UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

ESTIMATION OF SELECTED FLOW AND WATER-QUALITY CHARACTERISTICS OF ALASKAN STREAMS

by Bruce Parks and Robert J. Madison

U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS REPORT 84-4247

Anchorage, Alaska
1985

UNITED STATES DEPARTMENT OF THE INTERIOR

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Multiply	By	To obtain
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
ton per day (ton/d)	0.9072	Megagram per day (Mg/d)
ton per day per square mile [(ton/d)/mi^2]	0.3503	Megagram per day per square kilometer [(Mg/d)/km^2]
degree Fahrenheit (°F)	5/9(°F-32)	degree Celsius (°C)

Other abbreviations in this report are:

mg/L, milligram per liter
µg/g, microgram per gram
g/L, gram per liter

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ABSTRACT

Information on flow and water quality of Alaskan streams is needed for water resources planning. For many streams in the State, hydrologic measurements are lacking or inadequate and reliable estimates would therefore be useful. Such estimates, based on multiple linear regression techniques, are made and assessed herein, both for the entire State and for hydrologic regions of the State. In developing regression relations between flow and water quality on the one hand, and drainage basin, channel width, and available measured characteristics on the other, use was made of the U.S. Geological Survey's file of streamflow and basin characteristics. Also use was made of some other significant characteristics easily measured in the field or on aerial photographs.

The most reliable estimates of streamflow are provided by regression equations in which only drainage area and precipitation are independent variables. Equations in which only channel width is the independent variable have similar reliability for estimation of peak flow, but are less reliable for other flow characteristics.

The six hydrologic regions of the State differ significantly in their relation of streamflow to basin properties. Reliable estimates of flow frequencies can be made from the proposed regional equations for ungaged sites in the southeast, south-central and Yukon regions. For the northwest, Arctic Slope, and southwest regions, reliability is less, because the amount of measured flow data is less. In regions where data are inadequate, the statewide estimating equation can be used; but the error of the estimates may be greater than indicated by the error coefficients of the equations.

Mean suspended-sediment concentrations of glacial streams can be estimated from regression equations incorporating the available information on basin properties. Standard errors of estimate range from -50 to +100 percent. For nonglacial streams, which tend to have lower suspended-sediment loads and a greater variability in the relation of suspended-sediment load to discharge, the standard error of estimate ranges from -64 to +180 percent.

Hardness, total concentration of dissolved solids, and concentrations of calcium and bicarbonate in the streams of four regions can be estimated from regression equations in which only specific conductance is the independent variable. More than 80 percent of the variation in these qualities is accounted for by the equations, except in the northwest and Arctic Slope regions, where very few samples were available for analysis. For glacial streams in interior Alaska, regression equations have the potential for providing reliable estimates of dissolved solids. For maritime and nonglacial streams, the relation between basin properties and dissolved solids is less consistent.

Reliablity of the estimating equations proposed herein could be improved if more measurements of streamflow, water quality, and basin characteristics were available. Data most critical for this improvement are discussed, and data-collection strategies are suggested.

INTRODUCTION

Rapid economic development in Alaska, mainly by the petroleum and mining industries, and population growth have a direct or indirect effect on streams and water resources. In order to protect these resources and to make plans for their most effective use, information on streamflow and water quality is needed. In many areas of Alaska, hydrologic data adequate to define seasonal or annual variations in streamflow and water-quality characteristics are available for only a few streams. Hydrologic data have been collected over a period of many years for other streams, but only infrequently, for short periods, and with an unequal distribution throughout the State. Although the data collected for a particular stream may not be adequate for planning purposes, data collected on other streams in the same region may be applied by statistical techniques to make estimates sufficiently reliable to be useful.

The objectives of this report are (1) to present and assess empirical equations, derived by statistical techniques, for estimating the hydrologic characteristerics of streams for which no data are available, and (2) to assess deficiencies in existing data on streams and their drainage basins, and to suggest strategies for data collection that would improve the reliability of the estimating equations.

Of the techniques for regionalizing hydrologic information and estimating the flow and quality characteristics of streams, regression analysis is the best suited to the available data and size of area in Alaska. The more complex techniques for estimating sediment yields (U.S. Department of Agriculture, 1975) or flood flows (U.S. Department of Agriculture, 1977; OTT Water Engineers, 1979) require detailed information on such factors as soil erodibility, soil texture, land cover, rainfall-runoff relations, and the hydraulic geometry of streams. The required information is available only for specific sites or small areas in Alaska, and much time and expense would be required to collect it for the whole State. On the other hand, the regression technique makes optimum use of the available data on streams and drainage basins and is readily applicable to large regions.

By means of regression techniques, estimating equations have been derived for peak-flow frequencies, low-flow frequencies, mean annual flow, flood-flow volumes, major inorganic chemical constituents, dissolved-solids concentrations, and suspended-sediment loads or yields. Equations applicable to the whole State and equations for separate hydrologic regions are presented. In developing the regression relations, use was made of basin characteristics in the U.S. Geological Survey Streamflow/Basin Characteristics File. Use was also made of index characteristics measured in the field; for example, flow characteristics were related to channel width, and water quality to specific conductance and alkalinity.

MEASURED AND COMPUTED STREAMFLOW

In most of Alaska, streamflow data have been collected for a much shorter period than in the conterminous United States. Data collection began in the early 1900's in southeast Alaska, but the beginning date becomes successively later in a northward direction and the length of the period of record becomes shorter. Before the 1960's, the Federal hydrologic network in Alaska was mainly on major streams in the upper Tanana River basin, the Cook Inlet area, the Copper River basin, and southeast Alaska; and periods of record tend to be short. Federal-State cooperative programs developed in the early 1960's were directed toward obtaining hydrologic information for urban areas and for highway design and construction. Thus, much of the data are from sites along road networks and in areas of high population density. For the more remote areas, data have been collected mostly in the last decade and on the larger streams. Flow data on small streams are scarce throughout Alaska, except in the southeast part, in the Anchorage area, and on the Kenai Peninsula. Peak flows from small basins are somewhat better defined as a result of a program begun in 1962 to define the frequency of peaks for basins with less than about 50 mi^2 of drainage area, but the data are still generally restricted to sites along the road system.

Streamflow characteristics of most interest to designers and planners are the frequency and magnitude of peak flows and low flows, and the magnitude of seasonal and mean annual flows. For this report, peak flows are designated P_n, where n is the average recurrence interval in years; low flows are designated $M_{i,j}$, where M represents sustained low flows for i days with average recurrence intervals of j years; and flood-volume flows, designated $V_{30,2}$, represent the sustained high flow for a 30-day period with a 2-year recurrence interval (this value represents the summer high flows as opposed to the annual flow which includes long periods of low flow). Because of differences in length and completeness of stream-gaging records, not all of these flow characteristics can be defined at some sites. Peak-flow frequency curves were computed for 200 streams, low-flow frequency curves for 124 streams, the maximum 30-day high flow for 133 streams, and the mean annual flow for 172 streams.

In Alaska, 246 streamflow sites have periods of record adequate to compute one or more of the desired flow values. A list of these sites, the streamflow characteristics used in this analysis, and the number of years of data available are shown in table 1. The locations and distribution of the sites used in the regression analyses in this study and the Water Resources Council (WRC) Subregions (here designated as regions) are shown in figure 1 (U.S. Water Resources Council, 1970).

At sites having sufficient length of record, the desired flow values were computed by analysis of the annual data series, using the log-Pearson Type III distribution. In this analysis, the magnitude and frequency values at individual stations were computed by use of the mean, standard deviation, and skewness coefficient of the logs of annual flow characteristics. Peak flow magnitudes for the frequencies used were computed by methods described in U.S. Water Resources Council Bulletin 17B (1981b) with regional skew coefficients being those determined by Lamke (1979). The station and regional skews were weighted inversely proportional to their "mean square" errors. For low flows and flood-flow volumes, station skew was used for all cases.

Table 1. -- Stations used to develop surface-water regression equations

[G, glacial stream; N, nonglacial stream]

Station No.	Station name	Stream type	Area (mi²)	Years of record: Peak flows	Years of record: Daily flows	Data available: Peak flows	Data available: Mean annual flow	Data available: Low flow	Data available: Flood volume	Data available: Channel width
	SOUTHEAST									
15008000	Salmon R nr Hyder	G	94	--	10	-	-	-	-	-
15010000	Davis R nr Hyder	G	80	10	10	X	X	X	X	-
15011500	Red R nr Metlakatla	N	45.3	14	15	X	X	X	X	-
15012000	Winstanley C nr Ketchikan	N	15.5	29	29	X	X	X	X	X
15014000	Punchbowl LK Outl nr Ketchikan	N	12	3	6	-	-	-	-	-
15015600	Klahini R nr Bell Island	G	58	6	6	-	-	-	-	-
15018000	Shelokum LK Outl nr Bell Island	N	18	6	9	-	-	-	-	-
15020100	Tyee C at mouth nr Wrangell	G	16.1	8	8	-	-	-	-	-
15022000	Harding R nr Wrangell	G	67.4	28	29	X	X	X	X	X
15026000	Cascade C nr Petersburg	G	23	35	38	X	X	X	X	X
15030000	Sweetheart Falls C nr Juneau	G	27	5	10	-	-	-	-	-
15031000	Long R abv Long L nr Juneau	G	8.29	9	10	X	X	X	X	X
15034000	Long R nr Juneau	G	32.5	25	32	X	X	X	X	X
15036000	Speel R nr Juneau	G	226	16	16	X	X	X	X	X
15038000	Crater C nr Juneau	G	11.4	9	12	-	-	-	-	-
15040000	Dorothy C nr Juneau	G	15.2	35	36	X	X	X	X	X
15044000	Carlson C nr Juneau	G	24.3	10	10	X	X	X	X	-
15048000	Sheep C nr Juneau	G	4.57	30	29	X	X	X	X	-
15050000	Gold C at Juneau	G	9.76	37	37	X	X	X	X	X
15052000	Lemon C nr Juneau	G	12.1	22	20	X	X	X	X	X
15052500	Mendenhall R nr Auke Bay	G	85.1	11	15	X	X	X	X	X
15052800	Montana C nr Auke Bay	G	15.5	10	10	X	X	X	X	X
15053800	Lake C at Auke Bay	N	2.5	10	10	X	X	X	X	X
15054000	Auke C at Auke Bay	N	3.96	15	13	X	X	X	X	-
15054200	Herbert R nr Auke Bay	G	56.9	--	5	-	X	-	-	-
15054500	Bessie C nr Auke Bay	N	1.35	14	--	X	-	-	-	X
15056100	Skagway R at Skagway	G	145	17	17	X	X	X	X	-
15056200	West C nr Skagway	G	43.2	16	15	X	X	X	X	X
15056210	Taiya R nr Skagway	G	179	7	8	-	X	-	-	-
15056400	Chilkat R at gorge nr Klukwan	G	190	6	6	-	X	-	-	-
15057500	William Henry C nr Auke Bay	N	1.58	10	--	X	-	-	-	-
15058000	Purple LK Outl nr Metlakatla	N	6.8	8	9	-	X	-	-	-
15059500	Whipple C nr Ward Cove	N	5.29	11	12	X	X	X	X	X
15060000	Perseverance C nr Wacker	N	2.81	25	30	X	X	X	X	X
15064000	Ketchikan C at Ketchikan	N	13.5	9	8	-	X	-	-	-
15066000	Beaver Falls C nr Ketchikan	N	5.8	5	10	-	X	-	-	-
15068000	Mahoney C nr Ketchikan	N	5.7	18	26	X	X	X	X	-
15070000	Falls C nr Ketchikan	N	36.5	25	28	X	X	X	X	-
15072000	Fish C nr Ketchikan	N	32.1	59	62	X	X	X	X	X
15074000	Ella C nr Ketchikan	N	19.7	22	22	X	X	X	X	-
15076000	Manzanita C nr Ketchikan	N	33.9	30	30	X	X	X	X	X
15078000	Grace C nr Ketchikan	N	30.2	15	16	X	X	X	X	X
15080000	Orchard C nr Bell Island	N	59	7	12	-	X	X	X	-
15081490	Yatuk C nr Klawock	N	5.8	10	--	X	-	-	-	-
15081500	Staney C nr Craig	N	51.6	14	16	X	X	X	X	-
15081800	No Br Trocadero C nr Hydaburg	N	17.4	7	6	-	X	-	-	-
15081890	Natzuhini C nr Hydaburg	N	9.1	9	--	X	-	-	-	-
15082000	Reynolds C nr Hydaburg	N	5.7	5	5	-	X	-	-	-
15085100	Old Tom C nr Kasaan	N	5.9	30	31	X	X	X	X	-
15085600	Indian C nr Hollis	N	8.82	13	15	X	X	X	X	-
15085700	Harris C nr Hollis	N	28.7	15	15	X	X	X	X	-
15085800	Maybeso C at Hollis	N	15.1	11	14	X	X	X	X	-
15086000	Karta R nr Kasaan	N	49.5	5	7	-	X	-	-	-
15086500	Neck C nr Point Baker	N	17	6	7	-	X	-	-	-
15086600	Big C nr Point Baker	N	11.2	17	17	X	X	X	X	X
15086900	Red C nr Point Baker	N	11.2	10	--	X	-	-	-	-
15087250	Twin C nr Petersburg	N	3	13	--	X	-	-	-	X
15088000	Sawmill C nr Sitka	G	39	20	28	X	X	-	-	-
15090000	Green LK Outl nr Sitka	G	28.8	--	10	-	X	X	X	-
15092000	Maksoutof R nr Port Alexander	N	26	5	5	-	X	-	-	-
15093400	Sashin C nr Big Port Walter	N	3.7	14	14	X	X	X	X	X
15094000	Deer LK Outl nr Port Alexander	N	7.4	17	16	X	X	X	X	X
15098000	Baranof R at Baranof	G	32	25	29	X	X	X	X	X
15100000	Takatz C nr Baranof	G	17.5	18	18	X	X	X	X	X
15102000	Hasselborg C nr Angoon	G	56.2	17	17	X	X	X	X	X
15106920	Kadashan R abv Hook C nr Tenakee	N	10.2	10	10	X	X	X	X	X
15106940	Hook C abv Trib nr Tenakee	N	4.5	13	13	X	X	X	X	X
15106960	Hook C nr Tenakee	N	8	13	13	X	X	X	X	X
15106980	Tonalite C nr Tenakee	N	14.5	11	12	X	X	X	X	X
15107000	Kadashan R nr Tenakee	N	37.7	16	15	X	X	X	X	X
15108000	Pavlof R nr Tenakee	N	24.3	23	23	X	X	X	X	-
15108250	Game C nr Hoonah	N	42.8	10	--	X	-	-	-	X
15109000	Fish C nr Auke Bay	N	13.6	20	20	X	X	X	X	-

Table 1. -- Continued

[G, glacial stream; N, nonglacial stream]

Station No.	Station name	Stream type	Area (mi²)	Years of record: Peak flows	Years of record: Daily flows	Data available: Peak flows	Data available: Mean annual flow	Data available: Low flow	Data available: Flood volume	Data available: Channel width
	SOUTH-CENTRAL									
15195000	Dick C nr Cordova	N	7.9	10	10	X	X	X	X	-
15198500	Station C nr Mentasta	N	15.3	10	--	X	-	-	-	X
15199000	Copper R Trib nr Slana	N	4.3	18	--	X	-	-	-	-
15200000	Gakona R at Gakona	G	620	25	21	X	X	X	X	X
15200280	Gulkana R at Sourdough	N	1,770	6	6	X	X	-	-	X
15201000	Dry C nr Glennallen	N	11.4	17	--	X	-	-	-	X
15201100	Little Nelchina R Trib nr Eureka	N	7.8	15	--	X	-	-	-	X
15201900	Moose C Trib at Glennallen	N	7.1	12	--	X	-	-	-	X
15202000	Tazlina R nr Glennallen	G	2,670	--	22	-	X	X	X	-
15206000	Klutina R at Copper Center	G	880	16	17	X	X	X	X	X
15207800	Little Tonsina R nr Tonsina	N	22.7	6	6	X	X	-	-	X
15208000	Tonsina R at Tonsina	G	420	30	29	X	X	X	X	X
15208100	Squirrel C at Tonsina	N	70.5	17	10	X	X	X	X	X
15208200	Rock C nr Tonsina	N	14.3	15	--	X	-	-	-	X
15209000	Chititu C nr May C	G	30.9	7	--	X	-	-	-	X
15209100	May C nr May C	N	10.4	8	--	X	-	-	-	X
15211700	Strelna C nr Chitina	N	23.8	10	--	X	-	-	-	X
15211900	O'Brien C nr Chitina	N	44.8	10	--	X	-	-	-	X
15212000	Copper R nr Chitina	G	20,600	26	25	X	X	X	X	X
15212500	Boulder C nr Tiekel	N	9.8	17	--	X	-	-	-	X
15216000	Power C nr Cordova	G	20.5	33	33	X	X	X	X	-
15219000	West Fk Olsen Bay C nr Cordova	N	4.8	16	16	X	X	X	X	-
15219100	Control C nr Cordova	N	4.2	11	--	X	-	-	-	-
15226000	Solomon Gulch nr Valdez	G	19	7	7	-	X	-	-	-
15236200	Shakespeare C at Whittier	G	3	11	--	X	-	-	-	-
15236900	Wolverine C nr Lawing	G	9.5	12	12	X	X	X	X	-
15237400	Chalmers R nr Cordova	G	6.3	13	--	X	-	-	-	-
15238000	Lost C nr Seward	N	8	11	--	X	-	-	-	-
15238600	Spruce C nr Seward	G	9.3	14	12	X	X	X	X	-
15238820	Barbara C nr Seldovia	N	20.7	--	8	-	X	-	-	-
15239000	Bradley R nr Homer	G	54	21	19	X	X	-	-	-
15239500	Fritz C nr Homer	N	10.4	19	--	X	-	-	-	-
15239800	Diamond C nr Homer	N	5.3	19	--	X	-	-	-	-
15239900	Anchor R nr Anchor Point	N	137	13	10	X	X	X	X	-
15240000	Anchor R at Anchor Point	N	224	12	13	X	X	X	X	-
15240500	Cook Inlet Trib nr Ninilchik	N	5.2	15	--	X	-	-	-	-
15241600	Ninilchik R at Ninilchik	N	131	15	17	X	X	X	X	-
15242000	Kasilof R nr Kasilof	G	738	25	21	X	X	-	X	-
15243950	Porcupine C nr Primrose	G	16.8	18	--	X	-	-	-	-
15244000	Ptarmigan C at Lawing	G	32.6	7	11	-	X	X	X	-
15246000	Grant C nr Moose Pass	G	44.2	7	11	-	X	X	X	-
15248000	Trail R nr Lawing	G	181	25	27	X	X	X	X	-
15254000	Crescent C nr Cooper Landing	N	31.7	29	17	X	X	X	X	-
15258000	Kenai R at Cooper Landing	G	634	34	33	X	X	X	X	-
15260000	Cooper C nr Cooper Landing	G	31.8	11	9	X	X	X	X	-
15260500	Stetson C nr Cooper Landing	N	8.6	6	5	-	X	-	-	-
15264000	Russian R nr Cooper Landing	G	61.8	8	7	-	X	-	-	-
15266300	Kenai R at Soldotna	G	2,010	16	15	X	X	X	X	-
15266500	Beaver C nr Kenai	N	51	12	11	X	X	X	X	-
15267900	Resurrection C nr Hope	N	149	13	13	X	X	X	X	-
15269500	Granite C nr Portage	G	28.2	14	--	X	-	-	-	-
15270400	Donaldson C nr Wibel	N	4.1	10	--	X	-	-	-	-
15271900	Cub C nr Sunrise	N	1.8	15	--	X	-	-	-	-
15272530	California C at Girdwood	G	7	14	--	X	-	-	-	-
15272550	Glacier C at Girdwood	G	62	14	13	X	X	X	X	-
15273900	So Fk Campbell C at Canyon Mouth	N	25.2	13	13	X	X	X	X	-
15274000	So Fk Campbell C nr Anchorage	N	30.4	24	24	X	X	X	X	-
15274300	No Fk Campbell C nr Anchorage	N	13.4	14	6	X	X	-	-	-
15274600	Campbell C nr Spenard	N	69.7	12	14	X	X	X	X	-
15274800	So Br of So Fk Chester C nr Anchorage	N	10.8	11	--	X	-	-	-	-
15275000	Chester C at Anchorage	N	20	13	18	X	X	X	X	-
15275100	Chester C at Arctic Blvd.	N	27.2	11	14	X	X	X	X	-
15276000	Ship C nr Anchorage	N	90.5	33	34	X	X	X	X	-
15277100	Eagle R at Eagle R	G	192	15	15	X	X	X	X	-
15277200	Meadow C at Eagle R	N	7.4	10	--	X	-	-	-	-
15277410	Peters C nr Birchwood	G	87.8	--	7	-	X	-	-	-
15281000	Knik R nr Palmer	G	1,180	15	21	X	X	X	X	-
15282000	Caribou C nr Sutton	N	289	22	23	X	X	X	X	-
15282400	Puritan C nr Sutton	N	8.5	17	--	X	-	-	-	-
15291000	Susitna R nr Denali	G	950	20	21	X	X	X	X	-

Table 1. -- Continued

[G, glacial stream; N, nonglacial stream]

Station No.	Station name	Stream type	Area (mi²)	Years of record: Peak flows	Years of record: Daily flows	Data available: Peak flows	Data available: Mean annual flow	Data available: Low flow	Data available: Flood volume	Data available: Channel width
	SOUTH-CENTRAL--Continued									
15291200	Maclaren R nr Paxson	G	280	22	22	X	X	X	X	-
16291500	Susitna R nr Cantwell	G	4,140	9	11	X	X	X	X	-
15292000	Susitna R at Gold C	G	6,160	28	31	X	X	X	X	-
15292400	Chulitna R nr Talkeetna	G	2,570	20	14	X	X	X	X	-
15292700	Talkeetna R nr Talkeetna	G	2,006	17	16	X	X	X	X	-
15293000	Caswell C nr Caswell	N	19.6	18	--	X	-	-	-	-
15294300	Skwentna R nr Skwentna	G	2,250	19	21	X	X	X	X	-
15294350	Susitna R at Susitna Station	G	19,400	--	6	-	X	-	-	-
15294500	Chakachatna R nr Tyonek	G	1,120	9	13	-	X	X	X	-
16295600	Terror R nr Kodiak	G	15	--	8	-	X	X	X	-
15296000	Uganik R nr Kodiak	N	123	27	27	X	X	X	X	-
15296550	Upper Thumb R nr Larsen Bay	N	18.8	--	6	-	X	-	-	-
15297200	Myrtle C nr Kodiak	N	4.7	18	17	X	X	X	X	-
15297475	Red Cloud C Trib nr Kodiak	N	1.5	18	--	X	-	-	-	-
	SOUTHWEST									
15297900	Eskimo C at King Salmon	N	16.1	13	6	X	X	-	-	-
15298000	Tanalian R nr Port Alsworth	G	200	6	5	-	X	-	-	-
15300000	Newhalen R nr Iliamna	G	3,478	26	16	X	X	X	X	-
15300500	Kvichak R at Igiugig	G	6,500	11	13	X	X	X	X	-
15302000	Nuyakuk R nr Dillingham	N	1,490	24	27	X	X	X	X	-
15302800	Grant LK Outl nr Aleknagik	N	34.3	--	5	-	X	-	-	-
15302900	Moody C at Aleknagik	N	1.3	11	--	X	-	-	-	-
15303000	Wood R nr Aleknagik	N	1,110	13	13	X	X	X	X	-
15303010	Silver Salmon C nr Aleknagik	N	4.5	15	--	X	-	-	-	-
15303150	Snake R nr Dillingham	N	113	--	7	-	X	-	-	-
15303600	Kuskokwim R at McGrath	N	11,700	9	10	X	X	X	X	-
15304000	Kuskokwim R at Crooked C	G	31,100	22	29	X	X	X	X	-
	YUKON									
15305900	Dennison Fk nr Tetlin Jct	N	3	16	--	X	-	-	-	-
15305920	West Fk Trib nr Tetlin Jct	N	1	14	--	X	-	-	-	-
15305950	Taylor C nr Chicken	N	38	14	--	X	-	-	-	-
15356000	Yukon R at Eagle	G	113,500	32	32	X	X	X	X	-
15365000	Discovery Fk American C nr Eagle	N	6	10	--	X	-	-	-	-
15367500	Bluff C nr Eagle	N	3	10	--	X	-	-	-	-
15389000	Porcupine R nr Fort Yukon	N	29,500	15	15	X	X	X	X	-
15389500	Chandalar R nr Venetie	N	9,330	11	10	X	X	-	X	-
15438500	Bedrock C nr Central	N	10	11	--	X	-	-	-	-
15439800	Boulder C nr Central	N	31	15	14	X	X	-	X	-
15442500	Quartz C nr Central	N	17	9	--	X	-	-	-	-
15457800	Hess C nr Livengood	N	662	8	8	-	X	X	X	-
15468000	Yukon R at Rampart	G	199,400	10	12	X	X	X	X	-
15469900	Silver C nr Northway Jct	N	12	10	--	X	-	-	-	-
15470000	Chisana R at Northway Jct	G	3,280	22	22	X	X	X	X	-
15471000	Bitters C nr Northway Jct	N	15	16	--	X	-	-	-	-
15471500	Tanana R Trib nr Tetlin Jct	N	2	16	--	X	-	-	-	-
15473600	Log Cabin C nr Log Cabin Inn	N	11	15	--	X	-	-	-	-
15473950	Clearwater C nr Tok	N	36	17	--	X	-	-	-	-
15476000	Tanana R nr Tanacross	G	8,550	28	27	X	X	X	X	-
15476200	Tanana R Trib nr Dot Lake	N	11	17	--	X	-	-	-	-
15476300	Berry C nr Dot Lake	G	65	17	9	X	X	X	X	-
15476400	Dry C nr Dot Lake	N	58	17	--	X	-	-	-	-
15478000	Tanana R at Big Delta	G	13,500	8	8	-	X	-	-	-
15478010	Rock C nr Paxson	N	50	18	--	X	-	-	-	-
15478040	Phelan C nr Paxson	G	12	12	12	X	X	X	X	-
15478050	McCallum C nr Paxson	G	16	14	--	X	-	-	-	-
15478500	Ruby C nr Donnelly	N	5	17	--	X	-	-	-	-
15480000	Banner C at Richardson	N	20	14	--	X	-	-	-	-
15484000	Salcha R nr Salchaket	N	2,170	30	32	X	X	X	X	-
15490000	Monument C at Chena Hot Springs	N	27	9	--	X	-	-	-	-
15493000	Chena R nr Two Rivers	N	941	13	13	X	X	X	X	-
15493500	Chena R nr North Pole	N	1,430	--	8	-	X	-	-	-
15511000	Little Chena R nr Fairbanks	N	372	14	14	X	X	X	X	-
15514000	Chena R at Fairbanks	N	1,980	33	32	X	X	X	X	-
15514500	Wood R nr Fairbanks	G	855	8	10	-	X	X	X	-
15515500	Tanana R at Nenana	G	25,600	19	18	X	X	X	X	-
15515800	Seattle C nr Cantwell	N	36	16	10	X	X	X	X	-
15515900	Lily C nr Cantwell	N	6	14	--	X	-	-	-	-
15516000	Nenana R nr Windy	G	710	26	21	X	X	X	X	-

Table 1. -- Continued

[G, glacial stream; N, nonglacial stream]

Station No.	Station name	Stream type	Area (mi^2)	Years of record		Data available				
				Peak flows	Daily flows	Peak flows	Mean annual flow	Low flow	Flood volume	Channel width
	YUKON--Continued									
15516200	Slime C nr Cantwell	N	7	15	--	X	-	-	-	-
15518000	Nenana R nr Healy	G	1,910	28	29	X	X	X	X	-
15518200	Rock C nr Ferry	N	8	12	--	X	-	-	-	-
15518250	Birch C nr Rex	N	4	15	--	X	-	-	-	-
15518350	Teklanika R nr Lignite	G	490	10	10	X	X	X	X	-
15519000	Bridge C nr Livengood	N	13	10	--	X	-	-	-	-
15519200	Brooks C Trib nr Livengood	N	8	17	--	X	-	-	-	-
15520000	Idaho C nr Miller House	N	5	17	--	X	-	-	-	-
15530000	Faith C nr Chena Hot Springs	N	61	10	--	X	-	-	-	-
15534900	Poker C nr Chatanika	N	23	5	7	-	X	-	-	-
15535000	Caribou C nr Chatanika	N	9	--	11	-	X	X	X	-
15541600	Globe C nr Livengood	N	23	17	--	X	-	-	-	-
15541650	Globe C Trib nr Livengood	N	9	10	--	X	-	-	-	-
15541800	Washington C nr Fox	N	47	10	--	X	-	-	-	-
15564600	Melozitna R nr Ruby	N	2,693	10	12	X	X	X	X	-
15564800	Yukon R at Ruby	G	259,000	22	22	X	X	X	X	-
15564875	Mid Fk Koyukuk R nr Wiseman	N	1,200	10	8	X	X	-	X	-
15564877	Wiseman C at Wiseman	N	49	8	8	X	X	-	X	-
15564885	Jim R nr Bettles	N	465	7	7	-	X	X	X	-
15564900	Koyukuk R at Hughes	N	18,700	18	20	X	X	X	X	-
15565200	Yukon R nr Kaltag	G	296,000	8	10	-	X	X	X	-
15565447	Yukon R at Pilot Station	G	321,000	--	5	-	X	-	-	-
	NORTHWEST									
15585000	Goldengate C nr Nome	N	2	--	--	X	-	-	-	X
15621000	Snake R nr Nome	N	86	13	15	X	X	X	X	X
15625000	Arctic C nr Nome	N	2	10	--	X	-	-	-	X
15633000	Washington C nr Nome	N	6	13	--	X	-	-	-	X
15668100	Star C nr Nome	N	4	16	--	X	-	-	-	X
15668200	Crater C nr Nome	N	22	16	5	X	X	-	-	X
15712000	Kuzitrin R nr Nome	N	1,720	5	11	X	X	X	X	X
15744000	Kobuk R at Ambler	N	6,570	9	13	X	X	X	X	X
15746000	Noatak R at Noatak	N	12,000	5	--	X	-	-	-	X
15748000	Ogotoruk R nr Point Hope	N	35	5	--	X	-	-	-	X
	ARCTIC SLOPE									
15798700	Nunavak C nr Barrow	N	3	--	9	-	X	-	X	-
15896000	Kuparuk R nr Deadhorse	N	3,130	10	9	X	X	-	X	-
15896700	Putuligayuk R nr Deadhorse	N	176	7	9	-	X	-	X	-
15910000	Sagavanirktok R nr Sagwon	N	2,208	10	8	X	X	-	X	-
15910200	Happy C at Happy Valley Camp nr Sagwon	N	35	9	--	X	-	-	-	-

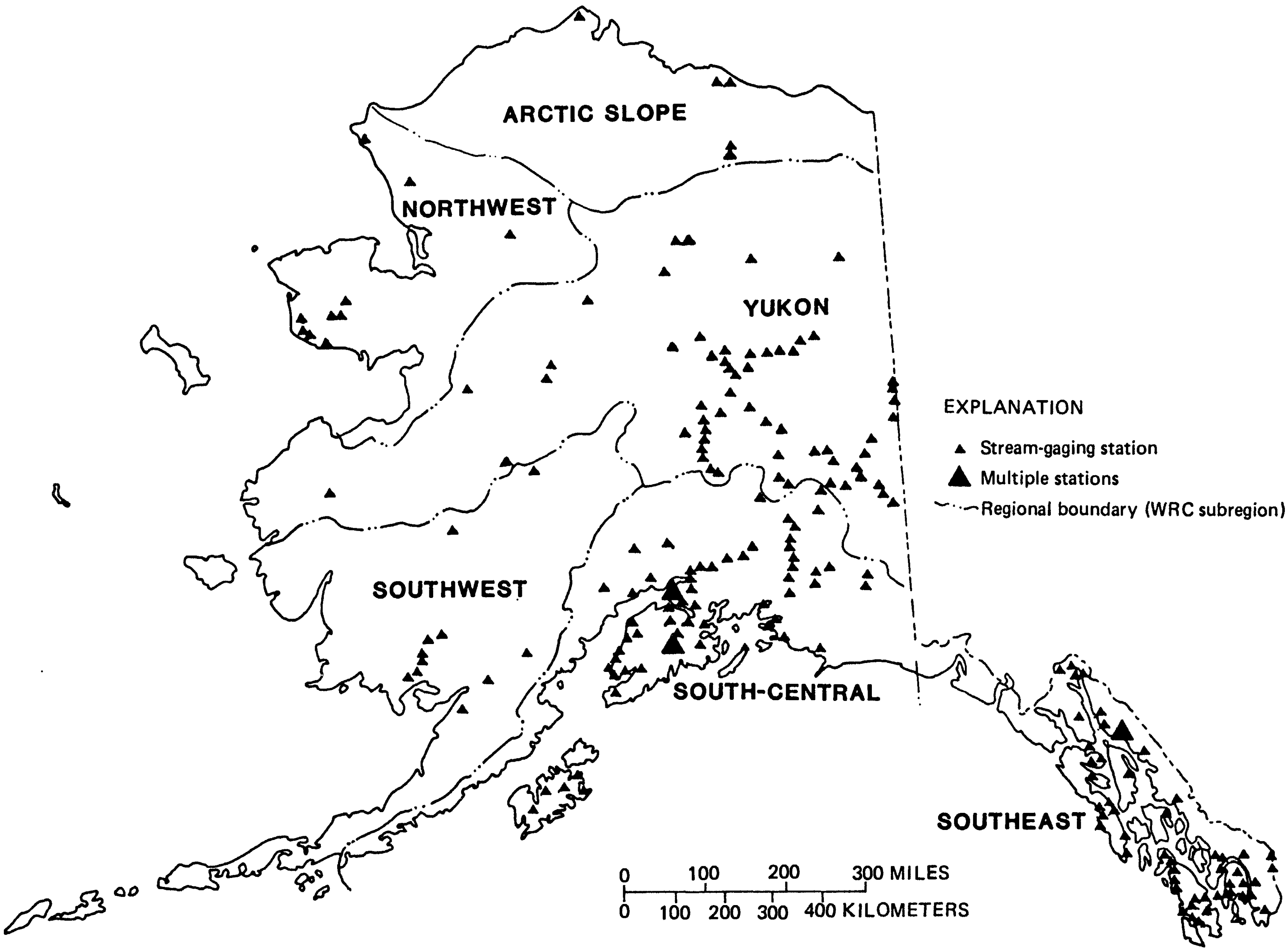

Figure 1.--Locations of stream-gaging stations and regional boundaries used for regression analyses in this report.

To obtain information in areas where few streams are gaged, peak-flow frequencies were computed for some stations having less than 10 years of peak-flow record. (A length of record greater than 10 years is recommended by the Water Resources Council.) The short-term stations used, and the length of peak-flow record at each, are as follows:

	Station No. and Name	Years
15031000	Long River above Long Lake near Juneau	9
15081890	Natzuhini Creek near Hydaburg	9
15200280	Gulkana River at Sourdough	6
15207800	Little Tonsina River near Tonsina	6
15209000	Chititu Creek near May Creek	7
15209100	May Creek near May Creek	8
15291500	Susitna River near Cantwell	9
15303600	Kuskokwim River near McGrath	9
15442500	Quartz Creek near Central	9
15490000	Monument Creek at Chena Hot Springs	9
15564877	Wiseman Creek at Wiseman	8
15585000	Goldengate Creek near Nome	5
15712000	Kuzitrin River near Nome	5
15744000	Kobuk River at Ambler	9
15746000	Noatak River at Noatak	5
15748000	Ogotoruk Creek near Point Hope	5
15910200	Happy Creek at Happy Valley Camp near Sagwon	9

For the computation of peak flow frequency and magnitude, streams in which peak flows result from breakouts of glacier-dammed lakes were not used unless the annual peaks caused by other than a breakout flood could be determined for each year. Because the magnitude of breakout peaks depends largely on the amount of water stored in the lake and the rapidity with which it is released, the peaks from these streams are not hydrologically analogous to those of other streams. Water can be stored in glacier-dammed lakes over periods ranging from several days to many years, and the volume stored is as much a function of the thickness of the glacier as it is of the runoff into the lake (Post and Mayo, 1971). For example, unit runoff for the highest breakout peak from Lake George on the Knik River, measured at station 15281000, Knik River at Palmer, was 304 $(ft^3/s)/mi^2$, whereas runoff of a 100-year flood of nonoutburst origin would be 53.7 $(ft^3/s)/mi^2$.

Because conditions at a glacier-dammed lake may change abruptly, standard statistical procedures cannot be used to make reliable estimates of the frequency or magnitude of future floods from glacier dammed drainages (Post and Mayo, 1971). Stations whose peaks may be affected by lake outbursts (and therefore not used in this report) are 15008000, Salmon River near Hyder and 15202000, Tazlina River near Glennallen. Station 15281000, Knik River near Palmer, experienced outburst floods prior to 1965, but has sufficient determinations of annual peaks not affected by outbursts to be used in this report. Techniques to define the potential and extent of outburst floods on ungaged streams are not addressed here but can be estimated from studies of the glaciological and historical data of the basin (Post and Mayo, 1971).

In the computation of low flows, data were not used for streams in which the winter flows approached zero during some years as the result of aufeis formations (successive layers of ice formed on top of each other in stream channels) upstream from the gaging sites. Where aufeis forms, much of the water that would normally flow past a gage during the winter goes into surface ice storage. Streams may have discontinuous flow along the entire reach during the winter and may or may not be flowing at the gage. Long periods of no flow may occur at the gage while there may be flow somewhere upstream. The Chandalar and Koyukuk Rivers draining the south slope of the Brooks Range, the Sagavanirktok and Kuparuk Rivers along the Arctic Slope, as well as many small streams in these areas and in the interior of the State behave in this manner.

ESTIMATION OF STREAMFLOW BY REGRESSION EQUATIONS

Linear Regression Equations

The general form of the multiple linear-regression equations which were used in this study is:

$$y = a + b_1x_1 + b_2x_2 + \ldots + b_nx_n$$

where y is the hydrologic characteristic (dependent variable);
a is the regression constant;
b's are regression coefficients;
x's are basin characteristics (independent variables); and
n is the number of basin characteristics.

The relationships between many hydrologic variables, especially flow characteristics and basin characteristics, are nonlinear. However, these relationships have been found to be more nearly linear if the variables are transformed to logarithms (Benson and Carter, 1973). The general form of a log-transformed regression equation is:

$$\text{Log } y = \text{Log } a + (b_1\text{Log } x_1) + (b_2\text{Log } x_2) + \ldots (b_n\text{Log} x_n)$$

An equivalent expression of the equation is:

$$y = ax_1^{b_1}\, x_2^{b_2} \ldots x_n^{b_n}$$

For this study the regression equations were developed using SAS (Statistical Analysis Systems)[1] programs (Barr and others, 1979). These programs are used to

[1] The use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

perform "stepwise" regression analysis in which the "best" equation is determined by bringing the independent variables into the regression equation one by one. Variables are retained or eliminated based on the significance of the variable coefficient until the best one-variable equation is found. The process may be repeated to find the best two-variable equations, three-variable equations and so on.

Two terms commonly used to describe the accuracy or error in a regression equation are the standard error of estimate (SE) and the correlation- or multiple-correlation coefficient. The standard error of estimate gives an indication of the variance about the regression and how precisely the estimated values used to form the equation fit the resulting equation. For example, in a regression equation using log-transformed data a standard error of 0.20 log units would indicate that approximately two-thirds of the measured values would fall within ±0.20 log units when compared to computed values. If the SE in log units is converted to a percentage error in non-log units the positive and negative errors will not be the same. For example, an error of plus or minus 0.20 log units is equivalent to a positive percentage error of 58.5 and a negative percentage error of 36.9. As the standard error increases the positive percentage error will be much greater than the negative percentage error (G. D. Tasker, U.S. Geological Survey, written commun., 1978).

The coefficient of determination (r^2), the square of the correlation coefficient (r), is a general indication of how well the data fit the equation. The coefficient of determination times 100 is defined as the percent of dependent variable variation (DVV) explained by the equation. An r^2 of 1.0 would indicate 100 percent of the DVV is explained, representing a perfect regression equation having no error. An r^2 of 0 indicates that the variation about the regression line is equivalent to the variation about the mean of the characteristic being estimated, in which case the equation would be of no value, and the mean value could be used as the estimated value for all cases.

Equations for Estimating Streamflow

Equations for the estimation of streamflow were derived from each of the following categories of independent variable: (1) Basin characteristics, (2) channel width, (3) mean annual flow, and (4) 2-year peak flow. Equations derived from basin characteristics and channel width can be applied to ungaged streams; those derived from mean annual flow and 2-year peak flow use measured values to estimate other values for a specific site with prior record. The magnitude of flows having low exceedance probabilities (low recurrence interval) cannot be reliably estimated for stations having short periods of record. However, reliability of the estimating equations can be improved by the use of regional relations based on other stations of longer record. In order to determine which category of independent variable provides the best estimate of flow, and also to compare equations applying to the entire State with equations for each region, estimating equations were derived for each category for the whole State and for each region.

An additional investigation of best estimate was made for the entire State by deriving separate equations for glacial streams (those receiving glacial meltwater) and nonglacial streams. An improvement in estimate by this separation seemed likely, because the two categories of streams may differ significantly in the timing and frequency of flow events.

Estimates from Basin Characteristics

The frequency and magnitude of flow events are generally related to certain physical and climatic characteristics of the watershed (Thomas and Benson, 1970). Multiple-regression equations utilizing basin characteristics as the independent variables are widely used to estimate streamflow for areas or sites with little or no data. For all sites at which long-term streamflow records are collected, the Geological Survey routinely determines values for a suite of basin characteristics which have been found to be closely related to streamflow frequency or variability. The values included in the Geological Survey's Streamflow/Basin Characteristics File, the methods by which they are computed, and a general discussion of their significance to streamflow characteristics in Alaska are given in table 2.

Flow characteristics at gaging stations were related to various combinations of physical and climatic characteristics by stepwise regression. Based on the standard error and a significance test, the best equations with only two independent variables were those using area and precipitation. Adding other variables did not significantly increase the reliability. For some areas in Alaska, inclusion of other basin characteristics might increase the reliability of the equations, but those areas were too small to analyze separately for this report. Equations based on two variables, area and precipitation, were selected here because of the evident significance of these variables and because they are the most accurately measured of the available basin characteristics.

Estimates from Channel Width

Several investigators have related measurements of channel geometry to streamflow. The premise of this method is that definable physical characteristics of a channel are a response to the peak-flow regime. Both width and depth were investigated as variables in these studies, but owing to the errors inherent in defining depth (Wahl, 1977), width is the only variable used here. Because field measurements could not be made specifically for this report, widths are from discharge and slope-area measurement notes for sites at which flood-magnitude and flood-frequency relations could be determined. Such widths were obtained only for a select group of sites in the southeast and northwest regions, and in the Copper River basin of the south-central region.

The computed widths apply to the 2-year peak flow, which corresponds approximately with bankfull stage. Wolman and Leopold (1957) found that in most rivers the annual flood reaches a stage near the surface of the flood plain about once every year or two. Similarly, Emmett (1972, p. 28) found that for seven sites in the Copper River basin and three sites in the Yukon basin, "the average value of bankfull frequency is about 1.5 years."

Table 2. -- Definition of characteristics in the U. S. Geological Survey Streamflow/Basin Characteristics File

Characteristic	Definition
Area	The total drainage area, in square miles. Generally the larger the area contributing to flow, the greater the flow.
Slope	The main channel slope, in feet per mile, measured at distances of 10 and 85 percent of the total main-channel length upstream from the point of interest. The steeper the slope, the faster runoff reaches the stream. Therefore, peaks will increase in magnitude as slope increases and, to a certain degree, low flows will decrease with an increase in slope (the recessions will be steeper, and minimum flows will be reached sooner and last longer). Slope will usually have little effect on the mean annual discharge and flood volume flows which are accumulative and averaged over a longer period of time.
Length	The main channel length, in miles. The length of a basin is usually related to drainage area and has essentially the same effect on flows as does the drainage area size; the longer the basin the larger the discharge. Stream length affects peaks, because travel time for river water in a lengthy basin will be greater than in a shorter but similar-size river. Runoff from the shorter basin will arrive sooner and will have a higher peak or unit runoff.
Elevation	Mean basin elevation, in feet above sea level. Runoff in Alaska generally increases with increased elevation to about 4,000-7,000 ft, then decreases to a negligible amount at about 9,000 ft (L. R. Mayo, U.S. Geological Survey, oral commun., 1982). This is because precipitation and temperature are related to elevation.
Storage	The percentage of the drainage area occupied by lakes, ponds, and swamps, measured by the grid sampling method. The amount of storage controls the rate at which water is released to a stream. Flows change less rapidly with more storage, peaks are not as sharp, and low flows will be sustained at a higher rate than in similar-size basins with less storage. Mean annual flows will be much less affected by storage, and the magnitude of flood-volume flows for a given number of days will be somewhat reduced by an increase in storage.
Lake area	The percentage of the drainage area occupied by lakes and ponds. Generally, lake area has the same effect as storage. Because swamps are not being delineated on new Geological Survey maps, lake area is commonly used as a surrogate for storage.

Table 2. -- Continued

Characteristic	Definition
Forest	The percentage of drainage area occupied by forest as tinted green on Geological Survey topographic maps. Water stored in lakes, ponds, or swamps is eventually released to the stream, whereas in forested areas some water is retained in the vegetative material and does not reach the streams. Evapotranspiration is higher in forested areas than in nonforested areas.
Glacier	The percentage of the drainage area occupied by glaciers. Glaciers act as storage and thus low flows will be higher in basins having glaciers than in unglaciated basins having similar characteristics. To a lesser degree, peaks will be attenuated because some of the precipitation during floods will be stored in the snowpack of the glaciers. The mean annual flow should be similar for nonglacial basins having equal size and equal precipitation.
Precipitation	Mean annual precipitation, in inches, averaged over the basin and determined from an isohyetal map (National Weather Service, 1972). The greater the precipitation, the greater the runoff. Peak flows, however, are more dependent on individual climatic events. Areas that experience higher annual precipitation usually experience larger individual precipitation as well.
I24-2	Precipitation intensity is the maximum precipitation, in inches, expected over a 24-hour period throughout the basin, and occurring at a 2-year average recurrence interval (Miller, 1963). Most of the flow values should be higher in areas with higher intensities because in Alaska those areas also have more total precipitation. For large basins this variable becomes less important because the intensity of precipitation events is generally not uniform throughout the basin.
Snowfall	Mean annual snowfall, in inches, averaged over the basin and determined from an isohyetal map (National Weather Service, 1972). This is the summation of all individual snowfalls and not the water content of the snowpack. Because snowfall is part of the total or mean annual precipitation, this variable has the same effect as precipitation, assuming all of a year's snowfall melts and contributes to the runoff. The amount of snowfall should have a direct correlation to the magnitude of the spring (snowmelt) peaks. However, except for floods caused by release of glacier-dammed lakes, the larger annual maximum flood events on large rivers are generally associated with rainfall events (Lamke, 1979). Low flows generally are not influenced by annual snowfall.

Table 2. -- Continued

Characteristic	Definition
JANMIN	Mean minimum January temperature, in degrees Fahrenheit, determined from an isothermal map (Johnson and Hartman, 1969). The lower the winter temperatures, the lower the low flows and usually the later the annual snowmelt period. This variable has more effect on seasonal timing than on the magnitude of the other flow characteristics and is believed to be an indirect geographic indicator of the presence or absence of permafrost and of the possibility of winter peaks in some areas (Lamke, 1979).
P(Y)	Annual instantaneous flood peak magnitude (P) which will be exceeded at intervals averaging (Y) years or with a probability of 100/Y percent in any one year. The flood peak characteristics used in this report are:
	P_2 = 2-year peak discharge with 50 percent exceedence probability
	P_5 = 5-year peak discharge with 20 percent exceedence probability
	P_{10} = 10-year peak discharge with 10 percent exceedence probability
	P_{25} = 25-year peak discharge with 4 percent exceedence probability
	P_{50} = 50-year peak discharge with 2 percent exceedence probability
	P_{100} = 100-year peak discharge with 1 percent exceedence probability
	These characteristics are from a log-Pearson Type III frequency curve fitted to the annual peaks at a gaging station (U.S. Water Resources Council, 1981b).

Table 2. – Continued

Characteristic	Definition
QA	Mean annual discharge, in cubic feet per second, computed by averaging the mean flows from each year for those stations with 5 or more years of complete record.
M(D),(Y)	The low flow, in cubic feet per second, for an annual minimum D-day mean discharge with a Y-year recurrence interval and a 100/Y percent probability of being less than the indicated value in any one year. Recurrence intervals and probabilities used in this report are: $M_{7,10}$ = 7-day, 10-year low flow with 10 percent nonexceedence probability $M_{30,10}$ = 30-day, 10-year low flow with 10 percent nonexceedence probability $M_{90,10}$ = 90-day, 10-year low flow with 10 percent nonexceedence probability
$V_{(30,2)}$	Flood volume, in cubic feet per second, for highest mean discharge in a 30-day period with a 2-year recurrence interval and a 50-percent probability of being exceeded in any one year.
Width	The surface width, in feet, at the time of a 2-year flood peak. (See section on channel widths equations.)

To determine the width for each site, a sample of 5 to 12 cross sections representing discharges ranging downward from those near the 2-year peak to those near the mean-annual flow were selected from available measurement notes. A width corresponding to the 2-year peak was then computed using an equation developed by a least-squares linear regression of log-transformed values of the widths and discharges. An example of the computation of two representative streams is shown in figure 2 and the sites used are listed in table 1.

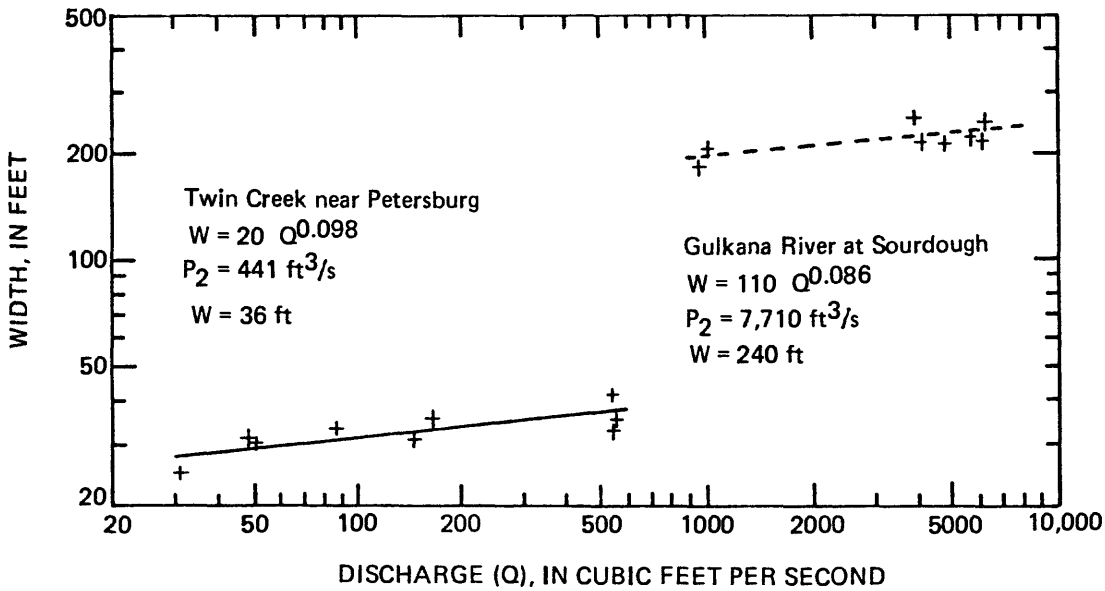

Figure 2.--Example of width determination method for two sites.

To apply the channel width equations to an ungaged site, a measurement of width is required. This measurement can be made in the field or, if available, from aerial photographs or large-scale topographic maps. Criteria for selecting a suitable reach of a stream are defined by Riggs (1978, p. 89): "(1) Channel shape should be uniform throughout; (2) the bed and banks should be of a material that has permitted the channel to develop into a normal size and shape for the flow regimen; and (3) channel banks should appear to have been permanent for some years." "The reference level for this section (bankfull stage) is variously defined by breaks in bank slope, by the edges of the flood plain, or by the lower limits of permanent vegetation."

The error associated with using these equations must include both the standard error of the regression relation and the error in the width measurement. The latter error is due to the uncertainty in selecting a representative cross section and the level at which the width is measured. Wahl (1977) suggested that 0.13 and 0.05 log units, respectively, be used for the variability and bias from this source. The standard errors shown for the channel-geometry equations in this report incorporated these additional errors by taking the square root of the sum of all the errors. (See also Overman and Clarke, 1960.)

Estimates from Mean Annual Flow

For those sites where 5 or more years of continuous discharge record are available, the mean annual flow for that site can be computed and other flow characteristics estimated from this computed value. The mean annual flow is the average of the mean discharges for each year from the period of record. For those sites where peak flows, low flows, or sustained high-flow volumes have also been computed, equations were derived relating those flow characteristics to the mean annual flow.

These estimating equations are based on long records (greater than 10 years) from a number of sites but can be applied to sites with shorter record (less than 10 years). Although the estimate requires at least 5 years of daily discharge record, it applies to sites where other flow characteristics cannot be reliably computed from the available data. At some remote sites, for example, the instantaneous annual peaks cannot be determined owing to a lack of gage-height data during flood events. At those sites, mean daily flows are available and the mean annual flow value is fairly reliable because its accuracy is not dependent on a single flow event.

The standard error in determining a streamflow characteristic from available records generally decreases as the length of record increases but at a decreasing rate (Hardison, 1969). Childers (1970a) showed that for Alaskan streams, the standard error in computing the mean annual flow from 5 years of record was 7 percent (0.03 log units) with an average variability index of 0.16 log units. These two values were used to adjust the standard error of the regression equations to show a realistic value of error for the equations when they are used to estimate flow at sites with only 5 years of record. The adjusted error was computed as follows:

$$\text{standard error} = \sqrt{(0.03)^2 + (0.16)^2 + (\text{SE of regression equation})^2}$$

Estimates from 2-Year Peak Flow

Lamke (1979) indicated that the 2-year peak flow could be determined for individual sites with as few as five annual peaks. Because the sample may not be representative, computing the peaks with lower exceedance probabilities from such short record is not recommended [WRC Bulletin 17b (1981b) recommends that 10 or more years of record be available for computing the low frequency peaks]. However, there is a relation between the 2-year peak and the larger peaks. Using those sites where long records are available, equations were developed using a log-transformed linear regression to relate the 2-year peak to the other peak-flow frequencies as well as to the low flow, mean annual, and high-flow volume characteristics.

To use these equations, at least five annual peaks must be obtained for a site and a log-Pearson Type III distribution applied to the data. The 2-year peak from this distribution will have an additional error associated with its computation that must be added to the errors associated with the equations. Hardison (1969) presented a technique to compute the accuracy with which a flow value could be estimated from an observed record of a given length. Using his method, the standard errors associated with the determination of the 2-year peak from 5 years of record are:

Region	Standard error (log units)
Southeast	0.07
South-central	.09
Southwest	.08
Yukon	.13
Northwest and Arctic Slope	.13
Statewide	.10

These errors are incorporated into the standard errors of the equations by the same method discussed in the channel-width section, that is, by taking the square root of the sum of the squares of the errors.

Evaluation of Equations for Estimating Streamflow

Results obtained from the different equations for estimating streamflow are best compared in tabular form. In table 3, beside each estimated streamflow value is given the number of data points used (n), the coefficient of determination (r^2), and the standard error of estimate (SE). Values for SE and r^2 were used to estimate the relative accuracy of the equations. In table 4, estimates of low flow, peak flow, mean annual flow, and flood-flow volume (as obtained from equations applying to the whole State) are compared.

In evaluating the equations for the estimation of low flow and peak flow, both the results obtained and the availability of data need to be considered. For low flow, equations using basin characteristics and those using mean annual flow give the best results and are similar in accuracy. Low-flow estimates based on the 2-year peak flow and on channel width are much less reliable and should be applied with caution. The value of estimates derived from those equations footnoted in table 3 as not statistically significant at the 95 percent confidence level is questionable. An average value may be just as statistically appropriate as a value derived from the regression equation. For estimation of peak flow, all the equations yield results of approximately equal accuracy, although the equation based on the 2-year peak flow is best. Equations based on flow measurements (2-year peak flow, mean annual flow) are not applicable where measurements are lacking or scarce. Estimates of flow characteristics made from equations based on channel width are not strictly comparable with estimates from the other equations, because the widths used are from only three of the six regions. This unequal distribution of data across the State introduces a bias that is probably significant but cannot be quantified.

Estimates of mean annual flow and flood-flow volumes from equations based on channel width are not considered reliable and should be used only where other variables are inadequate and the possibility of large errors in estimate are acceptable. The best estimates of mean annual flow are obtained by using equations based on basin characteristics; less reliable estimates are obtained from the 2-year peak flow.

Equally reliable estimates of flood-flow volumes can be made using equations based on either basin characteristics or the mean annual flow. Estimates made from equations based on the 2-year peak flow are somewhat less reliable.

Table 3. -- Parameter estimates for equations for streamflow characteristics

[Equation is $\log Q = \log a + b_1 \log x_1 + b_2 \log x_2$; n, number of observations used in regression; r^2, coefficient of determination ; and SE, standard error of estimate of regression, in log units]

Dependent variable (log Q)	Area (x_1) and precipitation (x_2) as independent variables				Channel widths (x_1) as independent variable				Mean annual flow (x_1) as independent variable				2-year peak (x_1) as independent variable			
	Parameters	n	r^2	SE	Parameters	n	r^2	SE	Parameters	n	r^2	SE	Parameters	n	r^2	SE
STATEWIDE																
$M_{7,10}$	log a = -2.81 b_1 = +1.08 b_2 = +1.09	124	.85	.44	log a = -2.45 b_1 = +1.75	37	.52	.62	log a = -1.54 b_1 = +1.11	124	.86	.46	log a = -2.71 b_1 = +1.16	112	.71	.61
$M_{30,10}$	log a = -2.76 b_1 = +1.04 b_2 = +1.15	124	.83	.46	log a = -2.06 b_1 = +1.61	37	.50	.60	log a = -1.35 b_1 = +1.06	124	.83	.48	log a = -2.44 b_1 = +1.10	112	.69	.61
$M_{90,10}$	log a = -3.03 b_1 = +1.02 b_2 = +1.40	124	.74	.57	log a = -1.24 b_1 = +1.28	37	.31	.70[1]	log a = -1.07 b_1 = +1.00	124	.74	.58	log a = -2.06 b_1 = +1.03	112	.67	.66
P_2	log a = -0.41 b_1 = +0.88 b_2 = +1.20	200	.93	.27	log a = -0.29 b_1 = +1.79	59	.90	.31	log a = +1.28 b_1 = +0.85	126	.92	.28	--	--	--	--
P_5	log a = +0.10 b_1 = +0.84 b_2 = +1.04	201	.92	.28	log a = +0.07 b_1 = +1.68	59	.90	.30	log a = +1.48 b_1 = +0.83	127	.91	.30	log a = +0.34 b_1 = +0.95	200	.99	.13
P_{10}	log a = +0.39 b_1 = +0.82 b_2 = +0.95	200	.91	.28	log a = +0.28 b_1 = +1.62	59	.90	.29	log a = +1.58 b_1 = +0.83	126	.90	.31	log a = +0.54 b_1 = +0.92	200	.98	.16
P_{25}	log a = +0.73 b_1 = +0.79 b_2 = +0.84	200	.89	.30	log a = +0.51 b_1 = +1.54	59	.88	.30	log a = +1.70 b_1 = +0.82	126	.88	.32	log a = +0.77 b_1 = +0.88	200	.96	.21
P_{50}	log a = +0.97 b_1 = +0.77 b_2 = +0.76	200	.88	.32	log a = +0.68 b_1 = +1.49	59	.87	.31	log a = +1.78 b_1 = +0.81	126	.87	.33	log a = +0.92 b_1 = +0.85	200	.94	.23
P_{100}	log a = +1.20 b_1 = +0.75 b_2 = +0.69	199	.86	.33	log a = +0.82 b_1 = +1.45	59	.85	.31	log a = +1.85 b_1 = +0.80	125	.86	.35	log a = +1.06 b_1 = +0.83	199	.92	.27
QA	log a = -1.51 b_1 = +0.98 b_2 = +1.19	172	.98	.15	log a = +1.03 b_1 = +1.70	40	.73	.40	--	--	--	--	log a = -1.18 b_1 = +1.08	126	.92	.28
$V_{30,2}$	log a = -0.59 b_1 = +0.98 b_2 = +0.93	133	.97	.17	log a = -0.91 b_1 = +1.88	37	.79	.38	log a = +0.46 b_1 = +1.01	132	.98	.22	log a = -0.97 b_1 = +1.15	119	.94	.27
SOUTHEAST REGION																
$M_{7,10}$	log a = -4.29 b_1 = +1.21 b_2 = +1.71	47	.79	.30	log a = -2.26 b_1 = +1.62	29	.35	.59	log a = -1.69 b_1 = +1.13	47	.74	.33	log a = -2.73 b_1 = +1.09	45	.49	.48
$M_{30,10}$	log a = -3.83 b_1 = +1.08 b_2 = +1.64	47	.72	.33	log a = -1.86 b_1 = +1.48	29	.34	.57	log a = -1.24 b_1 = +1.00	47	.64	.37	log a = -2.15 b_1 = +0.95	45	.42	.48
$M_{90,10}$	log a = -4.04 b_1 = +1.03 b_2 = +1.90	47	.68	.36	log a = -1.50 b_1 = +1.42	29	.32	.57	log a = -0.90 b_1 = +0.96	47	.58	.41	log a = -1.83 b_1 = +0.94	45	.40	.49

[1] Not significant at the 95 percent confidence level.

Table 3. -- Continued

Dependent variable (log Q)	Area (x_1) and precipitation (x_2) as independent variables				Channel widths (x_1) as independent variable				Mean annual flow (x_1) as independent variable				2-year peak (x_1) as independent variable			
	Parameters	n	r^2	SE	Parameters	n	r^2	SE	Parameters	n	r^2	SE	Parameters	n	r^2	SE
SOUTHEAST REGION -- Continued																
P_2	log a= +1.25 b_1 = +0.81 b_2 = +0.49	53	.83	.19	log a= +0.63 b_1 = +1.37	32	.77	.25	log a= +1.63 b_1 = +0.74	46	.77	.20	--	--	--	--
P_5	log a= +1.52 b_1 = +0.78 b_2 = +0.44	53	.80	.20	log a= +0.85 b_1 = +1.32	32	.74	.26	log a= +1.81 b_1 = +0.71	46	.73	.22	log a= +0.19 b_1 = +0.98	53	.99	.08
P_{10}	log a= +1.66 b_1 = +0.77 b_2 = +0.41	53	.78	.21	log a= +0.97 b_1 = +1.29	32	.72	.26	log a= +1.91 b_1 = +0.70	46	.70	.23	log a= +0.29 b_1 = +0.97	53	.98	.09
P_{25}	log a= +1.81 b_1 = +0.76 b_2 = +0.38	53	.75	.22	log a= +1.10 b_1 = +1.26	32	.70	.27	log a= +2.02 b_1 = +0.68	46	.67	.24	log a= +0.40 b_1 = +0.96	53	.97	.11
P_{50}	log a= +1.92 b_1 = +0.75 b_2 = +0.36	53	.74	.23	log a= +1.19 b_1 = +1.24	32	.68	.28	log a= +2.10 b_1 = +0.67	46	.65	.25	log a= +0.48 b_1 = +0.95	53	.95	.11
P_{100}	log a= +2.01 b_1 = +0.74 b_2 = +0.34	53	.72	.24	log a= +1.27 b_1 = +1.22	32	.66	.28	log a= +2.16 b_1 = +0.66	46	.63	.26	log a= +0.54 b_1 = +0.95	53	.94	.13
QA	log a= -0.46 b_1 = +1.01 b_2 = +0.68	66	.92	.14	log a= -0.60 b_1 = +1.48	29	.56	.37	--	--	--	--	log a= -1.17 b_1 = +1.04	46	.77	.25
$V_{30,2}$	log a= +0.05 b_1 = +1.05 b_2 = +0.59	47	.92	.14	log a= -0.23 b_1 = +1.49	29	.57	.37	log a= +0.38 b_1 = +1.00	47	.99	.07	log a= -0.87 b_1 = +1.06	45	.79	.23
SOUTH-CENTRAL REGION																
$M_{7,10}$	log a= -1.44 b_1 = +0.98 b_2 = +0.44	44	.86	.36	--	--	--	--	log a= -1.06 b_1 = +0.96	44	.81	.45	log a= -1.70 b_1 = +0.92	39	.66	.58
$M_{30,10}$	log a= -1.28 b_1 = +0.96 b_2 = +0.38	44	.83	.39	--	--	--	--	log a= -0.98 b_1 = +0.94	44	.77	.48	log a= -1.56 b_1 = +0.89	39	.61	.62
$M_{90,10}$	log a= -1.17 b_1 = +0.95 b_2 = +0.36	44	.81	.42	--	--	--	--	log a= -0.89 b_1 = +0.93	44	.75	.51	log a= -1.45 b_1 = +0.88	39	.58	.65
P_2	log a= -0.69 b_1 = +0.87 b_2 = +1.31	72	.93	.25	log a= -0.79 b_1 = +2.01	17	.97	.24	log a= +0.93 b_1 = +0.95	44	.95	.26	--	--	--	--
P_5	log a= -0.25 b_1 = +0.83 b_2 = +1.19	73	.93	.25	log a= -0.28 b_1 = +1.83	17	.95	.27	log a= +1.13 b_1 = +0.92	45	.94	.26	log a= +0.32 b_1 = +0.95	72	.99	.11
P_{10}	log a= +0.03 b_1 = +0.81 b_2 = +1.13	72	.92	.26	log a= +0.01 b_1 = +1.73	17	.93	.30	log a= +1.23 b_1 = +0.91	44	.94	.27	log a= +0.51 b_1 = +0.92	72	.98	.14
P_{25}	log a= +0.25 b_1 = +0.79 b_2 = +1.05	72	.90	.28	log a= +0.35 b_1 = +1.61	17	.89	.33	log a= +1.36 b_1 = +0.90	44	.93	.28	log a= +0.72 b_1 = +0.88	72	.97	.18
P_{50}	log a= +0.44 b_1 = +0.77 b_2 = +0.99	72	.89	.29	log a= +0.58 b_1 = +1.53	17	.86	.36	log a= +1.44 b_1 = +0.89	44	.92	.29	log a= +0.87 b_1 = +0.86	72	.95	.21

Table 3. -- Continued

Dependent variable (log Q)	Area (x_1) and precipitation (x_2) as independent variables				Channel widths (x_1) as independent variable				Mean annual flow (x_1) as independent variable				2-year peak (x_1) as independent variable			
	Parameters	n	r²	SE	Parameters	n	r²	SE	Parameters	n	r²	SE	Parameters	n	r²	SE
SOUTH-CENTRAL REGION -- Continued																
P_{100}	log a= +0.63 b_1 = +0.75 b_2 = +0.94	71	.87	.31	log a= +0.80 b_1 = +1.45	17	.82	.39	log a= +1.52 b_1 = +0.88	43	.91	.30	log a= +1.00 b_1 = +0.83	71	.93	.25
QA	log a= -1.33 b_1 = +0.96 b_2 = +1.11	56	.97	.16	--	--	--	--	--	--	--	--	log a= -0.80 b_1 = +1.00	44	.95	.22
$V_{30,2}$	log a= -1.05 b_1 = +1.02 b_2 = +1.15	45	.97	.17	--	--	--	--	log a= +0.36 b_1 = +1.05	45	.99	.19	log a= -0.61 b_1 = +1.09	40	.96	.22
SOUTHWEST REGION																
P_2	log a= +0.37 b_1 = +0.86 b_2 = +0.59	9	.99	.18	--	--	--	--	log a= +0.88 b_1 = +0.90	7	.99	.21	--	--	--	--
P_5	log a= +0.97 b_1 = +0.84 b_2 = +0.34	9	.99	.16	--	--	--	--	log a= +1.29 b_1 = +0.83	7	.98	.23	log a= +0.27 b_1 = +0.96	9	1.00	.11
P_{10}	log a= +1.33 b_1 = +0.83 b_2 = +0.19	9	.99	.15	--	--	--	--	log a= +1.53 b_1 = +0.78	7	.97	.25	log a= +0.43 b_1 = +0.95	9	.99	.14
P_{25}	log a= +1.73 b_1 = +0.82 b_2 = +0.02	9	.99	.15	--	--	--	--	log a= +1.80 b_1 = +0.74	7	.95	.27	log a= +0.61 b_1 = +0.92	9	.99	.18
P_{50}	log a= +2.01 b_1 = +0.81 b_2 = -0.10	9	.99	.15	--	--	--	--	log a= +1.98 b_1 = +0.70	7	.94	.28	log a= +0.74 b_1 = +0.91	9	.98	.21
P_{100}	log a= +2.27 b_1 = +0.80 b_2 = -0.20	9	.99	.16	--	--	--	--	log a= +2.15 b_1 = +0.67	7	.92	.30	log a= +0.85 b_1 = +0.89	9	.97	.23
QA	log a= -1.38 b_1 = +0.98 b_2 = +1.13	10	.99	.15	--	--	--	--	--	--	--	--	log a= -0.92 b_1 = +1.10	9	.99	.16
$V_{30,2}$	--	--	--	--	--	--	--	--	--	--	--	--	log a= +0.44 b_1 = +0.89	6	.99	.09
YUKON REGION																
$M_{7,10}$	log a= -3.91 b_1 = +1.16 b_2 = +1.62	24	.84	.61	--	--	--	--	log a= -1.63 b_1 = +1.12	24	.87	.56	log a= -2.88 b_1 = +1.21	19	.80	.59
$M_{30,10}$	log a= -3.91 b_1 = +1.16 b_2 = +1.63	24	.84	.61	--	--	--	--	log a= -1.63 b_1 = +1.11	24	.87	.56	log a= -2.89 b_1 = +1.21	19	.80	.59
$M_{90,10}$	log a= -4.28 b_1 = +1.17 b_2 = +1.86	24	.77	.78	--	--	--	--	log a= -1.68 b_1 = +1.12	24	.79	.74	log a= -2.82 b_1 = +1.19	19	.73	.71
P_2	log a= -0.20 b_1 = +0.91 b_2 = +1.02	53	.96	.25	--	--	--	--	log a= +1.44 b_1 = +0.83	23	.98	.22	--	--	--	--
P_5	log a= +0.39 b_1 = +0.85 b_2 = +0.85	53	.95	.26	--	--	--	--	log a= +1.73 b_1 = +0.79	23	.97	.24	log a= +0.42 b_1 = +0.94	53	1.00	.15

Table 3. -- Continued

Dependent variable (log Q)	Area (x_1) and precipitation (x_2) as independent variables				Mean annual flow (x_1) as independent variable				2-year peak (x_1) as independent variable			
	Parameters	n	r²	SE	Parameters	n	r²	SE	Parameters	n	r²	SE
	YUKON REGION - Continued											
P_{10}	log a = +0.73 b_1 = +0.82 b_2 = +0.74	53	.95	.28	log a = +1.90 b_1 = +0.77	23	.95	.26	log a = +0.67 b_1 = +0.91	53	.99	.18
P_{25}	log a = +1.13 b_1 = +0.78 b_2 = +0.62	53	.93	.30	log a = +2.10 b_1 = +0.74	23	.94	.28	log a = +0.95 b_1 = +0.87	53	.98	.21
P_{50}	log a = +1.39 b_1 = +0.76 b_2 = +0.54	53	.92	.32	log a = +2.23 b_1 = +0.73	23	.92	.31	log a = +1.14 b_1 = +0.84	53	.97	.24
P_{100}	log a = +1.64 b_1 = +0.73 b_2 = +0.47	53	.90	.34	log a = +2.35 b_1 = +0.71	23	.91	.32	log a = +1.32 b_1 = +0.82	53	.95	.26
QA	log a = -2.04 b_1 = +1.05 b_2 = +1.39	32	.99	.10	--	--	--	--	log a = -1.63 b_1 = +1.18	23	.98	.22
$V_{30,2}$	log a = -1.14 b_1 = +1.01 b_2 = +1.26	28	.99	.14	log a = +0.72 b_1 = +0.96	28	.99	.20	log a = -0.87 b_1 = +1.14	23	.99	.16

Table 4. -- Comparison of regression statistics for statewide flow equations

Equation	Sample size	Coefficient of determination (r²)	Standard error of estimate, in log units (SE)
	Low flow ($M_{7,10}$)		
Basin characteristics	124	0.85	0.44
Channel width	37	.52	.62
Mean annual flow	124	.86	.43
2-year peak	112	.71	.61
	Peak flow (P_{25})		
Basin characteristics	200	0.89	0.30
Channel width	59	.88	.30
Mean annual flow	126	.88	.28
2-year peak	200	.96	.21
	Mean annual flow (QA)		
Basin characteristics	172	0.98	0.15
Channel width	40	.73	.40
Mean annual flow	--	--	--
2-year peak	126	.92	.28
	Flood volume ($V_{30,2}$)		
Basin characteristics	133	0.97	0.17
Channel width	37	.79	.38
Mean annual flow	132	.98	.15
2-year peak	119	.94	.27

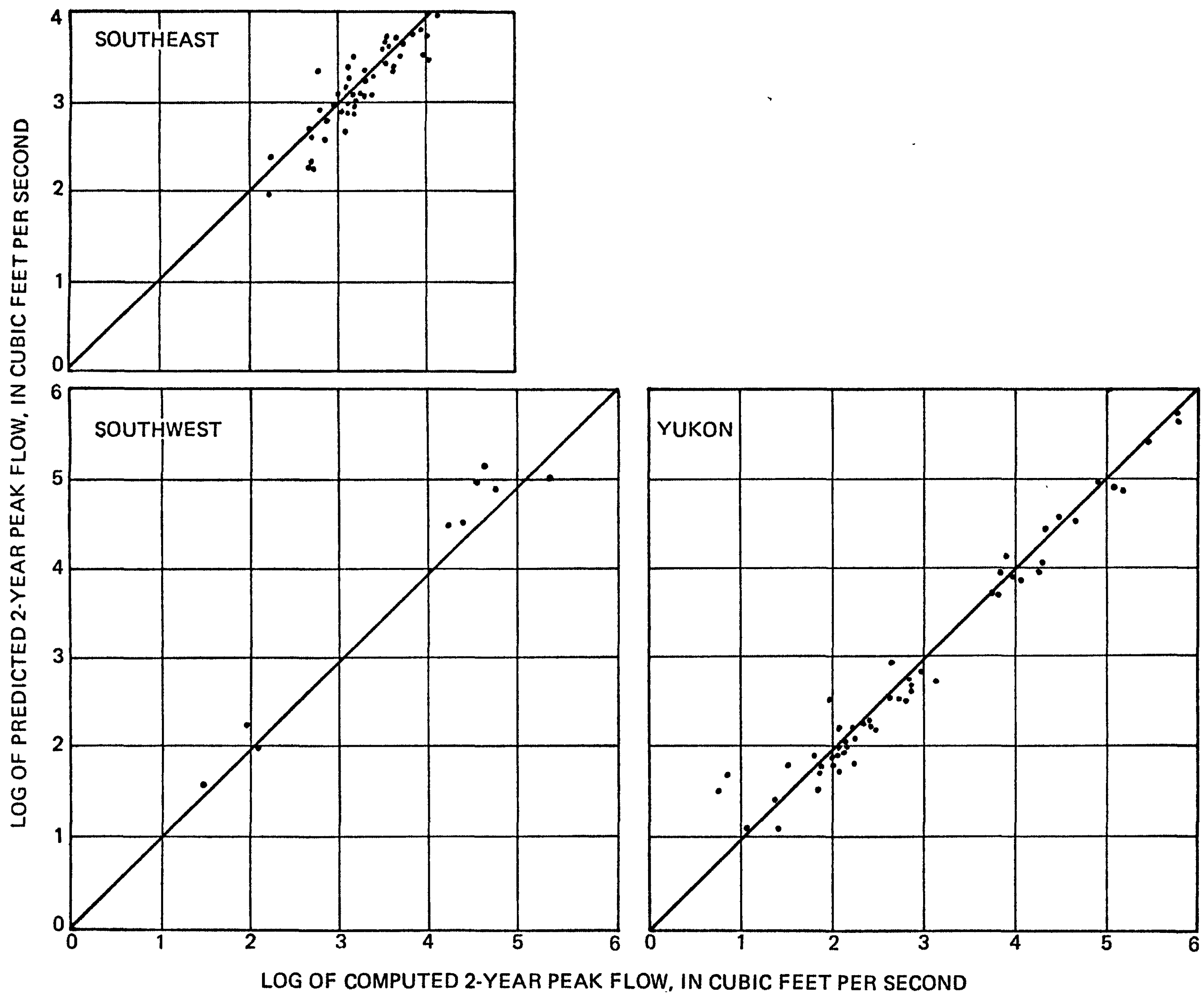

Figure 3.--Actual (computed) 2-year peak flow versus values estimated by the statewide equation for each region.

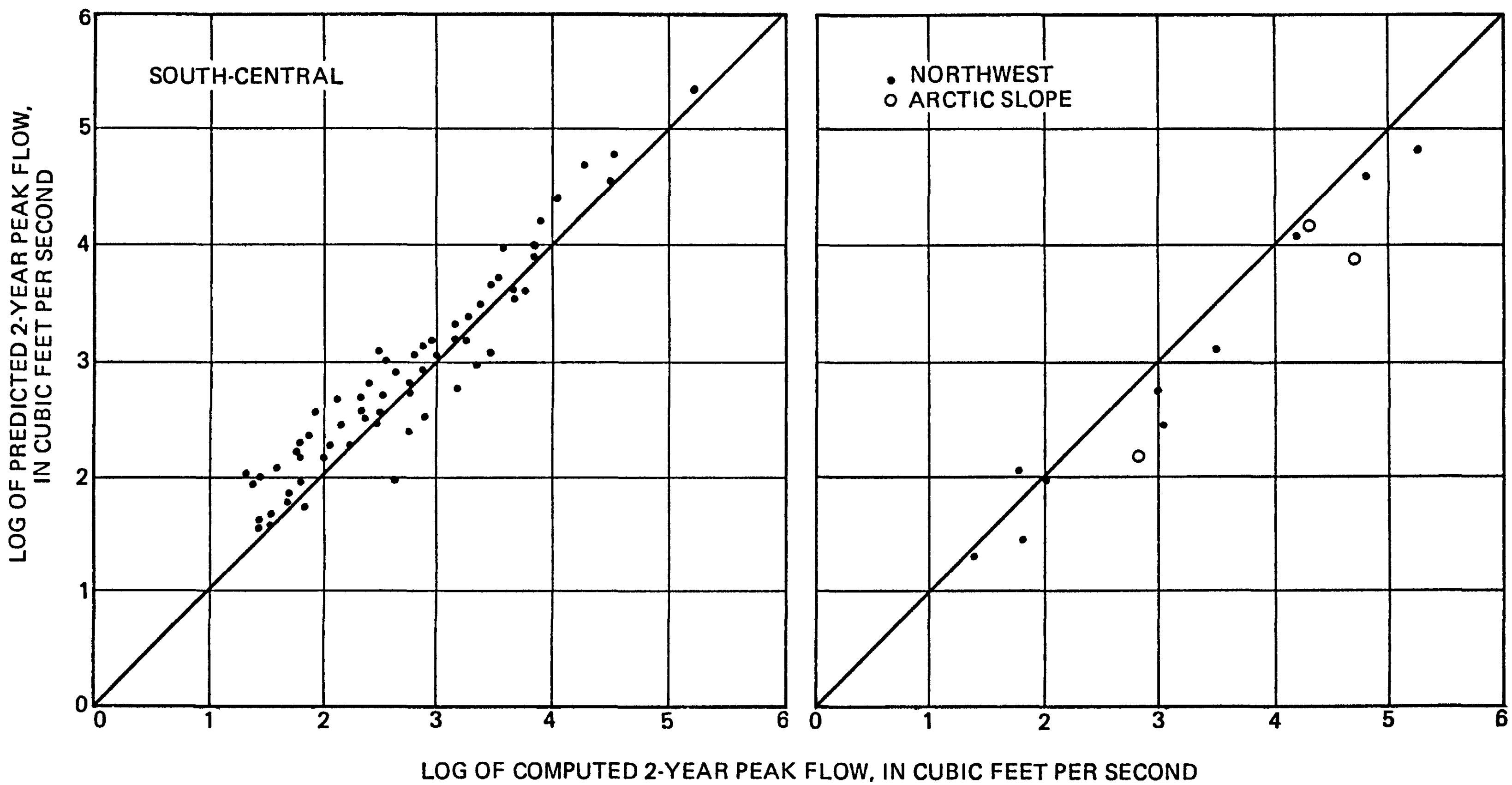

Figure 3.--Actual (computed) 2-year peak flow versus values estimated by the statewide equation for each region. (continued)

Because equations derived from flow values have limited applicability and those derived from channel widths lack a large data base, equations using basin characteristics would seem to offer the best general means of estimating streamflow at ungaged sites in Alaska. For statewide equations using basin characteristics, an evaluation of residuals (the difference between actual values and those estimated by the equations) indicates differences among the regions (fig. 3). For the south-central region, 80 percent of the estimated values were higher than the actual peaks; for the southeast and Yukon regions however, approximately 70 percent of the estimated values were lower than the actual peaks.

The regression coefficients and error statistics for equations derived from basin characteristics for individual regions confirm that there are significant differences in the relationship of flow values to basin characteristics among the regions (table 5). Although the coefficients for area are relatively consistent, the coefficients for precipitation and the intercepts vary widely among regions. Regression coefficients and error statistics for some regions and some flow characteristics were not computed because of insufficient data.

The deviation of estimated values from actual values of the 25-year peak flow for glacial and nonglacial streams shows fairly equal distribution about the line of equality (fig. 4). No significant increase in reliability of estimation is obtained by the use of separate statewide equations as compared with the use of a single equation that applies to both types of streams. This applies not only to the 25-year peak but also to other streamflow characteristics, and therefore separate equations are not given.

In summary, the evaluation indicates that the regression equations can be useful in estimating flow characteristics of Alaskan streams. The most generally useful equations are derived from basin characteristics; equations derived from computed flow values offer no advantage in reliability and can only be employed where flow values have been measured. Equations derived from channel width may be applicable, particularly for estimating peak flows, but the equations presented here are not based on a representative sample of widths throughout the State and must therefore be used with caution.

Comparison of streamflow estimates made using regional equations with those made using statewide equations indicates that the regional equations are more reliable for the southeast, south-central, and Yukon regions. For the northwest, Arctic Slope, and southwest regions, where there are few data available, statewide equations now offer the best alternative for estimating flow at ungaged sites. Because of differences among these regions, however, the error of the estimates may be greater than indicated by the error coefficient of the equations. One should use caution in using any of these equations outside the range of observed values with which they were developed because the estimate of error is invalid outside this range. The standard error of prediction was not computed; because of the paucity of data for Alaska, an independent data set could not be extracted for use in calibration without reducing the reliability of the regression equations.

An alternative to applying the statewide equations in regions where data are sparse is to use an equation developed for a nearby region that is hydrologically similar. Another option is to develop equations using data from not only the region with the sparse data but also from similar sites in other regions. For example, the northwest region has few data, so equations for this region could be generated using data for sites from the region and some data from hydrologically similar sites in the Yukon and Arctic Slope regions.

Table 5. -- Regression coefficients and error statistics for equations derived from regional basin characteristics

Region	Regression coefficients			Sample size (n)	Coefficient of determination (r^2)	Standard error of estimate (log units)
	Intercept	Area	Precipitation			
			Low flow ($M_{7,10}$)			
Southeast	-4.29	1.21	1.71	47	0.79	0.30
South-central	-1.44	.98	.44	44	.86	.36
Southwest	--	--	--	--	--	--
Yukon	-3.91	1.16	1.62	24	.84	.61
Statewide	-2.81	1.08	1.09	124	.85	.44
			Peak flow (P_{25})			
Southeast	1.81	0.76	0.38	53	0.75	0.22
South-central	- .25	.79	1.05	72	.90	.28
Southwest	1.73	.82	.02	9	.99	.15
Yukon	1.13	.78	.62	53	.93	.30
Statewide	- .73	.79	.84	200	.89	.30
			Mean annual flow (QA)			
Southeast	- .46	1.01	0.68	66	0.92	0.14
South-central	-1.33	.96	1.11	56	.97	.16
Southwest	-1.38	.98	1.13	10	.99	.15
Yukon	-2.04	1.05	1.39	32	.99	.10
Statewide	-1.51	.98	1.19	172	.98	.15
			Flood volume ($V_{30,2}$)			
Southeast	0.05	1.05	0.59	47	0.92	0.14
South-central	-1.05	1.02	1.15	45	.97	.17
Southwest	--	--	--	--	--	--
Yukon	-1.14	1.01	1.26	28	.99	.14
Statewide	- .59	.98	.93	133	.97	.17

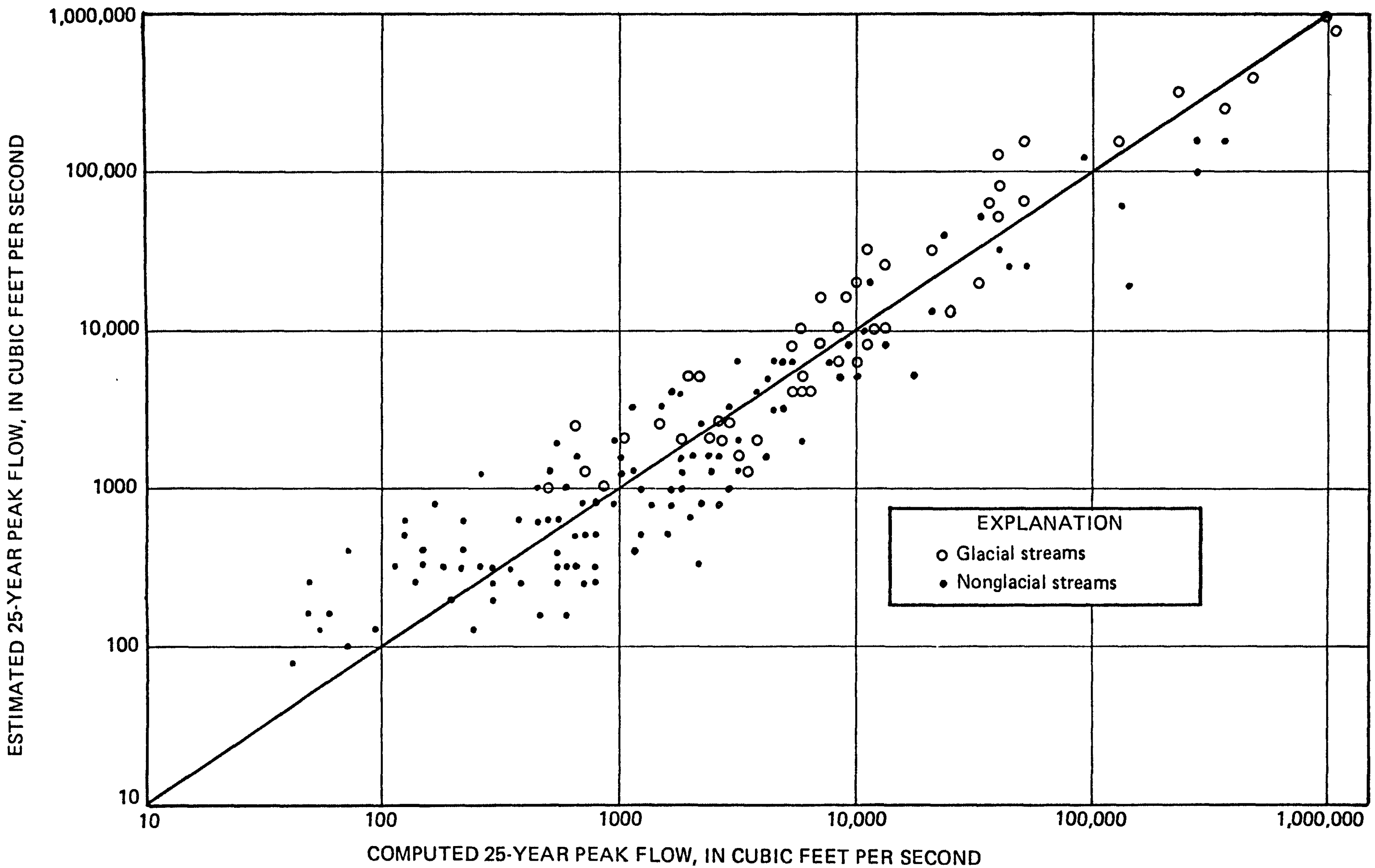

Figure 4.-- Actual (computed) 25-year peak flow versus that estimated by the basin characteristics equation for glacial and nonglacial streams.

MEASURED AND COMPUTED WATER-QUALITY PROPERTIES

Suspended-sediment and dissolved-constituent data have been collected by the U.S. Geological Survey at more than 850 sites throughout Alaska from the late 1940's to the present. Most of these sites have been sampled on only an intermittent basis, and over half the sites have been sampled fewer than 10 times. About 30 percent of the sediment-sampling sites and about 10 percent of the water-quality sites have more than 20 samples. In addition, once-daily samples have been collected at 13 sediment sites and 25 water-quality sites. The period of record for these daily stations ranges from 1 to 13 years. For some stations and some years, once-daily samples were collected for the entire open-water season; at others samples were taken during only a part of the open-water season. The distribution of the sampling sites by region is shown in table 6.

Table 6. -- Distribution of sediment and water-quality sampling sites in Alaska

Region	Total number of sampling sites		Number of sites at which 10 or more samples have been collected		Number of sites with daily records		Earliest sample date	
	Sediment	Water quality	Sediment	Water quality	Sediment	Water quality	Sediment	Water quality
Southeast	71	168	31	21	2	2	1960	1948
South-central	98	392	57	81	7	15	1952	1948
Southwest	10	62	6	6	--	1	1966	1950
Yukon	67	187	29	43	4	8	1953	1949
Northwest	9	38	5	6	--	--	1964	1952
Arctic Slope	12	32	4	5	--	--	1969	1953
Total	267	879	132	162	13	26		

An initial analysis of the existing data base was made to determine those sites for which data were adequate to use in developing regression equations for the prediction of mean suspended sediment or dissolved-solids values. The sites selected for the analysis were those for which:

1. Long-term daily streamflow records were of adequate length to approximate mean flow conditions (5 or more years) and which could be used with discharge-sediment or discharge-dissolved-solids relationships to compute mean concentrations or loads. Not all daily-record stations were used to develop the estimating equations but were "reserved" to test the validity of the equations.

2. Data were adequate (at least 10 samples) to develop relationships of dissolved solids or sediment with instantaneous discharge.

3. As far as was known the land was relatively undisturbed by activities such as placer mining or urbanization.

4. Basin characteristics data were available in the Geological Survey Streamflow/Basin Characteristics File.

The 63 sites which met the above criteria are listed on table 7, and their locations shown in figure 5. Three of the sites (stations 15241600, 15254000 and 15266500) did not have adequate suspended-sediment data but were used in developing the dissolved-solids equations.

Table 7. -- Stations used to develop sediment and dissolved-solids regression equations

[M, maritime-glacial; I, interior-glacial; N, nonglacial]

Station No.	Station name	Stream type
	SOUTHEAST	
15015600	Klahini River near Bell Island	M
15022000	Harding River near Wrangell	M
15048000	Sheep Creek near Juneau	M
15052000	Lemon Creek near Juneau	M
15052500	Mendenhall River near Auke Bay	M
15052800	Montana Creek near Auke Bay	M
15056100	Skagway River at Skagway	M
15056200	West Creek near Skagway	M
15059500	Whipple Creek near Ward Cove	N
15106920	Kadashan River above Hook Creek near Tenakee	N
15106940	Hook Creek above tributary near Tenakee	N
15106980	Tonalite Creek near Tenakee	N
15107000	Kadashan River near Tenakee	N
15109000	Fish Creek near Auke Bay	N
	SOUTH-CENTRAL	
15200000	Gakona River at Gakona	I
15206000	Klutina River at Copper Center	M*
15208000	Tonsina River at Tonsina	M*
15208100	Squirrel Creek at Tonsina	N
15212000	Copper River near Chitina	I
15216000	Power Creek near Cordova	M
15238600	Spruce Creek near Seward	M
15239900	Anchor River near Anchor Point	N
15240000	Anchor River at Anchor Point	N
15241600	Ninilchik River at Ninilchik	N
15254000	Crescent Creek near Cooper Landing	N
15266300	Kenai River at Soldotna	M*
15266500	Beaver Creek near Kenai	N
15267900	Resurrection Creek near Hope	N
15277100	Eagle River at Eagle River	M*
15281000	Knik River near Palmer	M*
15282000	Caribou Creek near Sutton	N
15290000	Little Susitna River near Palmer	M*
15291000	Susitna River near Denali	I
15291200	Mclaren River near Paxson	I
15291500	Susitna River near Cantwell	I

* Included as maritime but could be considered as transitional between maritime and interior.

Table 7. -- Continued

Station No.	Station Name	Stream type
15292000	Susitna River at Gold Creek	I
15292400	Chulitna River near Talkeetna	I
15292700	Talkeetna River near Talkeetna	I
	SOUTHWEST	
15303600	Kuskokwim River at McGrath	N
15304000	Kuskokwim River at Crooked Creek	I
	YUKON	
15356000	Yukon River at Eagle	I
15389000	Porcupine River near Fort Yukon	N
15389500	Chandalar River near Venetie	N
15457800	Hess Creek near Livengood	N
15468000	Yukon River at Rampart	I
15470000	Chisana River at Northway Junction	I
15476000	Tanana River near Tanacross	I
15484000	Salcha River near Salchaket	N
15493500	Chena River near North Pole	N
15511000	Little Chena River near Fairbanks	N
15514000	Chena River at Fairbanks	N
15514500	Wood River near Fairbanks	I
15515500	Tanana River at Nenana	I
15515800	Seattle Creek near Cantwell	N
15516000	Nenana River near Windy	I
15564600	Melozitna River near Ruby	N
15564800	Yukon River at Ruby	I
15564885	Jim River near Bettles	N
15564900	Koyukuk River at Hughes	N
	NORTHWEST	
15621000	Snake River near Nome	N
15744000	Kobuk River at Ambler	N
15744500	Kobuk River near Kiana	N
	ARCTIC SLOPE	
15896000	Kuparuk River near Deadhorse	N
15896700	Putuligayuk River near Deadhorse	N

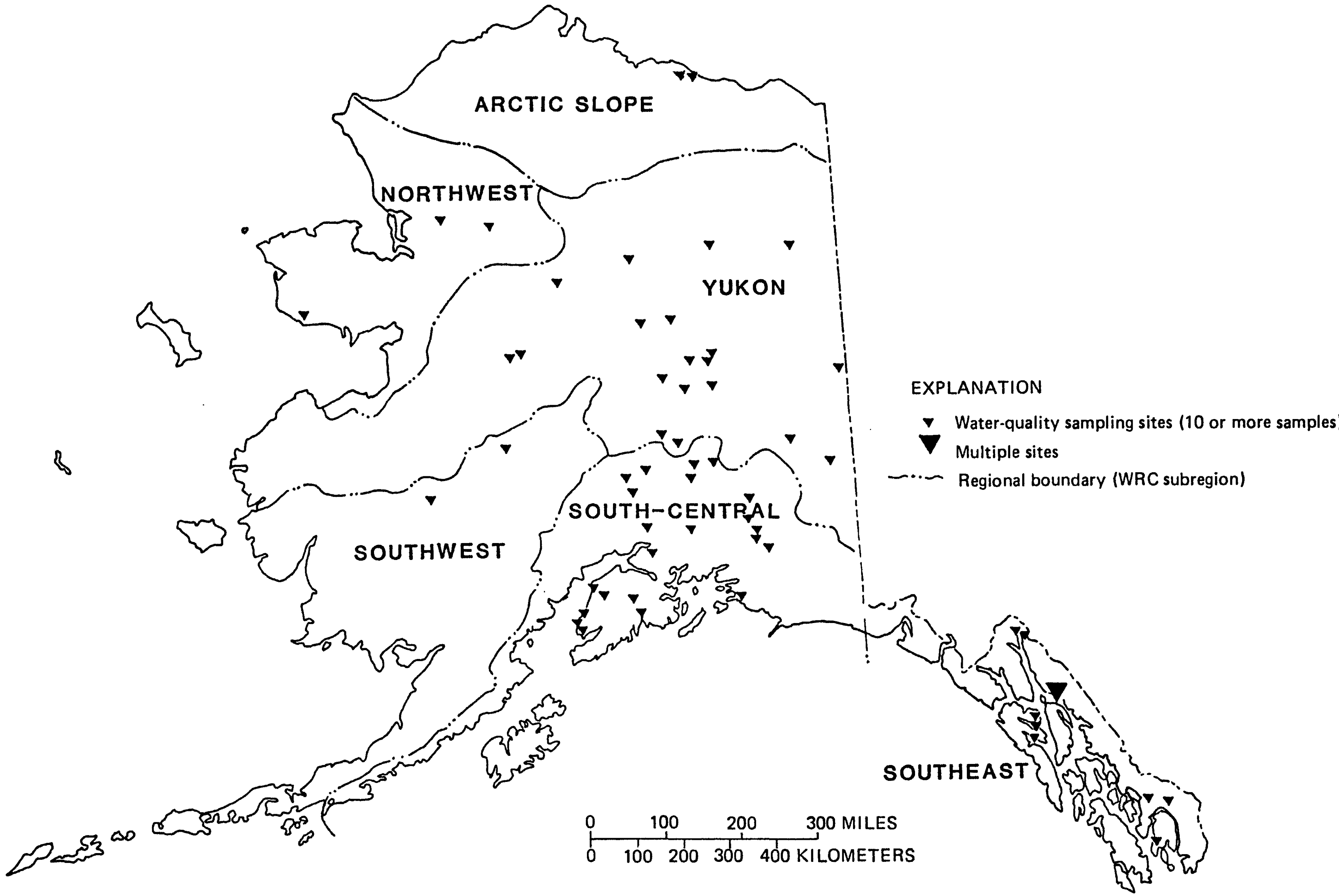

Figure 5.-- Locations of water-quality sampling sites and regional boundaries used in regression analyses in this report.

Mean suspended-sediment discharge can be estimated from short-term intermittent data by a method that uses an instantaneous sediment-transport curve and the daily flow values from a long-term surface-water record. Sediment-transport curves have been described in some detail by Colby (1956). The method of estimating mean sediment discharge from sediment-transport curves has been widely discussed in the literature: for example, Anttila and Tobin (1978); Miller (1951); U.S. Department of Agriculture (1975). Instantaneous sediment discharges are plotted against concurrent streamflows on logarithmic coordinates. Instantaneous sediment discharges are calculated from the equation :

$$Q_s = 0.0027\ Q_w C,$$

where Q_s is instantaneous suspended-sediment discharge, in tons per day;
Q_w is instantaneous water discharge, in cubic feet per second;
C is instantaneous suspended-sediment concentration in milligrams per liter;
and the constant 0.0027 is a units conversion factor.

The sediment-transport equation can then be used with the daily values of surface-water flow to compute daily means or long-term mean suspended-sediment discharges for the period of surface-water record.

For the 60 sites having adequate data, sediment-transport and sediment-discharge curves were plotted. Figures 6 and 7 show the typical relationships between water discharge and both the concentration and discharge of suspended sediment. The graphs show a much better relationship during the open-water season than for the winter period.

For most sites very few samples have been collected in winter. When streams are ice covered and the discharge is low, suspended-sediment concentrations typically range from 0 to 10 mg/L and there is little correlation between flow and sediment concentration. For those sites having a daily sediment record throughout the year, the computed winter load of suspended sediment was usually less than 1 percent of the total yearly load. Because of the very small amount of sediment transported during the winter and the paucity of data it was decided to use only the data for the open-water season for further analysis.

The equations for the sediment-transport curves were used with the daily mean flows for the period of flow record to compute daily-mean and annual sediment concentrations and loads. The sediment yield (in tons per day per square mile) was also computed by dividing the load by the drainage area.

Instantaneous water discharge and instantaneous dissolved-solids concentrations were used to compute a mean dissolved-solids concentration in a manner similar to that described for suspended sediment. These means, which apply only to the open-water season, were computed only for those sites for which 10 or more samples have been analyzed.

ESTIMATION OF WATER-QUALITY PROPERTIES BY REGRESSION EQUATIONS

Properties of Suspended Sediment Estimated from Basin Characteristics

The relationships between mean suspended-sediment concentrations and loads and

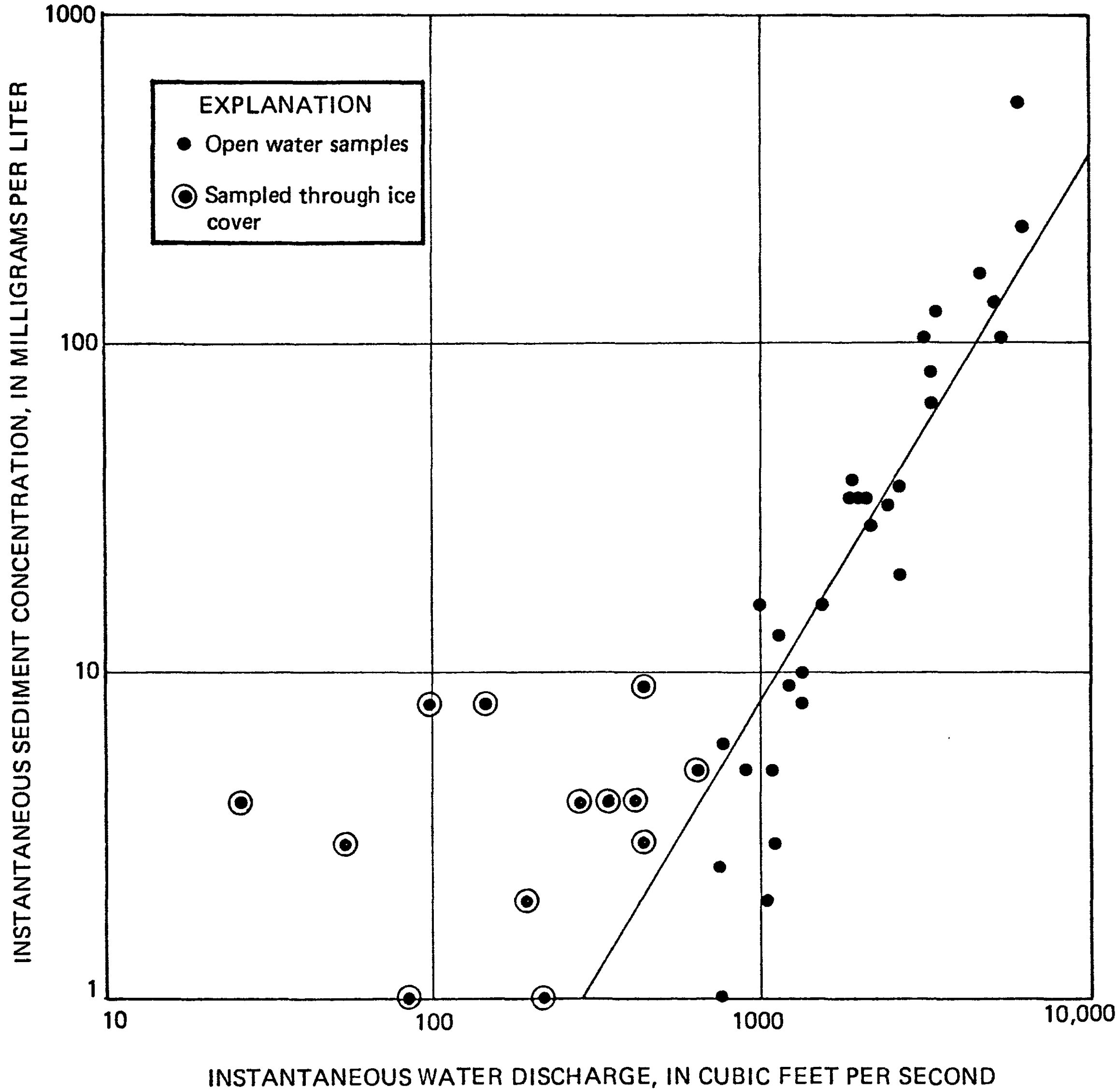

Figure 6.--Representative suspended-sediment-concentration curve (Chena River near North Pole).

basin characteristics at gaging stations were defined by stepwise multiple-regression using data from all 60 sites. The basin characteristics used and the parameters obtained for the statewide equations are shown in table 8. The low correlation coefficients and the high standard errors of these equations indicate that a single statewide equation is probably inappropriate. An analysis of the residuals from the regression equations suggests that better relationships may exist for certain stream types or for certain regions of the State.

Figures 8 and 9 show the residuals from the statewide regression equations for sediment load (independent variables: percent glacier and drainage area). For nonglacial streams (fig. 8), errors are randomly distributed about the regression

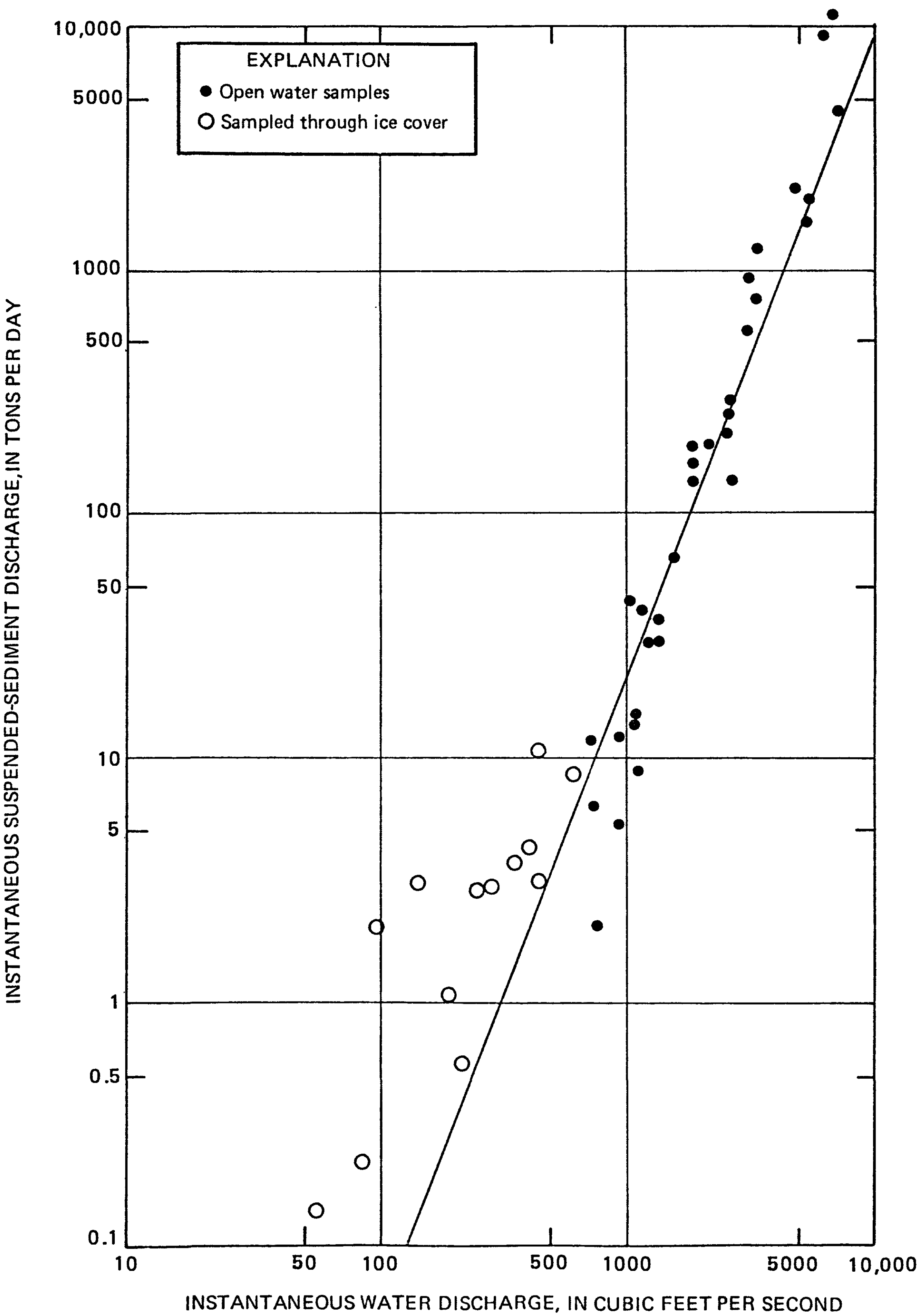

Figure 7.--Representative suspended-sediment discharge curve (Chena River near North Pole).

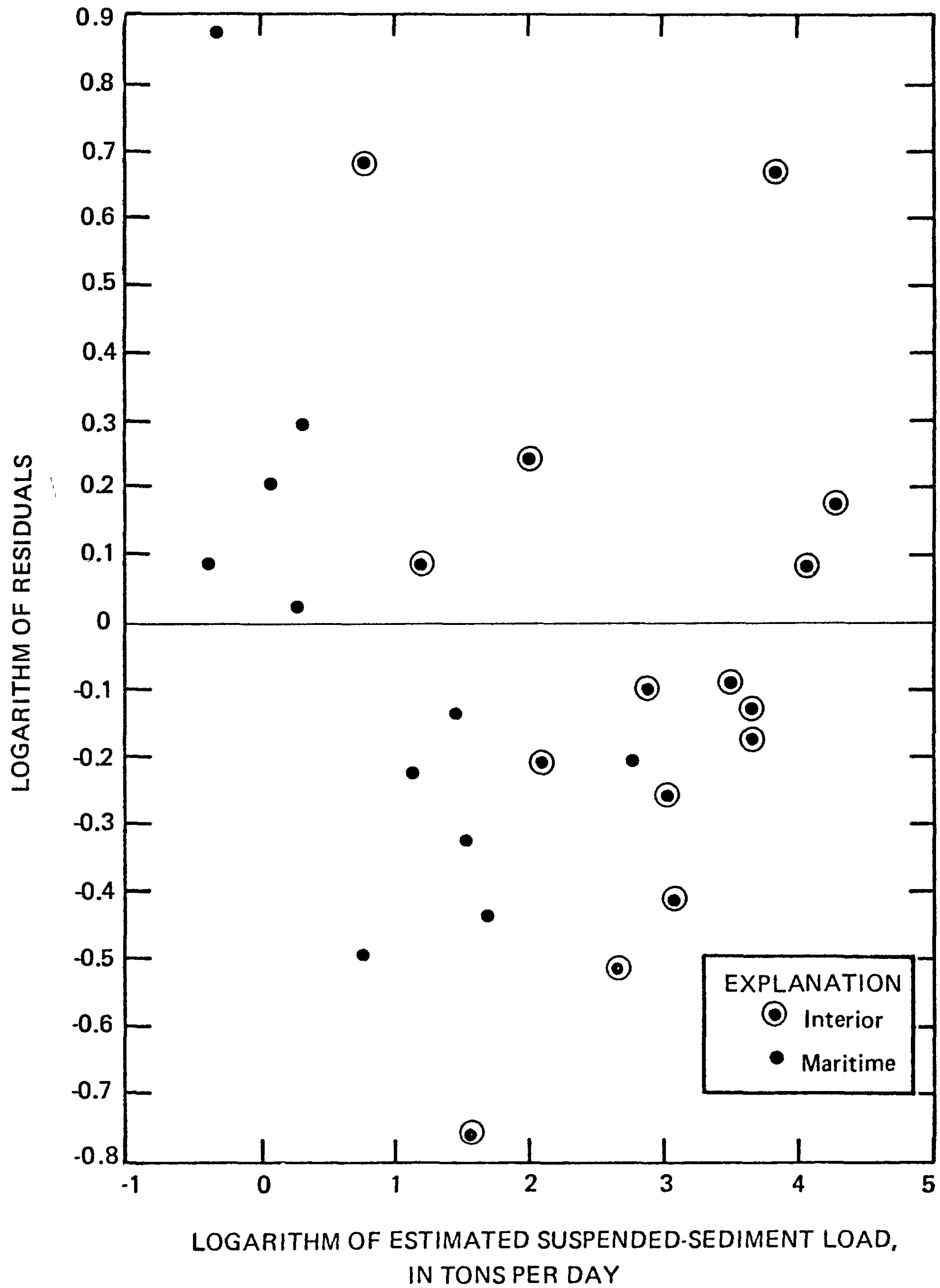

Figure 8.--Residuals from statewide suspended-sediment equation--nonglacial streams.

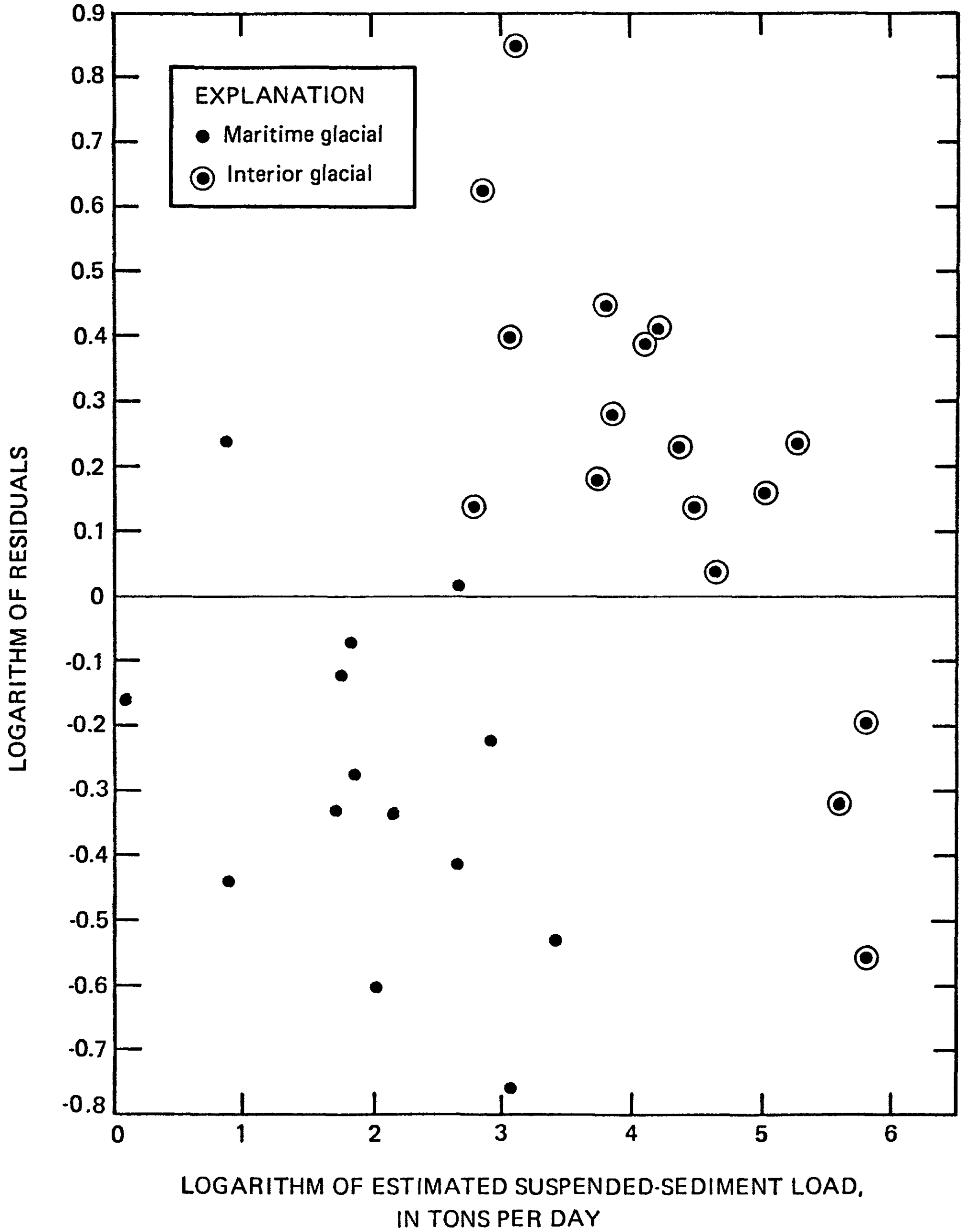

Figure 9.--Residuals from statewide suspended-sediment equation--glacial streams.

line regardless of region. For glacial streams (fig. 9), however, there are two distinct groupings of the data -- those for interior Alaska and for maritime areas. The regression equation for sediment yield using percent glaciers as the independent variable (fig. 10) shows a similar separation of the two types of glacial streams.

In an attempt to improve on the statewide analysis, a second set of regression equations was developed after the data set was separated into nonglacial, maritime-glacial and interior-glacial streams. The regression coefficients and error statistics for the "best" two-variable equations for the reduced data set and the statewide analysis are given in table 8. Based on standard error, coefficients of determination, and significance tests, the stepwise regression indicated that the "best" equations were those with only two independent variables and that adding more variables did not significantly improve the equations.

Of the 13 sites in Alaska that have daily sediment records, 7 sites have one or more years of continuous daily values for an entire open-water period. None of these stations has adequate data to define long-term mean annual suspended-sediment values which can be directly compared to the values estimated from the equations. However, a comparison with the range of observed mean annual values does give a general indication of the usefulness of the equations (table 9). The relation of the sediment values estimated by the two-variable basin characteristics equations to the observed mean values for the seven sites with available daily sediment data is shown in figures 11 to 13.

For glacial streams, regression equations based on basin characteristics provide estimates of mean suspended-sediment values, with standard errors of estimate of approximately -50 to +100 percent (table 8). Nonglacial streams usually have lower suspended-sediment yields but greater variability in sediment-discharge relationships among streams. This is reflected in the larger standard errors of the equations for nonglacial streams (about -64 to +180 percent) and the lack of statistical significance at the 95 percent confidence level for some of the independent variables (see table 8). The larger errors for maritime-glacial streams compared to those for interior-glacial streams may be related to differences in the influence of ice-free parts of their respective basins. Unit runoff from glacial basins in the maritime region is generally slightly higher than, but of the same order of magnitude as, that from glacial basins in the interior. Because of the much higher maritime precipitation, however, the unit runoff from nonglacial areas may be as much as 10 times greater for maritime streams than for interior streams.

Concentration of Dissolved Solids Estimated from Basin Characteristics

Regression techniques were also used to develop equations for estimating dissolved-solids concentrations. The coefficients and error factors for the resulting equations are given in table 10. As in the suspended-sediment analysis, the data set was separated into nonglacial, maritime glacial and interior-glacial streams. The mean dissolved-solids concentrations estimated from the regression equations are compared to the mean values observed at stations having daily records in table 11 and figure 14. The data from these daily stations were not used in developing the regression equations.

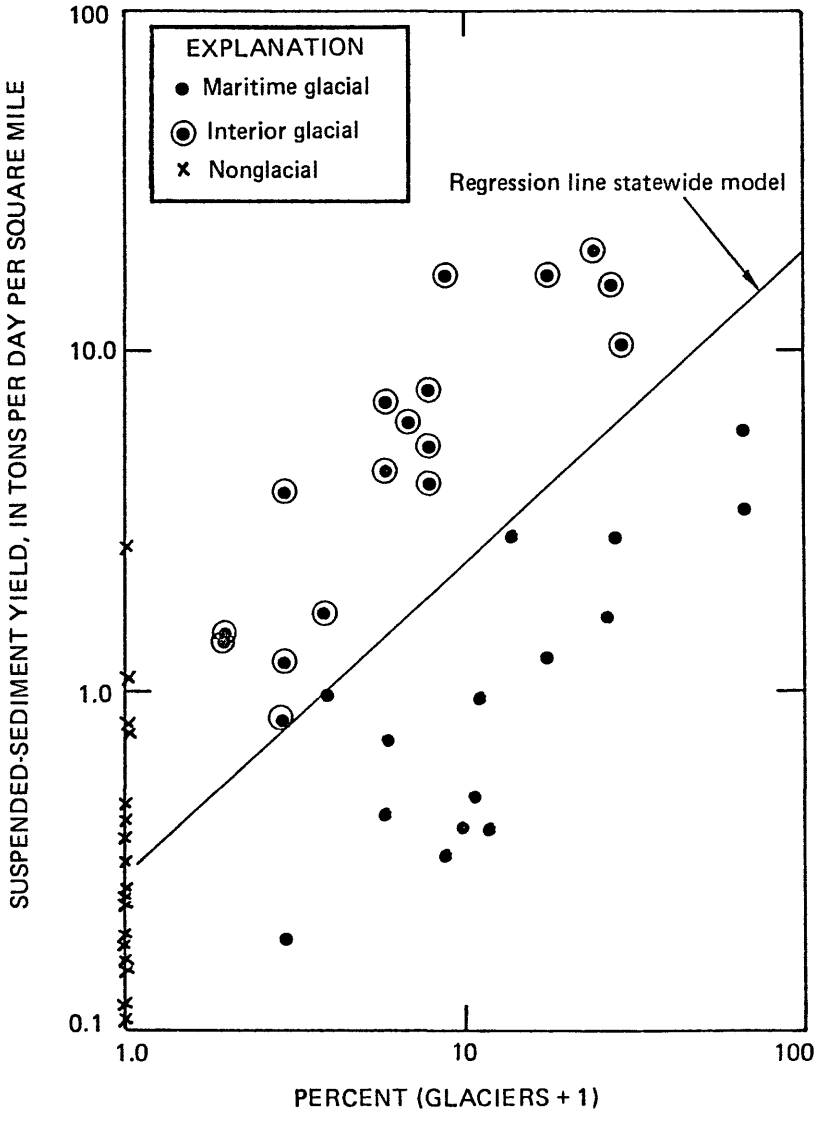

Figure 10.--Relation of percent glaciers in the drainage to suspended-sediment yield--all sites.

Table 8. -- Summary of regression coefficients for suspended-sediment equations

[Log dependent variable = Log a + b_1 Log x_1 + b_2 Log x_2; for x_1 and x_2, see table 2 for description of values used as regression coefficients; QA, mean annual discharge]

Dependent variable	Regression coefficients					Coefficient of determination (r^2)	Standard error of estimate	
	Log a	x_1	b_1	x_2	b_2		Log units	Percent
Sediment yield [(ton/d)/mi²]								
Statewide	-1.931	Glacier +1	0.949	Length	0.389	0.63	0.461	+189 -65
Nonglacial	-3.578	QA	.228	Elev.1/	.752	.34	.443	+177 -64
Maritime-glacial	- .384	Glacier	.881	QA	.214	.74	.241	+ 74 -43
Interior-glacial	3.598	Glacier	1.078	Elev.	-1.050	.83	.197	+ 57 -36
Sediment load (ton/d)								
Statewide	-1.135	Glacier +1	0.935	Area	1.220	0.92	0.455	+185 -65
Nonglacial	-3.218	Area	1.135	Elev.1/	.719	.90	.455	+185 -65
Maritime-glacial	- .809	Glacier +1	.835	Area	.959	.92	.272	+ 87 -47
Interior-glacial	.370	Glacier +1	.804	Area	.929	.94	.205	+ 60 -38
Sediment concentration (mg/L)								
Statewide	-4.496	Area	0.347	Elev.	1.661	0.64	0.482	+203 -67
Nonglacial	-2.884	Length	.603	Elev.	1.128	.58	.448	+181 -64
Maritime-glacial	2.712	Glacier +1	.696	Precip.	-1.019	.65	.303	+101 -50
Interior-glacial	3.739	Glacier +1	.833	Precip.	-1.039	.65	.217	+ 65 -39

1/ The regression equation as a whole is statistically significant at the 95 percent confidence level but the indicated independent variable is not.

Table 9. -- Summary of observed and estimated suspended-sediment values for stations with daily sediment records

[I, interior-glacial; M, maritime-glacial; N, nonglacial]

Station	Stream type	Year with daily record	May-Oct. mean flow for year sampled (ft³/s)	Long-term May-Oct. mean flow used in developing regressions (ft³/s)	Mean suspended-sediment load (ton/d): Observed for year with daily record	Mean suspended-sediment load (ton/d): Estimated A	Estimated B	Estimated C	Mean suspended-sediment concentration (mg/L): Observed for year with daily record	Mean suspended-sediment concentration (mg/L): Estimated A	Estimated B	Estimated C	Mean suspended-sediment yield [(ton/d)/mi²)]: Observed for year with daily record	Mean suspended-sediment yield [(ton/d)/mi²)]: Estimated A	Estimated B	Estimated C
Copper River	I	1965	60,100		316,600				1,950				15.4			
near Chitina.		1964	63,200		315,950				1,850				15.3			
		--	--	67,400	--	346,600	200,900	232,600	--	1,900	816	1,362	--	16.8	7.49	15.4
Eagle River at	M	1969	770		296				143				1.54			
Eagle River.		1968	886		335				140				1.74			
		--	--	968	--	554	528	187	--	212	126	57	--	2.89	3.08	1.04
Knik River	I	1966	13,430		43,300				1,190				36.7			
near Palmer.		1965	11,970		37,400				1,160				31.7			
		1964	12,020		31,700				978				26.9			
		--	--	13,000	--	30,700	17,400	41,400	--	873	357	1,270	--	26.0	12.4	48.2
Susitna River	I	1952	19,300		41,260				796				6.70			
at Gold Creek.		--	--	17,700	--	43,400	16,500	28,300	--	906	488	623	--	7.05	2.70	4.38
Yukon River	I	1965	135,100		92,600				254				.82			
at Eagle.		1964	195,300		205,200				389				1.81			
		--	--	144,600	--	188,100	395,300	281,200	--	482	1,288	1,035	--	1.66	3.05	2.59
Tanana River	I	1966	12,780		42,200				1,220				4.94			
at Tanacross.		1965	11,460		34,400				1,110				4.02			
		1964	20,570		42,200				760				4.93			
		--	--	13,300	--	45,000	32,200	50,300	--	1,250	668	1,376	--	5.26	3.83	5.54
Chena River at	N	1970	1,446		56				14				.03			
Fairbanks.		1969	1,919		337				65				.17			
		1968	2,236		626				104				.32			
		1967	4,831		2,806				215				1.42			
		1966	2,122		647				113				.33			
		1965	2,440		375				57				.19			
		1964	2,693		816				112				.41			
		1963	3,821		1,354				131				.69			
		--	--	2,394	--	683	772	772	--	106	110	107	--	.34	.42	.38

A From the discharge-sediment curve for the station and daily flow values for the period of record (see page 33).

B From the statewide two-variable basin characteristics equation for long-term mean of suspended-sediment load.

C From the appropriate two-variable basin characteristics equation for long-term mean suspended-sediment load of non-glacial, interior-glacial, or maritime-glacial streams.

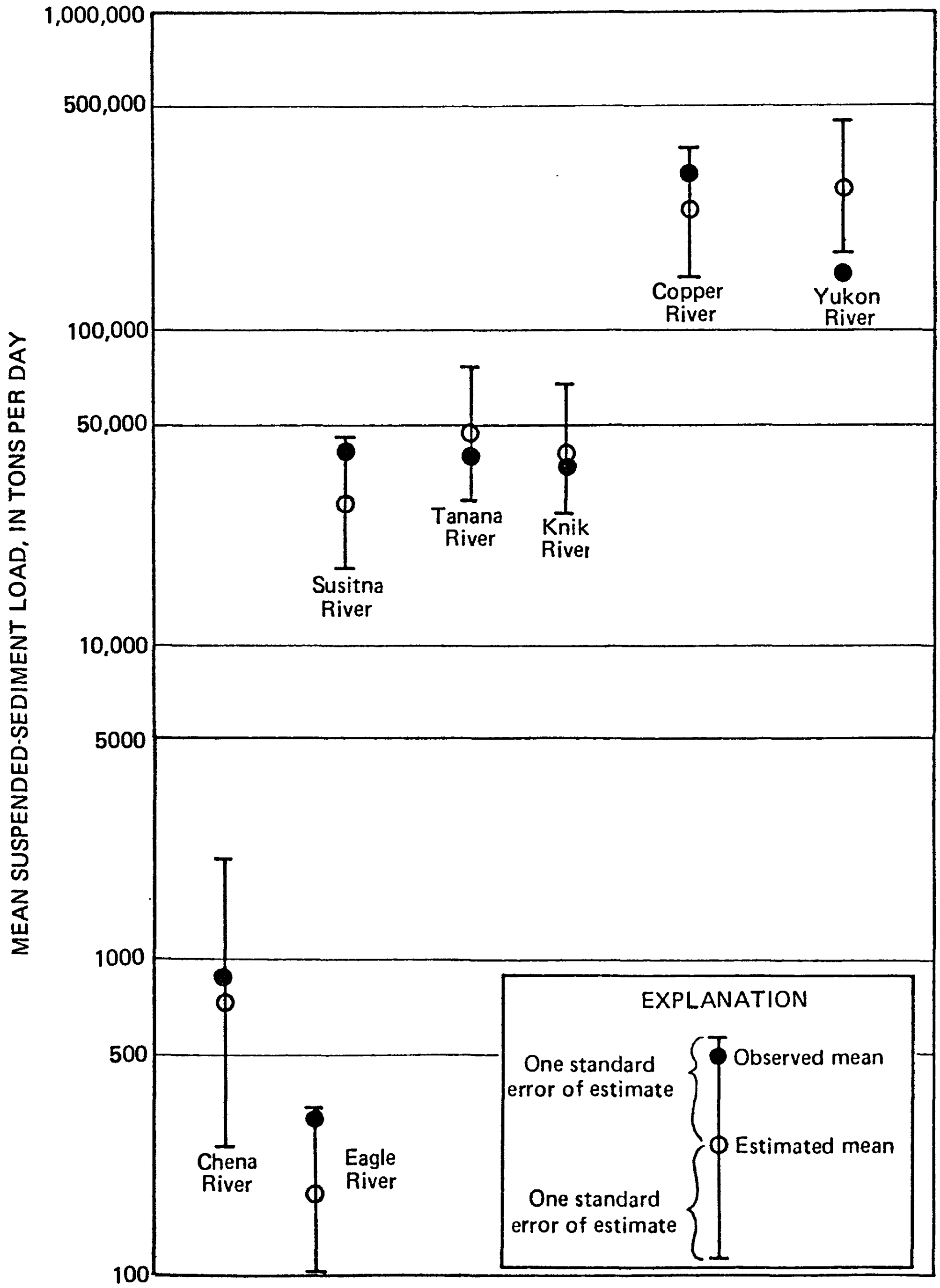

Figure 11.--Comparison of observed mean suspended-sediment loads with those estimated from the two-variable basin characteristics regression equations.

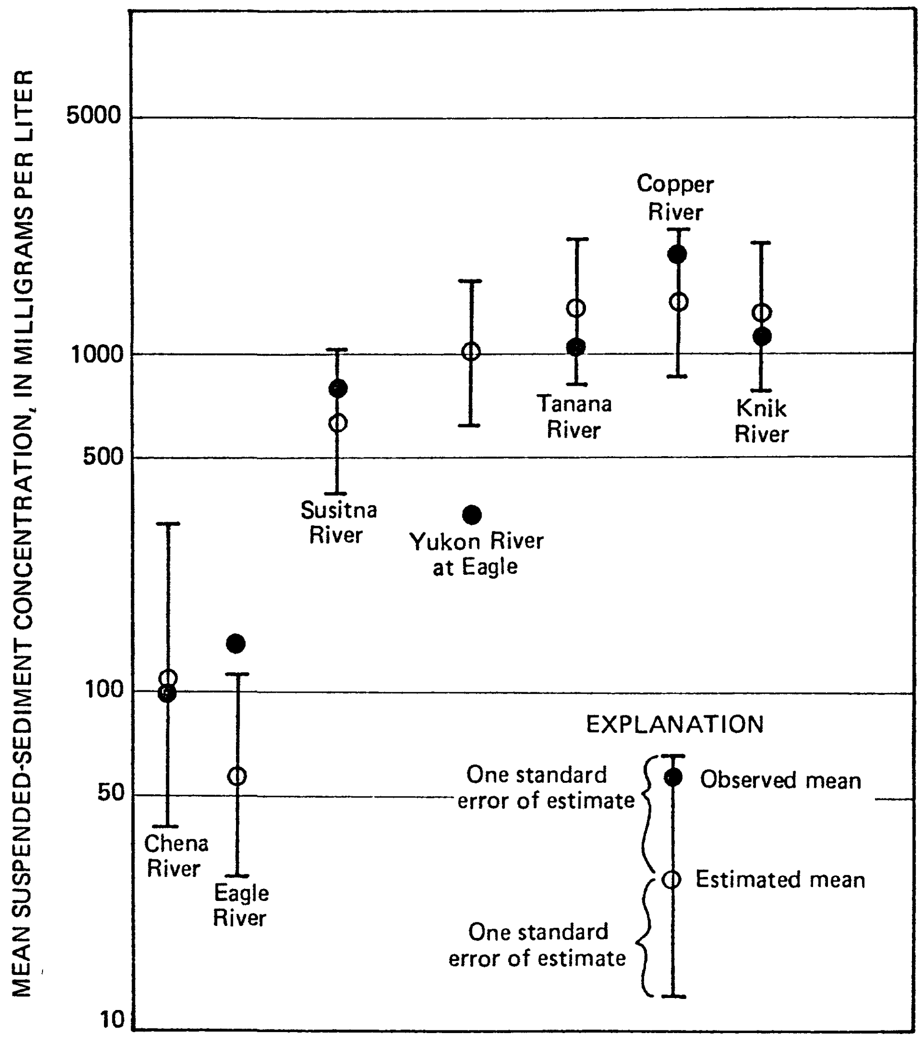

Figure 12.--Comparison of observed mean suspended-sediment concentrations with those estimated from the two-variable basin characteristics regression equations.

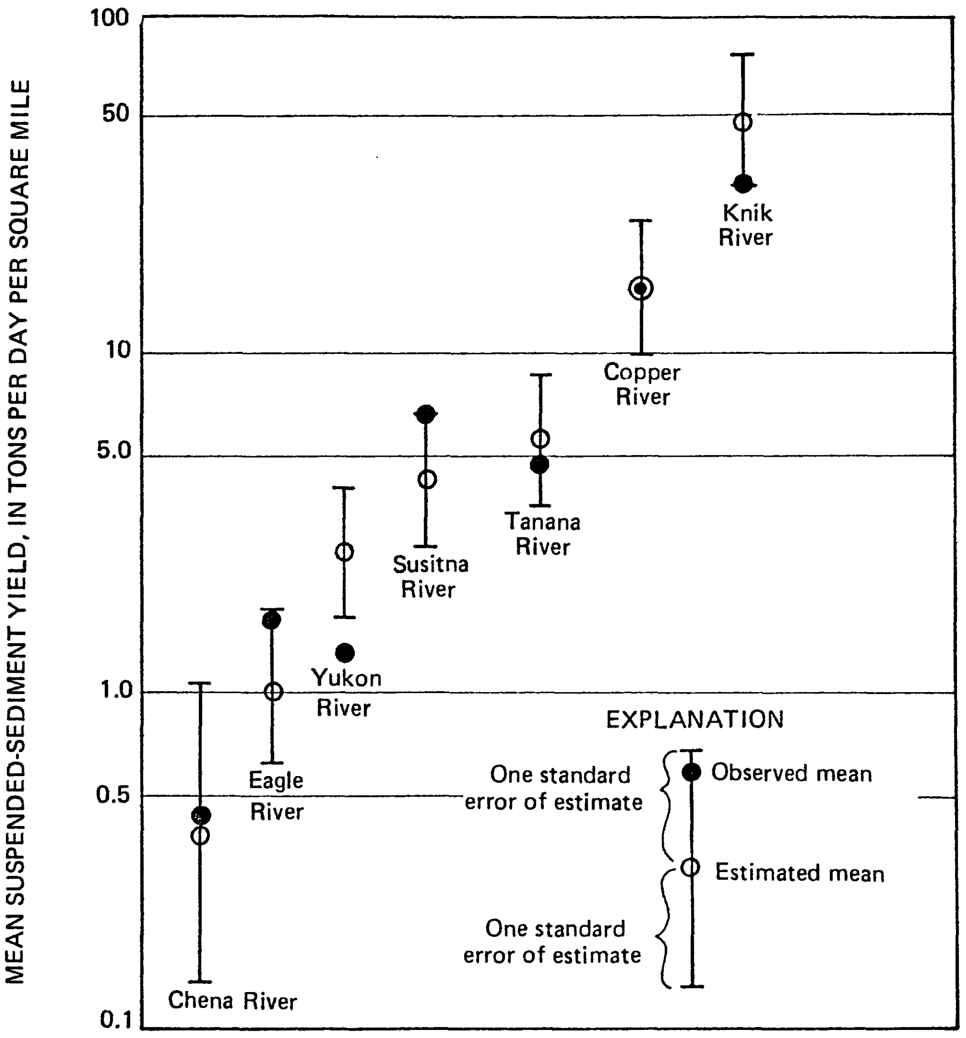

Figure 13.--Comparison of observed mean suspended-sediment yields with those estimated from the two-variable basin characteristics regression equations.

Table 10.-- Summary of regression coefficents for dissolved-solids concentration equations

[Log dissolved solids = Log a + b_1 Log x_1 + b_2 Log x_2; for x_1 and x_2, see table 2 for description of values used as regression coefficients]

Equation	Regression coefficients					Coefficient of determination	Standard error of estimate	
	Log a	x_1	b_1	x_2	b_2	(r^2)	Log units	Percent
Statewide	2.4260	Area	0.0735	Precip.	-0.4209	0.60	0.190	+55 -35
Nonglacial	2.4166	Slope[1/]	0.0980	Precip.	- .3200	.51	.179	+51 -34
Maritime-glacial	4.8228	Elev.[1/]	- .5277	Precip.	- .8289	.58	.184	+53 -35
Interior-glacial	2.6338	Slope	0.0735	Precip.	- .4951	.83	.052	+13 -11

1/ The regression equation as a whole is statistically significant at the 95 percent confidence level but the indicated independent variable is not.

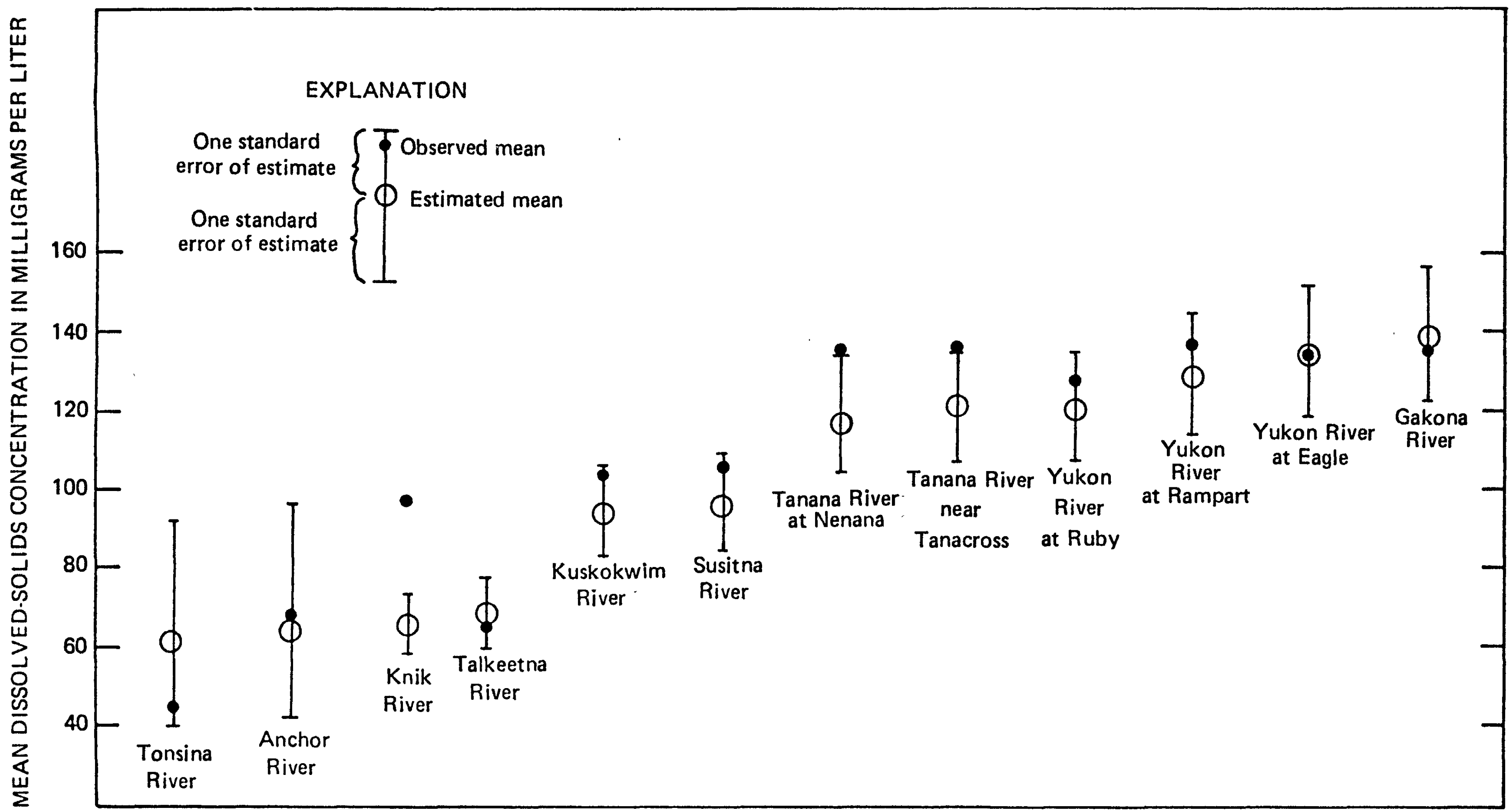

Figure 14.--Comparison of observed mean dissolved-solids concentrations with those estimated from the two-variable basin characteristics regression equations.

A statewide equation, based on data from 60 sites, explained 60 percent of the variability in dissolved-solids concentration with a standard error of 45 percent. The error coefficients for an equation for interior-glacial streams are lower. Although this equation is based on only 17 sites, a comparison of the estimated to observed values (table 11) suggests that the equations are valid. Ten of the 12 daily-record sites listed in table 11 are on interior-glacial streams and the estimated dissolved-solids concentrations for these streams were in close agreement with the observed values. For nonglacial and maritime-glacial streams, regression analysis based on basin characteristics provides a less precise relation and their use in estimating dissolved-solids concentrations may be limited. Although the regression equations for these stream types were statistically significant at the 95 percent confidence level, one of the two independent variables in the equation was not (see table 10).

Concentrations of Dissolved Inorganic Constituents Estimated from Field Measurements

Most major dissolved inorganic constituents in water are present as dissociated ions that can conduct an electrical current. The amount of current that can be conducted by water depends on the concentration of ions present and the relative charges. For this reason, specific conductance of water is a widely used indicator of the total concentration of dissolved ions. For water in which the relative percentages of the various dissolved ions do not vary appreciably, consistent relationships between individual dissolved ions and specific conductance may also exist.

Data on dissolved inorganic constituents and corresponding specific conductances have been collected at 879 sites on streams throughout Alaska at various times since the late 1940's. An initial review of these data indicated that the relationships between specific conductance and several of the major dissolved ions were virtually the same for many of the streams, and that a single relationship could probably represent large areas of the State. Because specific conductance can be simply and quickly measured in the field, a further evaluation of its usefulness for predicting concentrations of dissolved ions was made. The data were separated into two groups. The first group (162 sites, each having 10 or more analyses) was used to develop regression relationships of specific conductance to dissolved ions. The second group (717 sites with fewer than 10 analyses each) was used to compare observed values with those estimated by the regression equations. A single regression equation was developed from the data for each region for the winter (November to April) and open-water (May to October) periods. The regression equations and error statistics are shown in table 12. Except for the northwest and Arctic Slope regions, where very few samples were available for analysis, the regression equations explained more than 90 percent of the variation in concentrations of total dissolved solids, hardness, and calcium.

Bicarbonate and sulfate account for more than 90 percent of the dissolved anions in practically all streams in Alaska, but the relative percentages of the two ions vary considerably. Although bicarbonate usually predominates, sulfate may constitute nearly 50 percent of the dissolved anions at lower flows in some streams.

Table 11. -- Summary of observed and estimated dissolved-solids concentrations for stations with daily records

[I, interior-glacial; M, maritime-glacial; N, nonglacial]

Station	Stream type	Year with daily record	Number of days sampled (May-Oct.)	Mean dissolved-solids concentration(mg/L): Observed for year with daily record	Estimated A	Estimated B	Estimated C
Gakona River at Gakona	I	1954	119	138			
		1953	128	135			
		--	--	--	121	138	85
Tonsina River near Tonsina.	I	1966	171	46			
		1964	184	48			
		1963	164	40			
		1962	140	43			
		1961	148	42			
		1960	143	49			
		--	--	--	45	61	70
Anchor River near Anchor Point.	N	1966	154	65			
		--	--	--	70	64	64
Knik River at Palmer	M	1964	124	98			
		--	--	--	75	65	42
Susitna River at Gold Creek.	I	1952	172	100			
		1951	155	104			
		--	--	--	87	96	80
Talkeetna River near Talkeetna.	I	1954	184	65			
		--	--	--	63	68	51
Kuskokwim River at Crooked Creek.	I	1966	144	102			
		1965	151	94			
		1961	146	102			
		1957	164	121			
		--	--	--	94	94	101
Yukon River at Eagle	I	1962	106	114			
		1951	142	156			
		--	--	--	117	134	144
Yukon River at Rampart	I	1964	153	136			
		1962	95	133			
		1956	113	140			
		--	--	--	122	128	145
Tanana River near Tanacross.	I	1966	149	139			
		1965	152	148			
		1964	153	139			
		1963	118	124			
		1962	157	135			
		1961	157	135			
		1960	163	140			
		--	--	--	136	121	100
Tanana River at Nenana	I	1956	106	127			
		1954	167	143			
		--	--	--	134	117	111
Yukon River at Ruby	I	1973	146	123			
		1972	127	122			
		1967	150	124			
		1966	144	140			
		--	--	--	125	121	43

A From the discharge-dissolved solids curve for the station and daily flow values for the period of record.

B From the appropriate two-variable basin characteristics equation for non-glacial, interior glacial or maritime glacial streams.

C From the statewide two-variable basin characteristics equation.

Table 12. -- Summary of regression coefficients for equations to estimate concentrations of water-quality constituents

[Dependent variable = a + b_1 (specific conductance) + b_2 (bicarbonate); all constituents are in mg/L]

Dependent variable (region)	November-April period						May-October period					
	Sample size1/	Regression coefficients			Coefficient of determination	Standard error of estimate (SE)	Sample size1/	Regression coefficients			Coefficient of determination	Standard error of estimate (SE)
		a	b_1	b_2	(r^2)	(mg/L)		a	b_1	b_2	(r^2)	(mg/L)
Dissolved solids (sum)												
Southeast	191	3.91	0.531	--	0.94	5.9	276	3.83	0.532	--	0.92	5.3
South-central	853	3.48	.593	--	.96	10.2	1809	6.15	.572	--	.94	8.6
Southwest	30	1.8	.591	--	.99	4.8	213	2.84	.581	--	.98	5.4
Yukon	260	5.54	.583	--	.96	10.7	1217	.51	.597	--	.98	5.7
Northwest	18	49.46	.333	--	.70	5.5	57	3.40	.550	--	.95	5.6
Arctic Slope	14	4.92	.534	--	.76	14.6	90	4.78	.527	--	.97	7.4
Hardness as $CaCO_3$												
Southeast	233	-2.88	0.454	--	0.94	4.9	336	-2.21	0.474	--	0.93	4.2
South-central	908	.22	.432	--	.96	8.3	1926	-1.04	.451	--	.96	5.4
Southwest	32	-5.78	.521	--	.97	8.8	217	-3.60	.513	--	.97	5.3
Yukon	277	-2.24	.500	--	.95	10.7	1238	-4.87	.505	--	.96	6.4
Northwest	18	80.48	.107	--	.26	4.6	59	-2.66	.507	--	.97	4.2
Arctic Slope	16	8.67	.484	--	.84	13.9	97	- .01	.501	--	.95	8.6
Calcium												
Southeast	219	-0.97	0.150	--	0.90	2.2	295	-0.90	0.162	--	0.92	1.7
South-central	874	.67	.130	--	.92	3.5	1848	- .35	.141	--	.90	2.7
Southwest	31	- .70	.146	--	.96	2.7	214	- .50	.146	--	.92	2.6
Yukon	262	.84	.138	--	.90	3.9	1224	- .33	.142	--	.93	2.5
Northwest	18	28.03	.019	--	.11	1.4	57	- .16	.153	--	.94	1.8
Arctic Slope	14	-1.21	.176	--	.67	6.0	92	- .21	.180	--	.93	3.7
Bicarbonate as HCO_3												
Southeast	194	-2.72	0.443	--	0.88	6.3	301	-1.77	0.479	--	0.86	6.3
South-central	995	6.51	.384	--	.86	13.5	2061	5.42	.391	--	.87	8.7
Southwest	41	-5.65	.568	--	.98	9.0	275	-1.33	.512	--	.96	6.1
Yukon	296	6.77	.478	--	.83	19.3	1319	-1.75	.475	--	.87	11.7
Northwest	17	94.64	.057	--	.02	11.3	56	2.99	.480	--	.93	6.3
Arctic Slope	17	22.46	.508	--	.81	17.7	171	-8.33	.601	--	.90	13.9
Sulfate2/												
Southeast	230	-0.81	0.105	--	0.48	4.8	326	0.81	0.075	--	0.27	4.1
South-central	892	-6.31	.144	--	.61	10.2	1952	-6.04	.163	--	.68	6.4
Southwest	40	- .48	.072	--	.92	2.1	272	-1.34	.102	--	.80	3.0
Yukon	271	-8.93	.134	--	.54	10.9	1251	-3.90	.141	--	.54	8.0
Northwest	18	4.45	.047	--	.11	3.3	57	-3.38	.111	--	.56	4.5
Arctic Slope	17	14.67	-.022	--	.09	5.1	91	3.88	.011	--	.02	6.9
Sulfate3/												
Southeast	178	-2.75	0.309	-.434	0.74	3.3	258	-0.42	0.266	-0.383	0.62	2.9
South-central	877	-3.22	.317	-.453	.75	8.2	1894	-3.05	.383	-.559	.86	4.3
Southwest	39	- .97	.116	-.078	.93	2.1	270	-1.43	.169	-.129	.82	2.9
Yukon	265	-5.25	.337	-.430	.83	6.8	1247	-5.24	.418	-.580	.87	4.2
Northwest	17	21.14	.057	-.178	.41	3.0	54	-2.68	.263	-.314	.65	4.2
Arctic Slope	17	15.42	-.005	-.033	.10	5.2	85	2.21	.155	-.233	.26	5.9

1/ Number of sites used to develop regression equations: Southeast - 21, South-central - 81, Southwest - 6, Yukon - 43, Northwest - 6, and Arctic Slope - 5.

2/ Sulfate = a+b_1 (specific conductance)

3/ Sulfate = a+b_1 (specific conductance) + b_2 (bicarbonate)

Because the percentages of other dissolved anions (nitrate, fluoride, and chloride) do not vary significantly, an increase in the percentage of sulfate will almost always result in a corresponding decrease in the percentage of bicarbonate. This variability in chemical composition creates a less precise relationship between conductance and these two ions than for streams with a more consistent chemical composition. This is reflected in the lower coefficients of determination for bicarbonate and sulfate. The prediction of sulfate concentrations is considerably improved by using a multiple regression equation with bicarbonate and specific conductance as independent variables (table 12). Like specific conductance, bicarbonate can be easily and quickly measured in the field.

The relationship between specific conductance and the concentrations of other major dissolved constituents (sodium, potassium, chloride) was in most cases too poor to be considered for estimation of those concentrations. These constituents are usually present in concentrations less than 10 mg/L.

To test their usefulness, the equations were used to estimate dissolved-ion concentrations from observed specific conductances at the 717 sites not used to derive them. Figures 15 to 18 present the estimated and observed values for the four regions of Alaska for which a large number of analyses are available. The average error, computed as the mean of the difference between the estimated and observed values, agreed closely with the standard error of estimate for the regression equations. The average error, $\overline{D}$, of the estimated values was computed using the equation:

$$\overline{D} = \left[\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{n - 2} \right]^{\frac{1}{2}}$$

where O_i is the i^{th} observation;
P_i is the i^{th} estimate; and
n is the number of observations.

The standard errors of the regressions and the average error of estimated values for the south-central region are shown in table 13. The agreement between regression error and average error for the estimated values was similar for the other regions. The comparison of observed and estimated values indicates that field measurements of specific conductance and alkalinity can provide a basis for estimates of the major dissolved constitutents on a regional basis.

Estimation of the Concentration of Minor Elements in Transport

Several investigators have shown that the concentration of minor elements transported in streams is related to both suspended-sediment concentration and to the abundance of those elements in the rocks of the basin. Minor elements are transported mainly as crystalline particles or as metal hydroxide coatings on the

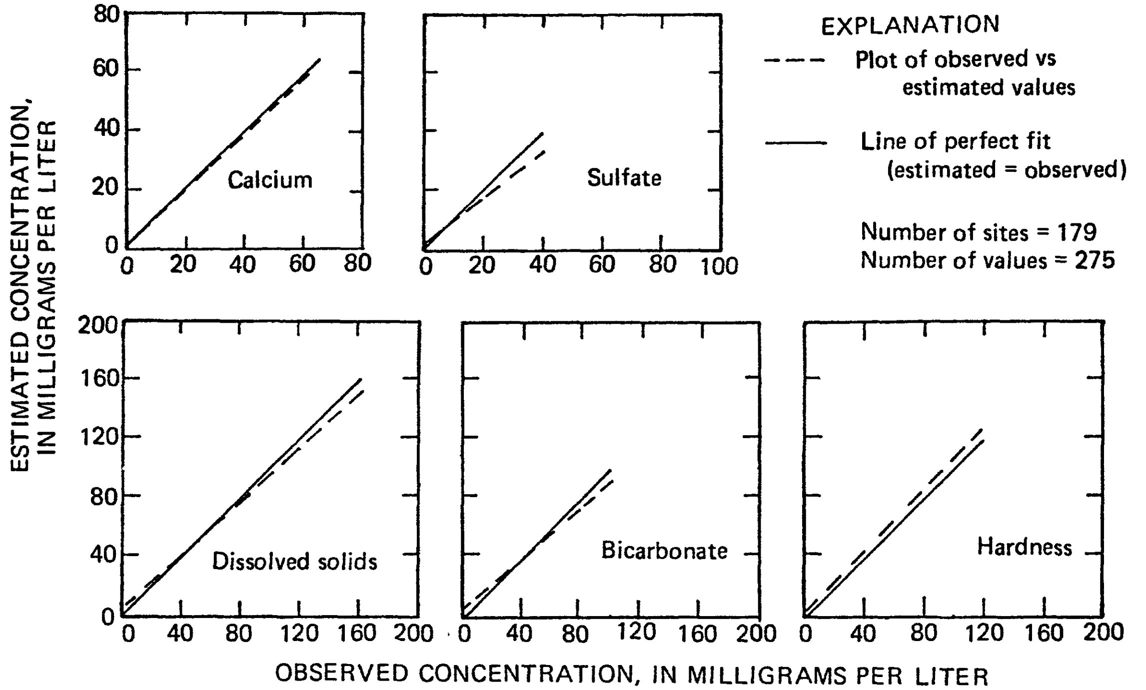

Figure 15.--Observed versus estimated concentrations of dissolved chemical constituents--southeast region.

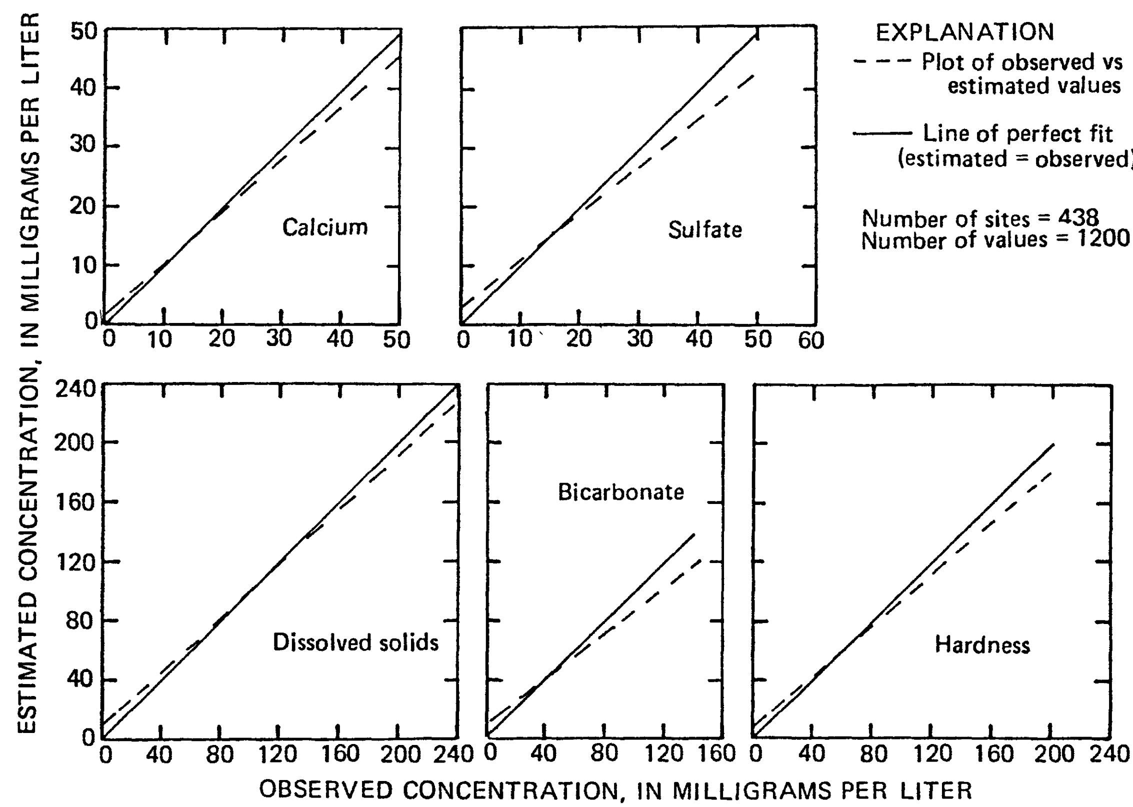

Figure 16.--Observed versus estimated concentrations of dissolved chemical constituents--south-central region.

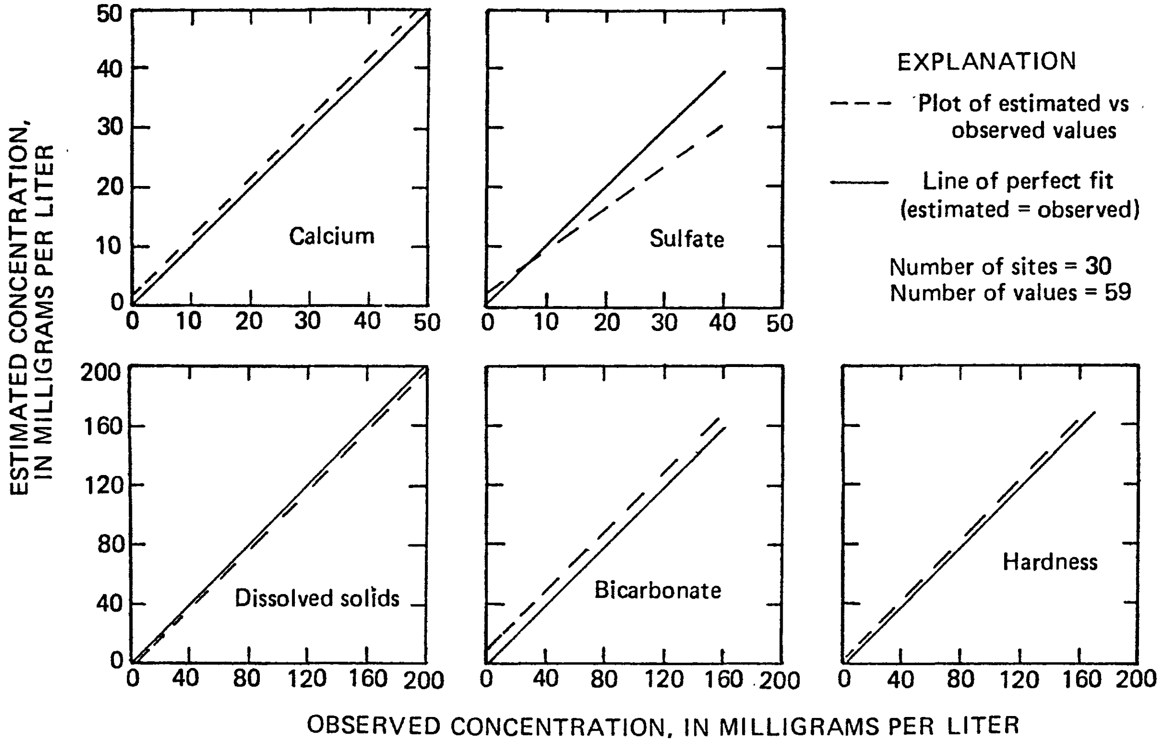

Figure 17.--Observed versus estimated concentrations of dissolved chemical constituents--southwest region.

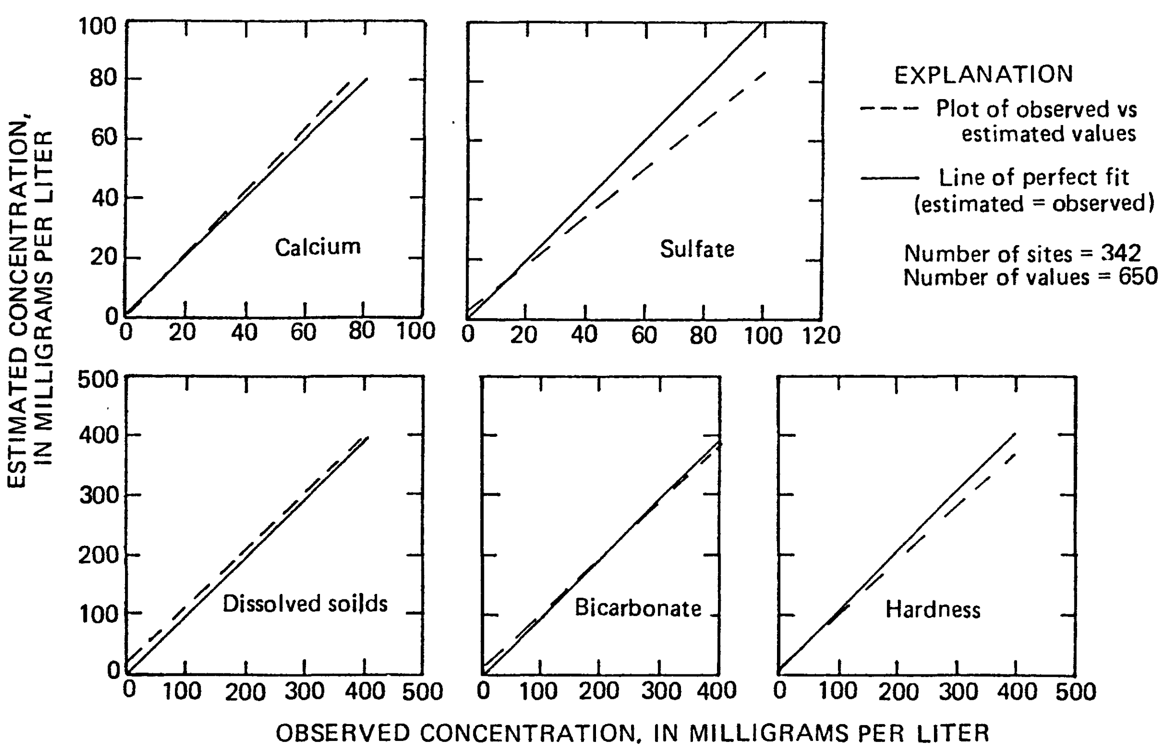

Figure 18.--Observed versus estimated concentrations of dissolved chemical constituents--Yukon region.

Table 13. -- Average error of estimated from observed values of dissolved-ion concentrations and standard error of estimates, south-central region

Constituent	Average error of estimated from observed values (mg/L)	Standard error of estimate for the regression equation (mg/L)	
		November-April	May-October
Dissolved solids	6.91	10.22	8.58
Alkalinity	12.38	13.48	8.74
Hardness	7.77	8.27	5.42
Calcium	3.16	3.46	2.70
Sulfate	5.88	10.24	6.42

Table 14. -- Concentration of minor elements in some common rock types and in suspended sediments of streams in the south-central region

Element	Mean concentration in common rock types (from Krauskopf, 1967) (µg/g)				Mean concentration, in stream suspended sediments (µg/g)
	Crustal materials	Granite	Basalt	Shale	
Iron	56,000	27,000	86,000	47,000	22,500
Lead	12.5	20	5	20	13
Zinc	70	40	100	80	75
Copper	55	10	100	57	60
Phosphorus	1,050	700	1,400	770	450

sediments (Gibbs, 1977). Less than 20 percent is usually transported in the dissolved phase. In unperturbed basins the concentration of a metal transported in the suspended phase should be related to the concentration of suspended sediment and the average concentration of that metal in rocks of the basin.

Few minor-element data are available for Alaskan streams. Of the available data, most are from large rivers which integrate the influence of different rock types. The data do indicate that the relationships for Alaskan streams may be consistent with those reported in the literature (table 14) for common rocks. In the south-central region, the concentration of iron in micrograms per gram of suspended sediment is consistent over a broad range of suspended-sediment concentration (fig. 19). The average concentration, 22,500 micrograms per gram, agrees closely with the reported values of iron content for several common rocks. Results of similar computations for several other minor elements are shown in table 14.

Our analysis suggests that the estimation of concentrations of minor elements in transport by Alaskan streams from information on suspended sediment and drainage basin geology may be a valid technique. However, much more information and analysis will be required to determine the reliability of the estimates.

DEFICIENCIES IN AVAILABLE DATA AND STRATEGIES FOR DATA COLLECTION

The reliability of the estimating equations given in this report is limited both by deficiencies in the available data and by an incomplete understanding of the relations between independent and dependent variables. Until more data become available, inherent errors cannot be significantly reduced and the errors of estimate cannot be accurately assessed. Programs directed toward collecting the kinds of data needed to improve the equations would also provide much of the information needed to plan the development and management of Alaska's water resources. In this section of the report, those deficiencies in the data base that are most critical in limiting the reliability of the estimating equations are outlined. In addition, data-collection strategies that would provide the information needed to better estimate streamflow and water quality are discussed.

Biases in Available Data

The estimating equations are based on available data, which are biased both areally and temporally. Records range in length from 5 to 62 years (average about 15 years) and many do not overlap in time. Very few sites in the southwest, northwest, and Arctic Slope regions have records of sufficient length to be included in our study. A better distribution of data both in time and in space would improve the estimating equations for all regions and all stream types. If, for practical reasons, areal distribution of data must be weighed against temporal correspondence, areal distribution is the more critical. Lack of temporal correspondence can be compensated, at least in part, by comparisons of long-term precipitation records.

Additional stream-gaging sites are needed in southwestern and northern Alaska. Until data from such sites become available, estimates of flow characteristics at

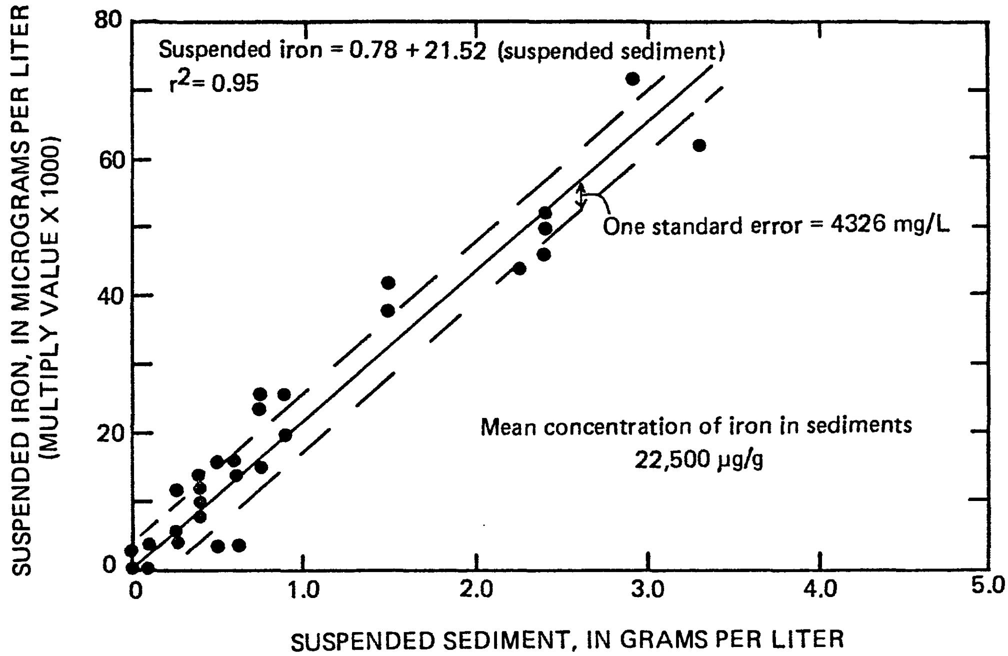

Figure 19.--Relation of suspended iron to suspended sediment for streams in south-central region.

ungaged sites in these areas will have large uncertainties. Data-collection sites should be selected to represent different basin sizes, climatic and physical characteristics, and variations in type. The transferability of the data to ungaged areas should be a prime consideration in network design. In southwestern Alaska, in the lower Yukon basin, and along the slopes of the Brooks Range, the collection of data from small streams (drainage area generally less than 50 mi^2) should be emphasized, because these are areas for which hydrologic data are sparse and where population and development will probably increase in the next few decades. In the southeastern region almost all the hydrologic data that have been collected are on small streams, and many sites have records longer than 20 years. About 30 percent of all active gaging stations in Alaska are in this region. The continued operation of more than two or three of those sites for the single purpose of better definition of flow frequencies or as long-term index stations is probably not warranted. To eliminate as much bias in basin size as possible, data collection in the region should now focus on sites having drainage areas greater than 100 mi^2 with less emphasis given to smaller streams.

At least two "benchmark" stations should be operated indefinitely in each of the six regions to define long-term, natural trends in streamflow (Childers, 1970b; Benson and Carter, 1973). Data from such stations, which by definition are in areas where no development has occurred and is not anticipated, can be used as a basis for distinguishing natural effects from man-induced effects in hydrologically similar basins.

It has been shown (Childers, 1970b; Benson and Carter, 1973) that an increase in the length of a record provides a decrease in the standard error of estimate for all flow characteristics. As the length of record increases, however, the improvement becomes progressively less because the error varies inversely as the square root of the number of years of record. If a small network of long-term benchmark stations were maintained, it would be unnecessary to continue other stations for extended periods. For ungaged sites, Benson and Carter (1973) suggested an accuracy goal equivalent to 10 years of record for minor streams and 25 years for principal streams.

Currently, there is no active network of benchmark stations in Alaska at which daily records of sediment or water quality are collected. A few daily record stations operated during the 1950's were used in this report to give a general indication of the accuracy of regression techniques in estimating values. However, those stations were primarily on glacial streams with large drainage areas. The establishment of a minimum network of daily-record water-quality stations at sites representative of the different regions and stream types should be a strong consideration in future program planning. The information gained would not only provide a much better definition of the seasonal and long-term variability in water-quality characteristics but would establish a basis for calibration of regional equations derived from data collected on a less frequent basis.

Determination of Channel Widths

The results of this study indicate that acceptable estimates of peak-flow events at ungaged sites can be made by using equations in which channel width is the independent variable. However, width measurements were available for only about 60 streams, which do not represent all areas of the State. The values of channel width used in the equations were obtained from discharge-measurement notes rather than collected specifically for the purpose of obtaining channel width. A reduction in the error of the equations may be possible if appropriate field measurements are obtained by standardized techniques at properly selected stream sections. Such measurements could be made with relatively little additional time and expense as a part of regular field visits to all gaging stations. Channel width measurements should also be obtained at discontinued data-collection sites.

In the absence of actual field measurements, channel width can be determined from aerial photographs (small streams) or topographic maps (large streams). For most Alaskan streams, such a simple, direct measurement involves fewer assumptions than does determination of average basin precipitation. Thus estimating equations based on channel widths can be applied with more confidence to a larger number of stations than can equations based on basin characteristics (for which a precipitation value is required).

Instantaneous Suspended-Sediment Transport Curves

The accuracy of an instantaneous suspended-sediment transport curve is dependent on the assumption that the data are reasonably well distributed over the range of expected discharges and are normally distributed about a mean line. Because the highest concentrations or loads of suspended sediment commonly occur during highest flows, these flows must be adequately sampled. However, the logistics of field work in Alaska commonly make it difficult to reach sampling sites during storm events or during the period of spring breakup when higher flows occur. For more than half the sites, the highest discharge for which sediment data are available is significantly less than the mean annual peak discharge (figure 20). No site in the southeast region has been sampled at a discharge as great as the mean annual peak.

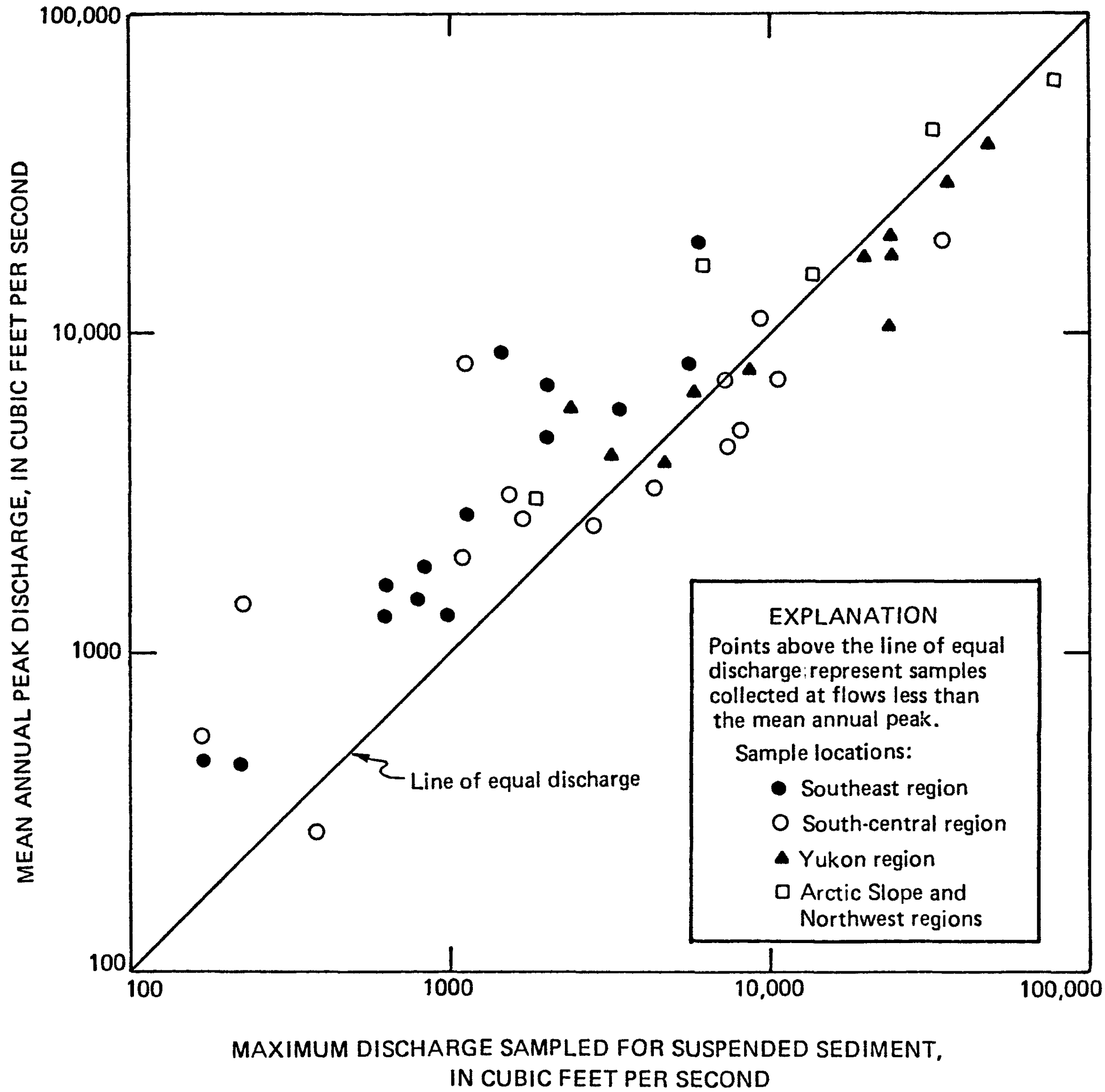

Figure 20.--Comparison of mean annual peak discharge to highest discharge at which suspended-sediment data were collected.

Sediment transport curves developed using data that are weighted toward lower flows will tend to have a greater slope and thus predict sediment values higher than actual for the higher flows. Figure 21 shows the sediment-transport curves developed from intermittent samples and from daily samples collected at two daily record stations. The 90 samples collected intermittently at the Tanana River at Tanacross were equally distributed throughout the flow range, and both daily and intermittent samples were collected at flows greater than the mean annual peak of 30,000 ft^3/s. The mean annual peak flow of the Yukon River at Eagle is 300,000 ft^3/s. Of the 26 samples collected intermittently at this site, 22 represented flows less than 200,000 ft^3/s and no samples were obtained at flows greater than 250,000 ft^3/s.

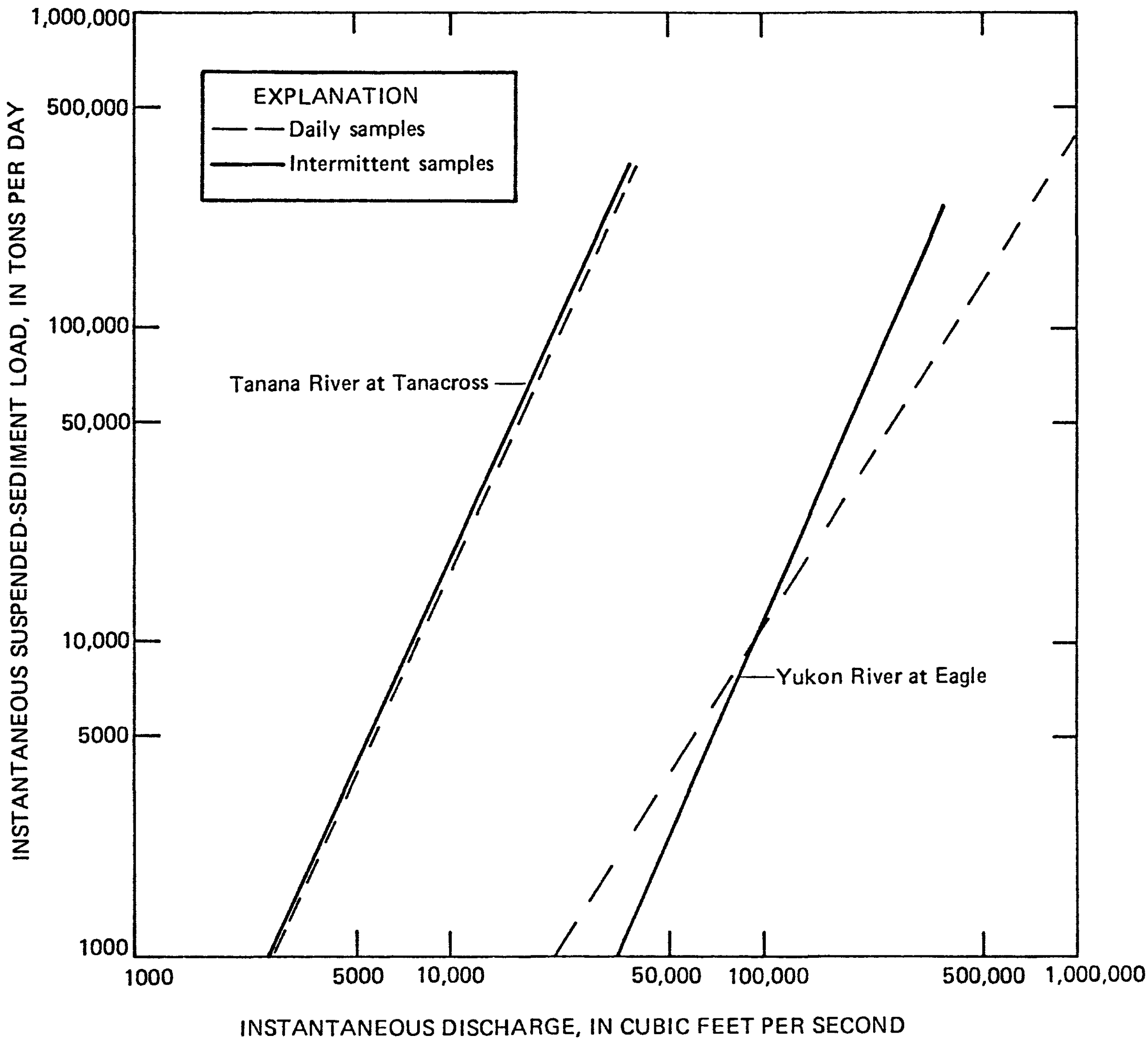

Figure 21.--Comparison of suspended-sediment transport curves derived from daily and intermittently collected samples.

The 1,728 daily samples for this station include those collected at flows greater than the 50-year flood (550,000 ft^3/s). The effect of inadequate sampling of the higher flows on the Yukon River is apparent from a comparison of the two transport curves for this stations.

In addition to the 60 sites for which data are adequate to define suspended-sediment transport curves, a small amount of sediment information is available at approximately 200 additional streams. These streams were not included in this report because higher flows had not been sampled adequately to define the relationship between water discharge and sediment concentration. The collection of a relatively small number of additional samples on many of these streams during high flows would result in a large improvement in the data base.

OTHER FACTORS AFFECTING FLOW AND QUALITY OF ALASKA STREAMS

Two factors of climate influence Alaska's streams in unique ways as compared with other states: heavy precipitation, much of it as snow, in the southern coastal areas; and long periods of sub-freezing temperatures in the mountains and in interior and northern regions of the State. Those factors result in the presence of glaciers at the land surface and permafrost beneath it, which in various ways influence both the flow and water quality of the streams.

Low flow of many Alaskan streams is influenced by factors in addition to basin geology and the duration of periods of little or no precipitation. Except for the relatively warm coastal areas of south-central and southeastern Alaska, winter precipitation is stored as snow or ice rather than producing immediate runoff to streams. The rate and amount of runoff from later melting of the snow and ice vary widely from one area to another and from year to year. In interior and northern parts of the State, permafrost (permanently frozen ground) as well as basin geology directly or indirectly controls (and commonly restricts) the amount of ground-water flow and thus the contribution of ground water to streams.

In glacier-fed streams most of the suspended-sediment load is generated by the glaciers. The percentage of the basin covered by glacier ice is a definable variable that seems to explain most of the variance in the estimating equations for suspended-sediment load in such streams. For nonglacial streams, however, the variability in suspended-sediment load may be better related to factors that have not, or cannot, be readily quantified. For example, soil type or precipitation intensity may have a stronger influence than factors such as mean precipitation, stream length, or elevation.

The factors that influence streamflow and sediment load are not homogeneous over large areas. Thus their effects on a particular stream or basin should be evaluated, and, if possible, quantified in future attempts to increase the reliability of estimating equations for flow and water quality.

SUMMARY

Estimates of flow and water quality for Alaskan streams can be made with empirical equations derived by multiple regression techniques. The reliability of estimates made from equations in this report, however, is compromised by deficiencies in available data, which are both scarce and biased in time and areal distribution. For this reason, the equations may not be sufficiently reliable for some design and planning purposes. Improvement of the equations will require collection of additional data.

The most reliable equations for estimating streamflow are those which use drainage area and precipitation as the independent variables. Channel widths can be used for estimating peak flows but are less applicable for estimating other flow characteristics. Use of equations developed from mean annual flow or the 2-year peak can provide useful estimates of other flow characteristics, but require some minimum amount of flow data. This latter requirement limits the number of sites to which these equations can be applied.

Suspended-sediment characteristics of glacial streams can be estimated using the equations derived from basin properties. For nonglacial streams, which tend to carry lower suspended-sediment loads, the estimating equations are less reliable. Similarly, concentrations of dissolved solids can be estimated using basin properties, although equations for interior glacial streams are more reliable than those for maritime glacial and nonglacial streams.

Concentrations of dissolved inorganic constituents can be estimated using equations derived from values of specific conductance and bicarbonate, properties that can be easily measured in the field. Estimating the concentrations of minor elements in transport must include information on both the suspended sediment in the stream and geology of the basin.

The scarcity and bias of the existing data can be offset in the future by directing data collection efforts toward filling specific voids. Operation of long-term index stations in each region will provide a basis for comparison with shorter records at other stations. Field measurements of channel widths specifically for use in estimating equations will improve those equations. Suspended sediment should be sampled at peak flows and analyzed not only for the suspended-sediment concentration but also for the full suite of water-quality variables. These additional analyses would provide the data necessary to refine the estimating equations.

SELECTED REFERENCES

American Society for Civil Engineers, 1980, Characteristics of low flow (by the Task Committee on Low-Flow Evaluation Methods and Needs of the Committee on Surface Water Hydrology): American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division, v. 106, no. HY5, p. 717-731.

Anttila, P. W., and Tobin, R. L., 1978, Fluvial sediment in Ohio: U.S. Geological Survey Water-Supply Paper 2045, 58 p.

Barr, A. J., Goodnight, J. H., and Sall, J. P., 1979, SAS users guide: SAS Institute Inc., Cary, North Carolina, 494 p.

Benson, M. A., and Carter, R. W., 1973, A national study of the streamflow data-collection program: U.S. Geological Survey Water-Supply Paper 2028, 44 p.

Carter, R. W., and Benson, M. A., 1970, Concepts for the design of streamflow data programs: U.S. Geological Survey open-file report, 33 p.

Childers, J. M., 1970a, Flood frequency in Alaska: U.S. Geological Survey open-file report, 30 p.

_____1970b, A proposed streamflow-data program in Alaska: U.S. Geological Survey open-file report, 55 p.

_____1972a, Channel erosion surveys along proposed TAPS routes, Alaska: U.S. Geological Survey open-file report, 79 p.
_____1972b, Flood surveys along proposed TAPS route, Alaska, July 1971: U.S. Geological Survey open-file report, 16 p.
_____1972c, Channel erosion surveys along proposed TAPS route, Alaska, July 1971: U.S. Geological Survey open-file report, 79 p.
_____1974, Flood surveys along TAPS route, Alaska: U.S. Geological Survey open-file report, 16 p.
_____1975, Channel erosion along southern segment of the TAPS route, Alaska, 1972 and 1973: U.S. Geological Survey open-file report, 57 p.
Childers, J. M., and Jones, S. H., 1975, Channel erosion surveys along the TAPS route, Alaska, 1974: U.S. Geological Survey open-file report, 145 p.
Childers, J. M., and Kernodle, D. R., 1981, Hydrologic reconnaissance of the Noatak River basin, Alaska, 1978: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-1005, 38 p.
Childers, J. M., Kernodle, D. R., and Loeffler, R. M., 1979, Hydrologic reconnaissance of western Arctic Alaska, 1976 and 1977: U.S. Geological Survey Open-File Report 79-699, 70 p.
Childers, J. M., and Lamke, R. D., 1973, Flood survey at proposed TAPS crossings of Yukon River near Stevens Village, Alaska: U.S. Geological Survey open-file report, 12 p.
Colby, B. R., 1956, Relationship of sediment discharge to streamflow: U.S. Geo.-logical open-file report, 170 p.
Dalrymple, Tate, 1960, Flood-frequency analysis: U.S. Geological Survey Water-Supply Paper 1543-A, 80 p.
Dawdy, D. R., Lichty, R. W., and Bergmann, J. M., 1972, A rainfall-runoff simulation model for estimation of flood peaks for small drainage basins: U.S. Geological Survey Professional Paper 506-B, 28 p.
Doyle, P. F., and Childers, J. M., 1975, Channel erosion surveys along TAPS route, Alaska, 1975: U.S. Geological Survey open-file report, 95 p. [1976].
Emmett, W. W., 1972, The hydraulic geometry of some Alaskan streams south of the Yukon River: U.S. Geological Survey open-file report, 102 p.
Gibbs, R. J., 1977, Transport phases of transition heavy metals in the Amazon and Yukon Rivers: Geological Society of America Bulletin, v. 88, p. 829-843.
Hardison, C. H., 1969, Accuracy of streamflow characteristics, in Geological Survey Research 1969: U.S. Geological Survey Professional Paper 650-D, p. D210-D214.
_____1971, Prediction error of regression estimates of streamflow characteristics at ungaged sites, in Geological Survey Research 1971: U.S. Geological Survey Professional Paper 750-C, p. C228-C236.
Hardison, C. H., and Moss, M. E., 1972, Accuracy of low-flow characteristics estimated by correlation of base-flow measurements, with a section on Outline of derivations, by E. J. Gilroy: U.S. Geological Survey Water-Supply Paper 1542-B, p. B1-B55.
Hedman, E. R. 1970, Mean annual runoff as related to channel geometry in selected streams in California: U.S. Geological Survey Water-Supply Paper 1999-E, 17 p.
Hedman, E. R., Kastner, W. M., and Hejl, H. R., 1974, Selected streamflow characteristics as related to active-channel geometry of streams in Kansas: Kansas Water Resources Board Technical Report No. 10, 21 p.

Johnson, P. R., and Hartman, C. W., 1969, Environmental atlas of Alaska: University of Alaska, Institute of Arctic Environmental Engineering and Institute of Water Resources, 111 p.

Krauskopf, K. B., 1967, Introduction to geochemistry: New York, McGraw-Hill, 721 p.

Lamke, R. L., 1979, Flood characteristics of Alaskan streams: U.S. Geological Survey Water-Resources Investigations 78-129, 61 p.

Leopold, L. B., and Maddock, Thomas, 1953, The hydraulic geometry of stream channels and some physiographic implications: U.S. Geological Survey Professional Paper 252, 57 p.

Lichty, R. W., and Liscum, F., 1978, A rainfall-runoff modeling procedure for improving estimates of T-year (annual) floods for small drainage basins: U.S. Geological Survey Water-Resources Investigations 78-7, 49 p.

McCuen, R. H., and others, 1977, Flood flow frequency for ungaged watersheds: A literature evaluation: U.S. Agricultural Research Service Report ARS-NE-86, 136 p.

Miller, C. R., 1951, Analysis of flow-duration, sediment-rating curve method of computing sediment yield: U.S. Bureau of Reclamation, Hydrology Branch, Project Planning Division, Denver, Colo., 55 p.

Miller, J. F., 1963, Probable maximum precipitation and rainfall-frequency data for Alaska: U.S. Weather Bureau Technical Paper No. 47, 69 p.

Moore, D. O., 1974, Estimating flood discharges in Nevada using channel-geometry measurements: State of Nevada, Highway Department Hydrologic Report No. 1, 43 p.

_____ 1976, Estimating peak discharges from small drainages in Nevada according to basin areas within elevation zones: State of Nevada, Highway Department Hydrologic Report No. 3, 17 p.

National Weather Service, 1972, Mean annual precipitation--inches: National Weather Service [Alaska], map.

Newton, D. W., and Herrin, J. C., 1982, Assessment of commonly used flood frequency methods: Washington D.C., National Academy of Science, National Research Council, Transportation Research Record Series, TRR 896, p. 10-30.

OTT Water Engineers, Inc., 1979, Water resources atlas for USDA Forest Service, Region 10 Juneau, Alaska: Redding, Calif., 7 p., 5 appendices.

Overman, R. P., and Clarke, H. M., 1960, Radio isotope techniques: New York, McGraw-Hill, p. 108-109.

Post, Austin, and Mayo, L. R., 1971, Glacier dammed lakes and outburst floods in Alaska: U.S. Geological Survey Hydrologic Investigation Atlas HA-455, 3 sheets.

Riggs, H. C., 1968a, Some statistical tools in hydrology: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 4, Chapter A1, 39 p.

_____ 1968b, Frequency curves: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 4, Chapter A2, 15 p.

_____ 1969, Mean streamflow from discharge measurements: International Association of Science Hydrology Bulletin, v. XIV, no. 4, Dec. 1969, p. 95-109.

_____ 1972, Low flow investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 4, Chapter B1, 18 p.

_____ 1973, Regional analysis of streamflow characteristics: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 4, Chapter B3, 15 p.

_____1978, Streamflow characteristics from channel size: American Society of Civil Engineers, Journal of Hydraulics Division, v. 104, no. HYI, p. 87-96.

Riggs, H. C., and Moore, D. O., 1965, A method of estimating mean runoff from ungaged basins in mountainous regions: U.S. Geological Survey Professional Paper 525-D, p. 199-202.

Santeford, H. S., 1976, A preliminary analysis of precipitation in the Chena River basin, Alaska: National Weather Service, NOAA Technical Memorandum NWS AR-15, 19 p.

Scully, D. R., Krumhardt, A. P., and Kernodle, D. R., 1981, Hydrologic reconnaissance of the Beluga, Peters Creek, and Healy coal areas, Alaska: U.S. Geological Survey Water-Resources Investigations 81-56, 71 p.

Searcy, J. K., 1959, Flow duration curves: U.S. Geological Survey Water-Supply Paper 1542-A, p. 1-33.

_____1960, Graphical correlation of gaging-station record: U.S. Geological Survey Water-Supply Paper 1541-C, p. 67-100.

Searcy, J. K., and Hardison, C. H., 1960, Double-mass curves, with a section on Fitting curves to cyclic data, by W. B. Langbein: U.S. Geological Survey Water-Supply Paper 1541-B, p. 31-66.

Sloan, C. E., Zenone, Chester, and Mayo, L. R., 1976, Icings along the trans-Alaska pipeline route: U.S. Geological Survey Professional Paper 979, 39 p.

Tangborn, W. V., and others, 1977, Combined ice and water balances of Maclure Glacier, California, South Cascade Glacier, Washington, and Wolverine and Gulkana Glaciers, Alaska, 1967 hydrologic year: U.S. Geological Survey Professional Paper 715-B, 20 p. 4 pl.

Thomas, D. M., and Benson, M. A., 1970, Generalization of streamflow characteristics from drainage basin characteristics: U.S. Geological Survey Water-Supply Paper 1975, 55 p.

U.S. Army Corps of Engineers, 1973, Computer program 723-X6-L2010, HEC-1 flood hydrograph package, Users manual: U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, Calif.

U.S. Department of Agriculture, 1975, Present and prospective technology for predicting sediment yields and sources, in Proceedings of Sedimentation Laboratory, Oxford, Miss., Nov. 28-30, 1972: U.S. Agricultural Research Service Report ARS-5-40, 285 p.

_____1977, Flood flow frequency for ungaged watersheds: A literature evaluation: U.S. Agricultural Research Service Report ARS-NE-86, 156 p.

U.S. Water Resources Council, 1966, Methods of flow frequency analysis: U.S. Water Resources Council, Subcommittee on Hydrology - Interagency Committee on Water Resources, April 1966, 42 p.

_____1967, A uniform technique for determining flood flow frequencies: U.S. Water Resources Council Bulletin 15, 15 p.

_____1970, Water resources regions and subregions for the national assessment of water and related land resources: Washington, D.C., U.S. Water Resources Council, 188 p., 6 pl.

_____1977, Guidelines for determining flood flow frequencies: U.S Water Resources Council Bulletin 17A, 106 p.

_____1981a, Estimating peak flow frequencies for natural ungaged watersheds, A proposed nationwide test: U.S. Water Resources Council - Hydrology Committee, 346 p.

_____1981b, Guidelines for determining flood flow frequencies: U.S. Water Resources Council Bulletin 17B, 28 p., 14 appendices.

U.S. Weather Bureau, 1963, Probable maximum precipitation and rainfall frequency data for Alaska: U.S. Weather Bureau Technical Paper No. 47.

Wahl, R. L., 1977, Accuracy of channel measurements and the implications in estimating streamflow characteristics: U.S. Geological Survey Journal of Research, v. 5, no. 6, p. 811-814.

Wolman, M. G., and Leopold, L. B., 1957, River flood plains -- Some observations on their formation: U.S. Geological Survey Professional Paper 282-C, p. 87-109.