FLOOD FREQUENCY DETERMINATIONS
FOR THE
ALASKAN SEGMENT
OF THE
ALASKA NATURAL GAS TRANSPORTATION SYSTEM (ANGTS)

Prepared for
NORTHWEST ALASKAN PIPELINE COMPANY

by
NORTHERN TECHNICAL SERVICES

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ALASKA NATURAL GAS TRANSPORTATION SYSTEM (ANGTS)

1.0 INTRODUCTION, PURPOSE, AND SCOPE OF STUDY

Floods of a particular frequency or return period are required for design of structures along the pipeline corridor. The mean annual (two-year) flood is required for design for fish passage on fish streams, the five-year flood for design of drainage structures for temporary facilities, the fifty-year flood for permanent facilities, and the ten- and twenty-five-year floods are required to define flood elevations at temporary camps and facilities. The one hundred-year flood is required for siting of solid waste disposal sites and for permanent structures. Recorded data are seldom available at a particular site of interest. Therefore, some means is required by which data collected for streams in the vicinity may be used to develop estimates for floods of various frequencies at sites for which no data exist. The method developed for use along the pipeline corridor uses U.S. Geological Survey data to develop regional relations in which floods are related to the drainage area for the basin above the point of interest.

2.0 DATA AVAILABLE

The data for 74 gaging stations were available for this analysis. Those stations are listed in Table 1 and are shown on Figure 1. Of those stations, fifteen were screened out as not being representative of the hydrology along the pipeline route. The deleted data are indicated by an asterisk on Table 1. Those data were deleted mainly for two reasons. One group of stations drained into the Tanana River from south of the Alaska Range. The other group represented glacial melt streams, and a significant part of their drainage area is covered by glaciers. Explanation of the deletions is given in Table 2. The data, which were used in the analysis, included six streams on the North Slope, seven streams in the Koyukuk River Basin, and forty-six in the Yukon-Tanana River Basin.

Canadian data were surveyed for possible use in the flood frequency analysis. Canadian data are not extensive, and none were felt appropriate for inclusion in the analysis. According to the 1979 Surface Water Data Index of the Water Survey of Canada (1), there are nine stream gages under 500 square miles (1300 square kilometers) in the Yukon Territory area. Three of those are under 100 square miles (250 square kilometers). Those three are:

Number	Station	Drainage Area (mi^2)	Length of Record: Continuous Recorder	Length of Record: Staff Gage	Distance from Border (miles)
09AA011	Tagish Cr.	30	6	2	250
09BC003	Rose Cr.	80	0	2	250
10AB003	King Cr.	5.3	4	0	400

In addition, the Department of Indian and Northern Affairs maintains a small streams network for highway design. Their latest report (2) includes data on instantaneous peaks collected through 1981. The maximum length of record of these stations is 5 years, which is the minimum considered for use in this study. Most stations have less than 5 years of record.

TABLE 1
GAGING STATIONS IN ALASKA

Station No.	Name	Drainage Area (mi^2)	a Q_2 (cfs)	b Q_2 (cfs)	Years of Record	Max. Peak of Record (cfs)
Yukon-Tanana						
15305900	Dennison F nr Tetlin Junction	2.93	26	24	15	128
15305920	W F Tr nr Tetlin Junction	1.02	25	26	13	102
15305950	Taylor C nr Chicken	38.4	86	105	13	600
* 15348000	Fortymile R nr Steel Creek	5,880.	-	35,700	6	84,000
* 15356000	Yukon R at Eagle	113,500.	288,000	288,000	31	545,000
* 15365000	Discovery F American C nr Eagle	5.53	7	7	11	52
* 15367500	Bluff C nr Eagle	3.38	6	6	10	41
* 15389000	Porcupine R nr Fort Yukon	29,500.	159,000	153,000	15	299,000
15389500	Chandalar R nr Venetie	9,330.	46,100	47,400	11	62,800
15438500	Bedrock C nr Central	9.94	120	121	11	405
15439800	Boulder C nr Central	31.3	273	250	14	1,150
15442500	Quartz C nr Central	17.2	166	162	11	500
15457700	Erickson C nr Livengood	26.3	-	293	7	860
15457800	Hess C nr Livengood	662.	4,560	5,560	8	10,000
* 15468000	Yukon R at Rampart	199,400.	591,000	545,000	10	950,000
15469900	Silver C nr Northway Junction	11.7	32	31	10	355
15470000	Chisana R at Northway Junction	3,280.	7,650	7,740	22	12,000
15470340	Jack C nr Nabesna	115.	-	1,260	5	2,440
15471000	Bitters C nr Northway Junction	15.4	93	99	15	1,010
15471500	Tanana R Tr nr Tetlin Junction	2.43	15	13	15	45
15473600	Log Cabin C nr Log Cabin Inn	10.7	106	105	14	350
15473950	Clearwater C nr Tok	37.5	431	339	16	1,040
15476000	Tanana R nr Tanacross	8,550.	29,400	30,100	27	39,100
15476049	Tanana R Tr nr Cathedral Rapids	3.09	-	92	8	332
15476050	Tanana R Tr nr Tanacross	3.32	103	117	8	297
15476200	Tanana R Tr nr Dot Lake	11.0	75	66	16	146
15476300	Berry C nr Dot Lake	65.1	698	670	16	2,800
15476400	Dry C nr Dot Lake	57.6	943	741	16	2,200
15478000	Tanana R at Big Delta	13,500.	48,900	48,300	8	62,800
* 15478010	Rock C nr Paxson	50.3	726	648	17	1,800
* 15478040	Phelan C nr Paxson	12.2	900	944	12	2,320

TABLE 1 (Continued)

	Station No.	Name	Drainage Area (mi^2)	a Q_2 (cfs)	b Q_2 (cfs)	Years of Record	Max. Peak of Record (cfs)
	Yukon-Tanana						
*	15478050	McCallum C nr Pason	15.5	456	405	13	1,010
*	15478500	Ruby C nr Donnelly	5.32	105	114	17	400
	15480000	Banner C at Richardson	20.2	156	142	16	732
	15484000	Salcha R nr Salchaket	2,170.	18,300	16,500	29	97,000
	15490000	Monument C at Chena Hot Springs	26.7	554	298	10	1,700
	15493000	Chena R nr Two Rivers	941.	7,210	6,040	13	16,800
	15493500	Chena R nr N Pole	1,430.	-	5,350	8	12,300
	15511000	L Chena R nr Fairbanks	372.	1,790	1,920	13	17,000
	15511500	Steele C nr Fairbanks	10.7	27	20	6	340
	15514000	Chena R at Fairbanks	1,980.	9,920	9,500	32	74,400
	15514500	Wood R nr Fairbanks	855.	4,210	4,130	8	5,510
	15515500	Tanana R at Nenana	25,600.	80,600	79,700	19	186,000
*	15515800	Seattle C nr Cantwell	36.2	596	574	15	3,100
*	15515900	Lily C nr Cantwell	5.63	90	73	13	191
*	15516000	Nenana R nr Windy	710.	6,710	6,410	25	11,900
*	15516200	Slime C nr Cantwell	6.90	156	174	14	685
*	15518000	Nenana R nr Healy	1,910.	21,200	20,900	28	46,800
	15518200	Rock C nr Ferry	8.17	194	168	11	880
	15518250	Birch C nr Rex	4.10	87	66	14	464
	15518350	Teklanika R nr Lignite	490.	4,950	5,680	10	33,100
	15519000	Bridge C nr Livengood	12.6	175	182	10	1,070
	15519200	Brooks C Tr nr Livengood	7.81	56	63	16	168
	15520000	Idaho C nr Miller House	5.31	136	118	17	813
	15530000	Faith C nr Chena Hot Springs	61.1	1,210	1,320	10	4,950
	15534900	Poker C nr Chatanika	23.1	-	104	5	240
	15535000	Caribou C nr Chatanika	9.19	82	64	6	117
	15541600	Globe C nr Livengood	23.0	250	252	16	1,240
	15541650	Globe C Tr nr Livengood	9.01	119	118	10	490
	15541800	Washington C nr Fox	46.7	623	589	10	2,500
	15564600	Melozitna R nr Ruby	2,693.	21,100	22,400	10	28,200
*	15564800	Yukon R at Ruby	259,000.	625,000	570,000	22	97,000

TABLE 1 (Continued)

Station No.	Name	Drainage Area (mi^2)	a Q_2 (cfs)	b Q_2 (cfs)	Years of Record	Max. Peak of Record (cfs)
Koyukuk						
15564872	Nugget C nr Wiseman	9.47	-	138	5	167
15564875	M F Koyukuk R nr Wiseman	1,200. +	9,110	9,930	10	19,100
15564877	Wiseman C at Wiseman	49.2	486	404	8	686
15564884	Prospect C nr Prospect Camp	110.	-	1,690	6	6,800
15564885	Jim R nr Bettles	465.	8,570	8,500	7	12,800
15564887	Bonanza C Tr nr Prospect Camp	11.7	-	96	5	220
15564900	Koyukuk R at Hughes	18,700.	130,000	119,000	17	266,000
North Slope						
15798700	Nunavak C nr Barrow	2.79	-	29	6	66
15896000	Kuparuk R nr Deadhorse	3,130.	44,000	46,500	9	118,000
15896700	Putuliguyak R nr Deadhorse	176.	-	3,390	7	5,800
15905000	Galbraith Lk Tr nr Galbraith Camp	7.55	-	32	5	46
15910000	Sagavanirktok R nr Sagwon	2,208.	21,800	17,800	11	34,900
15910200	Happy C nr Happy Valley Camp	34.5	-	640	8	1,390

a - Q_2 from all record through 1975 water year (Lamke's report)

b - Q_2 from all record through 1979 water year (Used in this analysis)

* - Different hydrologic environment - not used in analysis

+ - Revised in 1979 from 1,426 mi^2 to 1,200 mi^2.

N.B. - Years of record include all years for which measurements are available. However, some peaks were excluded from the analysis, either because they were historic peaks or the peak discharges were not recorded.

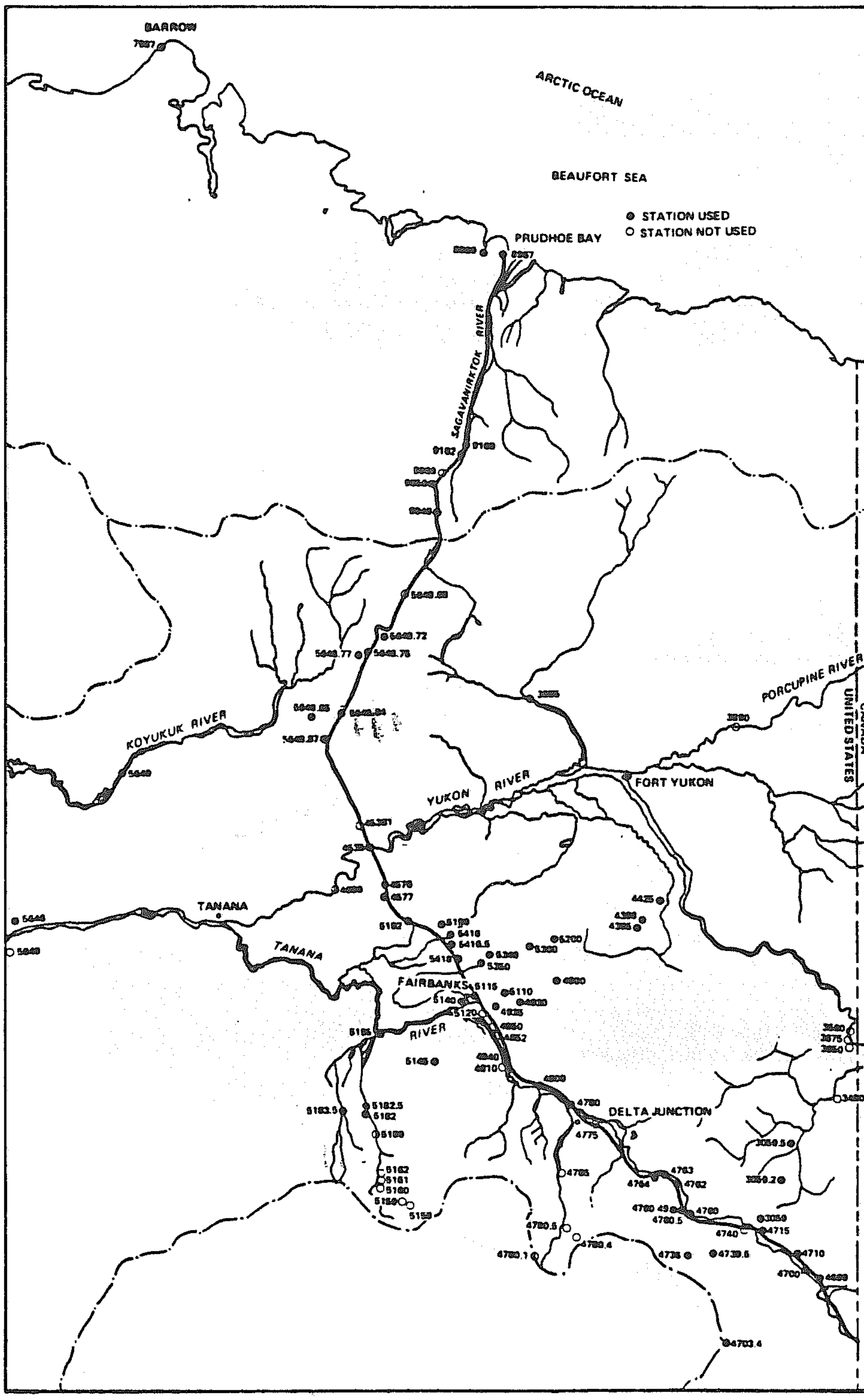


FIGURE 1

FLUOR

PROJECT MANAGEMENT CONTRACTOR

NORTEC

NORTHERN TECHNICAL SERVICES

ALASKAN NORTHWEST NATURAL GAS TRANSPORATION COMPANY

GAGING STATIONS IN ALASKA AVAILABLE FOR USE IN THE FLOOD FREQUENCY ANALYSIS

ALASKA SEGMENT OF THE ALASKA NATURAL GAS TRANSPORTATION SYSTEM

		DATE	REV.	BY	APP.	DATE
DES./DWN.	/					
CHK./APP.	/					
PMC /NWA	/					

DRAWING NUMBER	REV.

TABLE 2
STATIONS LISTED IN TABLE 1 WHICH ARE
NOT USED IN SUBSEQUENT ANALYSES

15348000	Fortymile R. nr Steel Creek	All are in drainage basin north and east of Tanana Basin across the relatively high Forty mile mountains [illegible] a different hydrologic province.
15356000	Yukon R. at Eagle (DA in Canada)	
15365000	Discovery F. American C. nr. Eagle	
15367500	Bluff C. nr Eagle	
15389000	Porcupine R. nr Fort Yukon	
15478010	Rock C. nr Paxson	All drain south side of Alaska range with annual rainfall of 60"-80", whereas pipeline route along Tanana Basin intersects streams having 10" to 20" of rainfall.
15478040	Phelan C. nr Paxson (69% of basin glacier)	
15478050	McCallum C. nr Paxson	
15478500	Ruby C. nr Donnely	
15515800	Seattle C. nr Cantwell	
15515900	Lily C. nr Cantwell	
15516200	Slime C. nr Cantwell	
15516000	Nenana R. nr Windy	Most of the drainage area is on south side of Alaska range with much higher annual precipitation than the remainder of the Tanana Basin.
15518000	Nenana R. nr Healy	
15564800	Yukon R. at Ruby	Major river basin, not apropos to frequency flood needs for NWPA.

Three stations along the Alaskan Highway appeared possible candidates for use. All other stations with 5 years of record were too far from the Canadian border or else had an orographic barrier between them and the border. Those 3 stations and a summary of their instantaneous peak flow statistics are:

Number	Station	Area (mi^2)	Peak Flow (cfs/mi^2) Minimum	Median	Maximum
29AC001	Mendenhall Cr.	299	0.57	1.27	2.50
29CB001	Long's Cr.	40.4	9.38	12.8	22.3
29CB002	Dry Cr. #2	59.0	1.66	5.56	9.88

Thus, there is an order of magnitude spread in their flooding experience. This could result from sampling variability because of the short period of record, from orographic effects, or from other causes. The conclusion is that there are no long, good Canadian records for use in our analyses. Evidence of that fact is given in the Shakwak Highway Project Report (3). The authors complain of lack of Canadian data and recommend the use of the Lamke report for estimation of flood frequencies in the Yukon Territory.

2.1 REGIONAL SKEW VALUE

For the fifty-nine stations available, maximum annual instantaneous flood peaks were used to determine the floods of various frequencies shown in Table 3. Those floods were derived by the use of a logarithmic Pearson Type III analysis applied to the streamflow data. These analyses were provided by the U.S. Geological Survey and follow the guidelines set down by the Water Resources Council (4) for flood frequency analysis. A skew value of 0.53 was used in these analyses, based on the work of Lamke (5). Sample values of skew are subject to large errors unless records are very long, and only the longer streamflow records should be used to compute a regional skew. The weighted average skew for the 17 longest records is 0.26, for the longest 7 records is 0.62, and for the 5 longest records is 0.69. The values, shown in Table 4, seem to validate Lamke's value of 0.53. The Water Resources Council Bulletin 17A gives a value for regional skew of 0.70, but that result is applied uniformly to all of Alaska, whereas Lamke's result excludes Southern Alaska.

TABLE 3
COMPUTED FLOODS OF VARIOUS FREQUENCIES FOR GAGING STATIONS IN ALASKA USED IN THE ANALYSES

Station Number	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
Yukon-Tanana						
15305900	24	45	65	100	134	177
15305920	26	47	66	97	126	162
15305950	105	207	307	482	656	878
15389500	47400	54800	59700	65700	70300	110000
15438500	121	209	287	412	528	666
15439800	250	455	644	960	1260	1630
15442500	162	274	372	528	671	840
15457700	293	637	998	1670	2380	3310
15457800	5560	7500	8920	10900	12500	14200
15469900	32	91	167	336	542	849
15470000	7740	8900	9650	10600	11300	12000
15470340	1260	2130	2880	4090	5190	6490
15471000	99	211	327	539	760	1050
15471500	13	22	30	42	53	66
15473600	105	227	355	594	844	1170
15473950	339	610	859	1270	1660	2130
15476000	30100	33900	36400	39400	41600	43800
15476049	92	178	260	403	543	718
15476050	117	178	227	299	362	432
15476200	66	100	127	168	203	243
15476300	670	1160	1600	2310	2970	3760
15476400	741	1280	1760	2540	3250	4110
15478000	48300	55500	60200	66100	70400	70700
15480000	142	423	798	1650	2720	4330
15484000	16500	28000	38000	53900	68400	85500
15490000	298	754	1290	2400	3660	5440
15493000	6040	10700	14900	21700	28100	35800
15493500	5350	9470	13200	19300	25000	31900
15511000	1920	3790	5620	8840	12000	16100
15511500	20	50	86	160	245	365
15514000	9500	16400	22500	32400	41600	52600
15514500	4130	4880	5380	6000	6480	6950
15515500	79700	101000	116000	137000	152000	169000
15518200	168	472	859	1700	2730	4230
15518250	66	156	257	457	677	979
15518350	5680	11200	16500	25900	35200	46900
15519000	182	421	684	1190	1750	2500
15519200	63	97	125	166	202	243
15520000	118	262	417	710	1020	1440
15530000	1320	2180	2920	4080	5130	6360
15534900	104	221	343	567	800	1100
15535000	64	105	140	194	243	299
15541600	252	536	833	1380	1940	2690
15541650	118	227	332	514	693	917
15541800	589	1270	1990	3330	4730	6570
15564600	22400	25000	26600	28500	30000	31400

TABLE 3 (Continued)

Station Number	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
Koyukuk						
15564872	138	154	164	176	185	194
15564875	9930	14700	18500	24000	28700	34000
15564877	404	607	768	1010	1210	1440
15564884	1690	3580	5550	9160	12900	17800
15564885	8500	10400	11600	13300	14500	15800
15564887	96	186	274	426	577	766
15564900	119000	172000	213000	273000	323000	379000
North Slope						
15798700	29	47	62	85	105	129
15896000	46500	80100	110000	158000	202000	254000
15896700	3390	5120	6520	8580	10400	12400
15905000	32	44	52	63	73	83
15910000	17800	25700	31700	40500	47800	55900
15910200	640	1030	1360	1870	2330	2860

TABLE 4
STATION SAMPLE SKEW VALUES AND WEIGHTED AVERAGE SKEW FOR VARIOUS LENGTHS OF RECORD FOR STATIONS ALONG THE PIPELINE CORRIDOR

Station Number	Drainage Area (mi^2)	Years of Record	Station Skew	Years x Skew
15305900	2.93	15	0.757	11.36
15470000	3280	22	1.000	22.00
15471000	15.4	15	1.150	17.25
15471500	2.43	15	0.499	7.49
15473950	36.4	16	-0.398	- 6.37
15476000	8550	27	0.047	1.27
15476200	11.0	16	-0.405	- 6.48
15476300	65.1	16	0.344	5.50
15476400	57.6	16	-0.639	-10.22
15480000	13500	15	-0.674	-10.11
15484000	2170	29	0.216	6.26
15514000	1980	32	0.729	23.33
15515500	25600	19	1.869	35.51
15519200	7.81	16	-1.874	-29.98
15520000	5.31	17	0.670	11.39
15541600	23.0	16	0.203	3.25
15564900	18700	17	0.065	1.11
15 years of record & greater		319 (17)*		82.56 (0.26)**
17 years of record & greater		163 (7)		100.87 (0.62)
19 years of record & greater		129 (5)		88.37 (0.69)

* Number of stations included in total
** Average skew weighted by years of record

2.2 SAMPLING ERROR IN ALASKAN DATA

The major source of error in flood prediction, for an area such as Alaska, is sampling error. The estimate of discharge for a flood of a given frequency is based on the sample of data available. Each additional year of data produces a different, hopefully better, estimate. The shorter the period of record, the greater is the sampling error. A good example of the effect of sampling error is shown in Table 5 for Bridge Creek near Livengood. The Lamke (5) report used the record from 1963 through 1972 water years, Childers (6) had data only through 1968. The four additional years from 1969 through 1972 experienced the two lowest peaks of record, and all four were less than the 2-year flood estimated by Childers. The difference in predicted floods based on those data with 6 and 10 years of record are:

Return Period	Childers	Lamke	Ratio (L/C)
2	446	175	0.39
5	903	411	0.46
10	1230	692	0.56

This indicates the magnitude of errors to be expected when short periods of record are available. As shown in Table 1, 9 of the stations used in the analysis have 6 years of record or less, and 30 of them have 10 years or less.

TABLE 5
FLOOD PEAK DATA FOR BRIDGE CREEK
NEAR LIVENGOOD (U.S.G.S. STATION NUMBER 15519000)

Water Year	Discharge	Water Year	Ranked Discharge
1963	185	1964	1070
1964	1070	1967	788
1965	290	1965	290
1966	97	1971	220
1967	788	1963	185
1968	152	1968	152
1969	76	1970	131
1970	131	1966	97
1971	220	1969	76
1972	63	1972	63

One means to reduce sampling error in the annual peak data series might be by use of regression to extend the length of the series. For example, for some years, daily flow values may be available, and the maximum of those daily values might be used to estimate the instantaneous peak flow. However, such a procedure probably will not add to information about the flood frequency distribution.

There are several reasons for this. First, the records concerned are short, so that the sample size on which to base an extension is small. Second, the relation of estimated maximum daily flows is not the same as that for measured maximum daily flows to instantaneous peak flows. Furthermore, there is no sample on which to base the relation of estimated maximum daily flows to instantaneous peak flows, because peak flows, by definition, are unavailable on those days, else the problem would not exist. Third, information must be added to both the mean and the variance of the flood frequency distribution if better estimates are to be computed. Studies in statistical information theory show that for concurrent records of 6 to 8 years, the correlation coefficient must be 0.6 in order not to lose information about the mean and must be 0.8 in order not to lose information about the variance (7). The stricter constraint of 0.8 probably could not be met, so that, statistically, the results are better without than with extension.

An impression of the effect of sampling variability can be gained by a study of the residual errors of a relation. For example, a multiple regression of peak flow against drainage area and slope was developed for the Yukon-Tanana region. Table 6 shows those stations for which the residuals from that relation exceed 0.2 in absolute value for floods of all frequencies. Those stations comprise two major groups. The first group contains four stations in the Upper Tanana Basin for which all floods are overestimated by from 60 to 414 percent. The second contains seven stations in the vicinity of Fairbanks for which all floods are underestimated by from 37 to 80 percent.

There are three possible hypotheses which could explain the deviations. First, precipitation (rainfall or snowfall) could be greater in one area relative to the other, or rainfall intensity could be greater. That hypothesis is not borne out by the data available. Second, other variables or some orographic or geographic influence may cause greater floods in one area than in the other. If adopted, that hypothesis must be accepted on faith. Third, the differences could be the result of sampling variability. Evidence for that hypothesis is shown in Table 7. The major difference between the two groups appears to be that the 1967 flood was centered near one group and not the other.

TABLE 6
RESIDUALS FOR STATIONS FOR WHICH
THE ABSOLUTE VALUE OF RESIDUALS EXCEEDS
0.2 FOR ALL FLOOD FREQUENCIES COMPUTED

Station	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
15305950	-0.608	-0.564	-0.537	-0.507	-0.486	-0.468
15470000	-0.339	-0.423	-0.470	-0.527	-0.565	-0.603
15471500	-0.337	-0.455	-0.522	-0.607	-0.664	-0.711
15476200	-0.206	-0.331	-0.405	-0.487	-0.544	-0.592
15511500	-0.664	-0.581	-0.528	-0.469	-0.428	-0.383
15518200	0.252	0.397	0.481	0.576	0.642	0.707
15518250	0.203	0.238	0.258	0.283	0.299	0.321
15518350	0.223	0.326	0.384	0.451	0.497	0.539
15519000	0.248	0.299	0.328	0.360	0.384	0.411
15520000	0.324	0.345	0.357	0.371	0.380	0.396
15530000	0.417	0.380	0.360	0.335	0.318	0.305
15541800	0.238	0.298	0.334	0.374	0.402	0.432
15476049	0.322	0.285	0.262	0.238	0.220	0.206

TABLE 7
SELECTED STATISTICS FOR STATIONS FOR WHICH THE ABSOLUTE VALUE OF RESIDUALS EXCEEDS 0.2 FOR ALL FLOOD FREQUENCIES COMPUTED

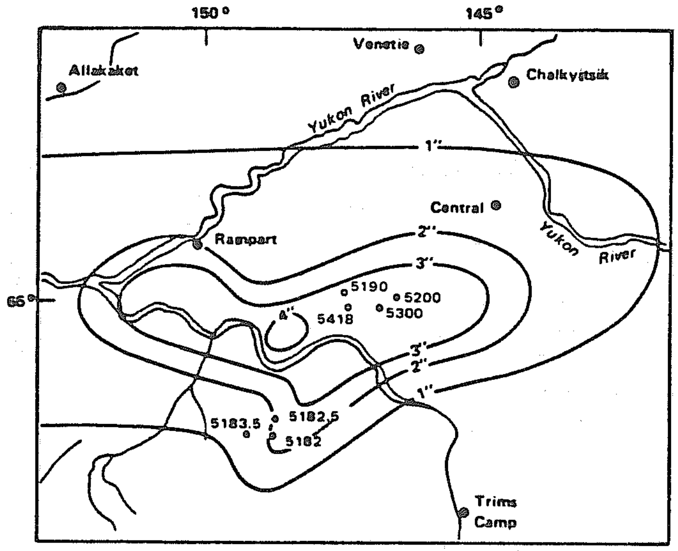
Station Number	Drainage Area (mi^2)	Maximum Discharge (cfs)	Year of Peak	Average Annual Peak (cfs)	Log-Pearson Type III Standard Deviation (cfs)	Ratio of Maximum to Average Discharge	Unit Discharge (cfs/mi^2) Maximum	Unit Discharge (cfs/mi^2) Average
15305950	38.4	600	1973	112.	0.3302	5.36	15.6	2.9
15470000	3280.	12,000	1964	7850.	0.0676	1.53	3.7	2.4
15471500	2.43	45	1973	14.	0.2519	3.21	18.5	5.8
15476200	11.0	146	1964	69.	0.2024	2.12	13.3	6.3
15511500	10.7	130	1972	21.4	0.3306	6.08	12.1	2.0
		340	1967*			15.9	31.8	
15518200	8.17	880	1967	186.	0.5010	4.72	108.0	22.8
		671	1965	160.		4.20	82.1	19.6
15518250	4.10	464	1967	71.4	0.4202	6.50	113.0	17.4
		183	1965	61.8		2.96	44.6	15.1
15518350	490.	33,100	1967	6070.	0.3280	5.45	67.6	12.4
		16,800	1970	5030.		3.34	34.3	10.3
15519000	12.6	1,070	1964	198.	0.4067	5.41	84.9	15.7
		788	1967	198.		3.98	62.5	15.7
15520000	5.31	813	1964	127.	0.3892	6.39	153.0	23.9
		626	1967	127.		4.93	118.0	23.9
15530000	61.1	4,950	1967	1380.	0.2447	3.58	81.0	22.6
		2,140	1970	1200.		1.78	35.0	19.6
15541800	46.7	2,500	1967	636.	0.3748	3.93	53.5	13.6
		1,430	1964	546.		2.62	30.6	11.7
15476049	3.09	332	1970	98.2	0.3192	3.38	107.4	31.8

* Excluded as outlier

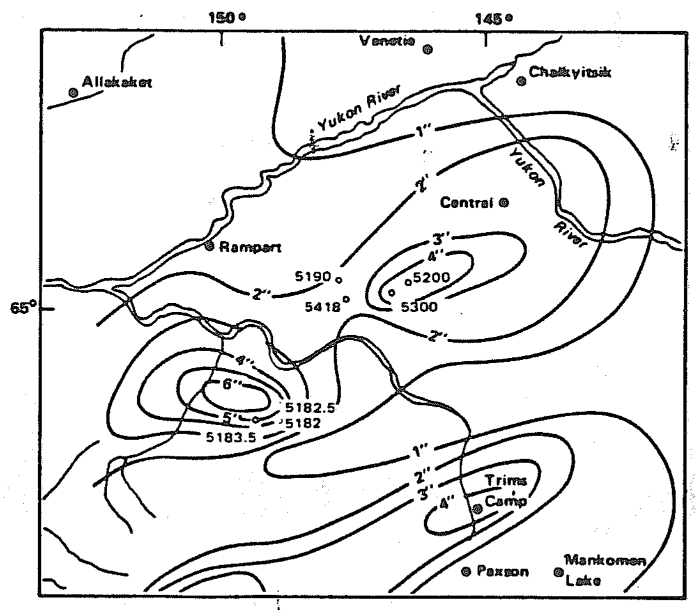
For the group of seven streams for which the residuals are positive, five had their maximum flood in 1967, the other two had their maximum in 1964 with the 1967 flood close behind. Figure 2 shows the location of those seven gaging station in relation to the flood of 1967. All statistics for the seven streams are greater than for the four in the Upper Tanana. Two streams are outside either group. The first is station 15511500, Steele Creek near Fairbanks. Its location is in the area affected by the 1967 storm. The 1967 peak there was 2.6 times the second highest flood, which occurred in 1972. Thus, that ratio is approximately the same as the residual error for the station. Therefore, 12 of the 13 highest residuals may be explained by sampling error rather than by a physical difference.

Four of the seven stations had ten years of record, and the longest had 17. Steele Creek had but six years of record. Thus, a single large event can distort the statistics. The remaining station with large residuals, which is outside either group, is station 15476049, Tanana River Tributary near Cathedral Rapids. That station had eight years of record from 1972 through 1979, which included 1978, the year with no flow. The peak of record was 1972, with a peak of 332 cfs, or 107 cfs/mi^2. This station remains an unexplained outlier.

Of the 59 stations used in the analysis, historic peaks outside the period of continuous record are available for 6 stations. The change in the peak flows and the percentage change as a result of the inclusion of the historic peak data is shown in Table 8. The effects on 3 of the six stations would result in changes of peak flows of less than 10 percent. For two others, the change would be between 10 and 15 percent. Only Steele Creek would be affected more than 15 percent, and its statistics are distorted by sampling error. None of the historic peaks add extensive length to the period of record, and their use was not felt justified.



Isohyets of total rainfall distribution, August 12.



Isohyets of total rainfall distribution, August 13 - 20.

O 5418 - U.S. GEOLOGICAL SURVEY GAGING STATIONS
● CENTRAL - U.S. WEATHER BUREAU PRECIPITATION GAGES
NOTE : FIGURES BASED ON FIGURES 5 & 9 IN U.S.G.S. WSP 1880 - A (REFERENCE 8)

FIGURE 2

FLUOR
PROJECT MANAGEMENT CONTRACTOR

NORTEC
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ALASKAN NORTHWEST NATURAL GAS TRANSPORATION COMPANY

LOCATIONS OF GAGING STATIONS FOR SEVEN STREAMS FOR WHICH THE RESIDUALS ARE POSITIVE

ALASKA SEGMENT OF THE ALASKA NATURAL GAS TRANSPORTATION SYSTEM

		DATE	REV.	BY	APP.	DATE
DES./DWN.	/					
CHK./APP.	/					
PMC /NWA	/					

DRAWING NUMBER | REV.

TABLE 8
POSSIBLE EFFECT OF USE OF HISTORIC PEAKS ON PEAK FLOW ESTIMATES

No. of Years of Record Not Including Historic Peak	9			5			18		
	Quartz Creek			Steele Creek			Tanana River		
Return Period (Year)	w/Historic Peak (cfs)	w/o Historic Peak (cfs)	% Change	w/Historic Peak (cfs)	w/o Historic Peak (cfs)	% Change	w/Historic Peak (cfs)	w/o Historic Peak (cfs)	% Change
100	852	840	1.4	1,759	365	382	176,188	168,743	4.4
50	688	671	2.5	884	245	261	158,224	152,329	3.9
25	547	528	3.6	437	160	173	141,122	136,578	3.3
10	390	372	4.8	165	86	92	119,475	116,439	2.6
5	289	274	5.5	75	50	50	103,375	101,291	2.1
2	171	162	5.6	23	20	15	80,735	79,682	1.3

TABLE 8 (continued)

No. of Years of Record Not Including Historic Peak	5			9			10		
	Prospect Creek			M. F. Koyukuk River			Sagavanirktok River		
Return Period (Year)	w/Historic Peak (cfs)	w/o Historic Peak (cfs)	% Change	w/Historic Peak (cfs)	w/o Historic Peak (cfs)	% Change	w/Historic Peak (cfs)	w/o Historic Peak (cfs)	% Change
100	19,557	17,780	10.0	38,891	33,974	14.5	59,986	55,852	7.4
50	14,259	12,896	10.6	32,757	28,725	14.0	50,798	47,789	6.3
25	10,172	9,157	11.1	27,202	24,018	13.3	42,506	40,467	5.0
10	6,200	5,551	11.7	20,612	18,489	11.5	32,780	31,735	3.3
5	4,016	3,585	12.0	16,069	14,712	9.2	26,140	25,664	1.9
2	1,892	1,688	12.1	10,279	9,926	3.6	17,737	17,805	-0.4

2.3 INFLUENCE OF SNOWMELT FLOODS

Most gaged streams along the pipeline corridor have an annual flood frequency distribution which is defined by a mixture of snowmelt floods and rainfall floods. The distribution of snowmelt floods usually has a higher mean annual flood and lower variance than does a distribution for rainfall floods for a similar basin, all other things being equal. Thus, for mixed distributions, the mean discharge is strongly influenced by snowmelt events. Rare events usually result from rainfall floods (or rainfall on a snow pack). The skewness is greater for the mixed distribution than for either of the two underlying distributions.

All streams along the pipeline corridor experience a snowmelt peak (or spring breakup flood) each year. However, the major rainfall peaks occurred in 1964 and 1967. The year of peak of record for streams used in this study is distributed as follows:

Year of Maximum	Number of Stations	Length of Record
1949	1	8
1962	2	10-27
1964	10	10-22
1966	1	16
1967	14	6-32
1968	3	6-16
1969	1	11
1970	2	8
1972	1	10
1973	3	13-15
1974	1	6
1975	9	5-16
1976	4	8-11
1977	4	5-10
1978	1	9
1979	1	5
1980	1	7
	59	

Thus, all long-term records with 16 years of record or longer, except one, had the maximum flood in 1968 or earlier. Rearranging the data:

Minimum Length of Record	Number of Stations	Number with Maximum Peak 1968 or earlier	Number with Maximum Peak 1969 or later
17	7	7	0
16	13	12	1
15	16	14	2
14	19	16	3

The long-term stations tend to have experienced their maximum flood in the rainstorm periods in July 1964 or in August 1967.

Ideally, one might preferably analyze snowmelt and rainfall floods separately and combine their distributions. However, even more data would be required for such an analysis than for a single distribution analysis. The paucity of data in Alaska precludes such an analysis. However, the knowledge of the existence of the dual causes of flooding in Alaskan streams does reinforce Lamke's use of a high value for regional skew for flood frequency distributions.

3.0 STATISTICAL ANALYSIS

The scarcity of data in the North Slope and the Koyukuk Basins led to the choice of an analysis of covariance to analyze the regional regression equations. An analysis of covariance allows the data to be used more efficiently in defining the regression equation. It does this by allowing data in different regions to be pooled to determine the regression coefficients. The model assumed was a regression model similar to that used by Lamke (5):

$$Q_T = aX_1^{b_1} X_2^{b_2} \ldots \qquad (1)$$

or

$$\log Q_T = \log a + b_1 (\log X_1) + b_2 (\log X_2) + \ldots \qquad (2)$$

where Q_T = flood peak, in cubic feet per second, with a return period of T years,

X_1, X_2 = physical parameters describing the drainage basin,

and a, b_1, b_2 = coefficients determined by the regression.

Equation 2 is linear in terms of the logarithms, and therefore standard linear statistical models may be used for analysis.

This report uses analysis of covariance to analyze the relation of floods of various frequencies (2-, 5-, 10-, 25-, 50-, and 100-year floods) to drainage area.

Although the analysis of covariance was used rather than the more usual stepwise multiple regression, various multiple regression analyses were performed to study the variability of results among regions and to study the relative influence of the various variables on the study results.

3.1 REGRESSION ANALYSES

The data used for regression analysis included: drainage area, main channel slope, main channel length, mean basin elevation, area of forest, area of glaciers, mean annual precipitation, precipitation intensity, mean annual snowfall, and mean January temperature. These data were abstracted from Lamke (5), where possible. For the 12 stations not included in Lamke's report because of their short length of record, data were reduced for this report. In addition, several obvious typographical errors were found in the published data, so that all of Lamke's published data values were rechecked and revised where necessary.

Stepwise linear regression analyses were performed separately for the Yukon-Tanana Basins and the North Slope-Koyukuk Basins. The independent variables used were all those listed earlier plus logarithmic transformations of all variables which do not have any stream with a value of zero for that variable. The results were different for the two sets of data, as was to be expected. Different variables entered the relations, and some results were counter-intuitive and not physically justifiable.

The physical justification for each of the variables is as follows:

Drainage area (DA) - The larger the drainage area, the larger the volume of flow and, thus, the larger the peak flow. However, as the drainage area increases, uniformity of precipitation over the basin decreases, so that the effect of drainage area on peak flow decreases with size. Therefore, the exponent of drainage area in an equation should be less than one. Major floods generally result from intense storms. General frontal systems are more likely to cause the less rare events. Therefore, the exponent of drainage area should decrease also with increasing return period.

Main channel slope(S) - The steeper the channel, the faster the velocity of flow and the greater the peak discharge.

Main channel length (CL) - The longer the channel the more the attenuation of the peak, all other things being equal. Therefore the coefficient for main channel length should be negative.

Mean basin elevation (ME) - This is a surrogate for orographic effects. In temperate zones, rainfall often increases with altitude. Farther north, changing elevation signifies a change in the relation of rainfall to snowfall.

Area of forest (AF) - The larger the area of forest, the less the volume of runoff, and thus, the smaller the peaks. In addition, forests may change the timing of snowmelt.

Area of glaciers (AG) - Higher elevations and greater snowfalls should be associated with glaciers. Glaciers store the snowfall from year to year. That tends to reduce the variance of the flood frequency curve.

Mean annual precipitation (MAP) - More precipitation implies more volume of runoff and, thus, larger peaks.

Precipitation intensity (PI) - The greater the intensity, the greater the peak for smaller drainage areas. For larger basins, this variable should have little effect.

Mean annual snowfall (MAS) - This should be an index of the relative importance of snowfall peaks.

Mean January temperature (MJT) - The warmer the climate, the more influence from rainfall. Also, snowmelt should occur earlier and faster, thus increasing snowmelt peaks.

Multiple stepwise regression analyses were performed for the Yukon-Tanana Basins using 46 stations, and for the North Slope - Koyukuk Basins using 13 stations. The first analysis in each case used all variables plus logarithmically transformed variables.

The results for the Yukon-Tanana Basins are shown in Table 9. The first set of results are for the usual stepwise multiple regression. For the 2-, 5-, 10-, and 25-year floods, channel length replaces drainage area as the primary independent variable. Channel slope never appears in any relation. This results from the high intercorrelation of those three variables. The cross-correlations for the 2-, 25-, and 50-year floods are:

	Log DA	Log S	Log Q_2	Log Q_{25}	Log Q_{50}
Log CL	0.9902	-0.9244	0.9713	0.9450	0.9324
Log DA	-	-0.9300	0.9696	0.9447	0.9325
Log S	-0.9300	-	-0.8802	-0.8634	-0.8538

Thus, large drainages have long channels and flat slopes, as one would expect. The combination of high interdependence of the independent variables and sampling error in the dependent variable precludes the definition of the independent effects of the three variables. Whichever of the three enters the relation first precludes the inclusion of the others.

The second column of results in Table 9 shows the effect of elimination of channel length from the analysis. As expected, drainage area becomes the primary variable. Area of forests is the second most important variable, but its influence decreases with increasing return period, until, for the 50- and 100-year floods, it is the third variable to enter. Most interesting is the fact that the change from channel length to drainage area as the primary variable drops mean annual precipitation from the relation and introduces mean January temperature in its place.

The third column of results in Table 9 shows the effect of elimination of both channel length and area of forests from the analysis.

The fourth column lists the results of an analysis of covariance for comparison.

TABLE 9
RESULTS OF MULTIPLE REGRESSION STUDY FOR YUKON - TANANA BASINS

Flood	With CL Step	With CL Variable	With CL SEE	Without CL Step	Without CL Variable	Without CL SEE	Without CL and AF Step	Without CL and AF Variable	Without CL and AF SEE	ANOCOVA Step	ANOCOVA Variable	ANOCOVA SEE
Q_2	1	log CL	.2476	1	log DA	.2546	1	log DA	.2546	1	log DA	.2478
	2	AF	.2123	2	AF	.2182	2	MJT	.2429	2	log S	.2437
	3	log MAP	.2033	3	MJT	.2090						
Q_5	1	log CL	.2527	1	log DA	.2568	1	log DA	.2568	1	log DA	.2528
	2	AF	.2222	2	AF	.2249	2	MJT	.2394	2	log S	.2488
	3	log MAP	.2113	3	MJT	.2100						
Q_{10}	1	log CL	.2674	1	log DA	.2698	1	log DA	.2698	1	log DA	.2678
	2	AF	.2412	2	AF	.2423	2	MJT	.2500	2	log S	.2638
	3	log MAP	.2303	3	MJT	.2251						
	4	AG	.2211									
Q_{25}	1	log CL	.2941	1	log DA	.2948	1	log DA	.2948	1	log DA	.2941
	2	AF	.2732	2	AF	.2727	2	MJT	.2731	2	log S	.2909
	3	log MAS	.2616	3	MJT	.2538						
	4	MJT	.2514									
Q_{50}	1	log DA	.3166				1	log DA	.3166	1	log DA	.3164
	2	MJT	.2940		Same as with CL		2	MJT	.2940	2	log S	.3134
	3	AF	.2783				3	log MAS	.2837			
	4	log MAS	.2671									
Q_{100}	1	log DA	.3397				1	log DA	.3397	1	log DA	.3397
	2	MJT	.3166		Same as with CL		2	MJT	.3166	2	log S	.3372
	3	log MAS	.3030				3	log MAS	.3030			
	4	AF	.2895									

Similar results for the combined North Slope and Koyukuk Basins are shown in Table 10. For the first analysis, drainage area is most important, mean elevation is second, and mean January temperature third. Mean elevation is a surrogate measure, not a true causative parameter. The last three columns show the relation when mean elevation is eliminated as an independent variable. Not only is mean elevation eliminated, but so is mean January temperature (MJT). Therefore, the only effect of MJT is through a joint correlation with elevation. Table 11 shows the coefficients for the regression equations for each set of variables. For the North Slope-Koyukuk, the higher the elevation, the less the peak, and the warmer the January temperature, the greater the peak.

The improvement in standard error of estimate is shown in Tables 9 and 10. With or without channel length, the standard error can be improved by about 15 percent for the Yukon-Tanana. Without channel length or area of forests, the standard error can be improved 5 to 10 percent. That improvement is not considered sufficient to justify the inclusion of parameters which are difficult to measure or give relations with little physical justification. For the North Slope and Koyukuk Basins, improvement is greater, but the resulting equations have even less physical justification. For example, Table 11 shows that the coefficient for drainage area varies from 0.987 to 1.012. That value is unreasonable at best. The Yukon-Tanana coefficient for drainage area varies from 0.835 for Q_2 to 0.611 for Q_{100}. The most reasonable results, based on past experience elsewhere, are those for the analysis of covariance (discussed later), for which the coefficient varies from 0.893 to 0.743. If drainage area alone is used, the standard error of estimate for the analysis of covariance is as good as those for the two regions derived by separate regressions.

3.2 CONCLUSIONS FROM REGRESSION ANALYSES

The results of separate analyses for the two groups of data yielded quite unrelated regression equations containing different sets of variables. The exponent for drainage area, which should be the most important causative variable, varied between the two regions, and each group departed considerably from values to be expected based on results elsewhere. The analysis of covariance gave a set of exponents for drainage area which are much more in agreement with experience.

Channel length served as a surrogate for drainage area. All other things being equal, an increase in channel length should attenuate flood peaks, so that channel length physically should have a negative exponent. Therefore, results which included channel length rather than drainage area as a major variable were rejected.

TABLE 10
RESULTS OF MUTLIPLE REGRESSION STUDY FOR
COMBINED NORTH SLOPE AND KOYUKUK BASINS

Flood	Step	Variable	SEE	Step	Variable	SEE
Q_2	1	log DA	.2191	1	log DA	.2191
	2	ME	.1819			
Q_5	1	log DA	.2367	1	log DA	.2367
	2	ME	.1803			
	3	MJT	.1474			
Q_{10}	1	log DA	.2589	1	log DA	.2589
	2	ME	.1947			
	3	MJT	.1552			
Q_{25}	1	log DA	.2909	1	log DA	.2909
	2	ME	.2212			
	3	MJT	.1780			
Q_{50}	1	log DA	.3152	1	log DA	.3152
	2	ME	.2433			
	3	MJT	.1984			
Q_{100}	1	log DA	.3399	1	log DA	.3399
	2	ME	.2665			
	3	MJT	.2216			

TABLE 11
COEFFICIENTS IN EQUATIONS RESULTING FROM MULTIPLE REGRESSION STUDY

		V	C	V	C	V	C	V	C	V	C	V	C
Q_2	YT	a	1.799	1	.835	2	.018	3	-.004				
	NSK	a	1.229	1	1.012							5	-0
	NSK	a	1.039	1	.995								
Q_5	YT	a	2.218	1	.775	2	.022	3	-.004				
	NSK	a	3.167	1	.991	2	.088					5	-0
	NSK	a	1.227	1	.993								
Q_{10}	YT	a	2.461	1	.741	2	.024	3	-.004				
	NSK	a	3.502	1	.990	2	.098					5	-0
	NSK	a	1.335	1	.992								
Q_{25}	YT	a	2.739	1	.701	2	.027	3	-.004				
	NSK	a	3.886	1	.989	2	.110					5	-0
	NSK	a	1.457	1	.991								
Q_{50}	YT	a	2.931	1	.674	2	.029	3	-.004				
	YT	a	2.047	1	.642	2	.028	3	-.004	4	.521		
	NSK	a	4.160	1	.988	2	.119					5	-0
	NSK	a	1.542	1	.990								
Q_{100}	YT	a	1.878	1	.632	2	.032			4	.613		
	YT	a	2.080	1	.611	2	.029	3	-.003	4	.607		
	NSK	a	4.402	1	.987	2	.126					5	-0
	NSK	a	1.622	1	.990								

a = coefficient
1 = log DA
2 = MJT
3 = AF
4 = log MAS
5 = ME

YT = Yukon and Tanana Basins
NSK = North Slope and Koyukuk Basins
V = Variable
C = Coefficient for variable in regression equation

Variables which entered the multiple regressions were not easily determined or, where they were, did not improve results significantly.

3.3 ANALYSIS OF COVARIANCE

Analysis of covariance was performed on the flood peak data to compare with the previously discussed regression analyses.

The analysis of covariance allowed the data along the pipeline corridor to be divided into sets of stations which were assumed to be representative of hydrologic regions. The "b" coefficients in equations 1 and 2 were then assumed constant for all regions, whereas the "a" coefficient varied from region to region. Thus the six stations in the North Slope and the seven stations in the Koyukuk were used to determine their particular "a" coefficients and to determine how they differed from that for the Tanana. All fifty-nine stations were then used to determine the "b" coefficients.

The "b" coefficients determine the influence of physical characteristics on the floods for a given frequency. Those coefficients need not be identical in all regions. For example, the coefficient for drainage area is less than one. The amount less than one is a measure of the decrease in basin rainfall as area increases. The depth-area relation may differ for regions of different climate. However, scarcity of data often precludes the definition of any difference in coefficients with sufficient accuracy to justify variation in the values used. In particular, the North Slope and Koyukuk data are so few that it was necessary to transfer as much information as possible from the relatively data rich Yukon - Tanana Basin.

The first test made was to determine whether the regional groupings were different from each other; that is, whether the "a" coefficients were different or could any differences result from random variation only. The probability that the groupings were the same is shown in Table 12. The final column compares the Tanana with a combined region which includes the North Slope and the Koyukuk data.

TABLE 12
PROBABILITY THAT REGIONS CAN BE COMBINED

	Tanana/ North Slope	Tanana/ Koyukuk	North Slope/ Koyukuk	Tanana/ Combined
Q_2	0.16	0.15	0.98	0.06
Q_5	0.40	0.37	0.998	0.24
Q_{10}	0.61	0.56	0.98	0.46
Q_{25}	0.86	0.79	0.96	0.77
Q_{50}	0.99	0.94	0.95	0.96
Q_{100}	0.87	0.94	0.95	0.87

As a result, the North Slope and Koyukuk stations were combined, and only two regions were considered to be necessary to describe the flood frequency relations along the pipeline corridor. The Tanana relation was determined by the forty-six records originally used, whereas the combined North Slope-Koyukuk relation was determined by the remaining thirteen records. The dividing point for use of the two relations is at mile post 318.4. For the 25-, 50-, and 100-year floods, the relation of flood peak to drainage area was derived from a single region along the entire pipeline corridor. Table 13 shows the resulting equations and the standard error of estimate for each return period.

Other variables were considered, but they were either not significant, or were difficult to estimate, or else the physical justification for the relation including them was not considered adequate. In general, improvement in the standard error of estimate was less than 20 percent even when three or four variables were included in the analysis. A second variable, which differed for different return periods, improved results on the order of 10 percent. The decision was made to use drainage area alone and to design on the basis of a 10 percent confidence level to handle the uncertainty resulting from the sampling error inherent in the data.

Figures 3 to 11 show the curves which relate peak discharge to drainage area.

TABLE 13
PREDICTION EQUATIONS AND RESULTANT ERRORS OF PREDICTION

	Return Period	a	b_1	Equation	Standard Error Log Units	Standard Error Percent
Tanana	2	1.10167	0.89317	$Q_2 = 12.6A^{0.89}$	0.2478	+77 -43
	5	1.44284	0.84510	$Q_5 = 27.7A^{0.85}$	0.2528	+79 -44
	10	1.64083	0.81733	$Q_{10} = 43.7A^{0.82}$	0.2678	+85 -46
	25	1.86709	0.78575	$Q_{25} = 73.6A^{0.79}$	0.2941	+97 -49
	50	2.02731	0.76386	$Q_{50} = 106.5A^{0.76}$	0.3164	+107 -52
	100	2.16814	0.74338	$Q_{100} = 147.3A^{0.74}$	0.3397	+119 -54

TABLE 13 (Continued)

	Return Period	a	b_1	Equation	Standard Error Log Units	Standard Error Percent
North Slope and Koyukuk combined	2	1.25648	0.89317	$Q_2 = 18.1A^{0.89}$	0.2478	+77 −43
	5	1.54280	0.84510	$Q_5 = 34.9A^{0.85}$	0.2528	+79 −44
	10	1.70821	0.81733	$Q_{10} = 51.1A^{0.82}$	0.2678	+85 −46
	25	1.89729	0.78575	$Q_{25} = 78.9A^{0.79}$	0.2941	+97 −49
	50	2.02735	0.76386	$Q_{50} = 106.5A^{0.76}$	0.3164	+107 −52
	100	2.14940	0.74338	$Q_{100} = 141.1A^{0.74}$	0.3397	+119 −54
Tanana, North Slope, and Koyukuk combined	25	1.87145	0.78691	$Q_{25} = 74.4A^{0.79}$	0.3153	+107 −52
	50	2.02320	0.76405	$Q_{50} = 105.5A^{0.76}$	0.3403	+119 −54
	100	2.16600	0.74300	$Q_{100} = 146.6A^{0.74}$	0.3663	+132 −57

RELATION OF 2 - YEAR FLOOD PEAK TO DRAINAGE AREA FOR TANANA RIVER BASIN AND FOR COMBINED NORTH SLOPE AND KOYUKUK RIVER BASINS

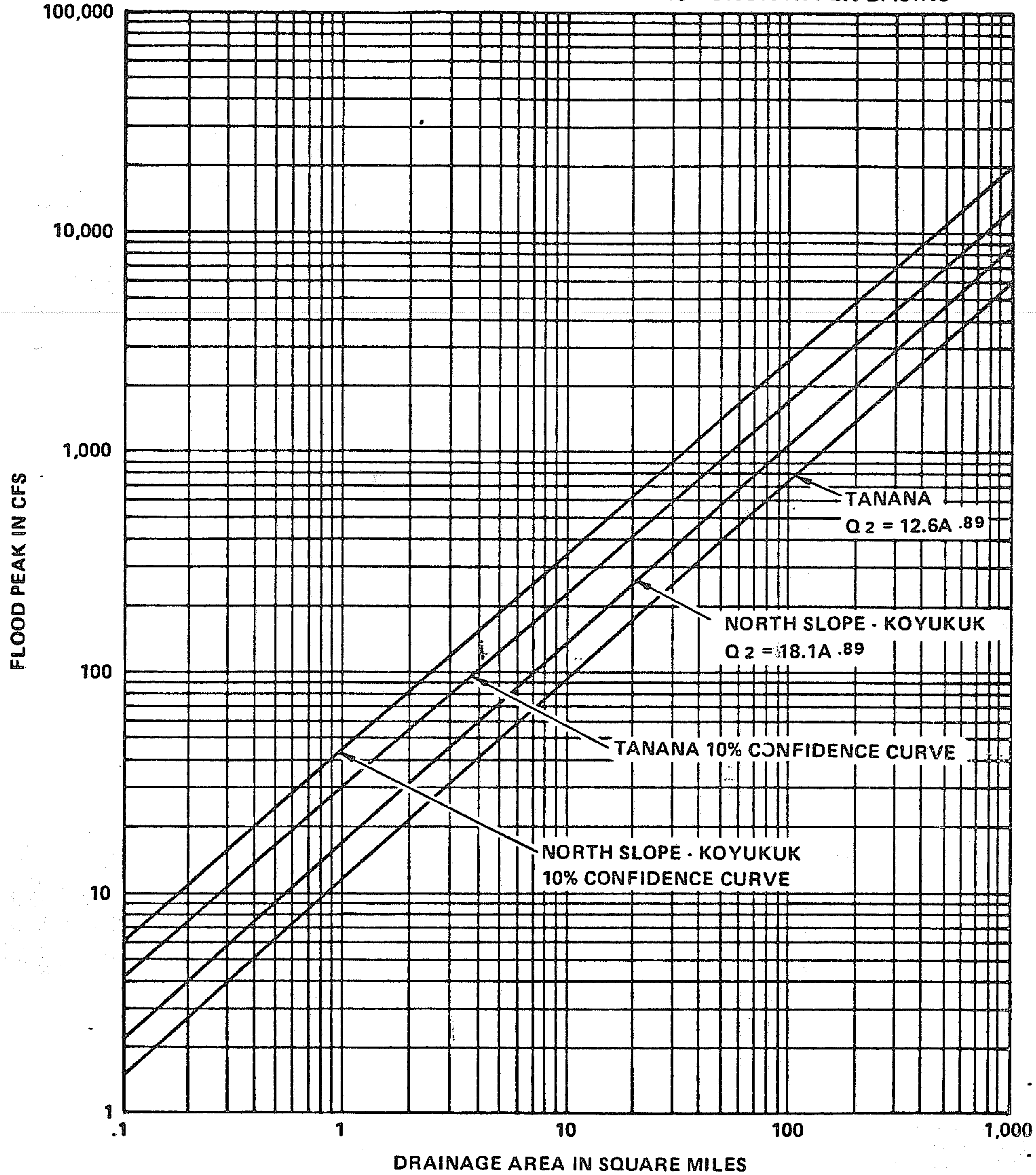

FIGURE 3

FLUOR
PROJECT MANAGEMENT CONTRACTOR

ALASKAN NORTHWEST NATURAL GAS TRANSPORATION COMPANY

NORTEC NORTHERN TECHNICAL SERVICES

ALASKA SEGMENT OF THE ALASKA NATURAL GAS TRANSPORTATION SYSTEM

		DATE	REV.	BY	APP.	DATE
DES./DWN.	/					
CHK./APP.	/					
PMC /NWA	/					

DRAWING NUMBER	REV.

RELATION OF 5 - YEAR FLOOD PEAK TO DRAINAGE AREA FOR TANANA RIVER BASIN AND FOR COMBINED NORTH SLOPE AND KOYUKUK RIVER BASINS

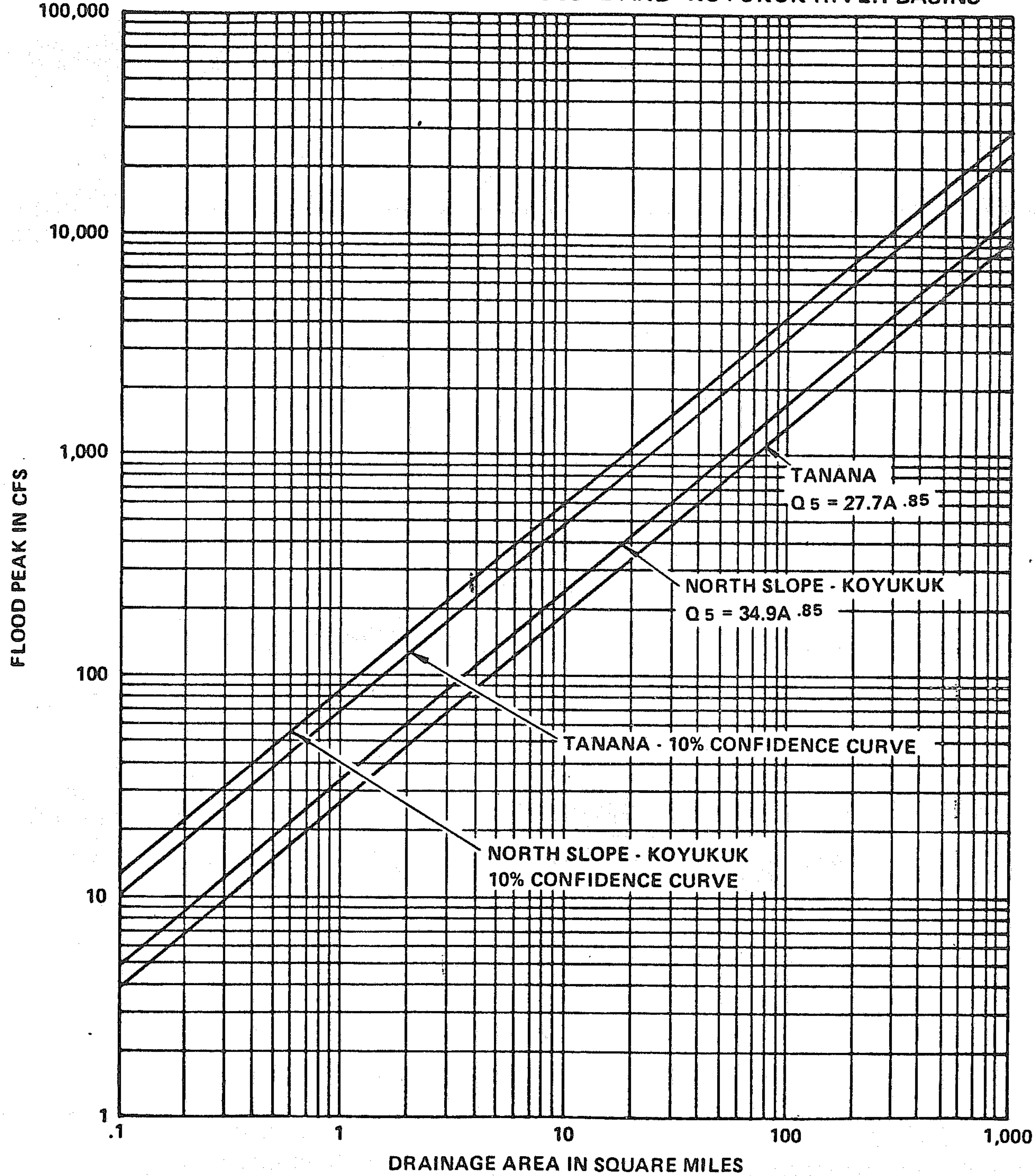

FIGURE 4

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RELATION OF 10 - YEAR FLOOD PEAK TO DRAINAGE AREA FOR TANANA RIVER BASIN AND FOR COMBINED NORTH SLOPE AND KOYUKUK RIVER BASINS

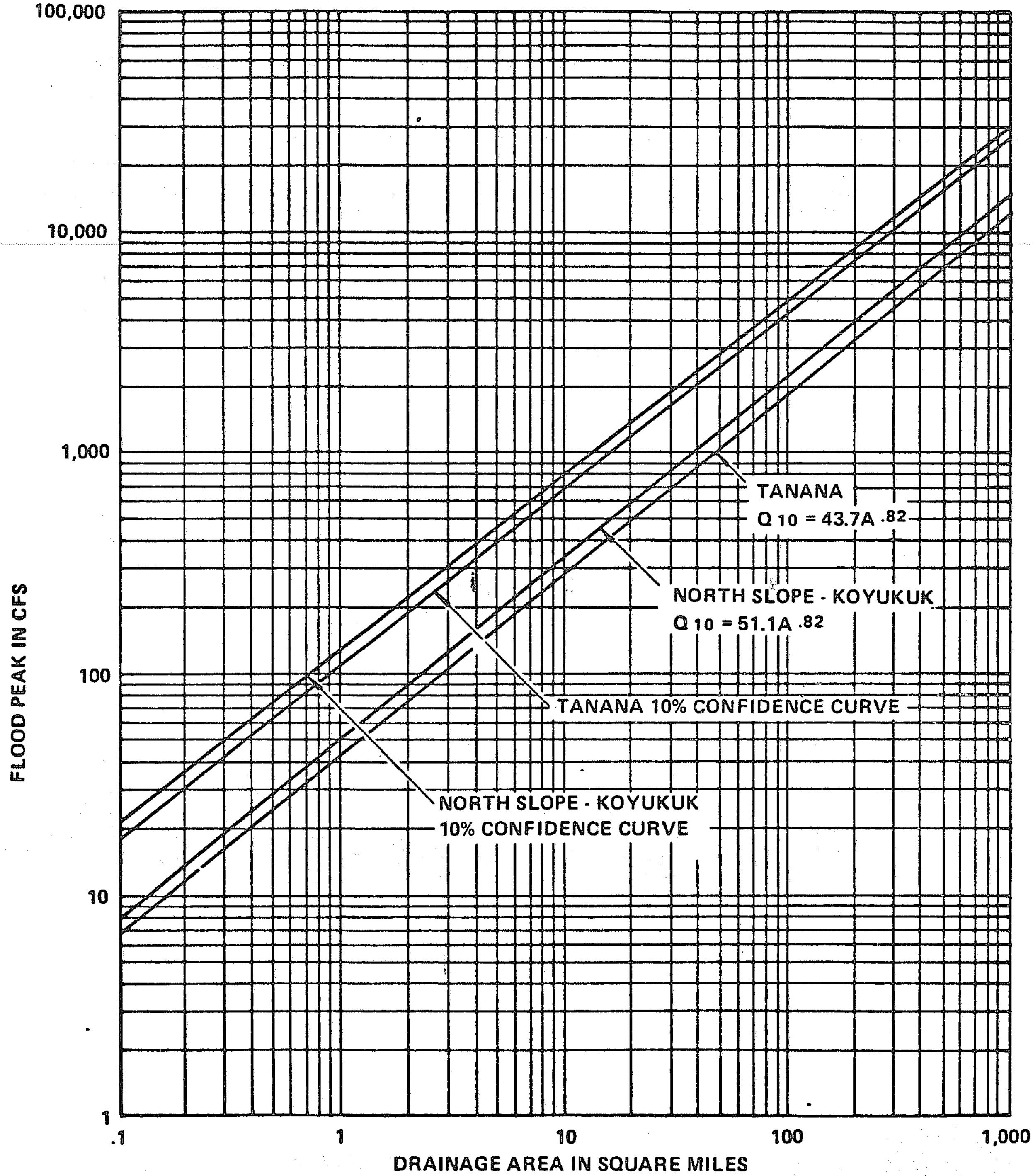

FIGURE 5

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RELATION OF 25 - YEAR FLOOD PEAK TO DRAINAGE AREA FOR TANANA RIVER BASIN AND FOR COMBINED NORTH SLOPE AND KOYUKUK RIVER BASINS

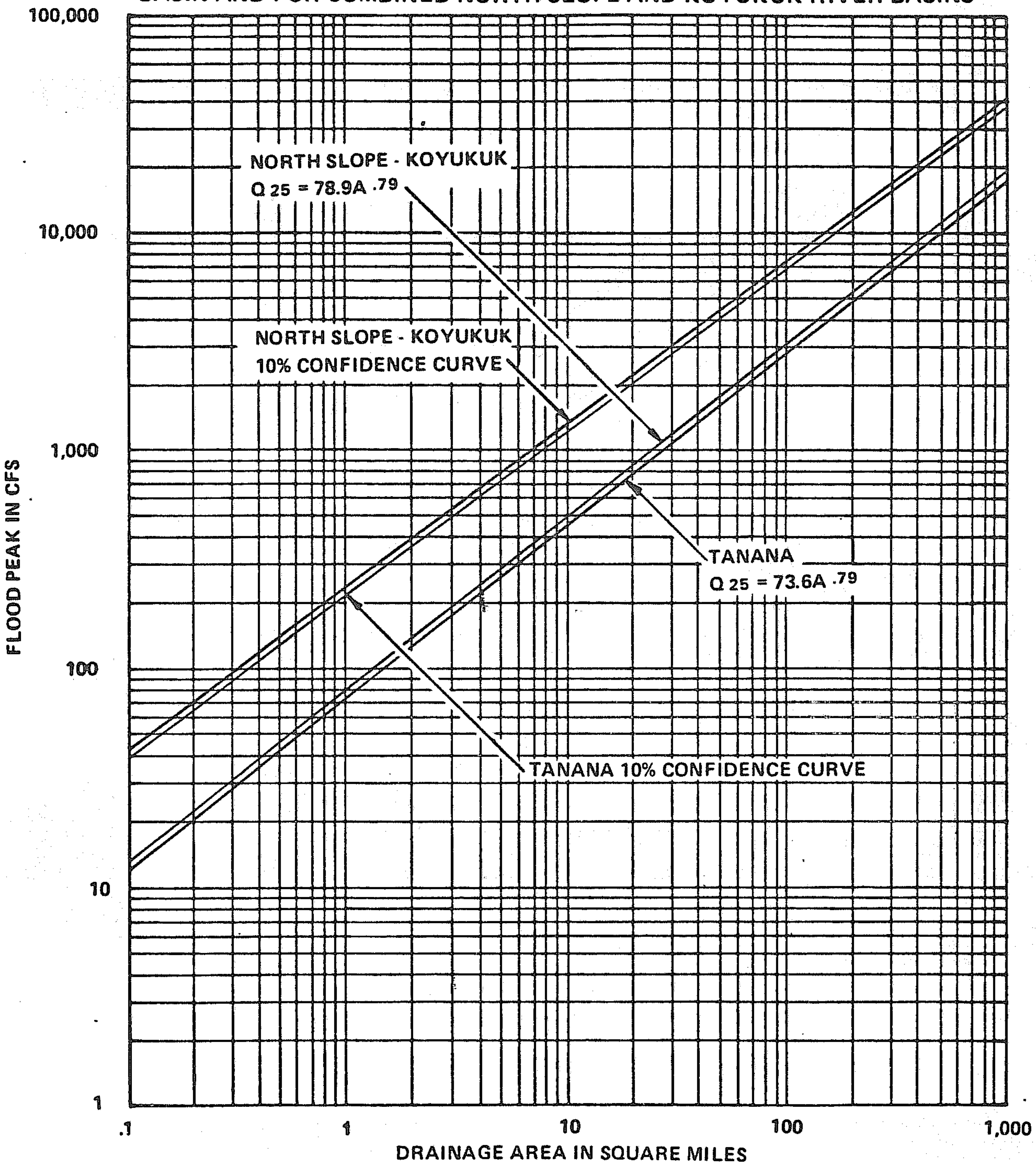

FIGURE 6

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RELATION OF 50 - YEAR FLOOD PEAK TO DRAINAGE AREA FOR TANANA RIVER BASIN AND FOR COMBINED NORTH SLOPE AND KOYUKUK RIVER BASINS

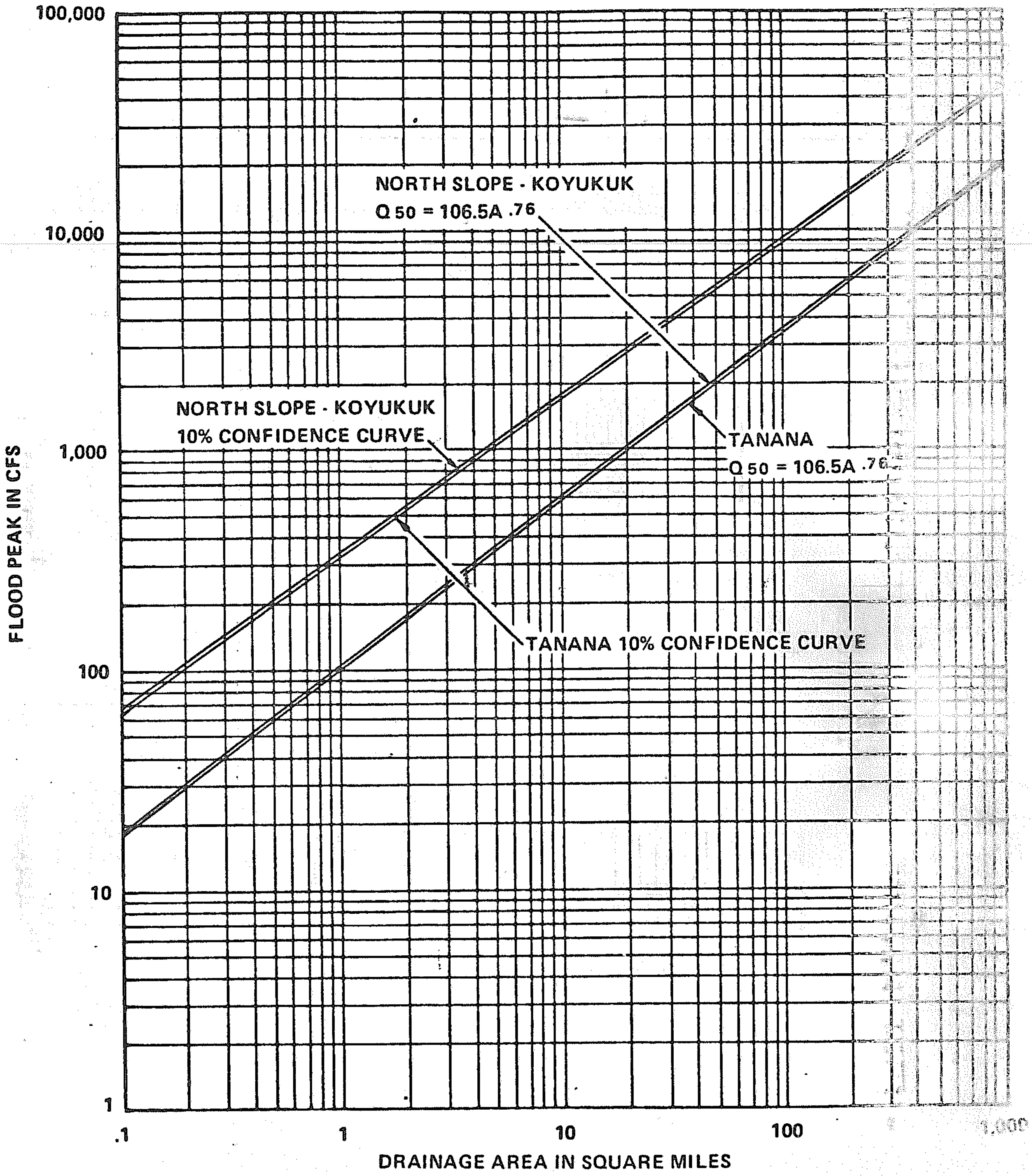

FIGURE 7

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RELATION OF 100 - YEAR FLOOD PEAK TO DRAINAGE AREA FOR TANANA RIVER BASIN AND FOR COMBINED NORTH SLOPE AND KOYUKUK RIVER BASINS

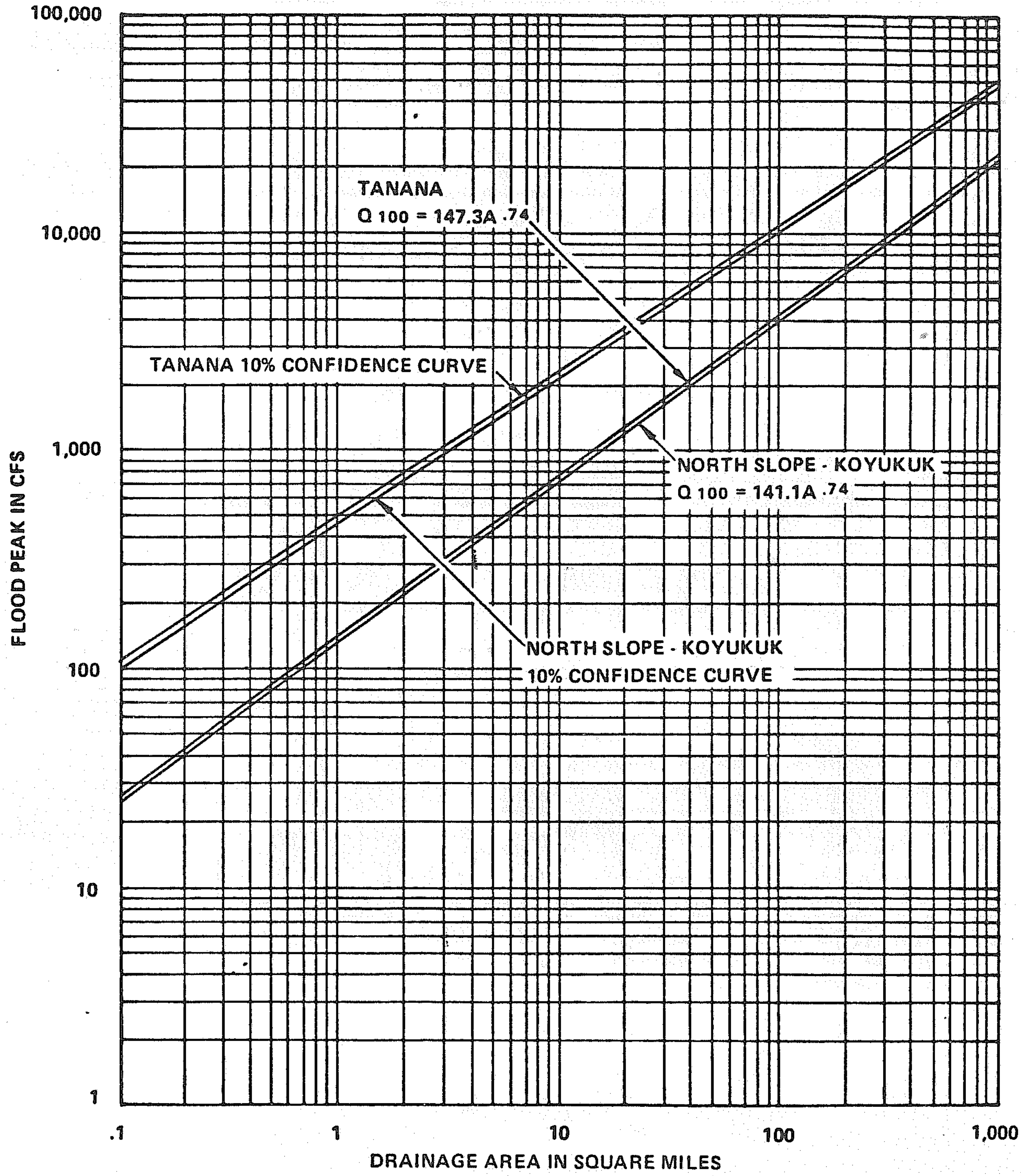

FIGURE 8

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RELATION OF 25 - YEAR FLOOD PEAK TO DRAINAGE AREA FOR TANANA RIVER BASIN COMBINED WITH NORTH SLOPE AND KOYUKUK RIVER BASINS

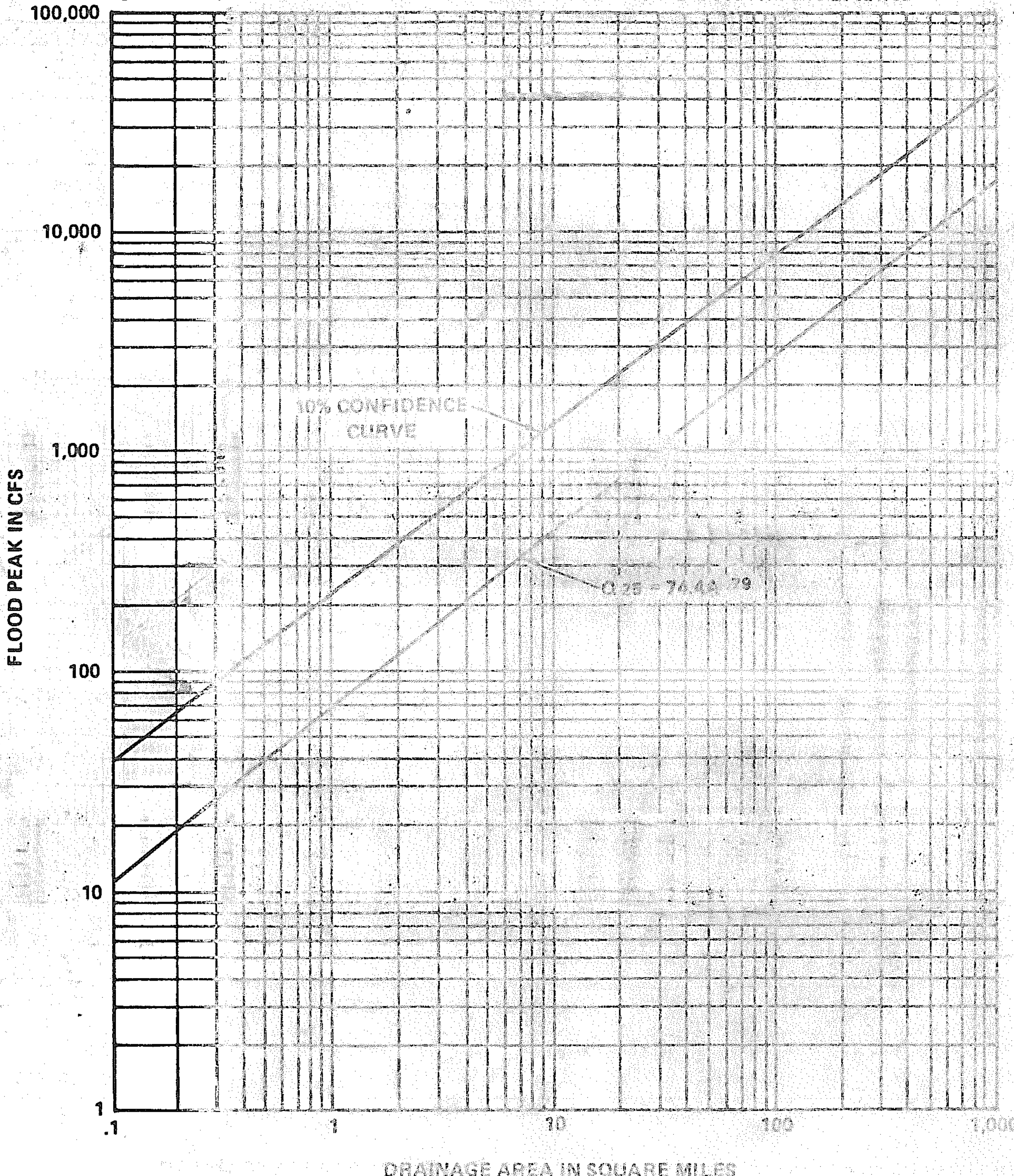

FIGURE 9

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RELATION OF 50 - YEAR FLOOD PEAK TO DRAINAGE AREA FOR TANANA RIVER BASIN COMBINED WITH NORTH SLOPE AND KOYUKUK RIVER BASINS

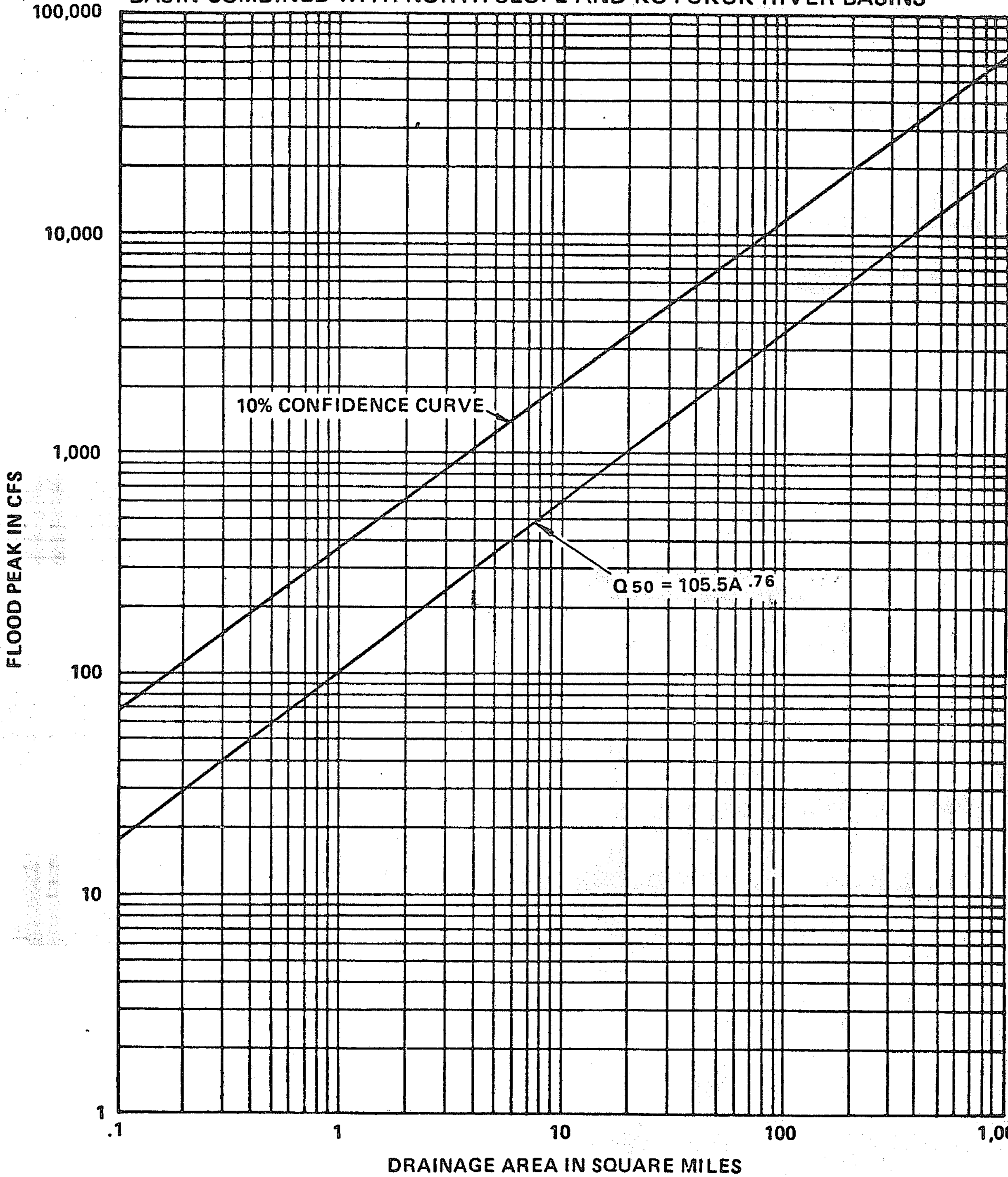

FIGURE 10

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RELATION OF 100 - YEAR FLOOD PEAK TO DRAINAGE AREA FOR TANANA RIVER BASIN COMBINED WITH NORTH SLOPE AND KOYUKUK RIVER BASINS

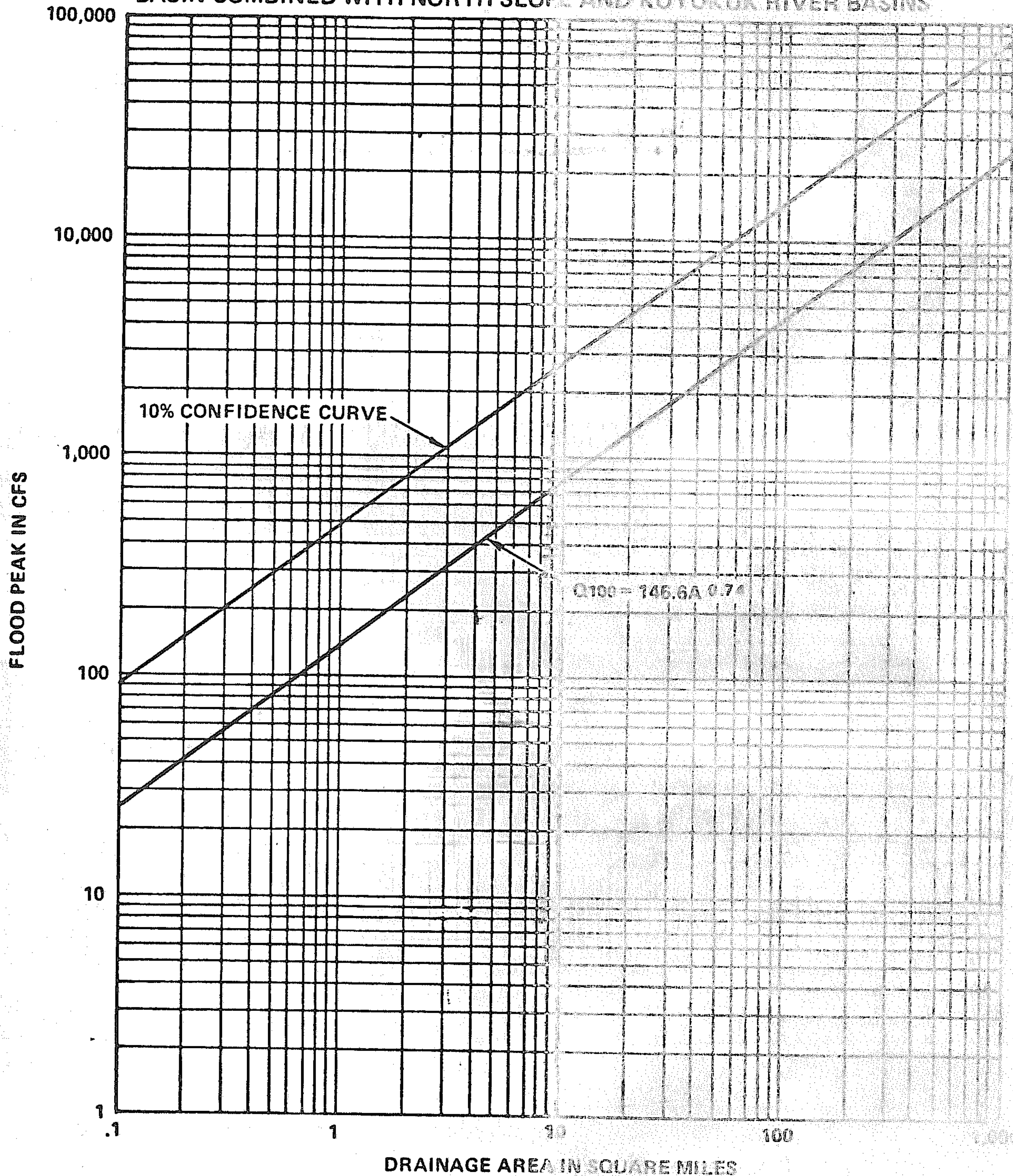

FIGURE 11

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3.4 CONFIDENCE LEVELS

The error of prediction which results from the use of Equation 1 has two parts. The first is a measure of how well the data used fit the derived equation. That is the standard error of estimate. The second results from the errors of estimation for the "b" coefficients. As a result,

$$SEP_{i,p} = K_p \left[SEE + SEb_1 \quad X_{i,1} - \overline{X_1} \quad + SEb_2 \quad X_{i,2} - \overline{X_2} \quad \right] \quad (3)$$

where

$SEP_{i,p}$ is the standard error of prediction for station "i" at a probability level (confidence level) "p",

SEE is the standard error of estimate for variable "n" for the relation,

K_p is the standardized deviate for probability level "p",

SEb_j is the standard error of the jth "b" coefficient,

$X_{i,j}$ is variable "j" for station "i",

and

$\overline{X_j}$ is the mean value for variable "j".

Equation 1 is a median relation. Confidence intervals about the regression equation may be computed using Equation 3. For a given set of independent variables describing a particular basin, a confidence level determines the "K" values, and the accuracy of prediction for that confidence level for the given basin may be computed. The necessary values to use Equation 3 are shown in Table 14. Those tabulated values were the basis for the 10 percent confidence curves shown on Figures 3 to 11. The probability is 10 percent that the true value of the flood being estimated is greater than the 10 percent confidence interval curve.

TABLE 14
ERROR TERMS FOR USE IN EQUATION 3

	Return Period	SEE	SEb_A
Tanana	2	0.2478	0.0290
or	5	0.2528	0.0305
North Slope	10	0.2678	0.0327
and	25	0.2941	0.0363
Koyukuk	50	0.3164	0.0392
combined	100	0.3397	0.0422
Tanana, North Slope, and Koyukuk combined	25	0.3153	0.0361
	50	0.3403	0.0389
	100	0.3663	0.0420

3.5 EFFECTS OF GLACIERS AND LAKES

A study was made of the possible improvements resulting from the use of area of glaciers in the flood frequency relations. Eight stations had a value other than zero for percent of area covered by glaciers listed in the Lamke report. All are in the Yukon-Tanana Basin, and all but three have drainage areas greater than 1000 square miles. Figure 12 shows the residuals from the analysis of covariance for those eight stations plotted against the percent of drainage area covered by glaciers. The three plots are for Q_2, Q_{10}, and Q_{100}. The drainage area is listed alongside the data points on the plot of Q_{100}. The three basins with drainage area less than 1000 square miles are circled on all three plots. Although there may be a statistical trend, it would not be based upon the smaller basins.

A similar study with similar results was undertaken for percent of area of basin covered by lakes. Nineteen stations had some area in lakes. Their distribution was as follows:

	Drainage Area (square miles)			
	Under 100	100-1000	Over 1000	Total
Yukon-Tanana	4	0	7	11
North Slope-Koyukuk	3	2	3	8
	7	2	10	19

These data are plotted in Figure 13. Drainage areas under 1000 square miles are listed alongside the data points on the plot of Q_{100}, and those data points are circled on all plots. There is no apparent relation. The effect of lakes should be to attenuate peaks, but the data are evenly divided between under and over prediction.

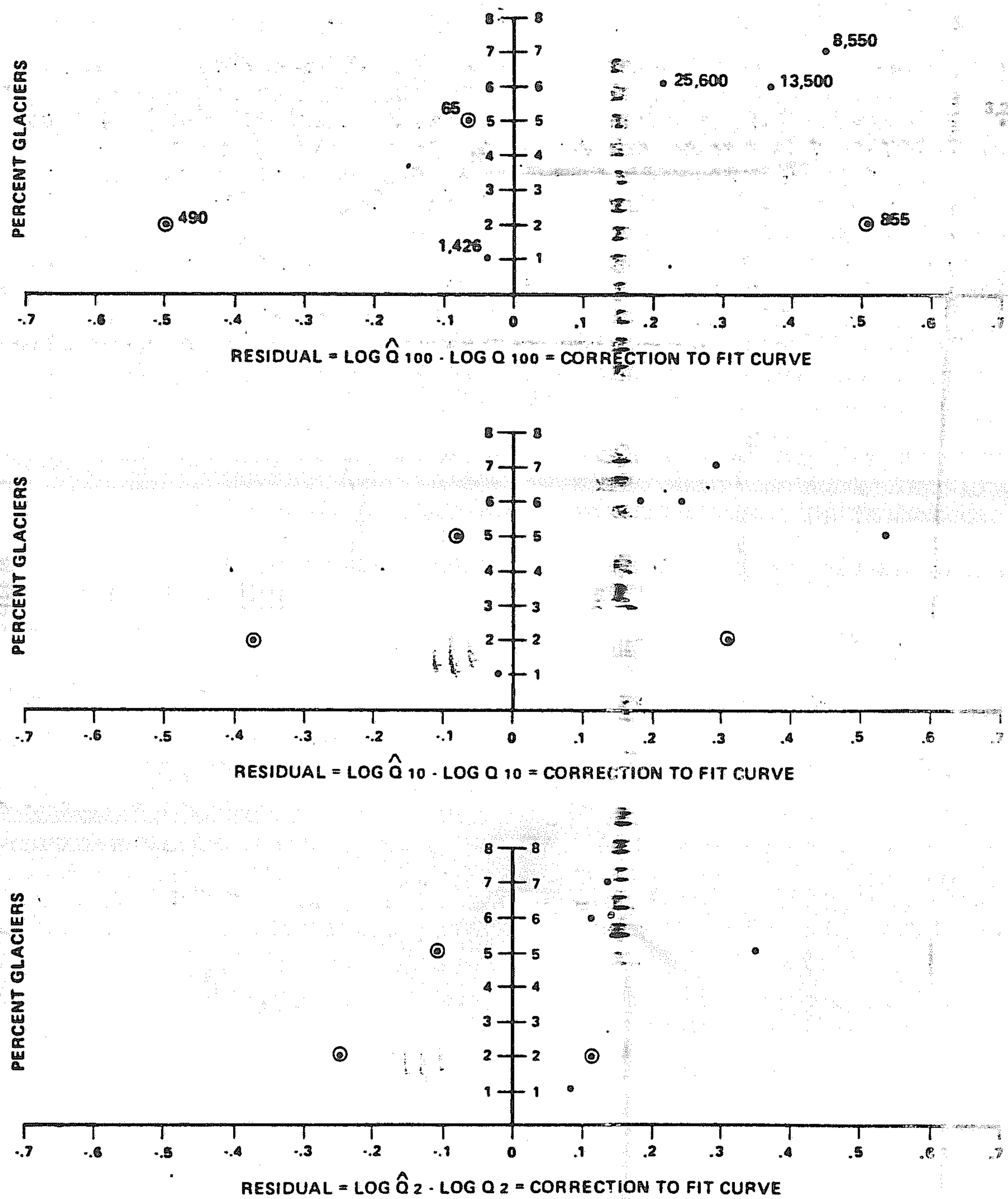

FIGURE 12

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PLOT OF RESIDUAL ERROR OF ESTIMATION FOR 2-, 10, AND 100 - YEAR FLOODS AND PERCENT OF DRAINAGE AREA COVERED BY GLACIERS

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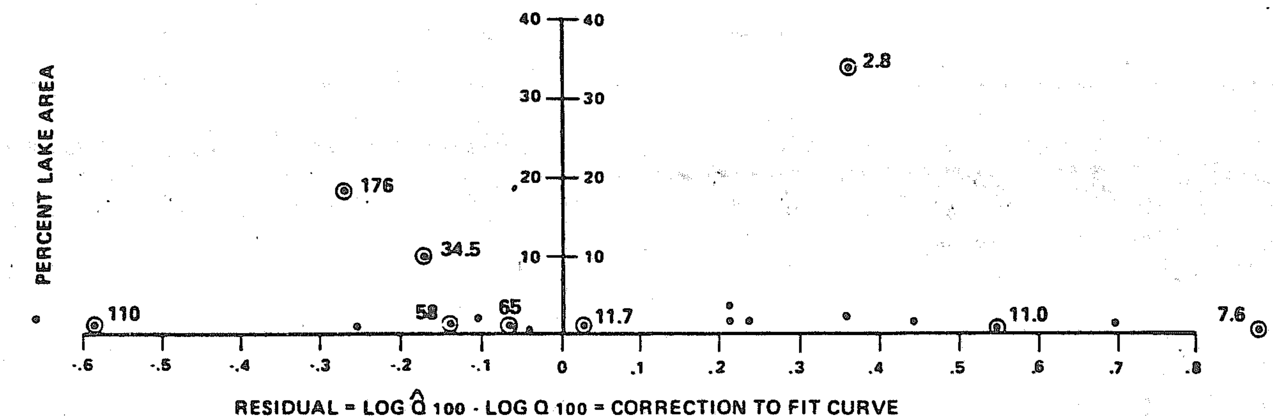

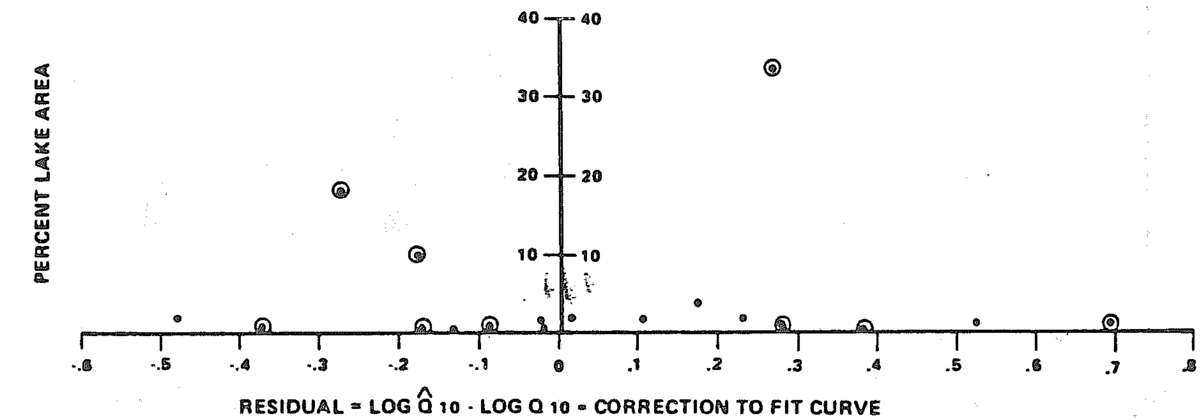

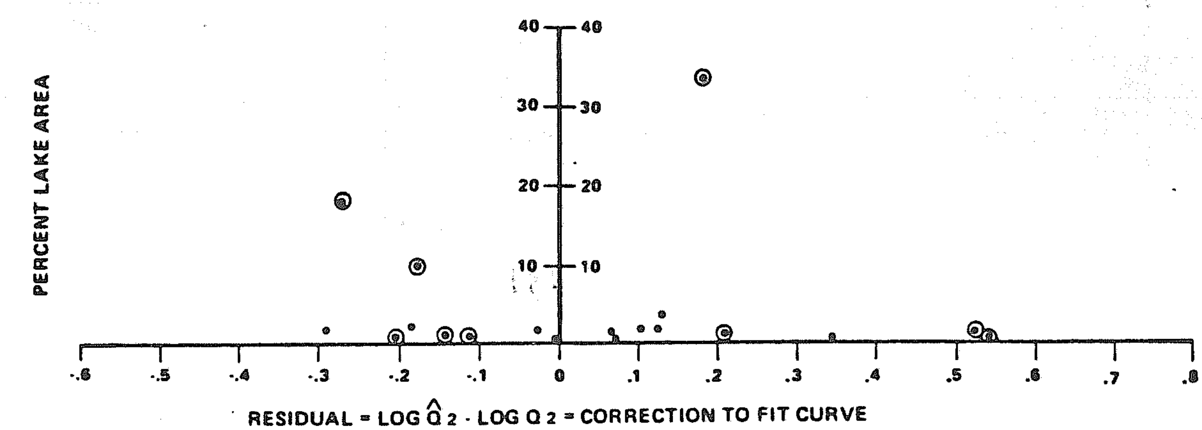

FIGURE 13

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PLOT OF RESIDUAL ERROR OF ESTIMATION FOR 2-, 10-, AND 100 - YEAR FLOODS AND PERCENT OF DRAINAGE AREA COVERED BY LAKES

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4.0 PREDICTION FOR SMALL DRAINAGE AREAS

The regional flood frequency relations shown in Table 13 and plotted in Figures 3 to 11 were defined by data which included stations with as little as one square mile in drainage area. Most of the data for the analysis were from stations under 50 square miles. Fifteen of the 59 stations used to define the relations have drainage areas less than 10 square miles. The distribution of the drainage areas is shown in Table 15.

TABLE 15
SIZE OF DRAINAGE AREAS FOR THE THREE REGIONS

Range in Drainage Area (mi^2)	Number of Stations	Tanana	Koyukuk	North Slope
1-10	15	12	1	2
10-50	19	16	2	1
50-100	3	3	0	0
100-500	6	3	2	1
500+	16	12	2	2
	59	46	7	6

Therefore, the relations are applicable for use in defining flood peaks on small basins. The curves shown in Figures 3 to 11 were drawn to include the range from 0.1 to 1000 square miles, which cover most needs. Confidence intervals were derived by the use of Equation 3 and Table 14.

5.0 EQUATIONS FOR PREDICTION

The analysis derived an equation for the mean relation, and a second equation for the 10 percent confidence curve for prediction of the floods with each return period -- 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year. Those equations relate the discharge to drainage area, with two such relations for both the Tanana River Basin and the combined North Slope and Koyukuk River Basin. In addition, 25-, 50-, and 100-year relations were also derived for all the three regions combined. These equations are applicable along the entire pipeline corridor. The various prediction equations are shown in Table 13. In order to use either the equations or the figures to estimate a flood for a particular site, the drainage area contributing flow to the site must be determined.

The drainage area is measured in square miles, and is the total drainage area upstream from the gaging station or measurement site. It may be measured on a U.S. Geological Survey topographic map on which the drainage divide is delineated.

Figures 3 to 11 present the relations based on the equations in Table 13, which relate peak discharge to drainage area and the 10 percent confidence curves for the equations. The curve showing the relation of peak discharge to drainage area will give an estimate of discharge which might equally well be too high or too low 50 percent of the time. However, the 10 percent confidence curve will give the estimate of discharge which will be too low only 10 percent of the time.

An example of the use of the curves is shown in Figure 3. The 2-year flood is determined for a drainage area of 10 square miles for a stream in the Tanana River Basin.

From Figure 3, the curve showing the peak discharge-drainage area relationship for Tanana River Basin gives the 2-year flood exceeded half the time as 98 cfs. From the same figure, the 10 percent confidence curve for Tanana River Basin gives the 2-year flood estimate which will be exceeded by the true value of the 2-year flood 10 percent of the time as 219 cfs.

Whereas the equations and curves for the 25-, 50-, and 100- year floods for the Tanana Basin and the combined North Slope - Koyukuk Basins have been included in this report, only the equations and curves given for all the three basins combined should be used to determine the 25-, 50-, and 100-year floods. The only reason separate equations for these three frequency floods have been included is to show that there would be very little change in the values irrespective of the location of the stream.

6.0 METHOD FOR APPLICATION

To use the method, the following steps are necessary:

A. To Use Figures 3-11:

1. Determine the drainage area upstream from the point of interest.

2. Choose the return period flood to be determined, and the figure which corresponds to that equation.

3. Draw a vertical line which corresponds to the drainage area.

4. Draw a horizontal line through the point where the vertical line intersects the curve of interest.

5. Read the discharge at the point where the horizontal line intersects the ordinate.

B. To Use Equation:

1. Determine the drainage area upstream from the point of interest.

2. Compute the required return period flood by using the appropriate equation in Table 13.

3. Choose SEE and SEb_A for the appropriate relation and return period in Table 14.

4. Compute value of 1.28155 ($SEE + SEb_A$ log(DA) - 1.8849).

5. Take the antilog of 4 above.

6. Multiply 5 above by 2 above to obtain the 10 percent confidence level for the flood of the desired frequency.

7.0 REFERENCES

1. Water Survey of Canada, 1979 Surface Water Data Index.

2. Orecklin, Mel, and McLachlan, Jerry, 1980, Small Stream Investigation Report, Candian Department of Indian and Northern Affairs, Whitehorse, Yukon, Canada (in press).

3. Canadian Department of Fisheries and Environment, 1978, Design Flows for the Shakwak Highway Project, Inland Water Directorate, Environmental Management Service.

4. U.S. Water Resources Council, 1977, Guidelines for Determining Flood Flow Frequency, U.S. Water Resources Council Hydrology Committee, Bulletin #17A.

5. Lamke, R.D., 1979, Flood Characteristics of Alaskan Streams, U.S. Geological Survey Water Resources Investigations 78-129.

6. Childers, J. M., 1970, Flood Frequency in Alaska: U. S. Geological Survey Open-File Report.

7. Fiering, M. B., 1962, Use of Correlation to Improve Estimates of the Mean and Variance, U.S. Geological Survey Professional Paper 434-C.

8. Childers, J. M., Meckel, J. P., and Anderson, G. S., 1972, Floods of August 1967 in East-Central Alaska, U.S. Geological Survey Water Supply Paper 1880-A.

9. UCLA, 1979, Biomedical Computer Program BMDP-79, P-Series, W.J. Dixon and M.B. Brown, editors, University of California Press.