV	1.9587	0.4219	21.5475	0.0001
DS W	-0.7939	0.1013	61.4329	0.0000
RA LKE	-0.3432	0.0874	15.4241	0.0005
RA FOR	-0.4537	0.1398	10.5371	0.0028
SE NW	-1.8166	0.2237	65.9406	0.0000

DS W distance to the sea to the west

Again all variables are logarithms to the base e.

3. MEAN ANNUAL FLOW VOLUME

Regression on Physiographic Parameters

For the Regression Study of mean annual flow, no logarithmic transformation was used. The response variable was the unit mean annual flow or mean annual flow per unit area. This transformation removed the spurious effect of drainage area.

42 stations were employed to develope the following equation:

Unit Mean Annual Flow (cfs/sq.mi.) = 3.3020 + 0.0152(SLP %) + 0.006671(DS N) - 0.004113DS NW) - 0.0008409(DSSW) + 0.1096(RA GLC) - 0.0002479(BH N) - 0.00002049(SE NW) (14)

The Standard Error was 19% of the mean response of 0.969 cfs/sq.mi. The skew of the residuals was 0.737 and the kurtosis was 3.37. The largest residuals occurred for the following stations:

Unit Mean Annual Flow - Largest Residuals in Cfs/Sq.mi.

River & Station No.		Observed	Predicted	Residual
Atlin	09AA006	1.270	0.976	0.294
Tutshi	09AA013	1.519	1.134	0.385
Swift	09AE003	1.352	1.046	0.306
Blue	10AC004	0.954	1.252	- 0.299
Cottonwood	10AC005	1.950	1.535	0.415
Coal	10BC001	1.027	0.714	0.313
Turnagain	10BA001	1.178	1.432	- 0.255
Aishihik	08AA001	0.336	0.608	- 0.272

A geographical plot revealed a cluster of negative residuals in the southwest corner of the Territory indicating the equation overpredicts in this region. Overall this equation may be applied to ungauged basins with fair confidence provided

3. MEAN ANNUAL FLOW VOLUME

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For the Regression Study of mean annual flow, no logarithmic transformation was used. The response variable was the unit mean annual flow or mean annual flow per unit area. This transformation removed the spurious effect of drainage area.

42 stations were employed to develope the following equation:

$$\text{Unit Mean Annual Flow (cfs/sq.mi.)} = 3.3020 + 0.0152(\text{SLP \%}) + 0.006671(\text{DS N}) - 0.004113\text{DS NW}) - 0.0008409(\text{DSSW}) + 0.1096(\text{RA GLC}) - 0.0002479(\text{BH N}) - 0.00002049(\text{SE NW}) \quad (14)$$

The Standard Error was 19% of the mean response of 0.969 cfs/sq.mi. The skew of the residuals was 0.737 and the kurtosis was 3.37. The largest residuals occurred for the following stations:

Unit Mean Annual Flow - Largest Residuals in Cfs/Sq.mi.

River & Station No.		Observed	Predicted	Residual
Atlin	09AA006	1.270	0.976	0.294
Tutshi	09AA013	1.519	1.134	0.385
Swift	09AE003	1.352	1.046	0.306
Blue	10AC004	0.954	1.252	- 0.299
Cottonwood	10AC005	1.950	1.535	0.415
Coal	10BC001	1.027	0.714	0.313
Turnagain	10BA001	1.178	1.432	- 0.255
Aishihik	08AA001	0.336	0.608	- 0.272

A geographical plot revealed a cluster of negative residuals in the southwest corner of the Territory indicating the equation overpredicts in this region. Overall this equation may be applied to ungauged basins with fair confidence provided that the physiographic parameters of that basin are not outside the range of those used in developing the equation.

4. LOW FLOWS

Low flow data in the form of annual 7-day average low flows were compiled and published by the Water Survey of Canada in 1974 (References 7 and 8).

For this study 47 gauging stations in the Yukon Territory and Northern British Columbia were utilized to extract the mean annual 7-day low flows (Q_2min), 10-year 7-day low flows, and 50-year 7-day low flows; the data are shown in Table 2.

1. Mean Annual 7-day Low Flow vs Drainage Area

The Q min values were plotted on log paper (Figure 6) against size of drainage area to study the relationship. As expected the size of the sample is too small to define a useful relationship. If necessary the following equation may be used to estimate low flows in ungauged areas where the pipeline may traverse:

$$\text{Log}_{10}(Q_2\text{min}) = -0.6770 + 0.9548\text{Log}_{10}(\text{Drainage Area}) \qquad (15)$$

2. Minimum Daily Discharge

The minimum daily discharges as recorded at over 50 gauging stations are listed in Table 3. These values are mean daily flows which are lower than the 7-day averages mentioned in the previous section. By dividing the mean daily low flow by the drainage area one derives a unit low flow in cfs per square mile, which may help in assessing the low unit discharge along the pipeline routes. There is no evidence that regional variations exist along different routes, which would refine the estimates.

3. Low Flow Regression Study

For low flow regression studies, three hydrologic quantities were studied: mean annual 7-day low flow, the 10-year

7-day low flow and the 50-year 7-day low flow. Logarithmic transformations were used for all equations. For the mean annual 7-day low flow, 44 stations produce the equation:

$$\text{Log}_{10}(\text{Mean Annual 7-day Low Flow in cfs}) (Q_2 min) = 11.5545 + 0.0811\text{Log}_{10}(\text{AREA}) - 2.3420\text{Log}_{10}(\text{ELEV}) + 1.0624\text{Log}_{10}(\text{SLP }\%) + 2.7878\text{Log}_{10}(\text{DS NW}) - 1.5352\text{Log}_{10}(\text{DSSW}) - 0.4549\text{Log}_{10}(\text{BH SW}) - 1.8878\text{Log}_{10}(\text{SE NW}) \quad (16)$$

The Standard Error was 328 cfs. The skew for the residuals was 0.519, kurtosis 6.76 so they are not normally distributed. (Figure 7) The largest residuals occurred for the largest basins:

Mean Annual 7-day Low Flow - Largest Residuals in Cfs

River & Station No.		Observed	Predicted	Residual
Yukon	09AB001	2,400	1,710	688
	09AB009	3,700	2,780	916
	09CD001	9,860	9,040	818
	09AH001	7,510	6,850	657
Pelly	09BC001	1,560	2,480	- 917
Stewart	09DD002	1,710	1,290	419
Atlin	09AA006	904	571	333

44 stations were used to develope the following equation for the 10-year, or 10 percent, 7-day low flow.

$$\text{Log}_{10}(Q_{10} min) = 17.7940 + 0.1060\text{Log}_{10}(\text{AREA}) - 3.2120\text{Log}_{10}(\text{ELEV}) + 1.2203\text{Log}_{10}(\text{SLP}\%) + 3.4080\text{Log}_{10}(\text{DS NW}) - 2.0580\text{Log}_{10}(\text{DS SW}) - 0.6166\text{Log}_{10}(\text{BH SW}) - 2.6299\text{Log}_{10}(\text{SE NW}) \quad (17)$$

$R^2 = 0.7573$ FPROB = 0.0000 S.E. = 0.1245 log units or 328 cfs. The skew was 3.33, the kurtosis 19.2 indicating a definitely non-normal distribution of residuals, so the equation is suspect although it provides relatively good results for the observations. Again the largest residuals occur for the largest basins, indicating the bias of the equation.

10-year 7-day Low Flow - Largest Residuals in Cfs

River & Station No.		Observed	Predicted	Residual
Yukon	09AB001	1,800	1,310	488
	09AB009	2,700	2,140	559
	09CD001	8,200	6,590	1,610
Pelly	09BC001	1,200	1,810	- 614
Atlin	09AA006	740	450	290

For the 50-year or 2 percent 7-day low flow 42 observations were used to develope the equation. Plots of selected physiographic parameters indicated that there was non-uniform variance even with the logarithmic transformation. This makes the equation unreliable with respect to significance of variables and coefficients.

$$\mathrm{Log}_{10}(Q_{50}\mathrm{min}) = 24.1632 + 0.1295\mathrm{Log}_{10}(\mathrm{AREA}) - 4.6780\mathrm{Log}_{10}(\mathrm{ELEV}) + 1.1952\mathrm{Log}_{10}(\mathrm{SLP}\ \%) + 6.4308\mathrm{Log}_{10}(\mathrm{DS\ NW}) - 3.0125\mathrm{Log}_{10}(\mathrm{DS\ SW}) - 0.9455\mathrm{Log}_{10}(\mathrm{BH\ N}) - 4.1279\mathrm{Log}_{10}(\mathrm{SE\ NW}) \quad (18)$$

R = 0.6660 FPROB = 0.0000 S.E. = 0.1683 log units or 309 cfs. The skew and kurtosis of the residuals were 3.40 and 19.4 respectively, bearing out the warning of the non-uniform variance. The largest residuals are again from the largest basins.

The largest residuals, using equation (18) are listed on the following page.

50-year 7-day Low Flow - Largest Residuals in Cfs

River & Station No.		Observed	Predicted	Residual
Yukon	09AB001	1,400	1,100	300
	09AB009	2,100	1,720	385
	09CD001	6,800	5,300	1,500
Liard	10AA001	1,600	1,210	394
Atlin	09AA006	640	352	288
Dease	10AC002	370	659	- 289

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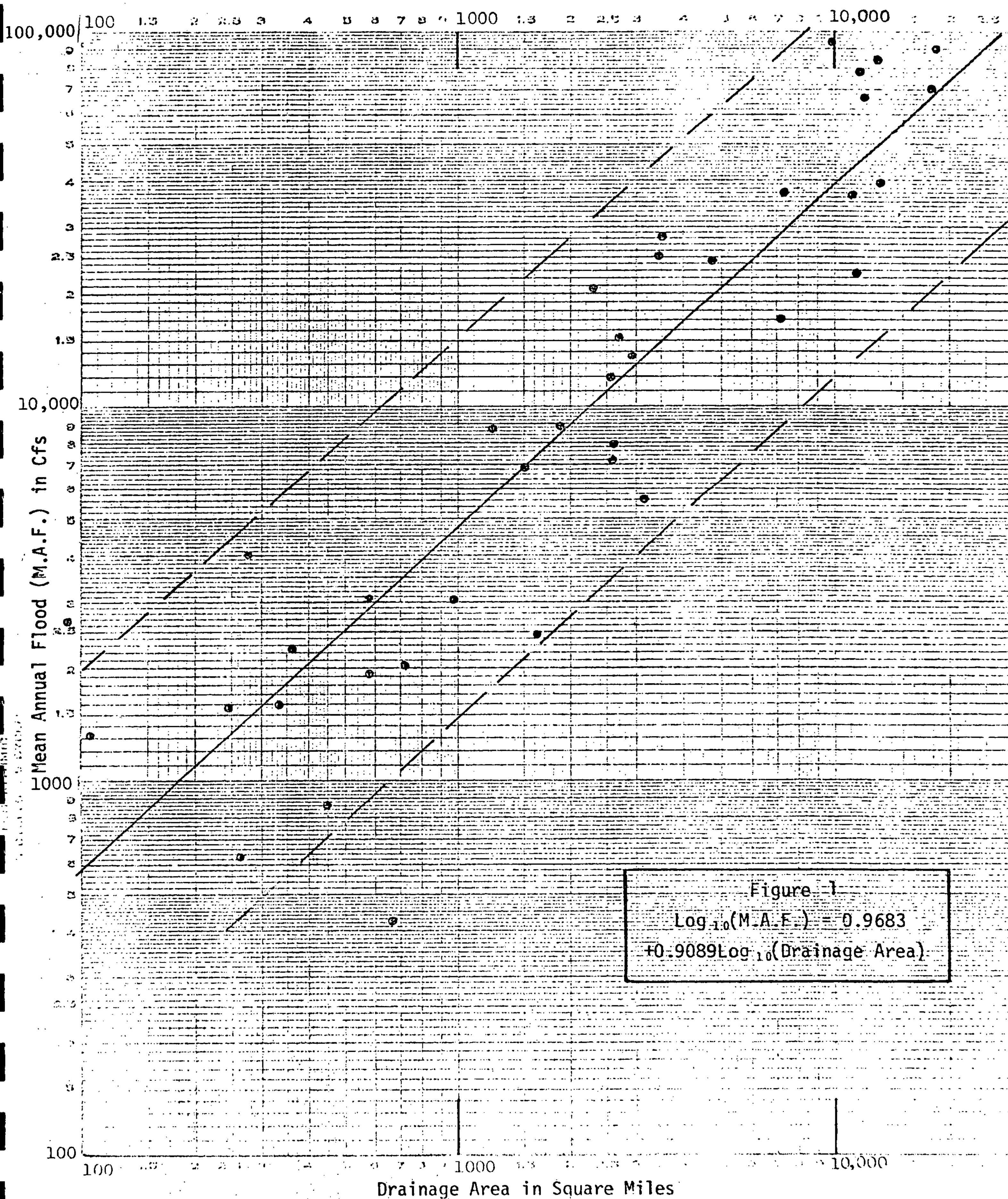

Mean Annual Flood (M.A.F.) in Cfs
100,000
10,000
1000
100
100
1000
10,000
Drainage Area in Square Miles
Figure 1
Log$_{10}$(M.A.F.) = 0.9683
+0.9089Log$_{10}$(Drainage Area)

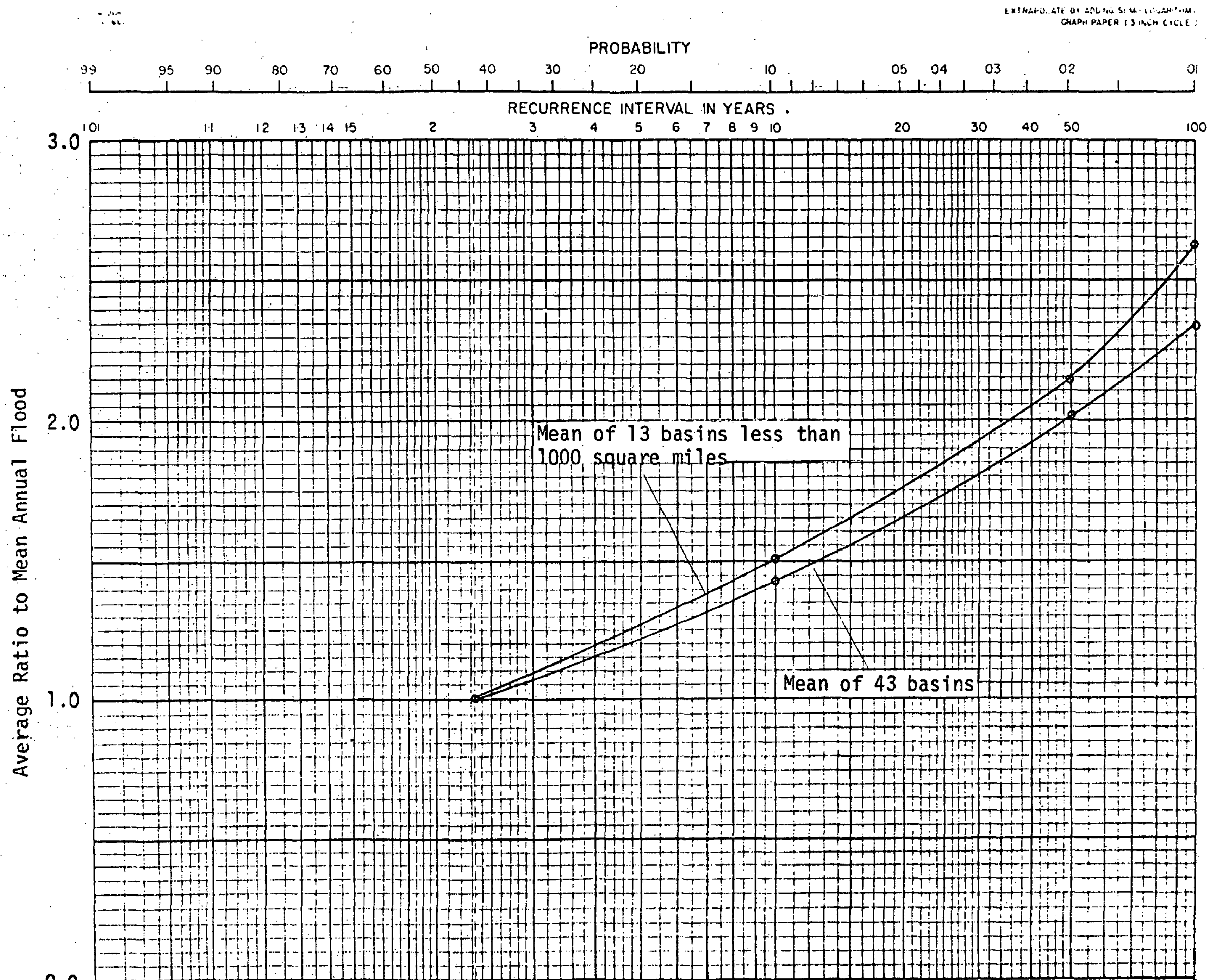
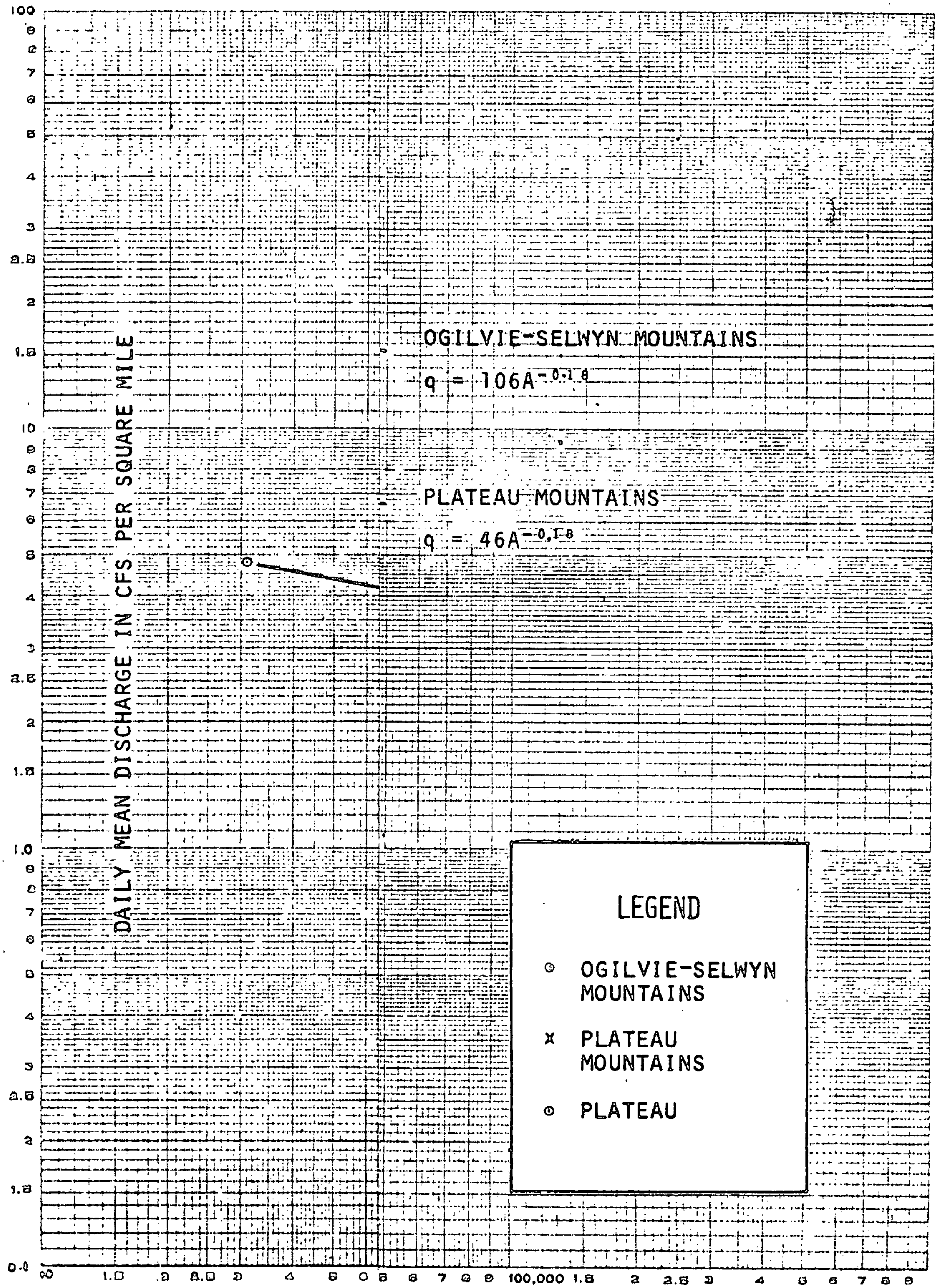


FIGURE 2 TITLE Flood Frequency Alcan Pipeline Routes

PREPARED BY W.L.K. DATE August 15/78



DAILY MEAN DISCHARGE IN CFS PER SQUARE MILE
OGILVIE-SELWYN MOUNTAINS
q = 106A^-0.18
PLATEAU MOUNTAINS
q = 46A^-0.18
LEGEND
OGILVIE-SELWYN MOUNTAINS
PLATEAU MOUNTAINS
PLATEAU

FIGURE 3

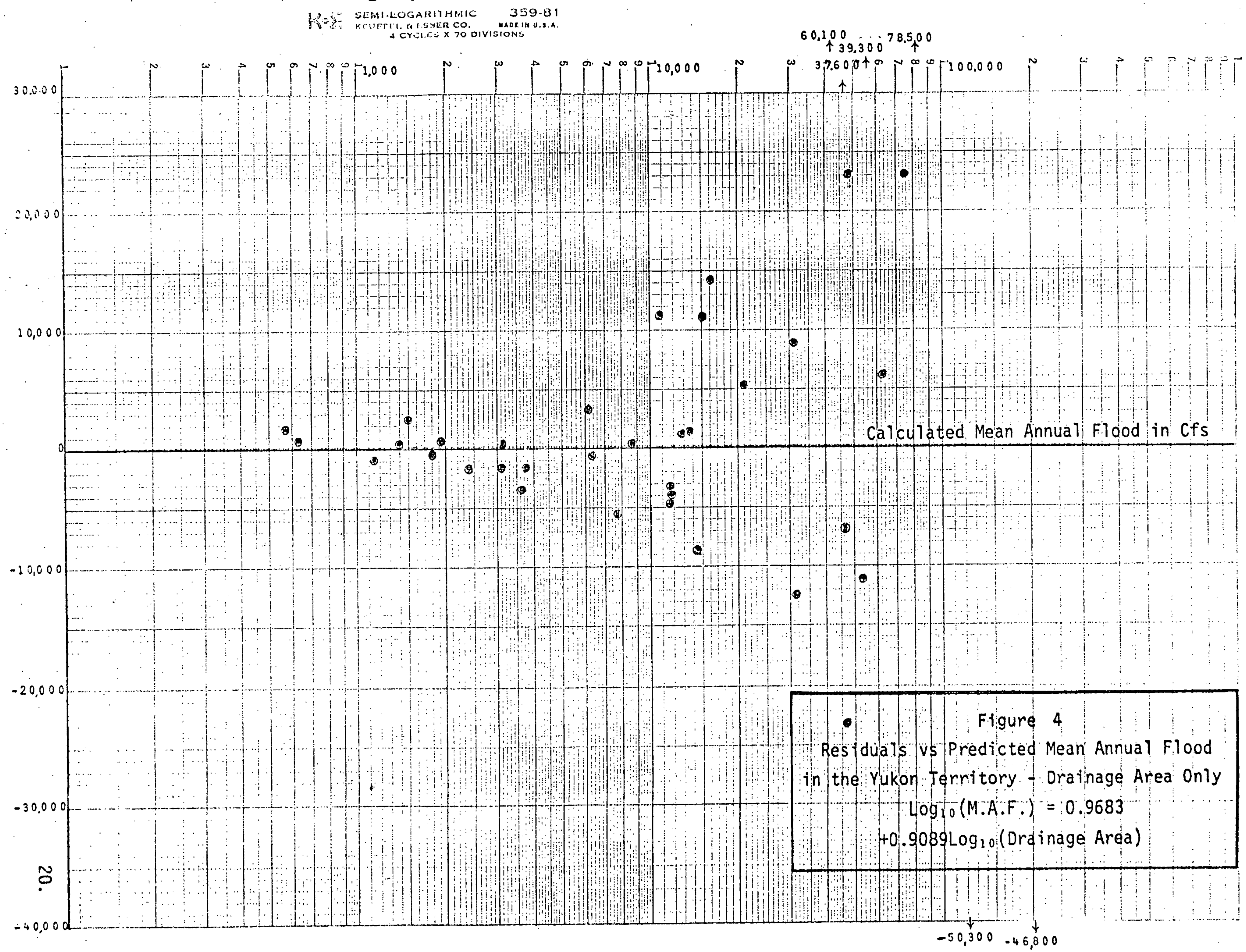


Figure 4

Residuals vs Predicted Mean Annual Flood in the Yukon Territory - Drainage Area Only

$\mathrm{Log}_{10}(\mathrm{M.A.F.}) = 0.9683 + 0.9089\,\mathrm{Log}_{10}(\mathrm{Drainage\ Area})$

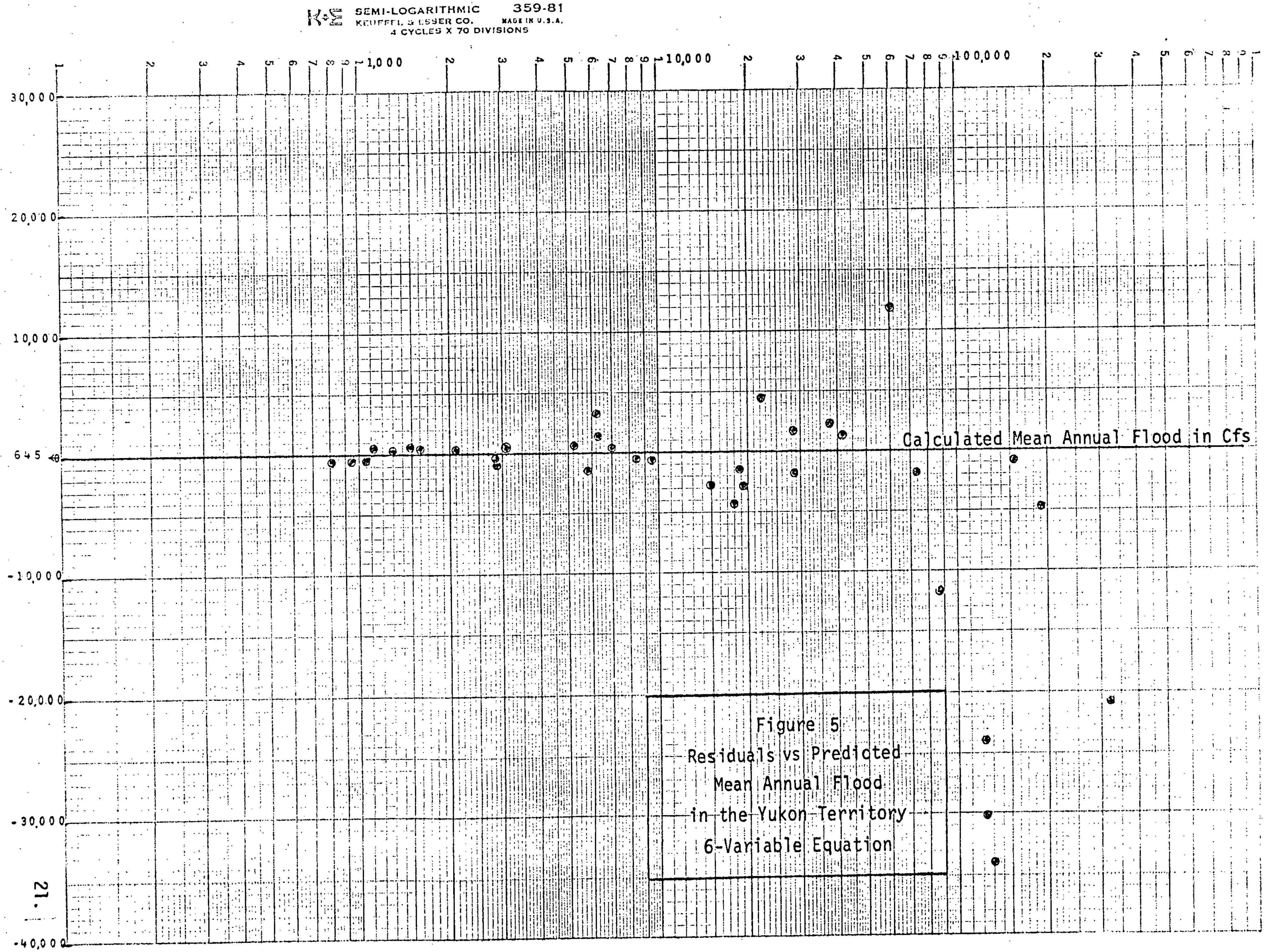


Figure 5
Residuals vs Predicted
Mean Annual Flood
in the Yukon Territory
6-Variable Equation

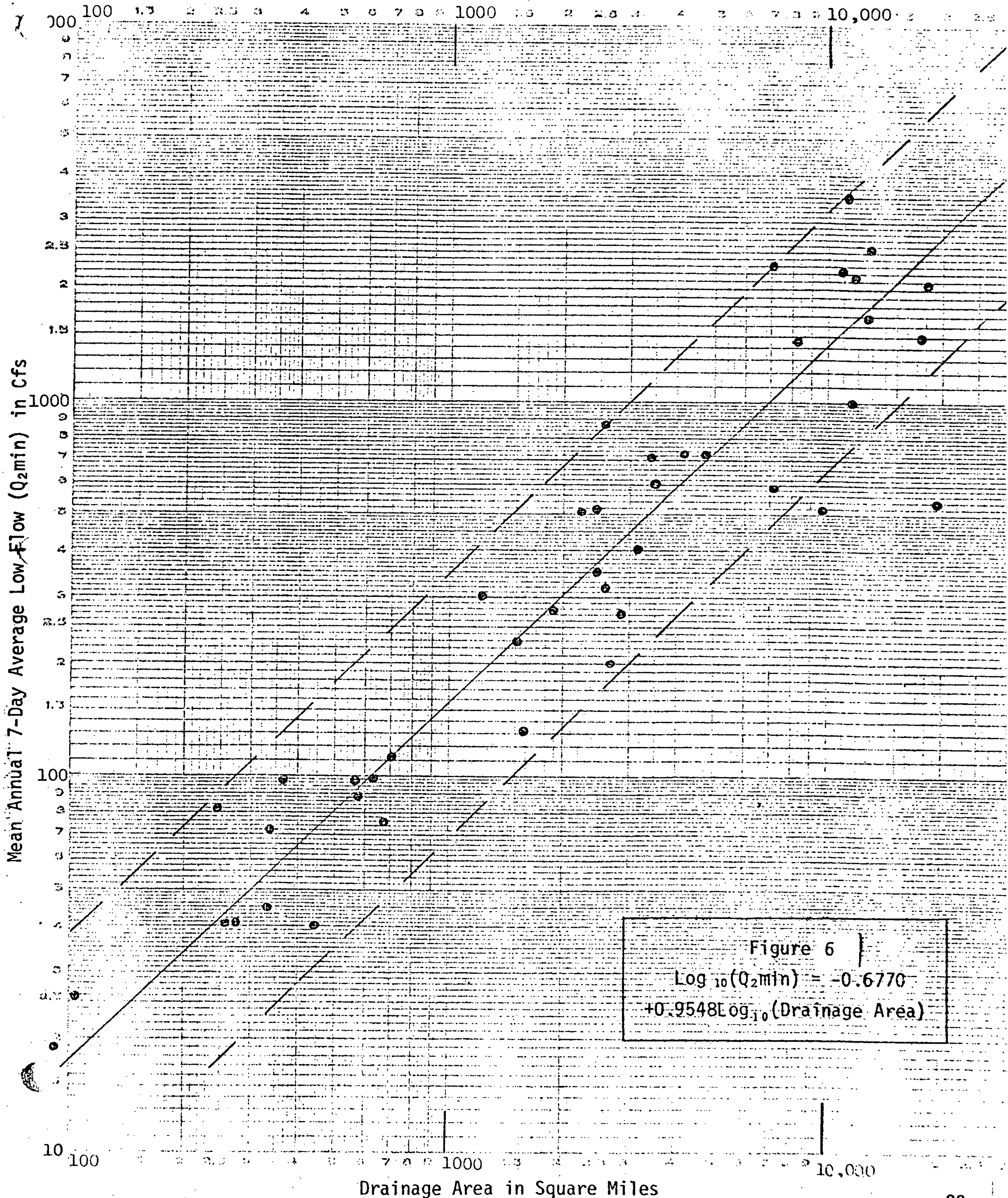


Figure 6
$\log_{10}(Q_2\text{min}) = -0.6770 + 0.9548 \log_{10}(\text{Drainage Area})$

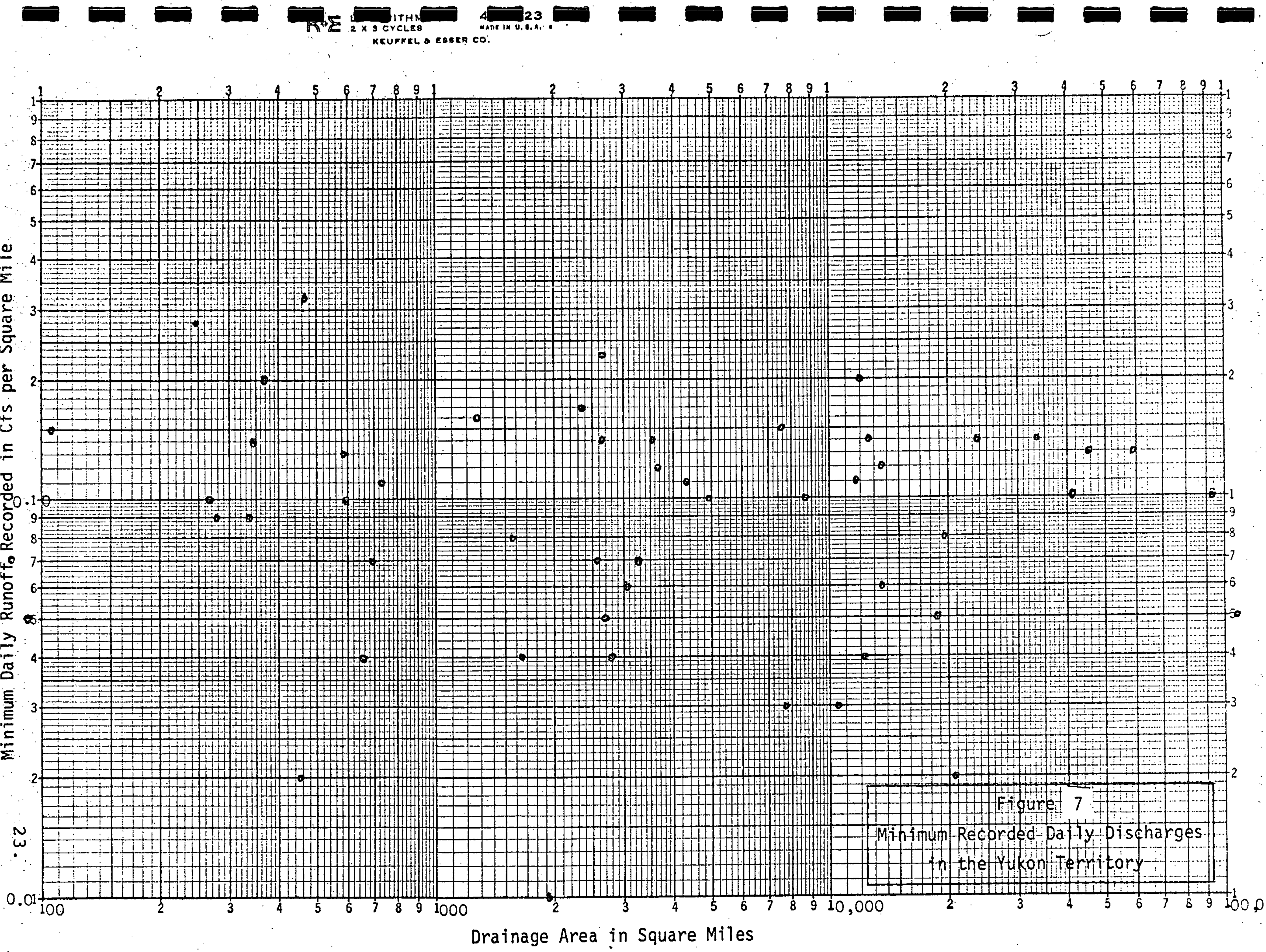


Figure 7
Minimum Recorded Daily Discharges
in the Yukon Territory

Table 1. **FLOOD DATA**

Station No. & Stream		D.A. sq.mi.	M.A.F. cfs	Q_{50} cfs	Q_{50} / M.A.F.	Q_{100} cfs	Q_{100} / M.A.F.
08AA003	Dezadeash	3280	5880	10900	1.85	11800	2.01
08AA001	Aishihik	1660	2570	5080	1.98	5560	2.16
08AA004	Kathleen	249	1630	3900	2.39	4600	2.82
09AA007	Lubbock	684	422	916	2.17	1050	2.49
09AA009	Watson	444	893	1840	2.06	2010	2.25
09AA011	Tagish Creek	30	70	150	2.14	166	2.37
09AA012	Wheaton	337	1740	2850	1.64	3060	1.76
09AB001	Yukon	7500	18500	23300	1.26	24000	1.30
09AB008	M'Clintock	655	2030	4350	2.14	4870	2.40
09AB009	Yukon	12000	24500	31700	1.29	32800	1.34
09AC001	Takhini	2700	8370	14500	1.73	15800	1.89
09AC004	Takhini	1570	7240	11500	1.59	12200	1.68
09AE001	Teslin	11700	39500	64800	1.64	69300	1.75
09AF001	Teslin	14100	42400	74800	1.76	81700	1.93
09AG001	Big Salmon	2610	12000	23500	1.96	26400	2.20
09AH001	Yukon	33600	70600	119000	1.69	129000	1.83
09BA001	Ross	2790	15900	29200	1.83	32500	2.04
09BC001	Pelly	18900	76700	173000	2.26	200000	2.61
09BC002	Pelly	7130	39700	76300	1.92	84700	2.13
09CA002	Kluane	1910	9410	14300	1.52	15200	1.62
09CD001	Yukon	57800	147000	307000	2.09	352000	2.39
09DC002	Stewart	12200	81900	143000	1.75	154000	1.88
09DD002	Stewart	13500	92100	192000	2.08	223000	2.42
09DD003	Stewart	19700	96300	313000	3.25	411000	4.27
09EA003	Klondike	3010	14800	25900	1.75	28700	1.94
09EB001	Yukon	102000	275000	477000	1.73	524000	1.91
09FD001	Porcupine	21400	161000	328000	2.04	363000	2.25
10AA001	Liard	12900	70300	168000	2.39	205000	2.92
10AB001	Frances	4950	26600	43600	1.64	46800	1.76
10AD001	Hyland	3650	30100	52900	1.76	59200	1.97
10MA001	Peel	9940	83700	315000	3.76	402000	4.80

Table 1. (Continued)

Station No. & Stream		D.A. sq.mi.	M.A.F. cfs	Q_{50} cfs	$\frac{Q_{50}}{M.A.F.}$	Q_{100} cfs	$\frac{Q_{100}}{M.A.F.}$
British Columbia							
09AA006	Atlin	2630	7760	15000	1.93	17000	2.19
09AA008	Pine Creek	269	642	1800	2.80	2200	3.43
09AA015	Wann	104	1380	2850	2.06	3300	2.39
09AA014	Fantail	277	4220	11000	2.61	13500	3.20
09AA013	Tutshi	366	2370	4750	2.00	5400	2.28
09AA010	Lindeman Creek	92	2280	5700	2.50	7000	3.07
09AE003	Swift	1280	9300	21000	2.26	25000	2.69
09AE004	Gladys	737	2120	4700	2.22	5500	2.59
10BE001	Liard	40300	190000	420000	2.21	500000	2.63
10AC003	Dease	588	3220	8200	2.55	10000	3.11
10AC002	Dease	2380	22300	45000	2.02	52000	2.33
10BC001	Coal	3550	27900	41700	1.49	43500	1.56

TABLE 2 - EXTREME MAXIMUM DAILY FLOWS

STATION NUMBER	STATION NAME	DRAINAGE AREA IN SQ MI	DATE	MAXIMUM DAILY FLOW IN CFS	MAXIMUM RUNOFF IN CFS/SQ MI
08AA001	AISHIHIK RIVER NEAR WHITEHORSE	1660	20 Jun 1962	5050	3.0
08AB001	ALSEK RIVER ABOVE BATES RIVER	6250	13 Jul 1975	39900	6.4
09AH003	BIG CREEK NEAR THE MOUTH	674	15 Jul 1976	7260	10.8
09AG001	BIG SALMON RIVER NEAR CARMACKS	2610	23 Jun 1962	23700	9.1
10BC001	COAL RIVER AT THE MOUTH	3550	30 May 1972	36900	10.4
08AA003	DEZADEASH RIVER AT HAINES JUNCTION	3280	28 Jun 1961	10100	3.1
10MD001	FIRTH RIVER NEAR THE MOUTH	2240	29 May 1975	27300	12.2
10AB001	FRANCES RIVER NEAR WATSON LAKE	4950	12 Jun 1964	38800	7.8
09DA001	HESS RIVER ABOVE EMERALD CREEK	1870	30 May 1977	17400	9.3
10AD002	HYLAND RIVER AT MILE 67.4 NAHANNI RANGE ROAD	211	21 Jun 1977	8700	41.2
10AD001	HYLAND RIVER NEAR LOWER POST	3650	10 Jun 1961	59800	16.4
08AA004	KATHLEEN RIVER NEAR HAINES JUNCTION	248	20 Jun 1964	2300	9.3
10AB003	KING CREEK AT MILE 13 NAHANNI RANGE ROAD	5.3	3 Jul 1976	63.8	12.0
09EA003	KLONDIKE RIVER ABOVE BONANZA CREEK	3010	29 May 1972	22600	7.5
09CA002	KLUANE RIVER AT OUTLET OF KLUANE LAKE	1910	14 Aug 1971	13500	7.1
10AA001	LIARD RIVER AT UPPER CROSSING	12900	2 Jun 1972	108000	8.4
09AA007	LUBBOCK RIVER NEAR ATLIN	684	4 Jun 1972	833	1.2
09AB008	M:CLINTOCK RIVER NEAR WHITEHORSE	655	1 Jun 1972	3680	5.6
09DC001	MAYO RIVER NEAR MAYO	873	6 Jun 1949	4260	4.9
09EA004	NORTH KLONDIKE RIVER NEAR THE MOUTH	423	4 Jun 1975	3030	7.2
10MA002	OGILVIE RIVER AT MILE 123 DEMPSTER HIGHWAY	2090	31 May 1975	23400	11.2
09FC001	OLD CROW RIVER NEAR THE MOUTH	5370	4 Jun 1977	59700	11.1
10MA001	PEEL RIVER ABOVE CANYON CREEK	9940	4 Jun 1964	202000	20.3
09BC001	PELLY RIVER AT PELLY CROSSING	18900	28 May 1957	152000	8.0
09BC002	PELLY RIVER AT ROSS RIVER	7130	7 Jun 1964	71000	10.0
09BC004	PELLY RIVER BELOW VANGORDA CREEK	8540	6 Jun 1975	46800	5.5
09FD001	PORCUPINE RIVER AT OLD CROW	21400	4 Jun 1964	237000	11.1
09FB001	PORCUPINE RIVER BELOW BELL RIVER	13900	19 May 1977	180000	12.9
09BC003	ROSE CREEK BELOW FARO CREEK	80.5	31 May 1967	1150	14.3
09BA001	ROSS RIVER AT ROSS RIVER	2790	1 Jun 1972	26200	9.4
10MB001	SNAKE RIVER ABOVE IRON CREEK	1070	7 Jun 1964	11400	10.7
10MB003	SNAKE RIVER NEAR THE MOUTH	3440	19 May 1977	40600	11.8
09BB001	SOUTH MACMILLAN RIVER AT MILE 249 CANOL ROAD	385	4 Jun 1975	4590	11.9
09DC002	STEWART RIVER AT MAYO	12200	10 Jun 1964	145000	11.9
09DD002	STEWART RIVER AT STEWART CROSSING	13500	11 Jun 1964	152000	11.3
09DD003	STEWART RIVER AT THE MOUTH	19700	12 Jun 1964	198000	10.1
09AE003	SWIFT RIVER NEAR SWIFT RIVER	1280	11 Jun 1964	15200	11.9
09AA011	TAGISH CREEK NEAR CARCROSS	30.0	21 May 1957	144	4.8
09AC004	TAKHINI RIVER AT OUTLET OF KUSAWA LAKE	1570	21 Jun 1964	9850	6.3
09AC001	TAKHINI RIVER NEAR WHITEHORSE	2700	2 Sep 1949	17200	6.4
09AE001	TESLIN RIVER NEAR TESLIN	11700	28 Jun 1962	65000	5.6
09AF001	TESLIN RIVER NEAR WHITEHORSE	14100	28 Jun 1962	65400	4.6
10AA002	TOM CREEK AT MILE 21.7 ROBERT CAMPBELL HIGHWAY	168	3 May 1976	1080	6.4
09AA009	WATSON RIVER NEAR CARCROSS	444	26 Jun 1971	1550	3.5
09AA012	WHEATON RIVER NEAR CARCROSS	337	10 Jun 1964	2420	7.2
09CB001	WHITE RIVER AT MILE 1169.2 ALASKA HIGHWAY	2410	2 Aug 1976	34000	14.1
09AB009	YUKON RIVER ABOVE FRANK CREEK	12000	29 Aug 1961	29100	2.4
09CD001	YUKON RIVER ABOVE WHITE RIVER	57800	25 Jun 1962	272000	4.7
09AH001	YUKON RIVER AT CARMACKS	33600	24 Jun 1962	127000	3.8
09ED001	YUKON RIVER AT DAWSON	102000	11 Jun 1964	526000	5.2
09EB002	YUKON RIVER AT STEWART RIVER	97100	12 Jun 1964	470000	4.8
09AB001	YUKON RIVER AT WHITEHORSE	7500	9 Aug 1953	22800	3.0

Table 3. LOW FLOW DATA

Station No.	& River	D.A. sq.mi.	Q_2min cfs	Q_{10}min cfs	Q_{50}min cfs	Qmin recorded	Qmin/D.A. cfs/sq.mi.
08AA003	Dezadeash	3280	419	300	240	238	0.07
08AA001	Aishihik	1660	133	85	68	79	0.04
08AA004	Kathleen	249	84	70	60	71	0.28
09AA007	Lubbock	684	77	50	36	52	0.07
09AA009	Watson	452	41	18	8	10	0.02
09AA011	Tagish Creek	31	4	3	2	3	0.09
09AA012	Wheaton	337	45	32	24	33	0.09
09AB001	Yukon	7500	2400	1800	1400	1150	0.15
09AB008	M'Clintock	597	89	63	50	60	0.10
09AB009	Yukon	12000	3700	2700	2100	2500	0.20
09AC001	Takhini	2700	324	240	175	153	0.05
09AC004	Takhini	1570	234	190	170	128	0.08
09AE001	Teslin	11700	2310	1600	1300	1350	0.11
09AF001	Teslin	13700	2640	1900	1650	1780	0.12
09AG001	Big Salmon	2610	535	440	360	388	0.14
09AH001	Yukon	33600	7510	5400	4100	4800	0.14
09BA001	Ross	2800	206	150	140	100	0.04
09BC001	Pelly	18900	1560	1200	1000	1000	0.05
09BC002	Pelly	7670	608	440	360	219	0.03
09BC003	Rose Creek	85	-	-	-	6	0.07
09CA002	Kluane	1910	283	-	-	19	0.01
09CD001	Yukon	58400	9860	8200	6800	8000	0.13
09DC002	Stewart	12100	1030	700	540	538	0.04
09DD002	Stewart	13500	1710	1100	760	900	0.06
09DD003	Stewart	19700	2160	1550	1200	1250	0.06
09EA003	Klondike	3010	279	170	115	170	0.06
09EB001	Yukon	106000	13500	8400	-	6350	0.05
09EB002	Yukon	97300	-	-	-	10600	0.10
09FD001	Porcupine	20900	554	420	330	425	0.02
10AA001	Liard	12500	2250	1750	1600	1740	0.14
10AB001	Frances	4950	759	580	470	486	0.10

Table 3. (Cont'd) LOW FLOW DATA

Station No. & River		D.A. sq.mi.	Q_2min cfs	Q_{10}min cfs	Q_{50}min cfs	Qmin recorded	Qmin/D.A. cfs/sq.mi.
10MA001	Peel	10200	536	380	290	404	0.03
10MB001	Snake	1070	-	-	-	0	-
British Columbia							
09AA006	Atlin	2630	904	740	640	623	0.23
09AA008	Pine Creek	269	41	28	20	27	0.10
09AA015	Wann	104	26	16	10	16	0.15
09AA014	Fantail	277	41	28	23	26	0.09
09AA013	Tutshi	366	98	80	70	74	0.20
09AA010	Lindeman Creek	92	19	11	6	5	0.05
09AE003	Swift	1280	310	235	190	205	0.16
09AE004	Gladys	737	115	96	86	83	0.11
10BE006	Liard	23800	-	-	-	3300	0.14
10BE001	Liard	40300	7100	5200	4500	4400	0.10
10BE005	Liard	45800	-	-	-	6100	0.13
10AC003	Dease	588	97	82	76	80	0.13
10AC002	Dease	2380	525	420	370	415	0.17
10AC005	Cottonwood	343	73	52	40	50	0.14
10AC004	Blue	658	100	-	-	32	0.04
10AD001	Hyland	3650	630	500	440	460	0.12
10BB002	Kechika	4310	746	520	340	480	0.11
10BB001	Kechika	8790	1520	900	570	895	0.10
10BA001	Turnagain	2550	360	165	86	203	0.07
10BC001	Coal	3550	740	600	520	530	0.14
10BE007	Trout	461	-	-	-	152	0.32

Table 4. PHYSIOGRAPHIC PARAMETERS

The Physiographic Parameters on the listing are in the following order, after the station number and the card number,

Parameter		Abbreviation	Units
drainage area		AREA	square miles
location of center of basin		NPOS I NPOS J	dimensionless
mean basin elevation		ELEV	feet
mean basin slope x 10		SLP	%
angle between the west-east direction and the horizontal projection of the line of steepest descent of the local slope		SLP AZ	degrees
distances to the sea	north	DSN	kilometres
	north-west	DSNW	
	west	DSW	
	south-west	DSSW	
relative areas	lakes	RALKE	%
	forest	RAFOR	
	swamp	RASWP	
	glacier	RAGLC	
	urban	RAURB	
barrier height	north	BHN	feet
	north-west	BHNW	
	west	BHW	
	south-west	BHSW	
shield effect	north	SEN	feet
	north-west	SENW	
	west	SEW	
	south-west	SESW	
signed slope	north-east	SSNE	feet/kilometres
	east	SSE	
	south-east	SSSE	

Table 4. (Cont'd)

PHYSIOGRAPHIC PARAMETERS FOR BASINS USED IN REGRESSION STUDIES IN THE YUKON TERRITORY

08AA001	1	1519	44	150	4190	54	66	890
08AA001	2	1498	1540	226	7	46	0	0
08AA001	3	0	1830	1540	6240	4140	24500	129200
08AA001	4	106800	15500	8	9	7		
08AA003	1	3019	45	147	3910	56	163	920
08AA003	2	1541	1580	226	5	46	0	0
08AA003	3	0	2200	2080	6770	3190	27000	131100
08AA003	4	108200	13300	7	7	4		
09AA006	1	2520	64	132	3460	39	253	1110
09AA006	2	1739	630	254	12	62	1	4
09AA006	3	0	2600	2270	3950	2400	37100	134300
09AA006	4	45200	12600	0	-4	-2		
09AA007	1	591	63	138	3300	34	256	1060
09AA007	2	1710	1440	296	6	84	2	0
09AA007	3	0	2790	2060	5990	2990	35100	128800
09AA007	4	101600	18000	-4	-9	-2		
09AA008	1	267	65	131	3880	41	245	1130
09AA008	2	1767	370	254	6	51	0	0
09AA008	3	0	2220	1420	2380	1760	37600	135500
09AA008	4	27100	11500	-5	-20	-14		
09AA009	1	452	56	139	3920	41	96	1030
09AA009	2	1654	1700	254	2	52	1	0
09AA009	3	0	2180	1910	6810	3680	30000	134100
09AA009	4	118600	18000	9	15	7		
09AA010	1	93	55	132	4840	50	46	958
09AA010	2	1497	241	186	2	22	0	3
09AA010	3	0	1618	1777	1458	2052	25610	123040
09AA010	4	17160	15380	19	8	2		
09AA011	1	31	59	139	3060	38	120	1060
09AA011	2	1682	7770	282	1	95	0	0
09AA011	3	0	2900	2160	1770	4450	32000	131500
09AA011	4	124700	20100	19	8	12		
09AA012	1	337	55	138	4620	56	57	1040
09AA012	2	1682	1380	240	2	27	0	1
09AA012	3	0	1530	1670	4670	3250	28700	136500
09AA012	4	99500	18700	18	22	21		
09AA013	1	368	57	133	4296	69	16	1108
09AA013	2	1723	340	231	6	43	1	0
09AA013	3	0	1922	2194	2188	2210	33390	139140
09AA013	4	25800	16840	15	1	-9		
09AA014	1	272	57	130	5032	56	68	1106
09AA014	2	1695	294	206	2	21	1	20
09AA014	3	0	1564	1388	2145	1264	35600	138120
09AA014	4	23710	12860	7	8	12		
09AA015	1	105	60	128	5309	78	14	1159
09AA015	2	1781	331	202	4	31	0	6
09AA015	3	0	1656	2226	3072	1468	37530	143760
09AA015	4	25990	9640	21	47	38		
09AB001	1	7190	61	135	3680	48	62	1080
09AB001	2	1710	870	254	8	57	1	5
09AB001	3	0	2370	2200	4460	2810	34100	133800
09AB001	4	61200	15400	5	8	4		
09AB008	1	597	60	144	3560	43	115	1010
09AB008	2	1640	1760	325	1	81	2	0
09AB008	3	0	2420	2110	7220	3830	30800	118900
09AB008	4	116300	19500	9	10	4		
09AB009	1	12000	57	138	3740	47	47	1030
09AB009	2	1668	1140	254	7	56	1	3
09AB009	3	0	2260	2130	5240	2660	32800	131200
09AB009	4	79200	15000	4	6	2		

Table 4. (Cont'd)

09AC001	1	2781	51	141	4270	54	30	960
09AC001	2	1626	1390	240	4	36	1	3
09AC001	3	0	1630	1820	5630	2190	35700	134800
09AC001	4	96400	13800	1	0	0		
09AC004	1	1594	51	138	4540	59	208	980
09AC004	2	1640	1190	212	5	23	0	6
09AC004	3	0	1470	1910	4640	2300	38300	137200
09AC004	4	84400	13900	0	0	-2		
09AE001	1	11700	78	138	3920	34	250	1080
09AE001	2	1753	1220	339	3	69	2	0
09AE001	3	0	2520	2250	4930	2170	31200	102400
09AE001	4	81000	17100	0	-1	0		
09AE003	1	1280	90	135	4230	36	382	1110
09AE003	2	1809	890	311	1	49	4	0
09AE003	3	0	2200	2150	3030	1270	32000	95700
09AE003	4	59500	14800	-7	-14	-7		
09AE004	1	737	68	132	4170	38	37	1140
09AE004	2	1781	420	268	5	59	0	0
09AE004	3	0	2230	1320	2430	1650	36000	132000
09AE004	4	29900	12400	6	1	3		
09AF001	1	13700	76	139	3880	35	253	1060
09AF001	2	1725	1300	339	3	70	2	0
09AF001	3	0	2510	2260	5270	2320	31200	102600
09AF001	4	86300	17500	-1	-2	0		
09AG001	1	2640	62	153	4140	41	296	920
09AG001	2	1569	1700	395	1	73	0	0
09AG001	3	0	1940	2290	4440	2220	27700	86500
09AG001	4	112400	19400	-4	-7	-4		
09AH001	1	33600	65	143	3770	40	1	1000
09AH001	2	1654	1320	311	4	67	1	1
09AH001	3	0	2370	2270	5050	2670	30700	111100
09AH001	4	88900	16800	0	1	0		
09BA001	1	2800	90	162	3590	29	279	850
09BA001	2	1484	1800	565	3	89	4	0
09BA001	3	0	2750	2420	4970	3620	21300	63200
09BA001	4	110600	27000	0	0	0		
09BC001	1	19700	75	163	3660	37	325	820
09BC001	2	1442	1720	523	2	82	1	0
09BC001	3	0	2520	2560	5000	3910	21700	68000
09BC001	4	108300	26000	0	0	0		
09BC002	1	7670	91	159	3870	30	324	880
09BC002	2	1527	1830	565	2	83	2	0
09BC002	3	0	2470	2230	4030	3130	22100	65700
09BC002	4	112900	27100	0	-1	0		
09CA002	1	1976	24	150	4390	65	149	900
09CA002	2	1456	1460	226	8	35	0	4
09CA002	3	0	1830	1410	5420	6050	26200	128600
09CA002	4	102100	23300	-2	0	0		
09CD001	1	58400	66	151	3680	39	344	920
09CD001	2	1569	1450	395	3	73	1	1
09CD001	3	0	2420	2400	5100	3370	27100	96300
09CD001	4	95200	21500	0	1	0		
09DC002	1	12100	66	178	3660	42	222	660
09DC002	2	1244	1620	622	2	73	0	0
09DC002	3	0	2340	2310	3990	6360	14700	52800
09DC002	4	102900	38700	0	-1	0		
09DD002	1	13500	71	177	3780	42	231	670
09DD002	2	1258	1650	622	2	74	0	0
09DD002	3	0	2240	2220	4150	5580	15100	52000
09DD002	4	104300	36300	-1	-2	0		

Table 4. (Cont'd)

09EA003	1	3058	33	182	3230	42	195	580
09EA003	2	1173	1390	523	0	62	0	0
09EA003	3	0	2260	3210	2860	3690	14000	67800
09EA003	4	93000	61400	-1	-2	0		
09EB001	1	106000	54	159	3590	40	339	840
09EB001	2	1456	1460	410	3	72	1	1
09EB001	3	0	2360	2390	4870	4300	24200	93100
09EB001	4	96500	30700	0	1	0		
09EB002	1	97300	57	157	3640	40	339	860
09EB002	2	1470	1470	410	3	72	1	2
09EB002	3	0	2350	2320	4920	4300	24700	94000
09EB002	4	96900	28400	0	1	0		
09FD001	1	20800	28	215	1810	18	20	260
09FD001	2	636	1090	1442	3	55	1	0
09FD001	3	0	1250	2490	1400	5390	5900	28600
09FD001	4	88200	104700	0	0	0		
10AA001	1	12500	97	145	3940	30	87	1050
10AA001	2	1695	1780	466	2	70	6	0
10AA001	3	0	2420	2360	5590	1990	26500	77600
10AA001	4	112500	18400	2	4	2		
10AB001	1	4950	100	151	4120	35	218	990
10AB001	2	1640	1960	537	3	68	4	0
10AB001	3	0	2270	1970	5050	1840	24600	69600
10AB001	4	122200	20100	0	1	0		
10AC002	1	2715	97	123	4090	43	221	1260
10AC002	2	1951	520	296	1	62	0	0
10AC002	3	0	2160	1960	3230	2890	32300	111900
10AC002	4	31700	16000	1	3	2		
10AC003	1	612	95	121	3930	39	14	1280
10AC003	2	1965	470	268	4	73	0	0
10AC003	3	0	2350	1870	2320	3120	35400	127100
10AC003	4	28800	15000	4	11	4		
10AC004	1	668	99	131	4120	29	55	1190
10AC004	2	1866	590	367	1	59	9	0
10AC004	3	0	2220	2340	2600	2660	28200	92500
10AC004	4	35700	16400	10	16	9		
10AC005	1	343	96	127	4640	43	242	1230
10AC005	2	1908	550	311	1	39	0	0
10AC005	3	0	1630	1610	3160	2190	33000	103100
10AC005	4	33700	15000	-2	-4	6		
10AD001	1	3749	105	147	4017	44	207	1059
10AD001	2	1695	2007	518	1	66	3	0
10AD001	3	0	2902	2214	5612	2169	32400	69320
10AD001	4	124560	20150	-1	-2	-1		
10BA001	1	2590	106	120	4730	50	331	1320
10BA001	2	2022	570	480	1	55	1	0
10BA001	3	0	2490	1670	2190	1980	42300	102400
10BA001	4	33100	21100	2	1	1		
10BB001	1	8778	113	120	4370	49	5	1280
10BB001	2	2022	630	537	1	62	1	0
10BB001	3	0	2970	2120	2720	2460	39900	94700
10BB001	4	36000	22500	1	2	1		
10BB002	1	4297	119	117	4650	59	336	1270
10BB002	2	2078	630	593	1	56	1	1
10BB002	3	0	2670	1910	2420	2100	38300	94100
10BB002	4	36100	23700	-2	0	-1		
10BC001	1	3681	111	143	3646	31	173	1059
10BC001	2	1757	1995	531	0	86	2	0
10BC001	3	0	4064	2585	6662	2940	33980	70450
10BC001	4	122490	20800	0	0	1		

Table 4. (Cont'd)

10BE001	1	40300	106	135	3920	37	18	1140
10BE001	2	1838	1270	480	2	70	3	0
10BE001	3	0	2960	2420	4540	2600	32500	83800
10BE001	4	78000	20200	1	1	0		
10BE006	1	23200	100	140	3390	34	108	1110
10BE006	2	1767	1450	438	2	69	4	0
10BE006	3	0	2660	2410	4930	2440	29700	82600
10BE006	4	90700	18500	2	3	1		
10MA001	1	9250	38	193	3320	33	20	460
10MA001	2	1046	1370	820	0	26	0	0
10MA001	3	0	800	2560	1520	4190	11300	51500
10MA001	4	91300	77500	2	3	2		

APPENDIX C

WATER INVESTIGATIONS

ALONG THE

ALASKA HIGHWAY PIPELINE ROUTE

IN THE YUKON TERRITORY

APPENDIX C

CHANNEL GEOMETRY OF STREAMS IN THE YUKON TERRITORY

by

P. W. Strilaeff and R. O. Lyons

December 1978

Inland Waters Directorate
Pacific and Yukon Region
Vancouver, B.C.

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CHANNEL GEOMETRY OF STREAMS IN THE YUKON TERRITORY

ABSTRACT

Relationships between channel geometry and flow characteristics of streams along the proposed Alaska Highway Gas Pipeline route have been determined and estimates of discharge for various return periods at ungauged sites made. Because of the sparsity of the hydrometric network, data from all gauging stations operated in the Yukon Territory have been used in the study. Five separate relationships have been identified, four representing geographic subregions and the fifth, representing mountain streams.

The development of the relationships involves the survey of channel geometry, determination of bankfull discharge and the establishment of dimensionless rating curve between channel size and discharge. Their application to ungauged locations includes the obtaining of one discharge measurement, the extension of the cross-section to bankfull stage and the use of the dimensionless rating curve.

Table 6 lists flood characteristics, and summarizes channel size data and other field information used in the calculations.

INTRODUCTION

Selection of the Alaska Highway as the route in the Yukon for a natural gas pipeline system from Prudhoe Bay in Alaska to markets in southern U.S.A. has necessitated an intensive effort to assess flood magnitudes of streams along that corridor. One of the major hazards to the pipeline and its associated roads and facilities is flooding. Flooding could disrupt drainage and inundate or erode the pipeline bed, could undermine the pipeline at river crossings, or could increase erosion in areas of construction activities. Damage to the environment from flood erosion could be the degradation of water quality and the resultant detrimental effects on ecosystem.

The pipeline route in the Yukon crosses about 250 streams and to assure adequate pipeline design and construction of channel crossings, criteria regarding the magnitude and frequency of floods must be available. Very few hydrologic data exist on which to base the determination of these criteria, particularly on streams with drainage areas less than 150 square miles. There are 19 streamflow observation sites in the near vicinity of the pipeline route, but usefulness of data at about half is very limited because of large upstream storage and the large-sized streams on which most stations are located. To help alleviate this inadequacy, ten new crest-stage stations were constructed late in 1977 along the pipeline route for the recording of the 1978 snow-melt event; it was evident, however, that these data could not alone provide reasonable measures of streamflow characteristics for planning and design. This led to the investigations covered by this report, wherein channel geometry is related to flow characteristics at existing gauging stations and, thereby, provides a basis for estimation of flow characteristics at ungauged locations. Northern British Columbia gauging stations located in the headwaters of the Yukon and Teslin River basins are included in the analysis.

The relationships in this report are based on average values of hydraulic and geometric properties of rivers. For their application to practical engineering problems, caution normally applicable to computations based on average values is recommended.

OBJECTIVE AND SCOPE

The objective of this investigation has been to develop hydraulic geometry relations for gauging stations in the Yukon Territory and to extrapolate them for the ungauged river systems traversed by the proposed Alaska Highway Gas Pipeline and the Klondike-Dempster lateral. Flows computed for several return periods for a variety of hydrologic regions are presented in this report and may be used to help check the adequacy of the proponent's "design" floods along the pipeline route.

BASIC PRINCIPLE

Channel geometry relationships are based on the premise that river channels are free to adjust their dimensions, shape, pattern and gradient in response to river flow conditions. Further, it is assumed that the most distinguishable channel shape is that formed to accommodate a dominant discharge. In this study, bankfull discharge is taken to be the channel forming discharge.

Principal channel features involved in the development of hydraulic geometry relations are the width, the mean depth, and the mean velocity. (Leopold and Maddock, 1953.) When these parameters are plotted against discharge on log-log paper, the relations are generally straight lines up to the bankfull stage; thus, each parameter increases with discharge in the form of a simple power function:

$$W = aQ^b$$
$$D = cQ^f$$
$$V = kQ^m$$

where W = width, D = mean depth, V = mean velocity, Q = discharge, and a, c, k, b, f, m are numerical constants. Values of the three exponents b, f and m, represent the slope of the log-log plots. The constants a, c and k are the intercepts of the log-log lines at unit discharge.

The technique involves surveys of channel geometry at selected sites, and transformation and computation of data so as to provide estimates of flow characteristics at ungauged locations. River Mechanics is not an exact science. Success or rigorousness with which the relationships are applied is dependent to a very large extent on experience and judgement of individuals involved.

DATA

Data forming the basis of relationships discussed in this report are streamflow measurements made at the Water Survey of Canada gauging stations and at crest-stage gauges operated by the Department of Indian & Northern Affairs. It is important to point out that the hydraulic geometry analyses are based on the assumption that the measured cross-section is typical of the river and is composed of a bed material that has permitted the channel to develop into normal size and shape for the flow regimen. Gauging stations, however, are sometimes located in bedrock channels and/or upstream from obstructions such as outcrops or gravel bars; they therefore may not be representative of the average river cross-sections. Anomalies may also occur in plots of widths, depths and velocities versus discharge where groundwater contributions are excessively greater than at an average cross-section.

DEFINITION OF BANKFULL STAGE

Vegetative evidence is generally utilized to determine bankfull stage. River channels usually are bounded by intermittently grassy or brush-covered sloping banks and/or overbank areas covered with trees, brush or muskeg. The bankfull stage is the lower edge of the permanent vegetation.

Another distinguishing feature is the upper limit of recent deposition or erosion near the top of the channel banks. Bankfull stage is generally less than the level that is commonly referred to as "flood stage".

DETERMINATION OF BANKFULL STAGE

Bankfull stage is normally determined during a channel geometry field survey program. However, because of the reconnaissance nature of the studies covered by this report, the bankfull stage at the existing gauging stations were determined from file information, including:

1. Station Description. Example: elevation and location of a bench mark at a river bank, supplemented by a photograph.
2. Station History File. Examples: photograph of staff gauge on a river bank; cableway and recorder installation report; reconnaisance survey sketch.
3. Photograph Files. Example: photograph of a corrugated iron pipe recorder well installation at a river bank at known gauge height and with known spacing of corrugations (Figure 1).
4. Curves of Hydraulic Geometry. Plots for some rivers show a break in slope at bankfull discharge (Figure 2).
5. Current-Meter Notes. Example: discharge measurement obtained at flood stage permits calculation of the flood plain level at either/or both banks.
6. "Hydrologic and Geomorphic Characteristics of Rivers and Drainage Basins in Y.T." - Dept. of Indian Affairs and Northern Development. (Porcupine-Peel subregion only.)

Bankfull stages which have been confirmed or revised after a field inspection are identified in Table 2 by an asterisk.

ANALYSIS OF DATA

A. At Gauging Stations

Summary data for current-meter notes including width of water surface, area of the water cross-section and the measured discharge are available on computer tape at WSC office in Vancouver. Width is the width of water surface at any given gauge height. The mean depth for a particular discharge was obtained by dividing the cross-sectional area at any given gauge height by the corresponding width of water surface. Velocity is the mean velocity of the cross-section as obtained by dividing the discharge at any given gauge height by the corresponding cross-sectional area.

In the first step of the analysis width, depth, velocity and discharge were plotted by computer on log-log paper. The straight line relations were fitted by eye to best represent the general conditions (Figure 2). Least-squares method was not considered appropriate for this purpose; when drawing channel geometry versus discharge curves, knowledge of cross-sections is an asset. These fitted lines defined the three hydraulic characteristic equations at each station:

$$W = aQ^b$$
$$D = cQ^f$$
$$V = kQ^m$$

With bankfull discharge (Q_B) known, values of bankfull width (W_B), depth (D_B), and velocity (V_B) were then determined from the above equations. The same calculation is involved in arriving at width and depth for the other discharge events shown in Table 3. As an alternative, these values may be read directly from the graphs.

The hydraulic geometry exponents b, f and m are shown in Table 1 for each gauging station. The computations of the geometric parameters were confirmed by the application of two mathematical laws:

since $W \times D \times V = Q$

then $b + f + m = 1$ (deviation of 5% was considered acceptable)*

and $a \times c \times k = 1$

These mathematical relationships are satisfied in practice when the product of the values of width, depth and velocity at any given discharge is equal to that discharge. This can be seen in Figure 2.

B. At Ungauged Locations

To enable estimation of discharge for any return period at an ungauged location, two transformations of data were made:

1. Bankfull discharges in Table 2 were plotted in cubic feet per second per square mile (R_B), versus drainage area (DA), in square miles, and curves fitted by the method of least squares (Figure 3). There are five relationships, four representing geographic subregions and the fifth representing mountain streams:

a. Atlin - Bennett - Dezadeash

$R_B = 238\ DA^{-0.63}$

since $Q_B = DA \times R_B$

then $Q_B = 238\ DA^{0.37}$

Note:

R_B = bankfull unit runoff in cfs/sq. mi.

Q_B = bankfull discharge in cfs

DA = drainage area in sq.mi.

b. Upper Yukon - Teslin - Takhini

$R_B = 196\ DA^{-0.47}$

$Q_B = 196\ DA^{0.53}$

c. Liard - Pelly - Stewart - Lower Yukon

$R_B = 88.7\ DA^{-0.30}$

$Q_B = 88.7\ DA^{0.70}$

* In some cases, the fitted lines could not be made to meet this criterion

d. Porcupine - Peel

$$R_B = 52.0\ DA^{-0.18}$$

$$Q_B = 52.0\ DA^{0.82}$$

e. Mountain Streams

$$R_B = 35.7\ DA^{-0.46}$$

$$Q_B = 35.7\ DA^{0.54}$$

The relationship between channel size and flood characteristics for Mountain Streams is independent of geographic location. The reason appears to be their morphological similarity: steep channel slopes, well-defined banks, generally high or supercritical velocities and minimal overbank discharge at flood flows.

2. The cross-sectional area and discharge for various frequencies were expressed as non-dimensional ratios to corresponding bankfull values for gauging stations included in the study (Tables 1 and 2) and listed in Tables 3 and 4. Expressions for these relationships are:

$$\frac{A}{A_B} = \left(\frac{Q}{Q_B}\right)^{b+f}$$

$$\frac{D}{D_B} = \left(\frac{Q}{Q_B}\right)^{f}$$

$$\frac{W}{W_B} = \left(\frac{Q}{Q_B}\right)^{b}$$

Average values for each of the runoff regions, defined in 1. above, were then plotted in Figures 5 and 6 and equations fitted to the relationships. The equations represent average non-dimensional rating curves; their reliability can be considered to be equal to the maximum deviation of the values b and f from the average. The more nearly equal are the ratio values for a particular discharge event (Table 4), the higher the degree of homogeneity within the subregion and the more reasonable the results will be from the application of the rating curves.

3. To permit approximation of flow for any desired return period at an ungauged location, it is necessary to establish a flow frequency dimension on Figure 5. This has been done by superimposing on the figure the ratios for various discharge events shown in Tables 3 and 4. The point of coincidence at unit value represents bankfull flow and its average frequency of occurrence for a subregion can be read directly off Figure 5.

APPLICATION OF DATA TO UNGAUGED LOCATIONS

Procedure is as follows:

1. Calculate the ratio $\frac{A}{A_B}$

   A is the cross-sectional area for the discharge measurement made at time of channel geometry surveys.

   A_B is the cross-sectional area for bankfull stage also determined at time of channel geometry surveys.

2. Having obtained the value for $\frac{A}{A_B}$, calculate the ratio $\frac{Q}{Q_B}$ from the equation applicable for the hydrologic subregion or read it directly off the rating curve. Both the equation and the rating curve are shown in Figure 5.

3. From the ratio $\frac{Q}{Q_B}$ Calculate Q_B

   Q is the discharge for the measurement made at time of channel geometry surveys referred to in 1. above.

4. With bankfull discharge known, discharge for any return period may now be calculated. For example, for 50-year flood, $\frac{Q}{Q_B}$ ratio for Atlin-Bennett-Dezadeash region is 1.81. Q_{50} then is 1.81 x Q_B (Figure 5 or Table 5).

The above procedure may also be applied using ratios based on depth, $(\frac{D}{D_B})$ or on width, $(\frac{W}{W_B})$ and by substituting Figure 6 for Figure 5. However, the results will not be as consistent. Generally if the value of $(\frac{D}{D_B})$ is somewhat less than average, value of $(\frac{W}{W_B})$ is somewhat greater. Thus, the rating based on area (depth x width) may be considered a more consistent and/or reliable average rating than that based on either depth or width alone.

The combination of Figure 5 with Figure 3 provides another method for approximating runoff for any return period. If, for example 50-year flood for a site having 300 square mile drainage area in the Atlin-Bennett-Dezadeash region is required, reference to Figure 3 will give a bankfull unit runoff of 6.4 cfs per square mile, or a discharge of 1,920 cfs. From Figure 5 or Table 5(a) $\frac{Q_{50}}{Q_B} = 1.81$; therefore, $Q_{50} = 3{,}480$ cfs.

Table 6 summarizes data and computations for ungauged locations.

Table 7 lists values of runoff computed for various sizes of drainage areas for mean annual flow, bankful stage and the 50-year flood using combination of Figures 3 and 5. Figure 3 indicates that for drainage areas of about 100 square miles unit runoff at bankfull stage is about the same for the three hydrologic subregions north of Atlin-Bennett-Dezadeash, or about 22.0 cfs per square mile.

FURTHER WORK REQUIREMENT

1. Operate a network of gauging stations on small streams for a minimum of five years to confirm the relationships in Figures 3 and 5. This information is required because for some streams it is not entirely clear whether the locations of plots in Figure 3 are due to geographic and morphologic differences, or whether they are due to inconsistencies in bankfull discharge determination; examples are the plots for M'Clintock River and Big Creek.

2. Test the applicability of the method described in this report to the ephemeral drainages at south side of Kluane Lake. To do this it is necessary to obtain reasonably reliable hydrometric record. Records on Duke River could possibly serve the purpose, but would require two gauging stations: one at the Alaska Highway bridge and the other in the headwaters, in order to deduct glacier runoff.

3. Confirm bankfull stages at WSC gauging stations located in the Liard-Pelly-Stewart-Lower Yukon and the Porcupine-Peel subregions before applying the relationships proposed in this report for the Klondike-Dempster pipeline lateral. Bankfull stages determined from file information are considered to be reasonably reliable; therefore, a spot check may be sufficient.

   For applying channel geometry technique to ungauged small streams in the above two subregions, obtain a discharge measurement at about medium stage at selected sites and extend the measured cross-section to bankfull stage.

   Prepare a tabulation for ungauged streams similar to Table 6. This will assist consideration of EIS for the Klondike-Dempster pipeline lateral.

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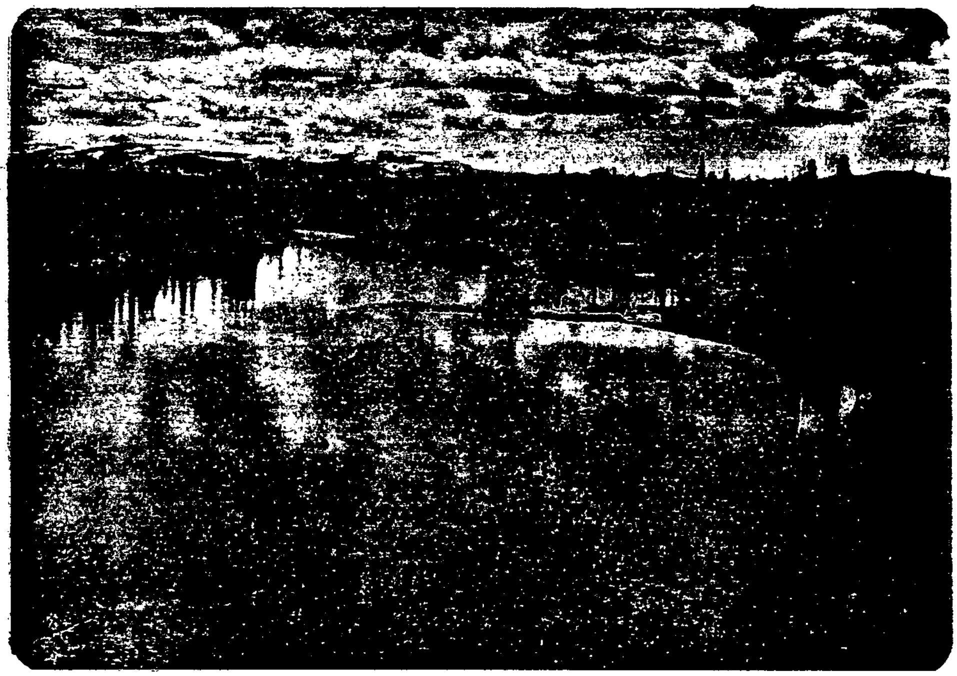
08AA003 - Dezadeash River at Haines Junction
View is upstream at gauge height of 9.04 feet on November 14, 1976. Bankfull stage is at gauge height of 12.4 feet or at 30th corrugation of the recorder well above water surface.

08AA001 - Aishihik River near Whitehorse
View is upstream at gauge height of 3.44 feet on November 13, 1976. Bankfull stage is at the lowest vegetation on right bank above the gravel bar, or gauge height of 10.6 feet. Corrugated pipe recorder well is seen at the left bank.

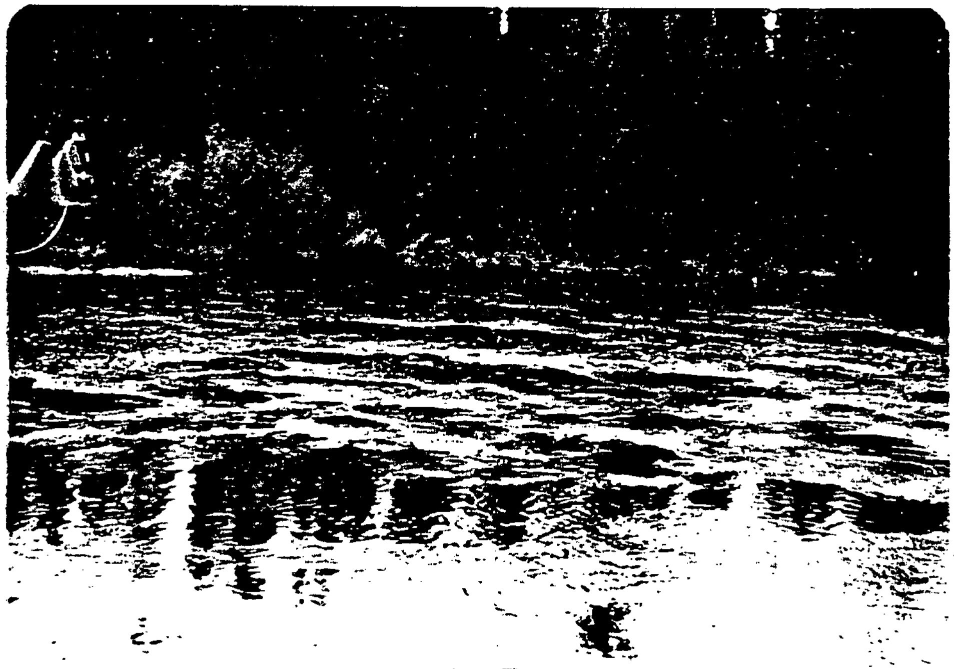
Figure 1 - SAMPLING OF PHOTOGRAPHS FOR DETERMINATION OF BANKFULL STAGE



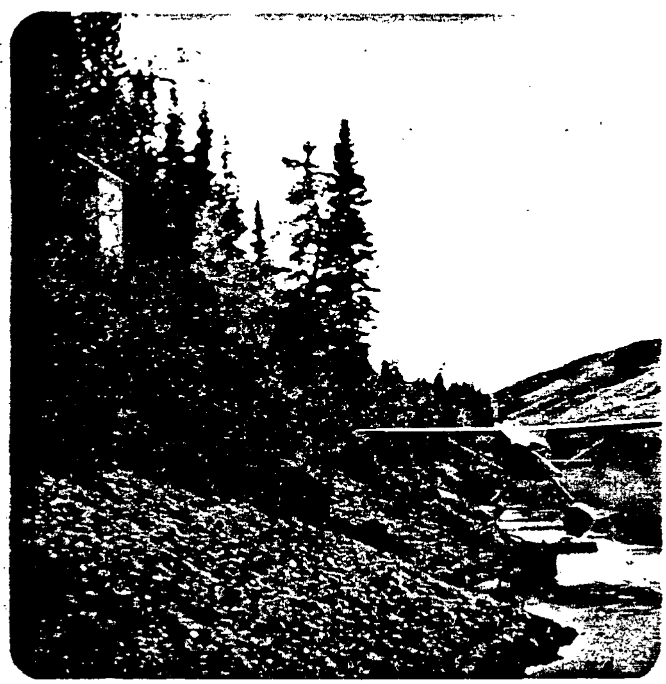
09AC001 - Takhini River near Whitehorse
View is upstream at gauge height of 9.97 feet on June 5, 1978. Bankfull stage is at lowest permanent vegetation on left bank, or gauge height of 19.0 feet.

09AE001 - Teslin River near Teslin
View is upstream taken on August 14, 1978. Bankfull stage is at bottom of level rod or gauge height of 25.0 feet.

Figure 1 (cont'd) - SAMPLING OF PHOTOGRAPHS FOR DETERMINATION OF BANKFULL STAGE



09AE003 - Swift River near Swift River
View is towards left bank at gauge height of 5.82 feet on June 9, 1978. Bankfull stage is at bottom of permanent vegetation or gauge height of 8.1 feet.



09DD003 - Stewart River at Mouth
View is downstream at gauge height of 85.33 feet on September 9, 1968. Bankfull stage is approximately level with the wing tip of Cessna 180 or gauge height of 95.2 feet.

Figure 1 (cont'd) - SAMPLING OF PHOTOGRAPHS FOR DETERMINATION OF BANKFULL STAGE

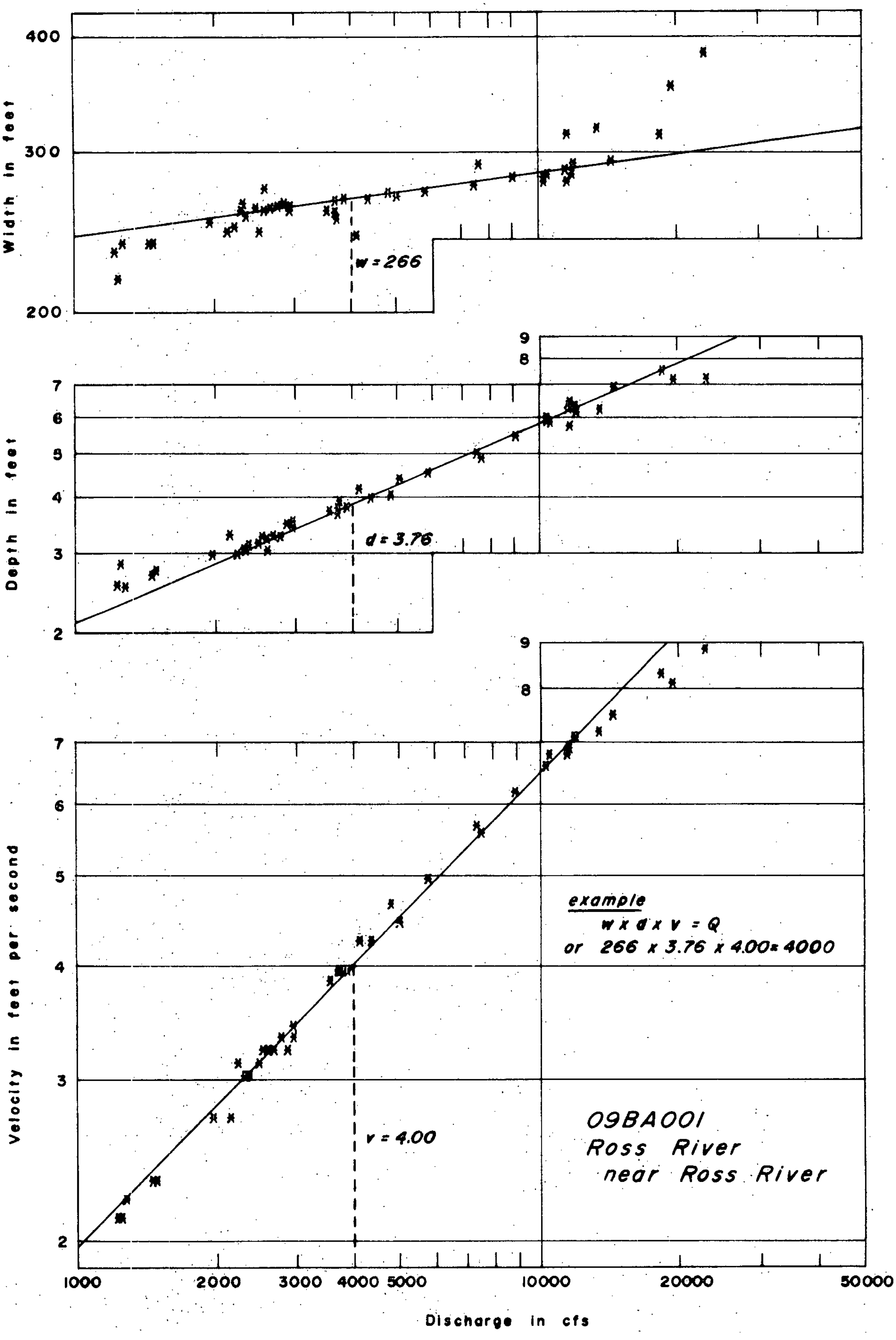


FIGURE 2 - CHANNEL GEOMETRY vs. DISCHARGE

BANKFULL RUNOFF
VS
DRAINAGE AREA
R_B = 51.3 DA^-0.176 (Porcupine - Peel Subregion)
R_B = 86.7 DA^-0.300 (Liard - Pelly - Stewart - Lower Yukon Subregion)
R_B = 196.0 DA^-0.469 (Upper Yukon - Teslin - Takhini Subregion)
R_B = 238.0 DA^-0.628 (Atlin - Bennett - Dezadeash Subregion)
R_B = 35.7 DA^-0.461 (Mountain Streams)
Bankfull Unit Runoff (R_B) in cfs per square mile
Drainage Area (DA) in square miles

Figure 3

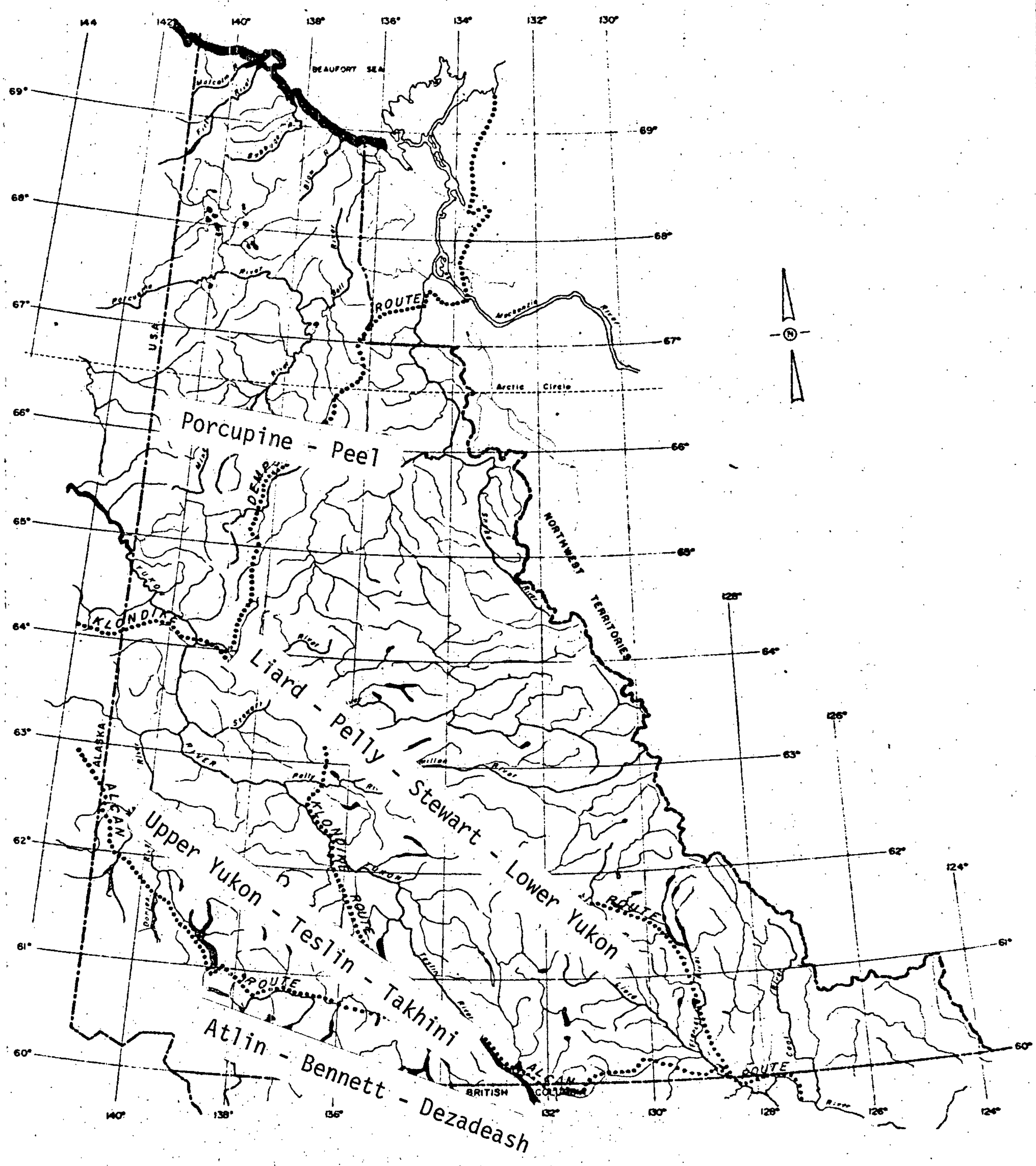
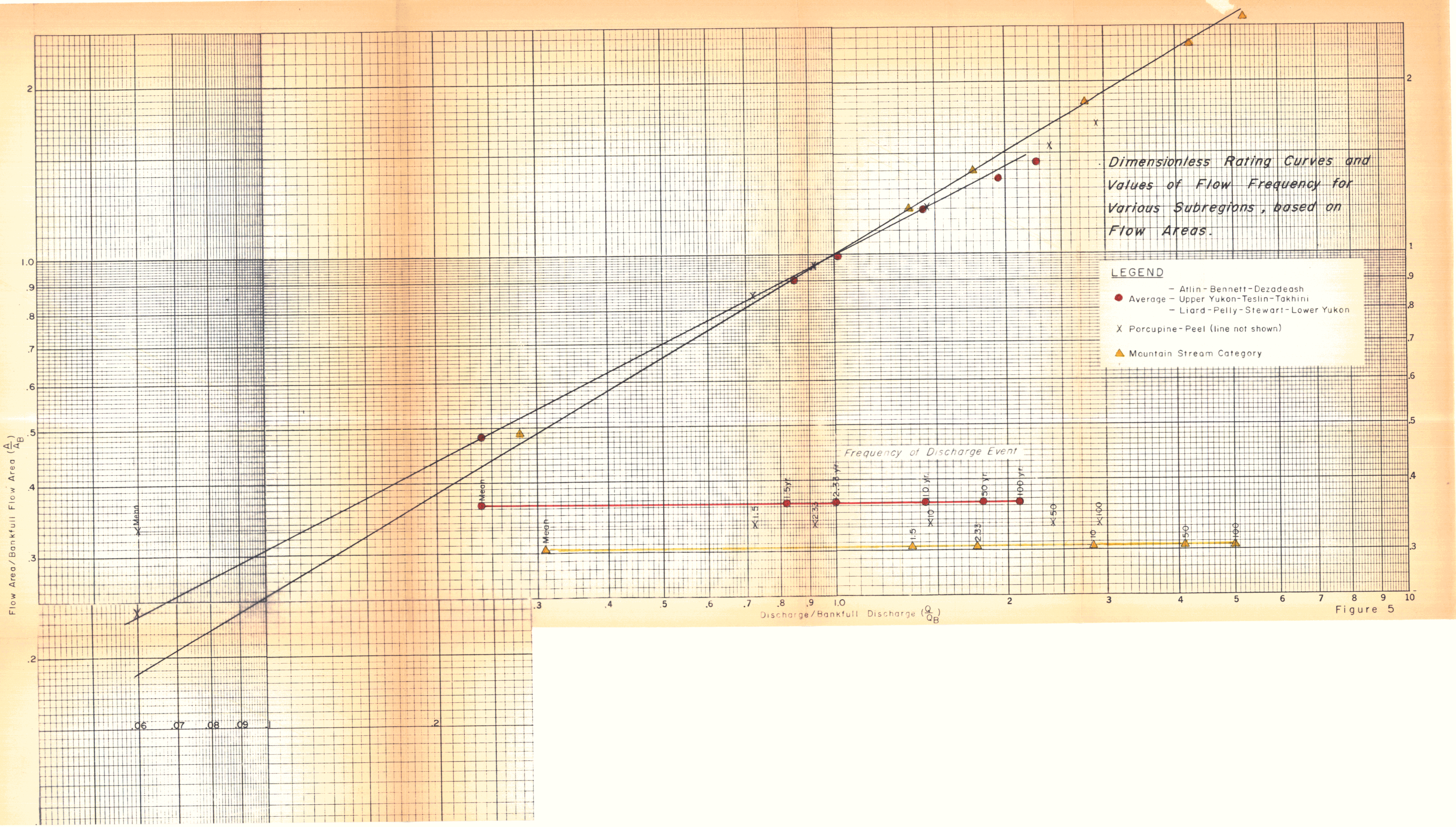


Figure 4 - HYDROLOGIC SUBREGIONS



Dimensionless Rating Curves and Values of Flow Frequency for Various Subregions, based on Flow Areas.
LEGEND
Average – Atlin-Bennett-Dezadeash – Upper Yukon-Teslin-Takhini – Liard-Pelly-Stewart-Lower Yukon
X Porcupine-Peel (line not shown)
Mountain Stream Category
Frequency of Discharge Event
Mean
1.5 yr.
2.33 yr.
10 yr.
50 yr.
100 yr.
Flow Area/Bankfull Flow Area ($\frac{A}{A_B}$)
Discharge/Bankfull Discharge ($\frac{Q}{Q_B}$)

Figure 5

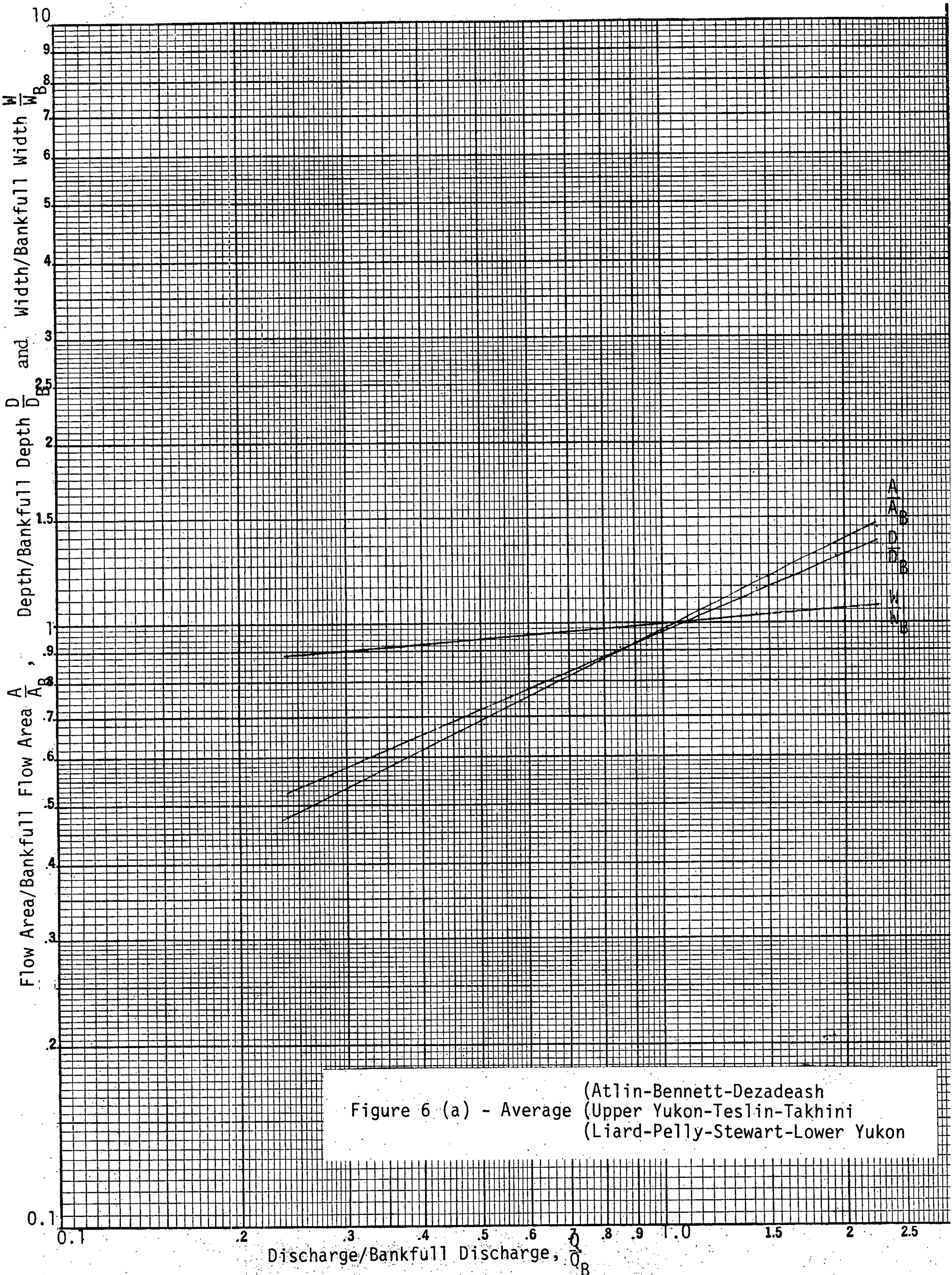


Figure 6 (a) - Average (Atlin-Bennett-Dezadeash
(Upper Yukon-Teslin-Takhini
(Liard-Pelly-Stewart-Lower Yukon

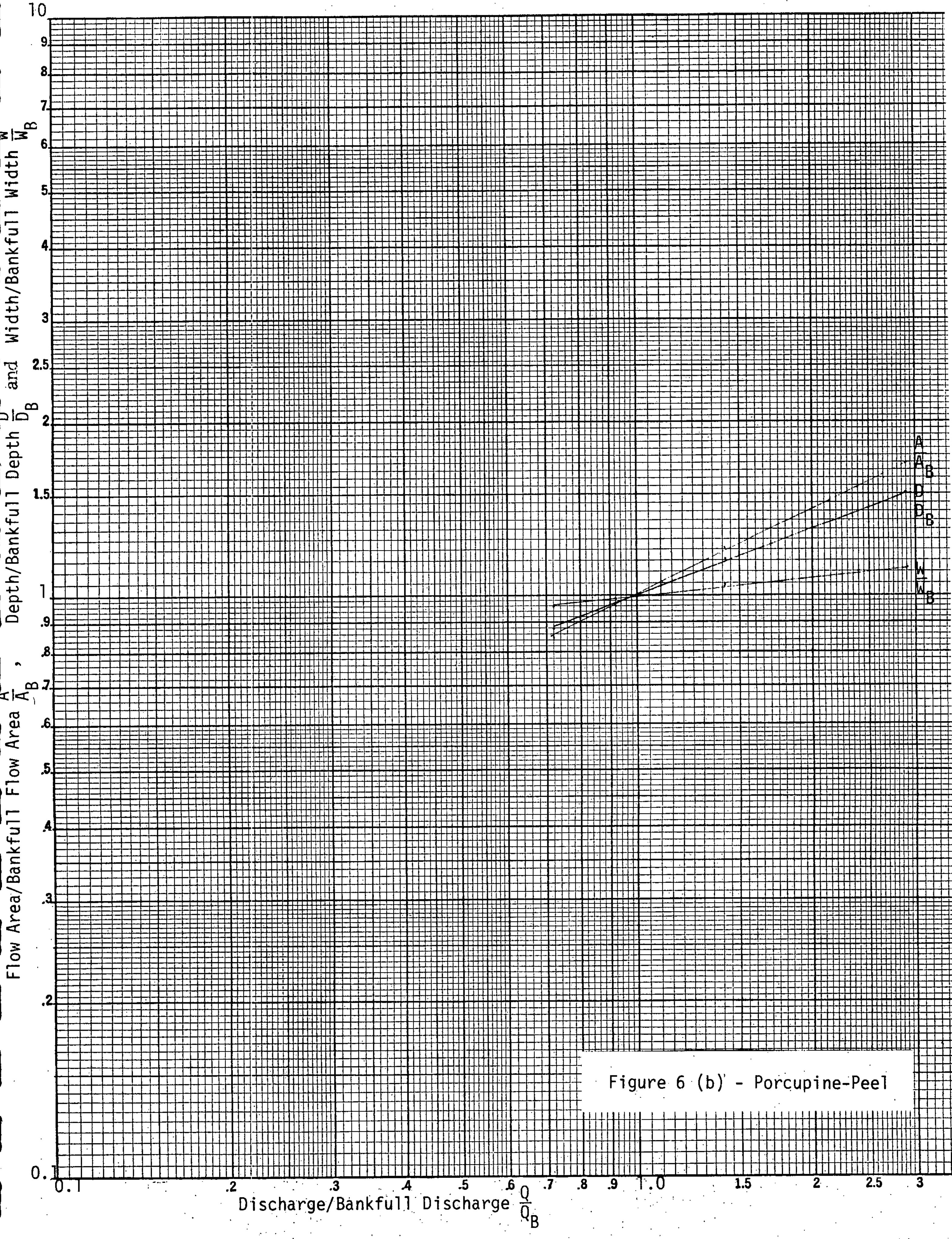


Figure 6 (b) - Porcupine-Peel

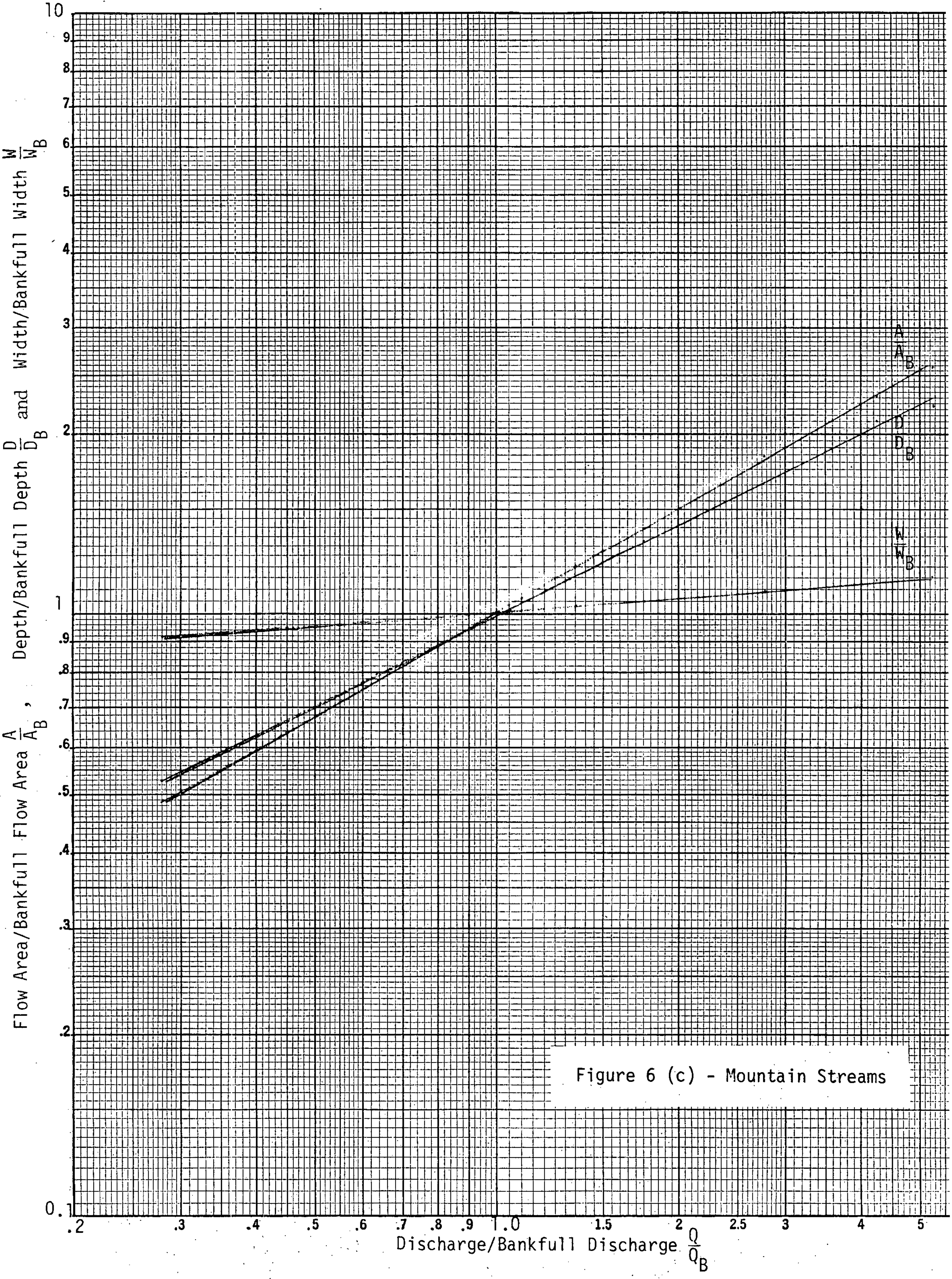


Figure 6 (c) - Mountain Streams

TABLE 1. - VALUES OF CHANNEL GEOMETRY EXPONENTS FOR RIVERS INCLUDED IN THE STUDY

Station No.	WSC No.	Station Name	Width b	Depth f	Velocity m
1	09AA006	Atlin River near Atlin	0.14	0.33	0.54
2	08AA001	Aishihik River near Witehorse	0.21	0.75	0.04
3	08AA003	Dezadeash River at Haines Junction	0.37	0.38	0.27
4	09AA014	Fantail River at outlet of Fantail Lake	0.32	0.41	0.19
5	09AE004	Gladys River at outlet of Gladys Lake			
6	08AA004	Kathleen River near Haines Junction	0.08	0.45	0.47
7	09AA010	Lindeman River near Bennett			
8	09AA007	Lubbock River near Atlin	0.24	0.49	0.25
9	09AA013	Tutshi River at outlet of Tutshi Lake			
10	09AA015	Wann River near Atlin			
11	09AA009	Watson River near Carcross	0.06	0.66	0.14
12	09AA012	Wheaton River near Carcross	0.01	0.68	0.31
13	09AG001	Big Salmon River near Carmacks	0.07	0.53	0.40
14	09CA002	Kluane River at outlet of Kluane Lake	0.16	0.29	0.13
15	09AE003	Swift River near Swift River	0.16	0.17	0.67
16	09AC004	Takhini River at outlet of Kusawa Lake	0.21	0.24	0.15
17	09AC001	Takhini River near Whitehorse	0.20	0.43	0.38
18	09AE001	Teslin River near Teslin	0.11	0.30	0.17
19	09AF001	Teslin River near Whitehorse	0.03	0.40	0.59
20	09CB001	White River at 1169.2 Alaska Highway	0.40	0.26	0.39
21	09AB009	Yukon River above Frank Creek	0.31	0.24	0.45
22	09AH001	Yukon River at Carmacks	0.16	0.52	0.32
23	09AB001	Yukon River at Whitehorse	0.12	0.50	0.24
24	10AB001	Frances River near Watson Lake	0.04	0.44	0.53
25	10AD001	Hyland River near Lower Post	0.10	0.51	0.39
26	09EA003	Klondike River above Bonanza Creek	0.07	0.44	0.48
27	10BE001	Liard River at Lower Crossing	0.04	0.46	0.49
28	10AA001	Liard River at Upper Crossing	0.07	0.35	0.61
29	09EA004	North Klondike River near Mouth			
30	09BC001	Pelly River at Pelly Crossing	0.05	0.40	0.54
31	09BC002	Pelly River at Ross River	0.03	0.56	0.43
32	09BA001	Ross River at Ross River	0.07	0.43	0.51

TABLE 1. (Cont'd)

Station No.	WSC No.	Station Name	Width b	Depth f	Velocity m
33	09DC002	Stewart River at Mayo	0.19	0.28	0.53
34	09DD002	Stewart River at Stewart Crossing	0.05	0.37	0.60
35	09DD003	Stewart River at the Mouth	0.04	0.37	0.60
36	09CD001	Yukon River above White River	0.07	0.29	0.65
37	09EB001	Yukon River at Dawson	0.03	0.36	0.63
38	USGS	Yukon River at Rampart	0.30	0.27	0.43
39	10MD002	Babbage River below Cariboo Creek			
40	10MD001	Firth River near Mouth			
41	10MA002	Ogilvie River at Mile 123 Dempster	0.10	0.47	0.46
42	10MA001	Peel River ab. Canyon Cr.	0.09	0.41	0.54
43	09FD001	Porcupine River at Old Crow	0.14	0.35	0.13
44	09FB001	Porcupine River below Bell River	0.09	0.46	0.46
45	10MB003	Snake River near Mouth	0.20	0.27	0.55
46	USGS	Turner River 69°35'56", 141°24'10"			
47	09AH003	Big Creek near Mouth			
48	10AB003	King Creek at Mile 13 Nahanni Rge. Rd.			
49	09AB008	M'Clintock River near Whitehorse	0.16	0.56	0.29
50	10AA002	Tom Creek at Robt. Campbell Hwy. Mi.21.7	0.00	0.44	0.55
		Average	0.13	0.42	0.41
		Alaskan Streams South of Yukon River (W.W. Emmett, 1972)	0.19	0.39	0.42

TABLE 2 - BANKFULL HYDROLOGIC DATA FOR RIVERS INCLUDED IN THE STUDY

Station No.	WSC No.	Station Name	Drainage Area DA (sq.mi.)	Bankfull Gauge Height (feet)	Bankfull Discharge Q_B (cfs)	Bankfull Unit Runoff Q_B/DA (cfs/sq.mi.)	Return Period (years)
ATLIN-BENNETT-DEZADEASH							
1	09AA006	Atlin River near Atlin	2630	-	-	-	-
2	08AA001	Aishihik River near Whitehorse	1660	10.6 *	3,260	1.96	5.6
3	08AA003	Dezadeash River at Haines Junction	3280	12.4 *	5,250	1.60	1.6
4	09AA014	Fantail River at outlet of Fantail Lake	289	5.1	2,170	7.50	-
5	09AE004	Gladys River at outlet of Gladys Lake	737	4.0	2,700	3.66	5.6
6	08AA004	Kathleen River near Haines Junction	249	6.5	1,900	7.63	3.2
7	09AA010	Lindeman River near Bennett	92	6.0	1,300	14.13	1.0
8	09AA007	Lubbock River near Atlin	684	-	-	-	-
9	09AA013	Tutshi River at outlet of Tutshi Lake	366	5.0	2,300	6.28	2.3
10	09AA015	Wann River near Atlin	104	5.7	1,250	12.00	1.9
11	09AA009	Watson River near Carcross	452	12.0	2,360	5.22	27.0
12	09AA012	Wheaton River near Carcross	337	6.2	1,850	5.50	2.2
UPPER YUKON-TESLIN-TAKHINI							
13	09AG001	Big Salmon River near Carmacks	2610	6.9	11,900	4.56	2.3
14	09CA002	Kluane River at outlet of Kluane Lake	1910	14.4 *	12,000	6.28	9.0
15	09AE003	Swift River near Swift River	1280	8.1 *	8,000	6.25	1.6
16	09AC004	Takhini River at outlet of Kusawa Lake	1570	11.0	9,900	6.30	11.0
17	09AC001	Takhini River near Whitehorse	2700	19.0 *	12,900	4.78	20.0
18	09AE001	Teslin River near Teslin	11700	25.0 *	25,700	2.20	1.1
19	09AF001	Teslin River near Whitehorse	13700	10.4	34,000	2.48	1.4
20	09CB001	White River at Alaska Hwy. Mi. 1169.2	2410	82.8 *	12,800	5.31	-

* Confirmed or revised on basis of field inspection

TABLE 2 (cont'd)

Station No.	WSC No.	Station Name	Drainage Area, DA (sq.mi.)	Bankfull Gauge Height (feet)	Bankfull Discharge, Q_B (cfs)	Bankfull Unit Runoff, Q_B/DA (cfs/sq.mi.)	Return Period (years)
UPPER YUKON-TESLIN-TAKHINI (Cont'd)							
21	09AB009	Yukon River above Frank Creek	12000	11.7	29,100	2.42	12.0
22	09AH001	Yukon River at Carmacks	33600	12.7	48,000	1.43	1.1
23	09AB001	Yukon River at Whitehorse	7500	6.8 *	22,800	3.04	7.5
LIARD-PELLY-STEWART-LOWER YUKON							
24	10AB001	Frances River near Watson Lake	4950	11.3	33,000	6.67	6.7
25	10AD001	Hyland River near Lower Post	3650	9.4	27,000	7.40	1.5
26	09EA003	Klondike River above Bonanza Creek	3010	10.5	22,800	7.57	19.0
27	10BE001	Liard River at Lower Crossing	40300	42.4	160,000	3.97	1.6
28	10AA001	Liard River at Upper Crossing	12500	18.4 *	68,800	5.50	2.0
29	09EA004	North Klondike River near Mouth	423	-	-	-	-
30	09BC001	Pelly River at Pelly Crossing	18900	16.5	94,600	5.00	4.2
31	09BC002	Pelly River at Ross River	7670	11.2	40,700	5.31	3.2
32	09BA001	Ross River at Ross River	2800	12.4	23,000	8.21	12.0
33	09DC002	Stewart River at Mayo	12100	23.7	71,000	5.86	1.6
34	09DD002	Stewart River at Stewart Crossing	13500	20.4	75,000	5.55	1.4
35	09DD003	Stewart River at the Mouth	19700	95.2	88,000	4.47	2.0
36	09CD001	Yukon River above White River	58400	13.5	182,000	3.11	5.0
37	09EB001	Yukon River at Dawson	106000	15.6	300,000	2.83	4.1
38	USGS	Yukon River at Rampart	199400	-	408,000	2.05	1.5

* Confirmed or revised on basis of field inspection

TABLE 2 (Cont'd)

Station No.	WSC No.	Station Name	Drainage Area DA (sq.mi.)	Bankfull Gauge Height (feet)	Bankfull Discharge Q_B (cfs)	Bankfull Unit Runoff Q_B/DA (cfs/sq.mi.)	Return Period (years)
PORCUPINE-PEEL							
39	10MD002	Babbage River below Cariboo Creek	521	-	-	-	-
40	10MD001	Firth River near Mouth	2240	24.0 *	-	-	-
41	10MA002	Ogilvie River at Mile 123 Dempster	1400	28.73 *	19,600	14.00	2.4
42	10MA001	Peel River above Canyon Creek	10200	15.75	108,000	10.59	4.0
43	09FD001	Porcupine River at Old Crow	20900	34.56	175,000	8.37	2.6
44	09FB001	Porcupine River below Bell River	13900	96.0 *	131,000	9.42	1.4
45	10MB003	Snake River near Mouth	3440	-	-	-	-
46	USGS	Turner River 69°35'56", 141°24'10"	51	-	1,300	25.49	-
MOUNTAIN STREAMS							
47	09AH003	Big Creek near Mouth	674	21.2	1,200	1.78	-
48	10AB003	King Creek at Mile 13 Nahanni Rge. Rd.	5.3	2.7 *	87	16.42	-
49	09AB008	M'Clintock River near Whitehorse	597	6.0 *	1,090	1.83	1.2
50	10AA002	Tom Creek at Robt. Campbell Hwy. Mile 21.7	168	3.1 *	580	3.45	1.1

* Confirmed or revised on basis of field inspection

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Atlin-Bennett-Dezadeash	2. Aishihik River near Whitehorse 08AA001	Bankfull Q_B	3,260	6.01	114.91	690.61	1.000	1.000	1.000	1.000
		Mean	514	1.50	78.14	117.21	0.158	0.170	0.250	0.680
		1.5 yr.	2,080	4.31	104.48	450.31	0.638	0.652	0.717	0.909
		2.33 yr.	2,570	5.03	109.36	550.08	0.788	0.797	0.837	0.952
		10 yr.	3,900	6.88	119.27	820.58	1.196	1.188	1.145	1.038
		50 yr.	5,080	8.40	126.02	1,058.57	1.558	1.533	1.398	1.097
		100 yr.	5,560	8.99	128.40	1,154.32	1.706	1.671	1.496	1.117
	3. Dezadeash River at Haines Junction 08AA003	Bankfull Q_B	5,250	4.61	276.89	1,276.46	1.000	1.000	1.000	1.000
		Mean	1,520	2.89	175.04	505.87	0.290	0.396	0.627	0.632
		1.5 yr.	4,800	4.46	267.93	1,194.97	0.914	0.936	0.968	0.968
		2.33 yr.	5,880	4.81	288.65	1,388.41	1.120	1.088	1.043	1.042
		10 yr.	8,500	5.52	330.35	1,824.08	1.619	1.429	1.197	1.193
		50 yr.	10,900	6.07	362.03	2,197.52	2.076	1.722	1.317	1.308
		100 yr.	11,800	6.25	372.72	2,329.50	2.248	1.825	1.356	1.346
	4. Fantail River at outlet of Fantail L. 09AA014	Bankfull Q_B	2,170	3.45	248.57	858.56	1.000	1.000	1.000	1.000
		Mean	741	2.23	175.62	391.98	0.342	0.457	0.646	0.707
		1.5 yr.	3,400	4.15	287.42	1,191.64	1.567	1.388	1.200	1.156
		2.33 yr.	4,220	4.53	308.21	1,394.96	1.945	1.625	1.310	1.240
		10 yr.	5,650	5.10	338.71	1,997.68	2.604	2.327	1.476	1.363
		50 yr.	7,850	5.83	376.71	2,194.34	3.618	2.556	1.687	1.516
		100 yr.	9,000	6.58	393.74	2,424.65	4.148	2.824	1.783	1.584

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Atlin-Bennett-Dezadeash (cont'd)	5. Gladys River at outlet Gladys L. 09AE004	Bankfull Q_B	2,700	2.13	174.16	370.44	1.000	1.000	1.000	1.000
		Mean	531	1.21	199.31	241.56	0.197	0.649	0.570	1.144
		1.5 yr.	1,780	1.84	180.32	332.15	0.659	0.897	0.866	1.035
		2.33 yr.	2,120	1.96	177.69	347.56	0.785	0.938	0.920	1.020
		10 yr.	3,200	2.26	171.73	387.42	1.185	1.046	1.061	0.986
		50 yr.	4,700	2.57	166.32	428.11	1.741	1.156	1.210	0.955
		100 yr.	5,400	2.70	164.43	444.45	2.000	1.120	1.271	0.944
	6. Kathleen River near Haines Junction 08AA004	Bankfull Q_B	1,900	3.74	115.67	432.61	1.000	1.000	1.000	1.000
		Mean	387	1.83	101.63	185.98	0.204	0.430	0.489	0.879
		1.5 yr.	1,350	3.21	112.50	361.12	0.710	0.835	0.858	0.973
		2.33 yr.	1,770	3.62	115.00	416.30	0.932	0.962	0.968	0.994
		10 yr.	2,500	4.23	118.28	500.32	1.316	1.157	1.131	1.023
		50 yr.	3,400	4.85	121.27	588.16	1.789	1.360	1.297	1.048
		100 yr.	4,000	5.22	122.88	641.43	2.105	1.483	1.396	1.062
	7. Lindeman Creek near Bennett 09AA010	Bankfull Q_B	1,300	2.08	76.16	158.18	1.000	1.000	1.000	1.000
		Mean	348	1.37	82.63	113.29	0.268	0.716	0.660	1.085
		1.5 yr.	1,800	2.30	74.64	171.97	1.385	1.087	1.109	0.980
		2.33 yr.	2,280	2.48	73.56	182.43	1.754	1.153	1.194	0.966
		10 yr.	3,500	2.40	71.63	203.36	2.692	1.286	1.367	0.941
		50 yr.	5,700	3.31	69.48	229.98	4.385	1.454	1.594	0.912
		100 yr.	7,600	3.63	68.28	247.58	5.846	1.565	1.746	0.897

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Atlin-Bennett-Dezadeash (cont'd)	9. Tutshi River at outlet of Tutshi L. 09AA013	Bankfull Q_B	2,300	7.05	56.78	400.41	1.000	1.000	1.000	1.000
		Mean	562	2.64	81.97	216.56	0.244	0.541	0.375	1.444
		1.5 yr.	2,000	6.40	58.86	376.70	0.870	0.941	0.908	1.037
		2.33 yr.	2,370	7.20	56.34	405.70	1.030	1.013	1.021	0.992
		10 yr.	3,300	9.07	51.68	468.69	1.435	1.171	1.286	0.910
		50 yr.	4,750	11.70	47.00	549.90	2.065	1.373	1.659	0.828
		100 yr.	5,400	12.78	45.45	580.85	2.348	1.451	1.812	0.801
	10. Wann River near Atlin 09AA015	Bankfull Q_B	1,250	2.38	56.82	135.46	1.000	1.000	1.000	1.000
		Mean	235	1.25	65.24	81.62	0.188	0.603	0.525	1.148
		1.5 yr.	1,160	2.32	56.98	132.19	0.928	0.976	0.973	1.003
		2.33 yr.	1,380	2.48	56.18	139.27	1.104	1.028	1.040	0.989
		10 yr.	1,950	2.83	54.57	154.60	1.560	1.141	1.188	0.960
		50 yr.	2,850	3.28	52.81	173.22	2.280	1.279	1.376	0.929
		100 yr.	4,100	3.78	51.25	193.47	3.280	1.428	1.583	0.902
	11. Watson River near Carcross 09AA009	Bankfull Q_B	2,360	11.77	56.93	669.90	1.000	1.000	1.000	1.000
		Mean	452	3.93	51.65	202.78	0.192	0.303	0.333	0.907
		1.5 yr.	720	5.35	53.08	283.71	0.305	0.424	0.455	0.932
		2.33 yr.	893	6.18	53.78	332.36	0.378	0.496	0.525	0.945
		10 yr.	1,400	8.32	55.22	459.60	0.593	0.686	0.707	0.970
		50 yr.	1,840	9.98	56.11	559.81	0.780	0.836	0.848	0.986
		100 yr.	2,010	10.58	56.40	596.66	0.852	0.891	0.899	0.991

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA Λ (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Atlin-Bennett-Dezadeash (cont'd)	12. Wheaton River near Carcross 09AA0012	Bankfull Q_B	1,850	4.44	95.97	426.59	1,000	1.000	1.000	1.000
		Mean	269	1.19	94.50	112.64	0.145	0.264	0.268	0.985
		1.5 yr.	1,430	3.73	95.77	357.03	0.773	0.837	0.839	0.998
		2.33 yr.	1,740	4.28	95.92	410.73	0.941	0.963	0.963	1.000
		10 yr.	2,350	5.26	96.15	505.46	1.270	1.185	1.183	1.002
		50 yr.	2,440	5.39	96.18	518.79	1.319	1.216	1.214	1.002
		100 yr.	2,490	5.47	96.19	526.06	1.346	1.233	1.230	1.002
		Bankfull Q_B								
		Mean								
		1.5 yr.								
		2.33 yr.								
		10 yr.								
		50 yr.								
		100 yr.								
		Bankfull Q_B								
		Mean								
		1.5 yr.								
		2.33 yr.								
		10 yr.								
		50 yr.								
		100 yr.								

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Upper Yukon-Teslin-Takhini	13. Big Salmon River near Carmacks 09AG001	Bankfull Q_B	11,900	6.54	287.52	1,878.94	1.000	1.000	1.000	1.000
		Mean	2,440	2.21	260.63	575.47	0.205	0.306	0.338	0.906
		1.5 yr.	10,100	5.99	284.62	1,703.45	0.849	0.907	0.916	0.990
		2.33 yr.	12,000	6.57	287.67	1,891.14	1.008	1.006	1.006	1.001
		10 yr.	17,300	8.50	294.27	2,501.00	1.454	1.331	1.301	1.023
		50 yr.	23,500	10.54	299.91	3,160.15	1.975	1.682	1.612	1.043
		100 yr.	26,400	11.43	302.08	3,453.98	2.218	1.838	1.750	1.051
	14. Kluane River at outlet Kluane L. 09CA002	Bankfull Q_B	12,000	8.26	203.97	1,685.20	1.000	1.000	1.000	1.000
		Mean	2,520	5.24	160.22	838.91	0.210	0.498	0.634	0.786
		1.5 yr.	8,200	7.39	192.30	1,421.48	0.683	0.844	0.895	0.943
		2.33 yr.	9,270	7.66	194.98	1,501.60	0.772	0.891	0.927	0.961
		10 yr.	12,100	8.26	204.83	1,692.92	1.008	1.005	1.000	1.004
		50 yr.	13,000	8.44	207.12	1,748.09	1.083	1.037	1.022	1.015
		100 yr.	13,400	8.52	208.09	1,771.89	1.117	1.051	1.032	1.020
	15. Swift River near Swift River 09AE003	Bankfull Q_B	8,000	4.17	118.91	495.38	1.000	1.000	1.000	1.000
		Mean	1,740	3.21	93.54	300.16	0.218	0.606	0.770	0.787
		1.5 yr.	7,800	4.14	118.58	491.04	0.975	0.991	0.994	0.997
		2.33 yr.	9,300	4.27	121.93	520.14	1.163	1.050	1.024	1.025
		10 yr.	14,000	4.57	130.07	594.69	1.750	1.200	1.097	1.094
		50 yr.	21,000	4.90	138.69	679.16	2.625	1.371	1.175	1.166
		100 yr.	35,500	5.36	150.69	806.96	4.438	1.628	1.285	1.267

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Upper Yukon-Teslin-Takhini (cont'd)	16. Takhini River at outlet Kusawa L. 09AC004	Bankfull Q_B	9,900	7.98	298.63	2,383.07	1.000	1.000	1.000	1.000
		Mean	1,800	5.27	209.46	1,103.85	0.182	0.463	0.660	0.701
		1.5 yr.	6,200	7.12	270.91	1,928.88	0.626	0.809	0.892	0.907
		2.33 yr.	7,240	7.39	279.81	2,067.80	0.731	0.868	0.926	0.937
		10 yr.	9,500	7.90	296.08	2,339.03	0.960	0.982	0.990	0.992
		50 yr.	10,900	8.17	304.67	2,489.15	1.101	1.045	1.024	1.020
		100 yr.	11,400	8.27	307.53	2,543.27	1.152	1.067	1.036	1.030
	17. Takhini River near Whitehorse 09AC001	Bankfull Q_B	12,900	11.60	245.77	2,850.93	1.000	1.000	1.000	1.000
		Mean	2,170	5.40	172.55	932.31	0.168	0.327	0.466	0.702
		1.5 yr.	6,900	8.88	217.46	1,931.04	0.535	0.677	0.766	0.885
		2.33 yr.	8,370	9.68	225.50	2,183.74	0.649	0.766	0.835	0.918
		10 yr.	11,400	11.06	239.80	2,651.12	0.884	0.930	0.953	0.976
		50 yr.	14,500	12.26	251.56	3,083.62	1.124	1.082	1.057	1.024
		100 yr.	15,800	12.72	255.89	3,254.41	1,225	1.142	1.097	1.041
	18. Teslin River near Teslin 09AE001	Bankfull Q_B	25,700	19.11	466.97	8,923.80	1.000	1.000	1.000	1.000
		Mean	10,900	14.83	425.64	6,312.24	0.424	0.707	0.776	0.912
		1.5 yr.	33,000	20.58	479.73	9,872.84	1.284	1.106	1.077	1.027
		2.33 yr.	39,500	21.71	489.14	10,619.23	1.537	1.190	1.136	1.048
		10 yr.	53,000	23.67	504.93	11,951.69	2.062	1.339	1.239	1.081
		50 yr.	64,800	25.13	516.02	12,967.58	2.521	1.453	1.315	1.105
		100 yr.	69,300	25.63	519.77	13,321.71	2.696	1.493	1.341	1.113

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Upper Yukon-Teslin-Takhini (cont'd)	19. Teslin River near Whitehorse 09AF001	Bankfull Q_B	34,000	11.42	645.13	7,367.38	1.000	1.000	1.000	1.000
		Mean	11,700	7.45	625.81	4,664.16	0.344	0.633	0.652	0.970
		1.5 yr.	36,000	11.70	646.18	7,558.37	1.059	1.026	1.024	1.002
		2.33 yr.	42,400	12.49	649.20	8,108.51	1.247	1.101	1.094	1.006
		10 yr.	59,000	14.24	655.34	9,335.32	1.735	1.267	1.247	1.016
		50 yr.	74,800	15.67	659.79	10,336.93	2.200	1.403	1.372	1.023
		100 yr.	81,700	16.23	661.45	10,735.99	2.403	1.457	1.421	1.025
	21. Yukon River above Frank Creek 09AB009	Bankfull Q_B	29,100	16.03	435.00	6,973.05	1.000	1.000	1.000	1.000
		Mean	11,300	12.76	327.17	4,174.69	0.388	0.599	0.796	0.752
		1.5 yr.	17,400	14.13	373.45	5,276.85	0.598	0.757	0.882	0.869
		2.33 yr.	24,500	15.39	412.69	6,351.30	0.842	0.911	0.960	0.949
		10 yr.	28,500	15.87	434.42	6,894.25	0.979	0.989	0.990	0.999
		50 yr.	31,700	16.35	446.54	7,300.93	1.089	1.047	1.020	1.027
		100 yr.	32,800	16.49	451.23	7,440.78	1.127	1.067	1.029	1.037
	22. Yukon River at Carmacks 09AH001	Bankfull Q_B	48,000	12.24	721.69	8,833.49	1.000	1.000	1.000	1.000
		Mean	26,200	8.95	654.28	5,855.81	0.546	0.663	0.731	0.907
		1.5 yr.	59,500	13.67	747.26	10,215.04	1.240	1.156	1.117	1.035
		2.33 yr.	70,600	14.93	768.26	11,470.12	1.471	1.298	1.220	1.064
		10 yr.	95,400	17.44	806.64	14,067.80	1.988	1.593	1.425	1.118
		50 yr.	119,000	19.55	836.04	16,344.58	2,479	1.850	1.597	1.158
		100 yr.	129,000	29.38	847.05	17,262,88	2.688	1.954	1.665	1.174

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Upper Yukon-Teslin-Takhini (cont'd)	23. Yukon River at Whitehorse 09AB001	Bankfull Q_B	22,800	18.94	363.37	6,882.23	1.000	1.000	1.000	1.000
		Mean	8,440	11.57	321.72	3,722.30	0.370	0.541	0.611	0.885
		1.5 yr.	17,300	16.52	351.29	5,803.31	0.759	0.843	0.872	0.967
		2.33 yr.	18,500	17.08	354.18	6,049.39	0.811	0.879	0.902	0.975
		10 yr.	21,500	18.40	358.96	6,604.86	0.943	0.960	0.972	0.988
		50 yr.	23,300	19.15	362.50	6,941.88	1.022	1.009	1.011	0.998
		100 yr.	24,000	19.43	363.81	7,068.83	1.053	1.027	1.026	1.001
		Bankfull Q_B								
		Mean								
		1.5 yr.								
		2.33 yr.								
		10 yr.								
		50 yr.								
		100 yr.								
		Bankfull Q_B								
		Mean								
		1.5 yr.								
		2.33 yr.								
		10 yr.								
		50 yr.								
		100 yr.								

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Liard-Pelly-Stewart-Lower Yukon	24. Frances River near Watson Lake	Bankfull Q_B	33,000	10.68	358.34	3,828.15	1.000	1.000	1.000	1.000
		Mean	5,880	4.97	332.72	1,655.28	0.178	0.432	0.466	0.929
		1.5 yr.	22,800	9.07	352.69	3,198.55	0.691	0.836	0.849	0.984
		2.33 yr.	26,500	9.69	354.98	3,441.18	0.803	0.899	0.907	0.991
		10 yr.	39,000	11.50	360.92	4,152.02	1.182	1.085	1.077	1.007
		50 yr.	43,600	12.09	362.66	4,383.11	1.321	1.145	1.131	1.012
		100 yr.	46,800	12.47	363.77	4,536.94	1.418	1.185	1.167	1.015
	25. Hyland River near Lower Post 10AD001	Bankfull Q_B	27,000	8.65	417.87	3,613.74	1.000	1.000	1.000	1.000
		Mean	5,010	3.72	353.85	1,314.91	0.186	0.364	0.430	0.847
		1.5 yr.	27,000	8.72	419.45	3,657.60	1.000	1.012	1.008	1.004
		2.33 yr.	30,300	9.26	424.73	3,933.00	1.122	1.088	1.071	1.016
		10 yr.	39,800	10.53	434.58	4,575.26	1.474	1.266	1.217	1.040
		50 yr.	52,900	12.16	447.25	5,439.46	1.959	1.505	1.406	1.070
		100 yr.	59,200	12.87	452.36	5,824.14	2.193	1.612	1.489	1.082
	26. Klondike River above Bonanza Creek 09EA003	Bankfull Q_B	25,000	10.33	206.47	2,132.42	1.000	1.000	1.000	1.000
		Mean	2,180	3.54	175.48	620.50	0.087	0.291	0.342	0.850
		1.5 yr.	12,000	7.48	196.61	1,470.84	0.480	0.690	0.724	0.952
		2.33 yr.	14,700	8.18	199.29	1,629.99	0.588	0.764	0.792	0.965
		10 yr.	21,500	9.67	204.41	1,975.83	0.860	0.927	0.936	0.990
		50 yr.	25,900	10.49	206.96	2,171.01	1.036	1.018	1.016	1.002
		100 yr.	28,700	10.97	208.38	2,286.76	1.148	1.072	1.063	1.009

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Liard-Pelly-Stewart-Lower Yukon (cont'd)	27. Liard River at Lower Crossing 10BE001	Bankfull Q_B	160,000	22.71	832.08	18,896.54	1.000	1.000	1.000	1.000
		Mean	40,800	12.09	787.82	9,524.74	0.254	0.504	0.532	0.946
		1.5 yr.	159,000	22.64	831.87	18,833.54	0.994	0.997	0.997	1.000
		2.33 yr.	187,000	24.40	837.29	20,429.88	1.169	1.081	1.074	1.006
		10 yr.	240,000	27.29	845.69	23,078.88	1.500	1.221	1.202	1.016
		50 yr.	305,000	30.48	853.83	26,024.74	1.906	1.377	1.342	1.026
		100 yr.	334,000	31.78	856.94	27,233.55	2.088	1.441	1.399	1.030
	28. Liard River at Upper Crossing 10AA001	Bankfull Q_B	68,800	18.98	456.78	8,669.68	1.000	1.000	1.000	1.000
		Mean	14,000	10.89	408.94	4,453.36	0.203	0.514	0.574	0.895
		1.5 yr.	59,800	18.08	452.36	8,178.67	0.869	0.943	0.953	0.990
		2.33 yr.	72,700	19.35	458.54	8,872.75	1.057	1.023	1.020	1.004
		10 yr.	104,000	21.92	470.09	10,304.37	1.512	1.189	1.154	1.029
		50 yr.	168,000	25.92	486.02	12,597.64	2.442	1.453	1.366	1.064
		100 yr.	205,000	27.78	492.80	13,689.98	2.980	1.579	1.464	1.079
	30. Pelly River at Pelly Crossing 098C001	Bankfull Q_B	94,600	15.55	732.90	11,393.66	1.000	1.000	1.000	1.000
		Mean	13,900	6.32	653.07	4,127.40	0.147	0.362	0.407	0.891
		1.5 yr.	61,000	12.65	714.03	9,032.48	0.645	0.793	0.814	0.974
		2.33 yr.	78,300	14.22	724.86	10,307.51	0.828	0.905	0.915	0.989
		10 yr.	118,000	17.24	742.73	12,807.64	1.247	1.124	1.109	1.013
		50 yr.	173,000	20.63	760.07	15,683.28	1.829	1.376	1.327	1.037
		100 yr.	200,000	22.09	766.74	16,934.22	2.114	1.486	1.421	1.046

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Liard-Pelly-Stewart-Lower Yukon (cont'd)	31. Pelly River at Ross River 09BC002	Bankfull Q_B	40,700	12.46	560.38	6,979.53	1.000	1.000	1.000	1.000
		Mean	6,600	4.47	531.10	2,373.49	0.162	0.340	0.359	0.948
		1.5 yr.	33,600	11.19	557.22	6,235.85	0.826	0.893	0.899	0.994
		2.33 yr.	40,000	12.35	560.09	6,915.43	0.983	0.991	0.991	0.999
		10 yr.	87,400	15.12	566.09	8,559.85	1.410	1.226	1.214	1.010
		50 yr.	76,300	17.75	570.86	10,135.05	1.875	1.452	1.425	1.019
		100 yr.	84,700	18.83	572.62	10,783.01	2.081	1.545	1.512	1.022
	32. Ross River at Ross River 09BA001	Bankfull Q_B	23,000	8.12	300.84	2,444.33	1.000	1.000	1.000	1.000
		Mean	2,340	3.03	256.37	777.57	0.102	0.318	0.373	0.852
		1.5 yr.	13,600	6.50	289.97	1,884.52	0.591	0.771	0.800	0.964
		2.33 yr.	16,100	6.99	293.41	2,051.23	0.700	0.839	0.860	0.975
		10 yr.	22,000	7.97	299.90	2,390.20	0.957	0.978	0.981	0.997
		50 yr.	29,200	9.01	305.91	2,755.94	1.270	1.127	1.109	1.017
		100 yr.	32,500	9.44	308.21	2,908.58	1.413	1.190	1.161	1.024
	33. Stewart River at Mayo 09DC002	Bankfull Q_B	71,000	16.49	738.04	12,170.28	1.000	1.000	1.000	1.000
		Mean	13,100	10.27	536.83	5,513.24	0.185	0.453	0.622	0.727
		1.5 yr.	74,000	16.67	744.68	12,413.82	1.042	1.020	1.011	1.009
		2.33 yr.	85,400	17.36	765.27	13,285.09	1.203	1.092	1.053	1.037
		10 yr.	115,000	18.87	808.47	15,255.83	1.620	1.254	1.144	1.095
		50 yr.	143,000	20.05	842.46	16,891.32	2.014	1.388	1.216	1.142
		100 yr.	154,000	20.47	854.35	17,488.55	2.169	1.437	1.241	1.158

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Liard-Pelly-Stewart-Lower Yukon (cont'd)	34. Stewart River at Stewart Crossing 09DD002	Bankfull Q_B	75,000	21.91	545.29	11,945.12	1.000	1.000	1.000	1.000
		Mean	14,700	12.03	501.80	6,037.65	0.196	0.505	0.549	0.920
		1.5 yr.	78,000	22.20	546.38	12,128.00	1.040	1.015	1.013	1.002
		2.33 yr.	92,100	23.60	551.03	13,002.10	1.228	1.088	1.077	1.011
		10 yr.	132,000	26.97	561.24	15,137.77	1.760	1.267	1.231	1.029
		50 yr.	192,000	30.96	572.07	17,711.29	2.560	1.483	1.413	1.049
		100 yr.	223,000	32.71	576.45	18,857.41	2.973	1.579	1.493	1.057
	35. Stewart River at the Mouth 09DD003	Bankfull Q_B	88,000	18.09	619.44	11,205.67	1.000	1.000	1.000	1.000
		Mean	16,400	9.75	583.09	5,685.13	0.186	0.507	0.539	0.941
		1.5 yr.	78,000	17.31	616.76	10,676.12	0.886	0.953	0.957	0.996
		2.33 yr.	98,100	18.83	621.87	11,709.81	1.115	1.044	1.041	1.004
		10 yr.	159,000	22.48	632.78	14,224.89	1.807	1.269	1.243	1.022
		50 yr.	313,000	28.85	648.40	18,706.34	3.557	1.669	1.595	1.047
		100 yr.	411,000	31.89	654.79	20,881.25	4.670	1.863	1.763	1.057
	36. Yukon River above White River 09CD001	Bankfull Q_B	182,000	21.79	910.65	19,843.06	1.000	1.000	1.000	1.000
		Mean	41,700	14.21	818.39	11,629.32	0.229	0.586	0.652	0.899
		1.5 yr.	127,000	19.55	887.21	17,344.96	0.698	0.874	0.897	0.974
		2.33 yr.	153,000	20.62	899.27	18,542.95	0.841	0.934	0.946	0.988
		10 yr.	215,000	22.86	921.72	21,070.52	1.181	1.062	1.049	1.012
		50 yr.	307,000	25.32	945.83	23,948.42	1.687	1.207	1.162	1.039
		100 yr.	352,000	26.33	955.26	25,152.00	1.934	1.268	1.208	1.049

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Liard-Pelly-Stewart-Lower Yukon (cont'd)	37. Yukon River at Dawson 09EB001	Bankfull Q_B	300,000	30.17	1,216.08	36,689.13	1.000	1.000	1.000	1.000
		Mean	78,400	18.52	1,161.06	21,502.83	0.261	0.586	0.614	0.955
		1.5 yr.	230,000	27.24	1,204.98	32,823.66	0.767	0.895	0.903	0.991
		2.33 yr.	278,000	29.15	1,212.88	35,355.45	0.927	0.964	0.966	0.997
		10 yr.	371,000	32.56	1,255.02	39,886.65	1.237	1.087	1.079	1.007
		50 yr.	477,000	35.63	1,235.70	44,027.99	1.590	1.200	1.181	1.016
		100 yr.	524,000	36.85	1,239.71	45,683.31	1.747	1.245	1.221	1.019
		Bankfull Q_B								
		Mean								
		1.5 yr.								
		2.33 yr.								
		10 yr.								
		50 yr.								
		100 yr.								
		Bankfull Q_B								
		Mean								
		1.5 yr.								
		2.33 yr.								
		10 yr.								
		50 yr.								
		100 yr.								

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Porcupine-Peel	41. Ogilvie River at Mi. 123 Dempster 10MA002	Bankfull Q_B	19,600	6.992	314.56	2,199.40	1.000	1.000	1.000	1.000
		Mean	1,100	1.825	238.23	434.77	0.056	0.197	0.261	0.757
		1.5 yr.								
		2.33 yr.								
		10 yr.								
		50 yr.								
		100 yr.								
	42. Peel River above Canyon Creek 10MA001	Bankfull Q_B	108,000	14.45	687.05	9,926.50	1.000	1.000	1.000	1.000
		Mean	6,450	4.51	533.89	2,408.91	0.060	0.243	0.312	0.777
		1.5 yr.	70,700	12.13	661.49	8,023.21	0.655	0.808	0.840	0.963
		2.33 yr.	101,000	14.05	682.95	9,598.18	0.935	0.967	0.973	0.994
		10 yr.	162,000	17.08	712.44	12,169.19	1.500	1.226	1.182	1.037
		50 yr.	315,000	22.48	756.13	16,997.80	2.917	1.712	1.556	1.101
		100 yr.	402,000	24.86	772.82	19,213.85	3.722	1.936	1.721	1.125
	45. Porcupine River at Old Crow 09FD001	Bankfull Q_B	175,000	27.69	807.79	22,367.71	1.000	1.000	1.000	1.000
		Mean	13,100	11.30	566.33	6,399.53	0.075	0.286	0.408	0.701
		1.5 yr.	135,000	25.32	779.57	19,738.71	0.771	0.883	0.914	0.965
		2.33 yr.	157,000	26.67	795.86	21,225.59	0.897	0.949	0.963	0.985
		10 yr.	246,000	31.31	846.39	26,500.47	1.406	1.185	1.131	1.048
		50 yr.	328,000	34.59	880.42	30,453.73	1.874	1.362	1.249	1.090
		100 yr.	363,000	35.82	892.73	31,977.59	2.074	1.430	1.294	1.105

Table 3 - CHANNEL CHARACTERISTICS FOR VARIOUS DISCHARGE EVENTS

REGION	GAUGING STATION NAME & NUMBER	DISCHARGE EVENT	DISCHARGE Q (cfs)	DEPTH D (ft.)	WIDTH W (ft.)	AREA A (sq.ft.)	$\frac{Q}{Q_B}$	$\frac{A}{A_B}$	$\frac{D}{D_B}$	$\frac{W}{W_B}$
Mountain Streams	49. M'Clintock River near Whitehorse 09AB008	Bankfull Q_B	1,090	6.45	74.55	480.85	1.000	1.000	1.000	1.000
		Mean	354	3.45	62.59	215.94	0.325	0.449	0.535	0.840
		1.5 yr.	1,630	8.08	79.36	641.23	1.495	1.334	1.253	1.065
		2.33 yr.	2,030	9.11	82.15	748.39	1.862	1.556	1.412	1.102
		10 yr.	3,200	11.74	88.19	1,035.35	2.936	2.153	1.820	1.183
		50 yr.	5,500	15.87	95.97	1,523.04	5.046	3.167	2.460	1.287
		100 yr.	6,500	17.42	98.50	1,715.87	5.963	3.568	2.701	1.321
	50. Tom Creek at Robert Campbell Highway 10AA02	Bankfull Q_B	580	3.23	48.53	156.95	1.000	1.000	1.000	1.000
		Mean	139	1.71	48.53	83.13	0.240	0.530	0.530	1.000
		1.5 yr.	700	3.52	48.53	170.63	1.207	1.087	1.087	1.000
		2.33 yr.	950	4.03	48.53	195.48	1.638	1.246	1.245	1.000
		10 yr.	1,500	4.94	48.53	239.54	2.586	1.526	1.526	1.000
		50 yr.	2,600	6.30	48.53	305.98	4.483	1.950	1.950	1.000
		100 yr.	3,500	7.20	48.53	349.22	6.034	2.225	2.225	1.000
		Bankfull Q_B								
		Mean								
		1.5 yr.								
		2.33 yr.								
		10 yr.								
		50 yr.								
		100 yr.								

TABLE 4(a) - VALUES OF RATIO OF DISCHARGE AND CHANNEL CHARACTERISTICS AT SELECTED DISCHARGE EVENTS;

ATLIN-BENNETT-DEZADEASH SUBREGION

A. Ratio of Discharge to Bankfull Discharge $(\frac{Q}{Q_B})$

Discharge Event	Station Number 1	2	3	4	5	6	7	8	9	10	11	12	Average
Mean	-	0.16	0.29	0.34	0.20	0.20	0.27	-	0.24	0.19	0.19	0.14	0.22
1.5 yr. flood	-	0.64	0.91	1.57	0.66	0.71	1.39	-	0.87	0.93	0.30	0.77	0.88
2.33	-	0.79	1.12	1.95	0.79	0.93	1.75	-	1.03	1.10	0.38	0.94	1.08
10	-	1.20	1.62	2.60	1.19	1.32	2.69	-	1.44	1.56	0.59	1.27	1.55
50	-	1.56	2.08	3.62	1.74	1.79	4.38	-	2.06	2.28	0.78	1.32	2.16
100	-	1.71	2.25	4.15	2.00	2.10	5.85	-	2.35	3.28	0.85	1.35	2.59

B. Ratio of Discharge Area to Bankfull Area $(\frac{A}{A_B})$

Discharge Event	1	2	3	4	5	6	7	8	9	10	11	12	Average
Mean	-	0.17	0.40	0.46	0.65	0.43	0.72	-	0.54	0.57	0.30	0.26	0.45
1.5 yr. flood	-	0.65	0.94	1.39	0.90	0.84	1.09	-	0.94	0.93	0.42	0.84	0.89
2.33	-	0.80	1.09	1.63	0.94	0.96	1.15	-	1.01	0.98	0.50	0.96	1.00
10	-	1.19	1.43	2.33	1.05	1.16	1.29	-	1.17	1.08	0.69	1.18	1.26
50	-	1.53	1.72	2.56	1.16	1.36	1.45	-	1.37	1.21	0.84	1.22	1.44
100	-	1.67	1.82	2.82	1.12	1.48	1.56	-	1.45	1.36	0.89	1.23	1.54

C. Ratio of Discharge Depth to Bankfull Depth $(\frac{D}{D_B})$

Discharge Event	1	2	3	4	5	6	7	8	9	10	11	12	Average
Mean	-	0.25	0.63	0.65	0.57	0.49	0.66	-	0.38	0.49	0.33	0.27	0.47
1.5 yr. flood	-	0.72	0.97	1.20	0.87	0.86	1.11	-	0.91	0.91	0.45	0.84	0.88
2.33	-	0.84	1.04	1.31	0.92	0.97	1.19	-	1.02	0.97	0.52	0.96	0.97
10	-	1.14	1.20	1.48	1.06	1.13	1.37	-	1.29	1.11	0.71	1.18	1.17
50	-	1.40	1.32	1.69	1.21	1.30	1.59	-	1.66	1.28	0.85	1.21	1.35
100	-	1.50	1.36	1.78	1.27	1.40	1.75	-	1.81	1.48	0.90	1.23	1.45

D. Ratio of Discharge Width to Bankfull Width $(\frac{W}{W_B})$

Discharge Event	1	2	3	4	5	6	7	8	9	10	11	12	Average
Mean	-	0.68	0.63	0.71	1.14	0.88	1.09	-	1.44	1.17	0.91	0.98	0.96
1.5 yr. flood	-	0.91	0.97	1.16	1.04	0.97	0.98	-	1.04	1.02	0.93	1.00	1.00
2.33	-	0.95	1.04	1.24	1.02	0.99	0.97	-	0.99	1.01	0.94	1.00	1.02
10	-	1.04	1.19	1.36	0.99	1.02	0.94	-	0.91	0.98	0.97	1.00	1.04
50	-	1.10	1.31	1.52	0.96	1.05	0.91	-	0.83	0.95	0.99	1.00	1.06
100	-	1.12	1.35	1.58	0.94	1.06	0.90	-	0.80	0.92	0.99	1.00	1.07

TABLE 4(b) - VALUES OF RATIO OF DISCHARGE AND CHANNEL CHARACTERISTICS AT SELECTED DISCHARGE EVENTS;

UPPER YUKON-TESLIN-TAKHINI SUBREGION

A. Ratio of Discharge to Bankfull Discharge ($\frac{Q}{Q_B}$)

Discharge Event	13	14	15	16	17	18	19	20	21	22	23	Average
Mean	0.21	0.21	0.22	0.18	0.17	0.42	0.34	-	0.39	0.55	0.37	0.31
1.5 yr.flood	0.85	0.68	0.98	0.63	0.54	1.28	1.06	-	0.60	1.24	0.76	0.86
2.33	1.01	0.77	1.16	0.73	0.65	1.54	1.25	-	0.84	1.47	0.81	1.02
10	1.45	1.01	1.75	0.96	0.88	2.06	1.74	-	0.98	1.99	0.94	1.38
50	1.98	1.08	2.63	1.10	1.12	2.52	2.20	-	1.09	2.48	1.02	1.72
100	2.22	1.12	4.44	1.15	1.23	2.70	2.40	-	1.13	2.69	1.05	2.01

(Station Number: 13–23)

B. Ratio of Discharge Area to Bankfull Area ($\frac{A}{A_B}$)

Discharge Event	13	14	15	16	17	18	19	20	21	22	23	Average
Mean	0.31	0.50	0.61	0.46	0.33	0.71	0.63	-	0.60	0.66	0.54	0.54
1.5 yr. flood	0.91	0.84	0.99	0.81	0.68	1.11	1.03	-	0.76	1.16	0.84	0.91
2.33	1.01	0.89	1.05	0.87	0.77	1.19	1.10	-	0.91	1.30	0.88	1.00
10	1.33	1.01	1.20	0.98	0.93	1.34	1.27	-	0.99	1.59	0.96	1.16
50	1.85	1.04	1.37	1.05	1.08	1.45	1.40	-	1.05	1.85	1.01	1.30
100	1.84	1.05	1.63	1.07	1.14	1.49	1.46	-	1.07	1.95	1.03	1.37

C. Ratio of Discharge Depth to Bankfull Depth ($\frac{D}{D_B}$)

Discharge Event	13	14	15	16	17	18	19	20	21	22	23	Average
Mean	0.34	0.63	0.77	0.66	0.47	0.78	0.65	-	0.80	0.73	0.61	0.64
1.5 yr.flood	0.92	0.90	0.99	0.89	0.77	1.08	1.02	-	0.88	1.12	0.87	0.94
2.33	1.01	0.93	1.02	0.93	0.84	1.14	1.09	-	0.96	1.22	0.90	1.00
10	1.30	1.00	1.10	0.99	0.95	1.24	1.25	-	0.99	1.43	0.97	1.12
50	1.61	1.02	1.18	1.02	1.06	1.32	1.37	-	1.02	1.60	1.01	1.22
100	1.75	1.03	1.29	1.04	1.10	1.34	1.42	-	1.03	1.67	1.03	1.27

D. Ratio of Discharge Width to Bankfull Width ($\frac{W}{W_B}$)

Discharge Event	13	14	15	16	17	18	19	20	21	22	23	Average
Mean	0.91	0.79	0.79	0.70	0.70	0.91	0.97	-	0.75	0.91	0.89	0.83
1.5 yr.flood	0.99	0.94	1.00	0.91	0.89	1.03	1.00	-	0.86	1.04	0.97	0.96
2.33	1.00	0.96	1.03	0.94	0.92	1.05	1.01	-	0.95	1.07	0.98	0.99
10	1.02	1.00	1.09	0.99	0.98	1.08	1.02	-	1.00	1.12	0.99	1.03
50	1.04	1.02	1.17	1.02	1.02	1.10	1.02	-	1.03	1.16	1.00	1.06
100	1.05	1.02	1.27	1.03	1.04	1.11	1.03	-	1.04	1.17	1.00	1.08

TABLE 4(c) - VALUES OF RATIO OF DISCHARGE AND CHANNEL CHARACTERISTICS AT SELECTED DISCHARGE EVENTS;

LIARD-PELLY-STEWART-LOWER YUKON SUBREGION

Discharge Event	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	Average
A. Ratio of Discharge to Bankfull Discharge ($\frac{Q}{Q_B}$)																
Mean	0.18	0.19	0.09	0.25	0.20	-	0.15	0.16	0.10	0.18	0.20	0.19	0.23	0.26	-	0.18
1.5 yr. flood	0.69	1.00	0.48	0.99	0.87	-	0.64	0.83	0.59	1.04	1.04	0.89	0.70	0.77	-	0.81
2.33	0.80	1.12	0.59	1.17	1.06	-	0.83	0.98	0.70	1.20	1.23	1.12	0.84	0.93	-	0.97
10	1.18	1.47	0.86	1.50	1.51	-	1.25	1.41	1.96	1.62	1.76	1.81	1.18	1.24	-	1.37
50	1.32	1.96	1.04	1.91	2.44	-	1.83	1.88	1.27	2.01	2.56	3.56	1.69	1.59	-	1.93
100	1.42	2.19	1.15	2.09	2.98	-	2.11	2.08	1.41	2.17	2.97	4.67	1.93	1.75	-	2.22
B. Ratio of Discharge Area to Bankfull Area ($\frac{A}{A_B}$)																
Mean	0.43	0.36	0.29	0.50	0.51	-	0.36	0.34	0.32	0.45	0.50	0.51	0.59	0.59	-	0.44
1.5 yr. flood	0.84	1.01	0.69	1.00	0.94	-	0.79	0.89	0.77	1.02	1.02	0.95	0.87	0.90	-	0.90
2.33	0.90	1.09	0.76	1.08	1.02	-	0.91	0.99	0.84	1.09	1.09	1.04	0.93	0.96	-	0.98
10	1.09	1.27	0.93	1.22	1.19	-	1.12	1.23	0.98	1.25	1.27	1.27	1.06	1.09	-	1.15
50	1.15	1.51	1.02	1.38	1.45	-	1.38	1.45	1.13	1.39	1.48	1.67	1.21	1.20	-	1.34
100	1.19	1.61	1.07	1.44	1.58	-	1.49	1.55	1.19	1.44	1.58	1.86	1.27	1.25	-	1.42
C. Ratio of Discharge Depth to Bankfull Depth ($\frac{D}{D_B}$)																
Mean	0.47	0.43	0.34	0.53	0.57	-	0.41	0.36	0.37	0.62	0.55	0.54	0.65	0.61	-	0.50
1.5 yr. flood	0.85	1.01	0.72	1.00	0.95	-	0.81	0.90	0.80	1.01	1.01	0.96	0.90	0.90	-	0.91
2.33	0.91	1.07	0.79	1.07	1.02	-	0.92	0.99	0.86	1.05	1.08	1.04	0.95	0.97	-	0.98
10	1.08	1.22	0.94	1.20	1.16	-	1.11	1.21	0.98	1.14	1.23	1.24	1.05	1.08	-	1.13
50	1.13	1.41	1.02	1.34	1.37	-	1.33	1.43	1.11	1.22	1.41	1.60	1.16	1.18	-	1.29
100	1.17	1.49	1.06	1.40	1.46	-	1.42	1.51	1.16	1.24	1.49	1.76	1.21	1.22	-	1.35
D. Ratio of Discharge Width to Bankfull Width ($\frac{W}{W_B}$)																
Mean	0.93	0.85	0.85	0.95	0.90	-	0.89	0.95	0.85	0.73	0.92	0.94	0.90	0.96	-	0.89
1.5 yr. flood	0.98	1.00	0.95	1.00	0.99	-	0.97	0.99	0.96	1.01	1.00	1.00	0.97	0.99	-	0.99
2.33	0.99	1.02	0.97	1.01	1.00	-	0.99	1.00	0.98	1.04	1.01	1.00	0.99	1.00	-	1.00
10	1.01	1.04	0.99	1.02	1.03	-	1.01	1.01	1.00	1.10	1.03	1.02	1.01	1.01	-	1.02
50	1.01	1.07	1.00	1.03	1.06	-	1.04	1.02	1.02	1.14	1.05	1.05	1.04	1.02	-	1.04
100	1.02	1.08	1.01	1.03	1.08	-	1.05	1.02	1.02	1.16	1.06	1.06	1.05	1.02	-	1.05

TABLE 4(d) - VALUES OF RATIO OF DISCHARGE AND CHANNEL CHARACTERISTICS AT SELECTED DISCHARGE EVENTS;

PORCUPINE-PEEL SUBREGION

A. Ratio of Discharge to Bankfull Discharge $(\frac{Q}{Q_B})$

Discharge Event	Station Number 39	40	41	42	43	44	45	46	Average
Mean	-	-	0.06	0.06	0.07	-	-	-	0.06
1.5 yr. flood	-	-	-	0.66	0.77	-	-	-	0.72
2.33	-	-	-	0.94	0.90	-	-	-	0.92
10	-	-	-	1.50	1.41	-	-	-	1.46
50	-	-	-	2.92	1.87	-	-	-	2.40
100	-	-	-	3.72	2.07	-	-	-	2.90

B. Ratio of Discharge Area to Bankfull Area $(\frac{A}{A_B})$

Discharge Event	39	40	41	42	43	44	45	46	Average
Mean	-	-	0.20	0.24	0.29	-	-	-	0.24
1.5 yr. flood	-	-	-	0.81	0.88	-	-	-	0.85
2.33	-	-	-	0.97	0.95	-	-	-	0.96
10	-	-	-	1.23	1.19	-	-	-	1.21
50	-	-	-	1.71	1.36	-	-	-	1.54
100	-	-	-	1.94	1.43	-	-	-	1.69

C. Ratio of Discharge Depth to Bankfull Depth $(\frac{D}{D_B})$

Discharge Event	39	40	41	42	43	44	45	46	Average
Mean	-	-	0.26	0.31	0.41	-	-	-	0.33
1.5 yr. flood	-	-	-	0.84	0.91	-	-	-	0.88
2.33	-	-	-	0.97	0.96	-	-	-	0.97
10	-	-	-	1.18	1.13	-	-	-	1.16
50	-	-	-	1.56	1.25	-	-	-	1.41
100	-	-	-	1.72	1.29	-	-	-	1.51

D. Ratio of Discharge Width to Bankfull Width $(\frac{W}{W_B})$

Discharge Event	39	40	41	42	43	44	45	46	Average
Mean		-	0.76	0.78	0.70	-	-	-	0.75
1.5 yr. flood	-	-	-	0.96	0.96	-	-	-	0.96
2.33	-	-	-	0.99	0.98	-	-	-	0.99
10	-	-	-	1.04	1.05	-	-	-	1.05
50	-	-	-	1.10	1.09	-	-	-	1.10
100	-	-	-	1.13	1.11	-	-	-	1.12

TABLE 4(e) - VALUES OF RATIO OF DISCHARGE AND CHANNEL CHARACTERISTICS AT SELECTED DISCHARGE EVENTS,

MOUNTAIN STREAMS

A. Ratio of Discharge to Bankfull Discharge $(\frac{Q}{Q_B})$

Discharge Event	Station Number 47	48	49	50	Average
Mean	-	-	0.32	0.24	0.28
1.5 yr. flood	-	-	1.50	1.21	1.35
2.33	-	-	1.86	1.64	1.75
10	-	-	2.94	2.59	2.76
50	-	-	5.05	4.48	4.76
100	-	-	5.96	6.03	6.00

B. Ratio of Discharge Area to Bankfull Area $(\frac{A}{A_B})$

Discharge Event	47	48	49	50	Average
Mean	-	-	0.45	0.53	0.49
1.5 yr. flood	-	-	1.33	1.09	1.21
2.33	-	-	1.56	1.25	1.40
10	-	-	2.15	1.53	1.84
50	-	-	3.17	1.95	2.56
100	-	-	3.57	2.22	2.90

C. Ratio of Discharge Depth to Bankfull Depth $(\frac{D}{D_B})$

Discharge Event	47	48	49	50	Average
Mean	-	-	0.54	0.53	0.53
1.5 yr. flood	-	-	1.25	1.09	1.17
2.33	-	-	1.41	1.25	1.33
10	-	-	1.82	1.53	1.67
50	-	-	2.46	1.95	2.21
100	-	-	2.70	2.22	2.46

D. Ratio of Discharge Width to Bankfull Width $(\frac{W}{W_B})$

Discharge Event	47	48	49	50	Average
Mean	-	-	0.84	1.00	0.92
1.5 yr. flood	-	-	1.06	1.00	1.03
2.33	-	-	1.10	1.00	1.05
10	-	-	1.18	1.00	1.09
50	-	-	1.29	1.00	1.14
100	-	-	1.32	1.00	1.16

TABLE 5 - SUMMARY OF RATIO OF DISCHARGE AND CHANNEL CHARACTERISTICS

A. Ratio of Discharge to Bankfull Discharge ($\frac{Q}{Q_B}$)

Subregion	Mean	$Q_{1.5}$	$Q_{2.33}$	Q_{10}	Q_{50}	Q_{100}
		Discharge Event				
Atlin-Bennett-Dezadeash	0.22	0.88	1.08	1.55	2.16	2.59
Upper Yukon-Teslin-Takhini	0.31	0.86	1.02	1.38	1.72	2.01
Liard-Pelly-Stewart-Lower Yukon	0.18	0.81	0.97	1.37	1.93	2.22
Average	0.24	0.85	1.02	1.43	1.94	2.27
From Figure 5	0.24	0.82	1.00	1.43	1.81	2.10
Porcupine-Peel	0.06	0.72	0.92	1.46	2.40	2.90
Mountain Streams	0.28	1.35	1.75	2.76	4.24	5.25
From Figure 5	0.31	1.36	1.76	2.82	4.10	5.00

B. Ratio of Discharge Area to Bankfull Area ($\frac{A}{A_B}$)

Subregion	Mean	$Q_{1.5}$	$Q_{2.33}$	Q_{10}	Q_{50}	Q_{100}
Atlin-Bennett-Dezadeash	0.45	0.89	1.00	1.26	1.44	1.54
Upper Yukon-Teslin-Takhini	0.54	0.91	1.00	1.16	1.30	1.37
Liard-Pelly-Stewart-Lower Yukon	0.44	0.90	0.98	1.15	1.34	1.42
Average	0.48	0.90	0.99	1.19	1.36	1.44
Porcupine-Peel	0.24	0.85	0.96	1.21	1.54	1.69
Mountain Streams	0.49	1.21	1.40	1.84	2.32	2.58

C. Ratio of Discharge Depth to Bankfull Depth ($\frac{D}{D_B}$)

Subregion	Mean	$Q_{1.5}$	$Q_{2.33}$	Q_{10}	Q_{50}	Q_{100}
Atlin-Bennett-Dezadeash	0.47	0.88	0.97	1.17	1.35	1.45
Upper Yukon-Teslin-Takhini	0.64	0.94	1.00	1.12	1.22	1.27
Liard-Pelly-Stewart-Lower Yukon	0.50	0.91	0.98	1.13	1.29	1.35
Average	0.54	0.91	0.98	1.14	1.29	1.36
Porcupine-Peel	0.33	0.88	0.97	1.16	1.41	1.51
Mountain Streams	0.53	1.17	1.33	1.67	2.21	2.46

D. Ratio of Discharge Width to Bankfull Width ($\frac{W}{W_B}$)

Subregion	Mean	$Q_{1.5}$	$Q_{2.33}$	Q_{10}	Q_{50}	Q_{100}
Atlin-Bennett-Dezadeash	0.96	1.00	1.02	1.04	1.06	1.07
Upper Yukon-Teslin-Takhini	0.83	0.96	0.99	1.03	1.06	1.08
Liard-Pelly-Stewart-Lower Yukon	0.89	0.99	1.00	1.02	1.04	1.05
Average	0.89	0.98	1.00	1.03	1.05	1.07
Porcupine-Peel	0.75	0.96	0.99	1.05	1.10	1.12
Mountain Streams	0.92	1.03	1.05	1.09	1.14	1.16

TABLE 6 - SUMMARY OF DATA AND COMPUTATIONS AT UNGAUGED LOCATIONS

Stream & Drainage Area	Milepost & Miles from Alaska Border	Streambed Material & Stream Classification (see Figure 5)	DISCHARGE MEASUREMENT CHANNEL: Date (1978)	Discharge Q (cfs)	Flow Area A (sq.ft)	Surface Width W (ft.)	Depth A/W (ft.)	Velocity Q/A (ft./sec.)	BANKFULL CHANNEL: Flow Area A_B (sq.ft.)	Surface Width W_B (ft.)	Depth D_B (A_B/W_B) (ft.)	A/A_B	Q/Q_B	Discharge Q_B (cfs)	Runoff R_B (Q_B/DA) (cfs/sq.mi.)	FLOOD CHARACTERISTICS: Mean (cfs)	$Q_{1.5}$ (cfs)	$Q_{2.33}$ (cfs)	Q_{10} (cfs)	Q_{50} (cfs)	Q_{100} (cfs)
Snag 380	1208 8.5	Silt - Sand Average	May 18	427	162	54.1	3.0	2.63	473	73.0	6.5	0.34	0.16	2,670	7.0	641	2,270	2,670	3,820	4,830	5,610
Beaver 737	1200.7 15.8	Sand - Cobblestones Average	Aug. 7	1,330	304	128	2.8	4.38	522	129	4.0	0.58	0.35	3,800	5.2	912	3,230	3,800	5,430	6,880	7,980
Dry 52	1184 31.0	Silt - Sand Average	May 18	18.0	29.8	25.8	1.4	0.72	87.6	29.0	3.0	0.34	0.12	150	2.9	36	123	150	215	272	315
Long's 44	1156 58.1	Sand - Cobblestones Average	May 19	127	77.7	34.0	2.3	1.63	256	48.9	5.2	0.30	0.10	1,270	28.9	305	1,040	1,270	1,820	2,300	2,670
Koidern 260	1152.2 62.5	Sand - Gravel Average	May 18	83.4	69.9	52.0	1.4	1.14	316	76.0	5.2	0.22	0.05	1,670	6.4	400	1,370	1,670	2,390	3,020	3,510
Burwash 64.8	1103.9 106.3	Boulders Mountain	May 20	97.7	64.1	29.2	1.0	3.31	64.1	31.0	2.2	0.46	0.27	363	5.6	112	494	639	1,020	1,490	1,820
Duke 255	1098.5 110.5	Boulders Average	Aug. 9	879	186	128	1.4	5.63	504	265	1.9	0.43	0.20	4,400	17.2	1,060	3,610	4,400	6,290	7,960	9,240
Halfbreed 26.7	1089.1 118.7	Cobblestones Mountain	Aug. 9	28.5	8.9	13.5	0.8	3.19	43.0	27.0	0.8	0.20	0.07	407	15.2	126	554	716	1,150	1,670	2,040
Silver 18.6	1053.8 154	Boulders Average	Aug. 10	80.2	17.2	24	0.7	4.66	63.7	26.0	2.4	0.27	0.11	729	19.1	175	598	729	1,040	1,320	1,530
Christmas 39.8	1048.8 -	Sand - Gravel Average	May 15	67.7	24.4	22.5	1.0	0.95	69.2	27.0	2.6	0.35	0.13	521	13.1	125	427	521	745	943	1,090
Jarvis 288	1034.6 169.8	Sand - Cobblestones Average	May 17	279	124	70.0	1.8	2.25	272	78.0	3.7	0.46	0.22	1,270	4.4	305	1,040	1,270	1,820	2,300	2,670
Bear 30	1022.1 176.5	Gravel - Cobblestones Average	May 21	86.9	24.2	23.0	1.0	3.59	78.0	26.0	3.0	0.31	0.10	869	29.0	209	713	869	1,240	1,570	1,820
Marshall 82.8	1005.6 192.1	Gravel Average	May 16	93.3	34.2	29.5	1.1	2.36	104	54.0	1.9	0.33	0.11	848	10.2	204	695	848	1,210	1,530	1,780
Mendenhall 293	968.0 228.5	Sand Average	May 22	148	85.9	25.7	3.1	1.73	279	34.0	8.2	0.31	0.10	1,480	5.1	355	1,210	1,480	2,120	2,680	3,110
Stoney 19	956.0 216.5	Gravel-Boulders Mountain	May 22	17.4	8.4	10.5	0.8	2.08	20.2	21.0	1.5	0.20	0.07	249	13.1	77	339	438	702	1,020	1,240
McIntyre 16	919.2 270.2	Sand - Gravel Average	May 22	36.0	12.9	25.5	0.6	2.79	55.7	32.0	2.1	0.23	0.06	600	37.5	144	492	600	876	1,090	1,260
Deadmans 84.2	822.4 350.8	Sand - Gravel Average	June 6	166	50.1	46.9	1.1	3.30	167	50.0	3.3	0.30	0.10	1,660	19.8	398	1,360	1,660	2,370	3,000	3,490
Morley 608	778 391.2	Sand - Gravel Average	Aug. 12	251	224	75.0	3.0	1.12	687	90.0	7.6	0.37	0.14	2,510	4.1	602	2,060	2,510	3,590	4,540	5,270
Smart 277	- -	Sand Average	Aug. 13	207	201	83.0	2.4	1.03	608	86.0	7.1	0.33	0.11	1,880	6.8	451	1,540	1,880	2,690	3,400	3,950
Logjam 33.5	751.7 414	Cobblestones Mountain	June 6	133	34.0	29.5	1.2	3.90	62.3	31.9	2.0	0.55	0.37	359	10.9	111	488	632	1,010	1,470	1,800
Screw 29	742.1 423	Gravel - Cobblestones Mountain	Aug. 13	25.2	18.3	23.0	0.8	1.38	70.7	33.0	2.1	0.25	0.10	252	8.7	78	343	444	710	1,030	1,260
Partridge 24	736.4 428	Gravel - Cobblestones Mountain	June 22	167.5	45.6	32.5	1.4	3.69	69.1	35.0	2.0	0.66	0.50	335	13.9	104	456	590	945	1,370	1,680
Seagull 31.5	- -	Gravel-Boulders Mountain	Aug. 12	27.6	37.5	38.0	1.0	0.74	139	50.0	2.8	0.27	0.11	251	7.8	78	341	442	708	1,030	1,260
Spencer 61.6	695.3 467.1	Gravel - Cobblestones Mountain	June 7	244	38.5	32.8	1.2	2.44	54.9	35.8	1.5	0.70	0.55	444	7.2	138	604	781	1,250	1,820	2,220
Big 405	674.1 487	Sand - Gravel Average	June 1/77	1,340	266	85.0	3.1	5.04	466	115	4.1	0.57	0.33	4,060	10.0	974	3,330	4,060	5,810	7,350	8,530
L.Rancheria 612	670.3 490.5	Sand - Gravel Average	June 1/77	2,590	489	118	4.1	5.30	672	125	5.4	0.73	0.54	4,800	7.8	1,150	3,940	4,800	6,860	8,690	10,100

TABLE 7 - COMPARISON OF VALUES OF RUNOFF FOR SELECTED DISCHARGE EVENTS

FOR VARIOUS SUBREGIONS

Unit Runoff (cfs/sq. mi.)

Drainage Area	Mean Annual (Q)					Bankfull (Q_B)					50 Year (Q)				
(sq. mi.)	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
100	3.07	5.40	5.40	1.35	1.30	12.8	22.5	22.5	22.5	4.2	23.2	40.7	40.7	54.4	17.2
500	1.13	2.64	3.31	1.00	0.62	4.7	11.0	13.8	16.7	2.0	8.5	19.9	25.0	40.1	8.2
1,000	0.72	1.82	3.00	0.89	0.46	3.0	7.6	12.5	14.9	1.5	5.4	13.8	22.6	35.8	6.2
10,000	-	0.62	1.39	2.38	-	-	2.6	5.8	9.9	-	-	4.7	10.5	23.8	-
50,000	-	0.29	0.86	0.45	-	-	1.2	3.6	7.5	-	-	2.2	6.5	18.0	-
* Q/Q_B =	0.24	0.24	0.24	0.06	0.31	1.00	1.00	1.00	1.00	1.00	1.81	1.81	1.81	2.40	4.10

1. Atlin - Bennett - Dezadeash
2. Upper Yukon - Teslin - Takhini
3. Liard - Pelly - Stewart - Lower Yukon
4. Porcupine-Peel
5. Mountain Streams

* From Figure 5 or Table 5

APPENDIX D

WATER INVESTIGATIONS

ALONG THE

ALASKA HIGHWAY PIPELINE ROUTE

IN THE YUKON TERRITORY

APPENDIX D

KINEMATIC WAVE MODEL

by

R. O. Lyons

December 1978

Water Planning & Management Branch
Inland Waters Directorate
Pacific and Yukon Region
Vancouver, B.C.

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KINEMATIC WAVE MODEL

The Kinematic Wave Model has been used to estimate streamflow along the Alaska Highway for three return periods; 2.33 year, 50 year, and 100 year. This appendix briefly describes the basic equations forming the model and discusses the way the model was calibrated with the objective of giving the reader an understanding of the procedures involved. Recommendations for further work are also provided.

Acknowledgement is given to the Department of Indian Affairs and Northern Development, Water Resources, Whitehorse Y.T. (DIAND), who provided the computer program and much of the required data, and to Charles Howard & Assoc. Ltd., who adapted the Kinematic Wave theory to the Canadian situation and who developed the computer program for DIAND.

Description of the Model

The model is based on the premise that probability of occurrence of a precipitation event varies inversely with its duration and intensity, regardless of geographic location. Rates of variation are defined by the average of measured precipitation durations and intensities in the area. The mathematics involved relate the precipitation events to catchment discharges using various catchment and channel parameters, such as drainage areas and slopes. The model was originally derived for rainstorms, however, it has been adapted to also simulate flood events for snowmelt-generated runoff.

The basic equation is:

$$\text{Prob}\left[Q_p \geq Q_o\right] = \int_{i = \frac{Q_o}{645\ AR}}^{\infty} \beta\, e^{-\beta i - \lambda\left(\frac{a}{i^{1/2}} + \frac{b}{i^{1/3}}\right)} di$$

(Definitions of symbols are given in sections following)

Much theory and mathematics are involved in its derivation. Basically, however, it computes the probability that a flood exceeding a given level Q_0 will result from any storm. This is done by integrating the probabilities of all storms large enough to produce a flood of Q_0. The complete mathematical procedure is known as the Kinematic Wave Frequency Model.

Solution of the equation is easily handled by numerical methods in an electronic computer. The parameters involved are described in the following sections (a) through (f).

a) Rainfall Duration and Intensity

An important step in this model is determining the probability of various durations and intensities of rainfall. Equations (1) and (2) below are the basis for the probability function of the model. They simply define, for any storm, the probability of a given duration of rainfall and the probability of a given intensity of rainfall. These are combined in the basic equation above, to provide the probability that any given storm will produce a flood equalling or exceeding a given discharge.

The probability that any storm will last a duration "t_{re}" is given by the equation:

$$f_T(t_{re}) = \lambda e^{-\lambda t_{re}} \tag{1}$$

where;

$f_T(t_{re})$	is the probability density function (i.e. probability of occurrence) of a storm duration t_{re}. If a storm occurs, it has a probability $f(t_{re})$ of a duration t_{re}.
λ	is the inverse of the area's average storm duration (1/hrs.)
t_{re}	is the storm's duration (hrs.)
e	is Napiers e (or 2.71828)

Likewise the probability that any storm will have an average intensity of rainfall "i" is given by:

$$f_I(i) = \beta e^{-\beta \bar{i}_e} \quad (2)$$

where;

$f_I(i)$ is the probability that if a storm occurs it will have an average intensity of i.

β is the inverse of the area's average rainfall intensity (hrs./in.)

$\bar{i}_e$ is the storm's average rainfall intensity (in./hr.)

By combining equations (1) and (2) we can compute the probability that if a storm occurs it will have an average intensity of i and a duration of t_{re}.

b) Rainfall to Discharge

To compute the probabilities of floods, it is necessary to convert rainfall to discharge. This is accomplished by equation (3).

For any known rainfall excess (the amount of rain that runs directly off the basin) it is a simple matter to compute the equivalent basin discharge if we assume that the rain has lasted long enough and was extensive enough for the discharge to have reached a steady state. In this condition runoff from all points in the basin has had time to reach the project site before the rain has stopped. The time required for this is termed the "time of concentration" of the basin or "t_*". Assuming that the storm duration is longer than t_* the rational formula for discharge applies as follows:

$$Q_p = 645 \text{ AR } \bar{i}_e \tag{3}$$

where;

Q_p is the basin discharge (cfs)

A is the total basin area (sq. mi.)

R is theoretically the ratio between area contributing to direct runoff and total basin area

i_e is the rainfall excess (in./hr.); or rainfall available for runoff after seepage, interception, etc.

c) <u>Basin Time-of-Concentration</u>

Equation (3), which converts rainfall to discharge, is applicable only when the storm duration exceeds the time of concentration of the basin (t_*). Therefore the "t" values used in equation (1) must equal or exceed t_*.

The equation for t_* is defined as;

$$t_* = t_c + t_s \tag{4}$$

where;

t_c is the time of concentration of the catchment; time required for the overland flow to reach a steady state under a constant rainfall (hrs),

t_s is the time of concentration of the stream; the time required for the stream discharge to reach a steady state after the basin's input to the stream has reached a steady state (hrs),

t_* is the basin time of concentration (hrs).

To relate t_* to various parameters of the catchment and river channel, and to rainfall intensities, the values of t_c and t_s are computed as follows:

$$t_c = 0.913978 \left[\frac{N_c A R}{\sqrt{S_c} L_s \bar{i}_e} \right]^{1/2} \tag{5}$$

$$t_s = 0.130104 \left[\frac{P_s N_s^2}{S_s A R \bar{i}_e} \right]^{1/3} \tag{6}$$

where;

$\bar{i}_e$	is the average rainfall intensity during a given storm (in/hr)
N_c	is Manning's n-value for the catchment (normally 0.30)
A	is the total drainage area (sq. mi)
R	is the ratio of area contributing to direct runoff to total area (see equation 3)
S_c	is the average slope of the catchment
L_s	is the stream length (mi)
P_s	is the wetted perimeter (normally substituted by width) of the stream at the project location (ft)
N_s	is Manning's n-value for the stream at the project location
S_s	is the average slope of the stream.

For simplicity these equations are written as;

$$t_c = a\,\bar{i}_e^{\,-1/2} \tag{7}$$

$$t_s = b\,\bar{i}_e^{\,-1/3} \tag{8}$$

where;

"a" and "b" are the appropriate basin and river constants respectively, computed from the basin parameters in equations (5) and (6)

d) The Frequency Equation

By putting together the relationships described in sections (a), (b) and (c) we can formulate an equation relating rainfall probabilities and basin responses for calculation of the probability that any storm will exceed a given flood level.

The equation is:

$$\text{Prob}\left[Q_p \geqslant Q_o\right] = \int_{\bar{i}_e = \frac{Q_p}{645\ AR}}^{\infty} \int_{t_{re} = t_*}^{\infty} f(\bar{i}_e,\ t_{re}) \quad dt_{re}\, d\bar{i}_e \tag{9}$$

where;

$f\ (\bar{i}_e, t_{re})$ is the probability that when a storm occurs, it has an average intensity of $\bar{i}_e$ and a duration of t_{re}.

This equation simply gives the probability that streamflow discharge due to any storm will equal or exceed Q_p. It is the summation of all the joint probabilities of rainfall intensities greater than "$\bar{i}_e$" and duration "t_{re}". It is important to note that the storm intensity and duration in each case is sufficient to cause a flood of Q_p.

The function $f(\bar{i}_e, t_{re})$ is equations (1) and (2) multiplied, giving the probability of both a rainfall intensity $\bar{i}_e$ and a duration t_{re}. In mathematical terms, $f(\bar{i}_e, t_{re})$ is;

$$\text{Prob}\left[i = \bar{i}_e \text{ and } t = t_{re}\right] = \lambda\beta e^{-\beta \bar{i}_e - \lambda t_{re}} \qquad (10)$$

Replacing $f(\bar{i}_e, t_{re})$ in equation (9) gives the equation:

$$\text{Prob}\left[Q_p \geq Q_o\right] = \int_{\bar{i}_e = \frac{Q_o}{645\ AR}}^{\infty} \int_{t_{re} = t_*}^{\infty} \lambda \beta\, e^{-\beta \bar{i}_e - \lambda t_{re}}\, dt_{re}\, d\bar{i}_e \qquad (11)$$

where;

λ is the inverse of average storm duration (1/hrs.)

β is the inverse of average rainfall intensity (hrs./in.)

$\bar{i}_e$ is the intensity of rainfall (in./hr.)

t_{re} is the duration of rainfall (hrs.)

Q_o is a given flood related to $\bar{i}_e$

Integrating this with respect to "t" (assuming t is constant) then substituting equations (7) and (8) for t_* gives:

$$\text{Prob}\left[Q_p \geqslant Q_o\right] = \int_{\bar{i}_e = \frac{Q_o}{645\,AR}}^{\infty} \beta\, e^{-\beta \bar{i}_e \; - \lambda\left(\frac{a}{\bar{i}_e^{1/2}} + \frac{b}{\bar{i}_e^{1/3}}\right)} \, d\bar{i}_e \qquad (12)$$

From definitions for equations (7) and (8);

$$a = 0.913978 \left[\frac{N_c AR}{\sqrt{S_c} L_s}\right]^{1/2} \qquad (13)$$

$$b = 0.130104 \left[\frac{P_s N_s^{\,2}}{S_s AR}\right]^{1/3} \qquad (14)$$

This is the basic equation of the Kinematic Wave Frequency Model. (see also page 1). The equation is computed using numerical integration, by an electronic computer. To define the flood-frequency curve at a stream, probabilities for several different floods (Q_o) are computed and are converted to return periods (T) by the following equation:

$$T\left[Q_{max} \geqslant Q_o\right] = \frac{1}{\text{Prob}\left[Q_p \geqslant Q_o\right] \theta\, \phi_{12}} \qquad (15)$$

where;

$T\left[Q_{max} \geqslant Q_o\right]$ is the return period for an annual maximum flood equal to or greater than Q_o (yrs),

$\text{Prob}\left[Q_p \geqslant Q_o\right]$ is the probability that any storm will produce a flood equal to or greater than Q_o (from equation 11),

θ is the average number of storms per year,

ϕ_{12} is the ratio of total precipitation to water running off the basin (i.e. precip. minus interception and groundwater recharge)

Equation (15) gives the return period of the flood Q_o in terms of an annual maximum flood. In other words, the flood Q_o will be equalled or exceeded on the average only once every T years.

e) Combined Rain and Snow Frequencies

Equations (12 through 15) have been derived for rainfall events. However, with the appropriate empirical values for the precipitation parameters (λ, β and θ) snowmelt runoff can also be simulated and the return periods for snowmelt-generated floods can be computed likewise.

The flood estimates included in "Hydrologic Reconnaissance of the Alaska Highway Pipeline Route" have been computed by combining the rainfall-generated floods and the snowmelt-generated floods. A flood-frequency curve was first generated for each of the two types of flood events, and subsequently combined using the following equation:

$$T_c = \frac{T_r\, T_s}{T_r + T_s - 1} \qquad (16)$$

where;

T_c is the composite return period for a flood Q_p (yrs),

T_r is the return period for a rainfall generated flood Q_p (yrs),

T_s is the return period for a snowmelt generated flood Q_p (yrs).

This equation is the final step in the model process. The resulting composite flood-frequency curve is very similar to the flood frequency curve produced from streamflow records, particularly at the higher return periods.

Calibration of the Model

Equations (11 through 14) contain twelve parameters defining meteorological, topographic and hydrologic conditions of a basin. These parameters are listed in Table 1 according to the three categories, together with results of sensitivity tests showing variation in discharge with a 100% change in a parameter value.

It is evident from this tabulation that the greatest opportunity for calibration lies in the average storm intensity (meteorologic parameter β) and in the effective drainage area (topographic parameter R). The meteorologic parameter values were provided by the Department of Indian Affairs and Northern Development (DIAND), Water Resources in Whitehorse. It was assumed that these are reasonably accurate and no attempt was made to refine them. However, in the conversion of the parameters from mean daily to hourly values for the purpose of this analysis, there may have resulted an under-estimate of the storm intensities and durations.

The ratio of effective drainage area to total area (parameter R) was, therefore, the main calibrating parameter. The procedure was to vary the ratios until a best fit was attained between modelled flood frequency curves and frequency curves computed from gauging station data. One alternative to this approach would be to determine the ratios by hydrograph analysis, but this was not attempted because of shortage of time.

As a second step, frequency curves were generated based on an identical ratio for all streams. The value chosen was 0.25, a value that produced reasonable results for gauged streams. The results of this test were carefully examined before further runs were made. The test showed a need to vary the ratio with drainage area. Also it was obvious that a better fit at gauged basins could be obtained if the ratios were regionalized. Relationships of the ratios versus drainage area gave good results when the regions were as follows;

- Liard-Rancheria-Swift
- Teslin Lake
- M'Clintock-Yukon-Dezadeash

In addition a ratio was developed for Kluane Lake-Beaver Creek area by hydrologic judgement based on the above three relationships. Table 3 shows equations for computing the ratio of effective drainage area to total area (parameter R) for each of these four regions. For glacier-fed streams such as the White and Donjek rivers, a fifth relationship would be required.

Since all gauged basins with sufficient data for calculating frequency curves have drainage areas greater than 200 square miles, it was not possible to develop parameter R versus drainage area relationships that could be proven valid for the many small basins along the pipeline route. From other correlation studies for the area, however, it has been shown that floods with a 100-year return period have straight line log-log relationships with drainage area, and slopes ranging between 0.82 and 0.96. The tests using a constant R-value produced results which plot roughly on a similar relationship, but with a 1.0 slope indicating very little variation of unit runoff with drainage area. It was felt that this lack of variation of unit runoff was a major fault of the model that must be corrected. Pending further studies, the relationship between parameter R and drainage area was based on a slope of 0.8.

The ratio of total runoff to precipitation (parameter ϕ_{12}) is the second most effective hydrologic calibration parameter; it represents the product of two ratios: the ratio of precipitation that reaches the ground to the total precipitation, and the ratio of direct runoff to water input that reaches the ground. The combined ratios (parameter ϕ_{12}) can be determined by matching rainfall records with streamflow data where such information is available. In the computations reported here, the values for ϕ_{12} were obtained for six gauged basins in the southern Yukon area from Reference 1. Using these six basins as a base, and with knowledge of the hydrology, topography and geology of the area, estimates of ϕ_{12} were made for each stream along the pipeline route. The values chosen ranged from 0.28 to 0.65.

Relationships discussed above provided results that fitted the gauged basins well. Also, their extrapolation to ungauged basins appear reasonable.

Recommendations for Further Work

The Kinematic Wave frequency model is a useful tool for estimating peak discharges at ungauged sites. The model has been used as one of several methods of estimating ungauged streamflows which can be compared in assessing environmental impacts of the pipeline. However, if this technique were to be used to compute design floods, additional more detailed calibration tests would be required, particularly with respect to the northern end of the pipeline route. Some recommended steps are outlined below:

i) re-compute values of λ, β and θ based on hourly precipitation data,

ii) compute R and ϕ values at gauged basins using hydrograph analysis,

iii) using short-term records and crest-gauge results, check the relationship of discharge to drainage area for small basins. Ensure that this is reflected by the model; adjust R-values to accomplish this if necessary,

iv) develop calibration procedures for mountainous areas such as the ephemeral drainages on south shore of Kluane Lake and for glacier-fed streams such as the Donjek or White Rivers.

The results computed by the Kinematic Wave Model, those presented in the report "Hydrologic Reconnaissance of the Alaska Highway Pipeline Route", of which this is an Appendix, are based on a preliminary calibration procedure. Nevertheless, they are considered to be fairly accurate for all areas east of Haines Junction. For areas west of Haines Junction, most parameters are less accurately defined because of unknown effects of mountains in that area.

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Table 1 SENSITIVITY OF PARAMETERS

Parameter	% Change in Q_{100} for +100% change in parameter	Parameter Description
a) Meteorological Category		
β	-52%	inverse of average storm intensity (hrs/in)
λ	-13%	inverse of average storm duration (1/hrs)
θ	+11%	no. of storms per year
b) Hydrologic Category		
ϕ	+11%	ratio of total runoff to precipitation input
R	+95%	ratio of effective drainage area to total drainage area
N_c	-2.1%	roughness coefficient for average basin surface
N_s	-2.0%	roughness coefficient of streambed at project site
c) Topographic Category		
A	not tested (see R)	total drainage basin area (sq. mi)
S_c	+1.3%	average slope of catchment
L_s	-1.4%	length of stream (mi)
P_s	-1.0%	width of stream at project site (ft.)
S_s	+0.8%	average stream slope

Table 2 TOPOGRAPHIC PARAMETER VALUES

See equations (5) and (6) for description of the parameters

Stream	Drainage Area A (sq.mi.)	Catchment Slope S_c	Stream Length L_s (mi.)	Stream Width P_s [1/] (ft.)	Stream Slope S_s
Snag Cr.	380	0.0164	39.5	73.0	0.0116
Beaver Cr.	737	0.0134	45.0	148	0.0138
Enger Cr.	52.4	0.0241	9.08	20 [2/]	0.0164
Dry Cr.	52.2	0.0192	11.0	29	0.0217
Sanpete Cr.	29.4	0.0344	15.7	30	0.0362
White R.	2410	0.0126	73.9	270	0.0146
Koidern R. (mi. 1164)	428	0.0146	34.8	100	0.0136
Longs Cr.	44.1	0.0262	15.3	49	0.0150
Koidern R. (mi. 1152)	260	0.0222	22.5	76	0.0272
Donjek R.	1687	0.0126	65.6	1000	0.0142
Swede Johnson Cr.	36.0	0.0359	8.3	20 [2/]	0.0484
Quill Cr.	26.4	0.0586	9.1	15 [2/]	0.357
Burwash Cr.	64.8	0.0370	17.2	31	0.0330
Duke R.	255	0.0238	35.6	265	0.0150
Kluane R.	1910	0.007	95.5	200	0.013
Halfbreed Cr.	26.7	0.0557	11.7	27	0.0461
Lewis Cr.	15.7	0.106	8.2	25	0.0915
Bock's Cr.	13.5	0.116	6.8	25 [2/]	0.096
Nines Cr.	23.5	0.0818	9.6	30 [2/]	0.0758
Congdon Cr.	19.5	0.0923	8.3	75	0.0599
Williscroft Cr.	4.9	0.198	3.7	15	0.197
Slims R.	927	0.0197	58.5	200	0.0231
Topham Cr.	1.97	0.0911	2.1	5 [2/]	0.0635
Silver Cr.	18.6	0.0853	9.3	26	0.0584
Christmas Cr.	39.8	0.0435	7.6	27	0.0601
Jarvis R.	288	0.0132	40.3	78	0.0040

Notes: 1/ P_s values were often estimated from photographs or from memory of field visits.

2/ An estimate made by comparison to other streams.

Table 2 TOPOGRAPHIC PARAMETER VALUES (Cont'd)

Stream	Drainage Area A (sq.mi.)	Catchment Slope S_c	Stream Length L_s (mi.)	Stream Width P_s 1/ (ft.)	Stream Slope S_s
Bear Cr.	29.9	0.0303	11.9	26	0.0337
Pine Cr.	63.1	0.0232	21.1	30 2/	0.0147
Dezadeash R. (at Haines Jctn.)	3280	0.006	102	50	0.003
Marshall Cr.	82.8	0.0381	16.6	54	0.0318
Aishihik R.	1660	0.0066	88.4	70	0.0037
Cracker Cr.	50.2	0.0404	12.7	30 2/	0.0404
Mendenhall R.	294	0.0127	34.5	34	0.0056
Stoney Cr.	19.4	0.0618	8.1	21	0.0435
Takhini R.	2700	0.0067	94.8	200	0.0037
McIntyre Cr. 3/	16.2	0.0321	8.7	32	0.0162
Wolf Cr.	69.5	0.0195	21.5	20 2/	0.0185
Cowley Cr.	76.7	0.0254	11.4	20 2/	0.00792
Yukon R. (nr. Whitehorse)	7500	0.0032	140	350	0.0001
M'Clintock R. (at highway)	689	0.0140	35.6	70	0.0023
Teslin R. (at Johnsons Crossing)	11700	0.0047	94.7	450	0.0037
Brooks Brook	27.4	0.0424	8.9	20	0.0424
Deadmans Cr.	84.2	0.0337	14.6	50	0.0204
Lone Tree Cr.	18.0	0.0480	9.0	12	0.0420
Tenmile Cr.	16.8	0.0605	6.9	15	0.0506
Fox Cr.	13.7	0.0440	7.6	10	0.0243
Hays Cr.	26.7	0.0335	11.1	10	0.0216
Strawberry Cr.	24.3	0.0335	9.2	15	0.0258
Morley R.	608	0.0109	44.2	90	0.0073
Hazel Cr.	21.7	0.0429	6.5	20	0.0497
Swift R. (WSC gauge)	1280	0.01	50.2	250	0.005
Smart R.	277	0.0144	35.2	86	0.0073
Logjam Cr.	33.5	0.0443	10.0	32	0.0291
Screw Cr.	29.6	0.0273	12.2	33	0.0169

Notes: 1/ P_s values were often estimated from photographs or from memory of field visits.

2/ An estimate made by comparison to other streams.

3/ The natural stream only; does not include diversions from Fish Lake and Porter Creek.

Table 2 TOPOGRAPHIC PARAMETER VALUES (Cont'd)

Stream	Drainage Area A (sq.mi.)	Catchment Slope S_c	Stream Length L_s (mi.)	Stream Width P_s 1/ (ft.)	Stream Slope S_s
Partridge Cr.	23.9	0.0436	10.8	35	0.0174
Seagull Cr.	31.5	0.0535	9.3	50	0.0298
Swift R. (at hwy. bridge)	105	0.0181	17.8	60	0.0129
Rancheria R. (at mi. 722)	261	0.0126	30.8	50	0.0112
Rancheria R. (at pipeline)	382	0.0090	46.0	100 2/	0.0077
Boulder Cr.	23.9	0.0408	8.5	30	0.0254
Spencer Cr.	61.6	0.0276	13.9	36	0.0229
Rancheria R. (at mi. 687)	837	0.0204	65.2	200	0.0054
Big Cr.	405	0.0060	58.8	115	0.0076
Little Rancheria R.	612	0.0059	77.0	125	0.0046
Albert Cr.	255	0.0082	31.6	50	0.0101
Liard R. (at Upper Crossing)	12900	0.0041	120	430	0.0003

Notes: 1/ P_s values were often estimated from photographs or from memory of field visits.

2/ An estimate made by comparison to other streams.

Comments:

a) Unless otherwise noted, drainage area is measured to the Alaska Highway which is approximately equivalent to the pipeline alignment as proposed in the summer of 1977. Canadian Topographic Series maps of 1:50,000 scale were used where available and 1:250,000 scale maps were used in other areas.

b) Stream lengths were measured to the end of the blue line, including the dashed-line portions, on the topographic maps. There appeared to be considerable variation in stream detail from one map to another.

c) Stream slopes (S_s) were computed by the formula:

$$S_s = \frac{(E_{85} - E_{15})}{0.70\ L_s}$$

where;

E_{15} is the stream elevation 15% of L_s upstream from the gauge point (feet),

E_{85} is the stream elevation 85% of L_s upstream from the gauge point (feet),

L_s is the stream length (feet).

d) Catchment slopes (S_c) were computed by the formula:

$$S_c = \frac{E_w - E_g}{L_s}$$

where;

E_w is the average elevation of the watershed divide, which was computed by averaging peak and valley elevations along the divide line (feet),

E_g is the stream elevation at the gauge point (feet),

L_s is the stream length (feet).

e) Stream widths were estimated at bankfull stage.

f) Measurements for S_c, L_s, P_s and S_s were made using considerable approximation and judgement. These should be considered preliminary until checked by independent measurements. Significant errors can be introduced by many factors; the definition of stream lengths, particularly where there are large lakes and many tributary streams; the method of interpreting and computing average divide elevation; and by interpolation between contour lines to estimate stream elevations. Therefore, considerable caution should be applied when using these parameter values.

Table 3 COMPUTATION OF PARAMETER R

(Ratio effective drainage area to total area)

$$R = k A^a$$

where A = basin drainage area (sq. mi.)

Area	k	a
Liard-Rancheria-Swift	1.46	-0.124
Teslin	1.22	-0.202
M'Clintock-Yukon-Dezadeash	0.914	-0.221
Kluane-Beaver Creek	1.197	-0.221