UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

COST-EFFECTIVENESS OF THE STREAM-GAGING PROGRAM IN ALASKA

By R. D. Lamke

U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS REPORT 84-4096

Anchorage, Alaska

1984

UNITED STATES DEPARTMENT OF THE INTERIOR

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Multiply inch-pound units	by	To obtain SI units
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
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]

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By R. D. Lamke

ABSTRACT

This report documents the results of a study of the cost-effectiveness of the stream-gaging program in Alaska. Data uses and funding sources were identified for the 110 continuous stream-gaging stations that were being operated in September 1983 with a budget of about $1,700,000 per year.

However, for the purposes of the report, only 98 stations were included in the analysis of cost-effectiveness. The current policy for operation of the 98-station program required $1,539,000 (1983 dollars) per year, which results in an average standard error of estimate of streamflow records for open-water periods of 18.4 percent. This overall level of accuracy at the 98 sites could be maintained with a budget of approximately $1,440,000 if the scheduling of visits and allocation of funds to the stations were changed.

A minimum budget of $1,381,000 is required to operate the 98 stations; a budget less than this does not permit proper service and maintenance of the gages and recorders. At the minimum budget, the average standard error is 19.8 percent. Several other budgets were analyzed; the maximum budget analyzed was $2,500,000, which resulted in an average standard error of 11.9 percent.

A significant portion of the standard error is attributable to loss of gage-height record, which is used to compute open-water discharge records. If gage-height record loss could be prevented, the average standard error could be reduced to 13.4 percent at the minimum operating budget of $1,381,000.

It was determined that the standard error of estimate of streamflow records could be reduced by changing some operational policies and by reducing the amount of missing gage-height record. Since there is no method to determine standard errors of Alaska's winter records of streamflow, it was concluded that such a technique should be developed.

More than half of western Alaska was identified as having insufficient streamflow data. It is suggested that steps be undertaken to remedy this situation as funds become available.

INTRODUCTION

The U.S. Geological Survey (USGS) is the principal Federal agency collecting surface-water data in the Nation. A major activity of the Water Resources Division of the USGS is the collection of these data in cooperation with State and local governments and other Federal agencies. Approximately 8,000 continuous-record gaging stations throughout the Nation are currently (1983) being operated by the USGS. Any long-term activity, such as the collection of surface-water data, should be reexamined periodically because of changes in objectives, technology, or external constraints. The last systematic nationwide evaluation of the streamflow information program was completed in 1970 (Benson and Carter, 1973). The USGS is presently (1983) undertaking another nationwide analysis of the stream-gaging program with the objective of defining and documenting the most cost-effective means of furnishing streamflow information.

For every active continuous-record gaging station in the Alaska stream-gaging program (as of September 1983), the first section of the analysis identifies the principal uses of the data and relates these uses to funding sources. Gaged sites are examined to determine if data collection is still needed, and deficient or unmet data demands are identified. In addition, the data availability at the gaging stations is classified as to whether the data are available to users immediately (as they are collected or recorded) or soon afterwards, on a provisional basis, or at the end of the water year.

The second aspect of the analysis is to identify less costly alternative methods of furnishing the needed information; among these are flow-routing models and statistical methods. The alternative methods should provide daily mean streamflow information with acceptable accuracy in place of the discharges obtained by operating a gaging station.

The final part of the analysis uses Kalman-filtering and mathematical-programming techniques to define operating strategies that minimize, for given operating budgets, the uncertainty in the streamflow records of stations in the network. Kalman-filtering techniques are used to compute uncertainty functions (relating the standard errors of computation or estimation of streamflow records to the frequencies of measurements and visits to the stream gages) for all stations in the analysis. A steepest descent optimization program uses these uncertainty functions, information on practical stream-gaging routes, the various costs associated with stream gaging, and the total operating budget to determine the visit frequency for each station that will minimize the overall uncertainty in the streamflow records. The resulting stream-gaging program will meet the expressed water-data needs in the most cost-effective manner.

This report is organized into five sections. The first is an introduction to the study and to stream-gaging activities in Alaska. The middle three sections each discuss an individual step of the analysis. Because of the sequential nature of the steps and the dependence of subsequent steps on the previous results, conclusions are made at the end of each of the middle three sections. The study, including all conclusions, is summarized in the final section.

Acknowledgment

This report is part of a series presenting results of the nationwide analysis of the stream-gaging program of the Geological Survey. The individual reports have portions in common and the structure of the individual reports is similar.

Portions of this report are taken directly from the prototype report, "Cost-Effectiveness of the Stream-Gaging Program in Maine" by Fontaine and others (1983). This statement applies particularly to the preceding introductory material and to later sections on theory and methods used in Kalman-filtering and mathematical-programming techniques.

History of the Stream-Gaging Program in Alaska

The program of surface-water investigations by the USGS in Alaska has changed and grown in scope over the years as Federal, State, and local interest in water resources has increased. The USGS has been involved in the collection and analysis of water-resources information in Alaska since 1906. Early data collection was sporadic and primarily provided water-supply data for site specific purposes. A comprehensive program of streamflow and other water-resources investigations was started in 1946. Early streamflow data-collection efforts are summarized in Water-Supply Paper 1372, "Compilation of Records of Quantity and Quality of Surface Water of Alaska through September 1950" (U.S. Geological Survey, 1957); a condensation of this summary follows:

> Collection of streamflow data by the Geological Survey in the Territory of Alaska began during the summer of 1906 in connection with placer mining for gold near Nome on the Seward Peninsula. Data collection expanded in 1907 on the Seward Peninsula and into the Yukon and Tanana River basins. Records were mostly seasonal and records end during the 1910-12 period. Efforts were shifted in 1913 to a general reconnaissance of water-power potential of many sites in the lower Copper River basin and Prince William Sound area. In 1915, the Survey began a study to evaluate water-power potential in southeast Alaska; data collection by USGS stopped in 1921. However, streamflow data collection continued at a reduced level until 1946 by private companies, the U.S. Forest Service, and Federal Power Comission permittees.

The program expanded after the establishment in 1946 of the Alaska District of the USGS. There were 47 active gaging stations in 1950, all of which were funded by Federal Government. Sixteen of these stations were in Southeast Alaska, 7 in the Copper River basin and Prince William Sound area, 16 in the Cook Inlet basin, 7 in the Tanana River basin, and 1 on the Yukon River at Eagle near the Canadian border. The U.S. Army Corps of Engineers and U.S. Bureau of Reclamation later funded stream-gaging stations that supplemented those funded by the USGS. Data collection began on Kodiak Island and on the Kuskokwim River in 1951. The Corps provided funds in the 1950's and 1960's for the expansion of streamgaging on the Yukon River and its principal tributaries. The Bureau (and its successor agency in Alaska, the Alaska Power Administration) funded stations needed for hydropower studies. Data collection started on the Seward Peninsula and northwest Alaska in the 1960's and on the Arctic Slope in 1969. Six short-term gaging stations were operated on Amchitka Island in the Aleutian Islands between 1967 and 1972.

The first locally funded gaging station was with the City of Seward in 1957. The cooperative program increased after Alaska became a state in 1959. The Alaska Department of Health and Welfare helped fund three stations beginning late in 1958. Since 1959, most of the significant increases in number of stream-gaging stations have been because of specific needs or investigations. A study was started in 1962 on peak flows of small streams in cooperation with the Alaska Department of Highways (now named Alaska Department of Transportation and Public Facilities), U.S. Bureau of Public Roads (now the Federal Highway Administration) and the U.S. Forest Service. Although most of the gages have been crest-stage partial-record gages, this program has cooperatively funded as many as eight continuous-record stations. (Currently, there are four continuous-record stations.) Collection of streamflow data to define urban-area hydrology and runoff from glaciers began in 1966. Efforts began in 1969 to define the hydrology along the oil pipeline route from the Arctic Slope to Valdez.

Although there has been an effort since 1913 to collect streamflow data at potential hydropower sites, the number of gaging stations operated for this purpose has increased since the establishment of the Alaska Power Authority (APA) in 1976. Similarly, the cooperative streamflow data program between the USGS and the Alaska Department of Natural Resources (ADNR) has grown since it began in 1959. The Division of Geological and Geophysical Surveys (DGGS) of ADNR was given the responsibility of coordinating state government needs for water-resource data and increased funding for water resources studies in 1979. The Alaska Water Resources Evaluation (AWARE) program cooperatively funded by DGGS and USGS has subsequently became the largest single source of funding for operating stream-gaging stations.

The source of funds for stream-gaging activities in Alaska has changed in the last few years. For example, of the 119 active gaging stations in water year 1973, 94 were entirely funded by seven Federal agencies, 10 were funded by the Trans-Alaska Pipeline System, and the remaining 15 stations were funded by five non-Federal agencies in cooperation with the Geological Survey. In 1983, 45 of the 110 active stations are funded entirely by three Federal agencies and the remaining 65 stations are funded partly or entirely by eight non-Federal agencies. (The USGS cooperatively funds 51 of the 65 sites.) The number of continuous-record stream-gaging stations operated annually in Alaska since 1946 is shown in figure 1.

Current Alaska Stream-Gaging Program

In 1974, the U.S. Water Resources Council divided the nation into Hydrologic Units, which are basically hydrographic in nature (U.S.Geological Survey, 1976). Alaska is Region 19; the region is further broken down into 6 subregions with 18 cataloguing units (called subareas in this report). These subregions and subareas and the distribution of the 110 stream gages currently operated by the Alaska District of the USGS are shown on figure 2. Most of the gaging stations are in relatively accessible or populated areas. Large areas without gaging stations, particularly in northern and western Alaska, are evident in figure 2.

Selected hydrologic data for the 110 stations are given in table 1; these data include drainage area and period of record. Mean annual flow values are given for stations with 5 or more complete water years of record (prior to the 1983 water year). Station identification numbers used throughout this report are the standard USGS station numbers.

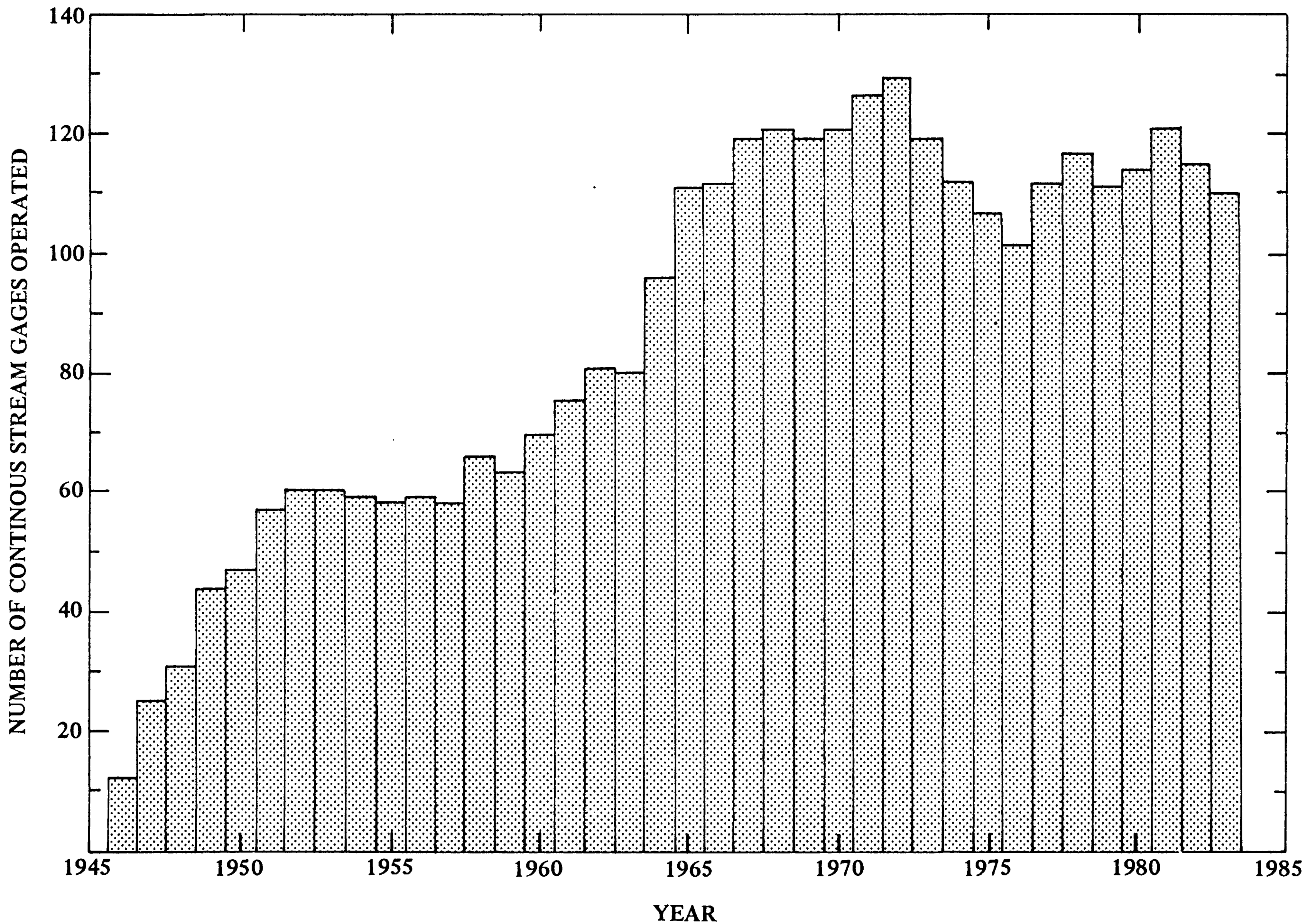
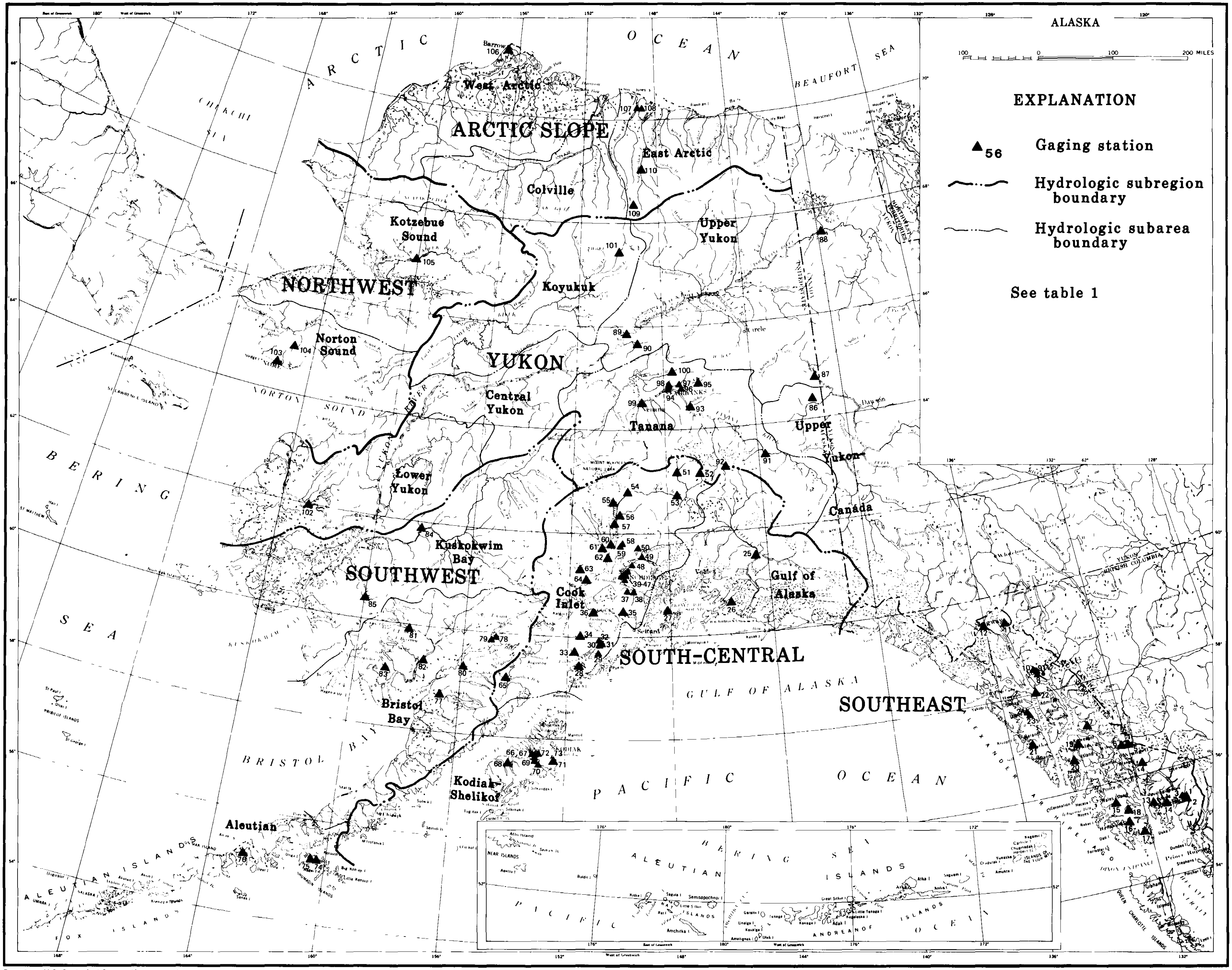


Figure 1.--History of continous stream gaging in Alaska since 1946.



Base from U.S. Geological Survey Alaska Map A

Figure 2. -- Location of stream gages.

Table 1.--Selected hydrologic data for stations in the Alaska surface-water program

[See figure 2 for locations]

Map index No.	Station No.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
		SOUTHEAST ALASKA			
1	15011870	White Creek near Ketchikan	2.70	1977-	27.3
2	15011880	Keta River near Ketchikan	74.2	1977-	773
3	15011894	Blossom River near Ketchikan	68.1	1981-	---
4	15022000	Harding River near Wrangell	67.4	1951-	732
5	15024750	Goat Creek near Wrangell	17.3	1976-	193
6	15024800	Stikine River near Wrangell	19,920	1976-	57,743
7	15028300	Farragut River near Petersburg	151	1977-	1,593
8	15051008	Salmon Creek above diversion near Juneau	9.77	1982-	---
9	15052009	Lemon Creek near mouth near Juneau	22.9	1982-	---
10	15052500	Mendenhall River near Auke Bay	85.1	1965-	1,128
11	15056100	Skagway River at Skagway	145	1963-	566
12	15056560	Klehini River near Klukwan	245	1981-	---
13	15067900	Upper Mahoney Lake outlet near Ketchikan	2.03	1977-	39.7
14	15072000	Fish Creek near Ketchikan	32.1	1915-36, 1938-	422
15	15081580	Black Bear Lake outlet near Klawock	1.82	1980-	---
16	15081995	Reynolds Creek below Lake Mellen near Hydaburg	5.20	1982-	---
17	15083500	Perkins Creek near Metlakatla	3.38	1976-	33.3
18	15085100	Old Tom Creek near Kasaan	5.90	1949-	38.8
19	15087570	Hamilton Creek near Kake	65.0	1972-73a, 1975-76a, 1976-	326
20	15087590	Rocky Pass Creek near Point Baker	2.72	1976-	10.8
21	15087690	Indian River near Sitka	10.1	1980-	---
22	15101500	Greens Creek near Juneau	22.8	1978-	---
23	15106920	Kadashan River above Hook Creek near Tenakee	10.2	1968-78, 1980-	63.3
24	15106980	Tonalite Creek near Tenakee	14.5	1968-	96.5

See footnotes at end of table.

Table 1.--Continued

Map index No.	Station No.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
		SOUTH-CENTRAL ALASKA			
25	15212000	Copper River near Chitina	20,600	1950b, 1952b, 1955-	37,670
26	15216000	Power Creek near Cordova	20.5	1913c, 1947-	251
27	15237020	Main Bay Creek near Port Nellie Juan	5.93	1980-	---
28	15238820	Barbara Creek near Seldovia	20.7	1972-	107
29	15238990	Upper Bradley River near Homer	10d	1979-	---
30	15239000	Bradley River near Homer	54d	1955b, 1957-	438
31	15239050	Bradley River tributary near Homer	9.25	1979-	---
32	15239070	Bradley River near tidewater near Homer	82	1983-	---
33	15239900	Anchor River near Anchor Point	137	1964-73, 1974a, 1978-	207
34	15241600	Ninilchik River at Ninilchik	131	1963-	109
35	15258000	Kenai River at Cooper Landing	634	1947-	2,830e
36	15266300	Kenai River at Soldotna	2,010	1965-	5,941
37	15267900	Resurrection Creek near Hope	149	1967-	283
38	15271000	Sixmile Creek near Hope	234	1979-	---
39	15273095	Little Rabbit Creek above Goldenview Drive at Anchorage	5.06	1980-	---
40	15274300	North Fork Campbell Creek near Anchorage	13.4	1967-74a, 1974-	18.4
41	15274600	Campbell Creek near Spenard	69.7	1966-	65.2
42	15274798	South Branch South Fork Chester Creek near 20th Avenue at Anchorage	9.39	1980-	---
43	15274820	South Branch South Fork Chester Creek tributary near Baxter Road at Anchorage	f	1982-	---
44	15275035	North Fork Chester Creek tributary near 20th Avenue at Anchorage	f	1982-	---
45	15275055	Chester Creek tributary near 36th Avenue at Anchorage	f	1982-	---
46	15275100	Chester Creek at Arctic Blvd. at Anchorage	27.2	1966-	17.9

See footnotes at end of table.

Table 1.--Continued

Map index No.	Station No.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
		SOUTH-CENTRAL ALASKA--Continued			
47	15276000	Ship Creek near Anchorage	90.5	1946-	163g
48	15277410	Peters Creek near Birchwood	87.8	1973-	120
49	15281000	Knik River near Palmer	1,180	1959h	6,952
50	15290000	Little Susitna River near Palmer	61.9	1948-	208
51	15291000	Susitna River near Denali	950	1957-66, 1967j, 1968-	2,756
52	15291200	Maclaren River near Paxson	280	1958-	978
53	15291500	Susitna River near Cantwell	4,140	1961-72, 1980-	6,396
54	15292000	Susitna River at Gold Creek	6,160	1949-	9,718
55	15292400	Chulitna River near Talkeetna	2,570	1958-72, 1973-77a, 1979a, 1980-	8,834
56	15292700	Talkeetna River near Talkeetna	2,006	1964-	4,078
57	15292780	Susitna River at Sunshine	11,100	1981-	---
58	15294005	Willow Creek near Willow	166	1978-	---
59	15294010	Deception Creek near Willow	48.0	1978-	---
60	15294100	Deshka River near Willow	592	1978-	---
61	15294345	Yentna River near Susitna Station	6,180	1980-	---
62	15294350	Susitna River at Susitna Station	19,400	1974-	50,700
63	15294410	Capps Creek below North Capps Creek near Tyonek	10.5	1979-	---
64	15294450	Chuitna River near Tyonek	131	1975-	380
65	15294900	Paint River near Kamishak	205	1983-	---
66	15295600	Terror River near Kodiak	15.0	1962-68, 1978-	138
67	15295700	Terror River at mouth near Kodiak	45.7	1964-68, 1981-	286
68	15296480	Larsen Bay Creek near Larsen Bay	3.92	1980-	---
69	15297100	Hidden Basin Creek near Port Lions	3.01	1982-	---
70	15297110	Hidden Basin Creek near mouth near Kodiak	11.9	1983-	---
71	15297200	Myrtle Creek near Kodiak	4.74	1963-	46.0

See footnotes at end of table.

Table 1.--Continued

Map index No.	Station No.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
		SOUTH-CENTRAL ALASKA--Continued			
72	15297482	Falls Creek near Port Lions	4.3	1980-	---
73	15297485	Kizhuyak River near Port Lions	27.5	1980-	---
		SOUTHWEST ALASKA			
74	15297602	Whiskey Bills Creek near Sand Point	0.3	1983-	---
75	15297603	Humboldt Creek at Sand Point	5.2	1983-	---
76	15297610	Russell Creek near Cold Bay	25	1981-	---
77	15297900	Eskimo Creek at King Salmon	16.1	1965-67a, 1969-73a, 1973-76, 1977-	12.9
78	15299900	Tazimina River near Nondalton	327	1981-	---
79	15300000	Newhalen River near Iliamna	3,478	1951-67, 1968-77a, 1982-	9,303
80	15300500	Kvichak River at Igiugig	6,500	1967-	18,110
81	15302000	Nuyakuk River near Dillingham	1,490	1953-	6,138
82	15302500	Nushagak River at Ekwok	9,850	1977-	25,046
83	15303150	Snake River near Dillingham	113	1973-	547
84	15304000	Kuskokwim River at Crooked Creek	31,100	1951-	41,450
85	15304200	Kisarlik River near Akiak	270	1979-	---
		YUKON ALASKA			
86	15344000	King Creek near Dome Creek	5.99	1975-82a, 1983-	---
87	15356000	Yukon River at Eagle	113,500	1911-13, 1950-	82,410
88	15388950	Porcupine River at Old Crow, Yukon Territory	21,400	1961-68, 1969-	k
89	15453500	Yukon River near Stevens Village	196,300	1976-	119,900
90	15457800	Hess Creek near Livengood	662	1970-78, 1982-	226
91	15476000	Tanana River near Tanacross	8,550	1953-	7,936
92	15478040	Phelan Creek near Paxson	12.2	1966-78, 1983-	69.7
93	15484000	Salcha River near Salchaket	2,170	1909-10b, 1948-	1,649
94	15485500	Tanana River at Fairbanks	m	1973-	18,970
95	15493000	Chena River near Two Rivers	941	1967-	649

See footnotes at end of table.

Table 1.--Continued

Map index No.	Station No.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
		YUKON ALASKA-Continued			
96	15493700	Chena River below Moose Creek Dam	1,430	1979-	---
97	15511000	Little Chena River near Fairbanks	372	1966-	204
98	15514000	Chena River at Fairbanks	1,980	1947-48b, 1948-	1,394
99	15515500	Tanana River at Nenana	25,600	1962-	23,530
100	15535000	Caribou Creek near Chatanika	9.19	1969-	4.86
101	15564875	Middle Fork Koyukuk River near Wiseman	1,200	1970-78, 1982-	709
102	15565447	Yukon River at Pilot Station	321,000	1975-	219,700
		NORTHWEST ALASKA			
103	15621000	Snake River near Nome	85.7	1965-81, 1982-	183
104	15668200	Crater Creek near Nome	21.9	1964-65a, 1967-75a, 1975-	55.1
105	15744500	Kobuk River near Kiana	9,520	1976-	15,540
		ARCTIC SLOPE ALASKA			
106	15798700	Nunavak Creek near Barrow	2.79	1971-	0.90
107	15896000	Kuparuk River near Deadhorse	3,130	1971-	1,386
108	15896700	Putuligayuk River near Deadhorse	176	1970-79, 1981-	41.6
109	15904900	Atigun River tributary near Pump Station 4	32.6	1976-	30.4
110	15908000	Sagavanirktok River near Pump Station 3	1,860	1982-	---

a Operated as a crest-stage gage.
b Seasonal summer record only.
c Fragmentary record.
d Drainage area not determinable to greater precision because it varies due to changes in route of meltwater stream from glacier at head of basin.
e Adjusted to exclude diversion from Cooper Lake.
f Not yet determined because drainage area depends on storm sewer network.
g Adjusted to include diversion for water supply.
h Flood peaks due to outbreak of glacier-dammed Lake George for 1948-62 and 1964-65 available.
j Only flood peak available.
k Average not determined, Canadian record.
m Drainage area undefined as part of river flows through Salchaket Slough and is ungaged.

The cost in fiscal year 1983 of operating these 110 stations and computing their discharge records was about $1,700,000. Additional funds were required to collect data at other surface-water sites visited regularly on scheduled data-collection routes, such as the 70 crest-stage partial-record stations and six sites with periodic measurements. Additional funds were also used for gaging station construction and rehabilitation, preparation and publication of reports, etc. The total surface-water program cost was $2,000,000 for the 1983 fiscal year.

Evaluation of Alaska Streamflow Data

The ultimate goal of collecting and analyzing water-resources data is to better understand the hydrology of the study area, basin, region, or state. Streamflow information collected at stations within the surface-water program (both past and present) provides a basis to evaluate the extent of our knowledge of the surface-water resources of Alaska. A determination of the number of gaging stations (discontinued and active) with records of sufficient length for regional analysis of streamflow characteristics within the state was made to demonstrate the disparity of geographic coverage of gaging station records throughout the state (table 2). At least 10 years of streamflow record are desirable before a station is included in a regional statistical analysis.

Balding (1976, p. 6-19) discussed some of the factors that control the availability of water resources in Alaska, such as physiography, climate, geology, permafrost, and glaciers. Some of the resultant diversity in runoff characteristics throughout the state is demonstrated in figure 3, which shows the estimated mean annual runoff throughout Alaska. Another way to show the diversity in runoff characteristics is to determine representative seasonal streamflow hydrographs for the hydrologic subdivisions of the state. These subdivisions are shown in figure 4.

Only a few of the hydrologic subareas in the state have sufficient data to identify quantitatively the different types of seasonal hydrographs that occur regionally. For example, in Southeast Alaska, there are at least three distinct seasonal patterns of streamflow because of different climatic and physiographic conditions. These differences are shown (fig. 5) by monthly hydrographs for three representative long-term stations:

Harding River near Wrangell (15022000)--Mainland stream with large summer snowmelt runoff and lesser runoff volume caused by fall rains.

Skagway River at Skagway (15056100)--Mainland stream with a large glacier-covered area in the basin which results in large summertime snowmelt runoff and extreme winter low flows.

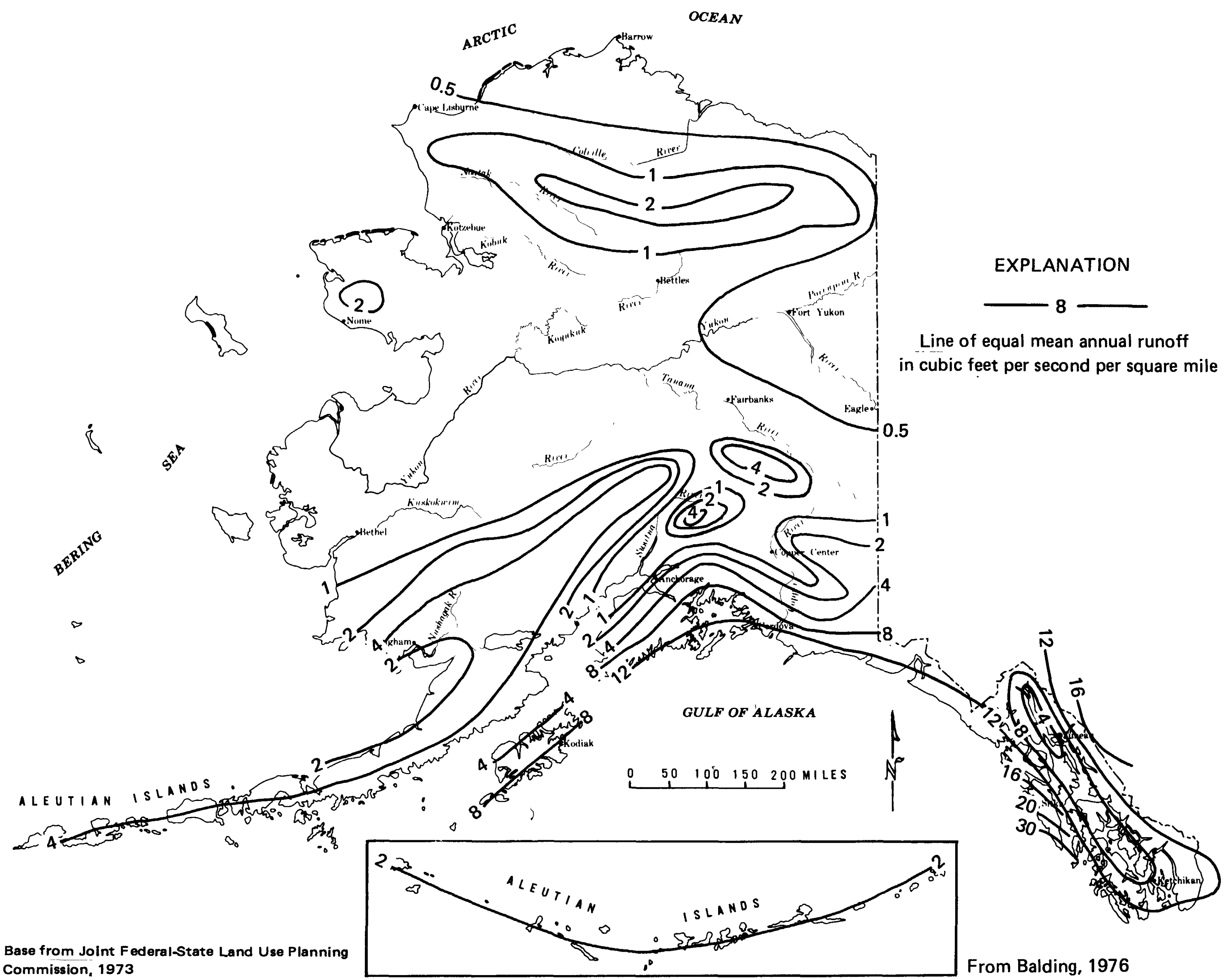
Fish Creek near Ketchikan (15072000)--Island stream with the higher flows from fall rains and lower snowmelt runoff in late spring and early summer.

Differences in seasonal streamflow characteristics for representative types of streams in the Cook Inlet and Gulf of Alaska subareas (excluding streams in the Copper River basin) are also shown in figure 5.

Monthly hydrographs (fig. 6) also have been prepared for streams in the Tanana subarea of the Yukon subregion and those in the Arctic Slope subregion. Only two

Table 2.--Summary of available records for proposed evaluation of streamflow program.

HYDROLOGIC UNIT	Area (mi^2)	Number of active stations	Record Length: 5 to 9 years		Record Length: 10 to 24 years		Record Length: 25 or more years	
			Active	Discontinued	Active	Discontinued	Active	Discontinued
ARCTIC								
West Arctic	31,000	1	0	0	1	0	0	0
Colville	24,000	0	0	0	0	0	0	0
East Arctic	26,000	4	1	1	2	0	0	0
Subtotal	81,000	5	1	1	3	0	0	0
NORTHWEST								
Kotzebue Sound	41,000	1	1	0	0	1	0	0
Norton Sound	26,000	2	1	0	1	1	0	0
Subtotal	67,000	3	2	0	1	2	0	0
YUKON								
Lower Yukon	38,000	1	1	1	0	0	0	0
Central Yukon	19,000	0	0	0	0	3	0	0
Koyukuk	33,000	1	1	2	0	1	0	0
Upper Yukon	60,000	4	2	0	0	3	1	0
Tanana	45,000	10	0	3	5	8	3	1
Upper Yukon-Canada	9,000	1	1	1	0	0	0	0
Subtotal	204,000	17	5	7	5	15	4	1
SOUTHWEST								
Kuskokwim Bay	58,000	2	0	0	0	1	1	0
Bristol Bay	40,000	7	1	2	3	1	1	0
Aleutian	11,000	3	0	0	0	0	0	0
Subtotal	109,000	12	1	2	3	2	2	0
SOUTH-CENTRAL								
Kodiak-Shelikof	11,000	8	1	1	2	0	0	1
Cook Inlet	38,000	38	3	5	14	16	5	1
Gulf of Alaska	34,000	3	0	3	0	8	2	1
Subtotal	83,000	49	4	9	16	24	7	3
SOUTHEAST								
Southeast	42,000	24	9	15	5	29	3	11
Subtotal	42,000	24	9	15	5	29	3	11
Total	586,000	110	22	34	33	72	16	15



Base from Joint Federal-State Land Use Planning Commission, 1973

From Balding, 1976

Figure 3.--Estimated mean annual runoff.

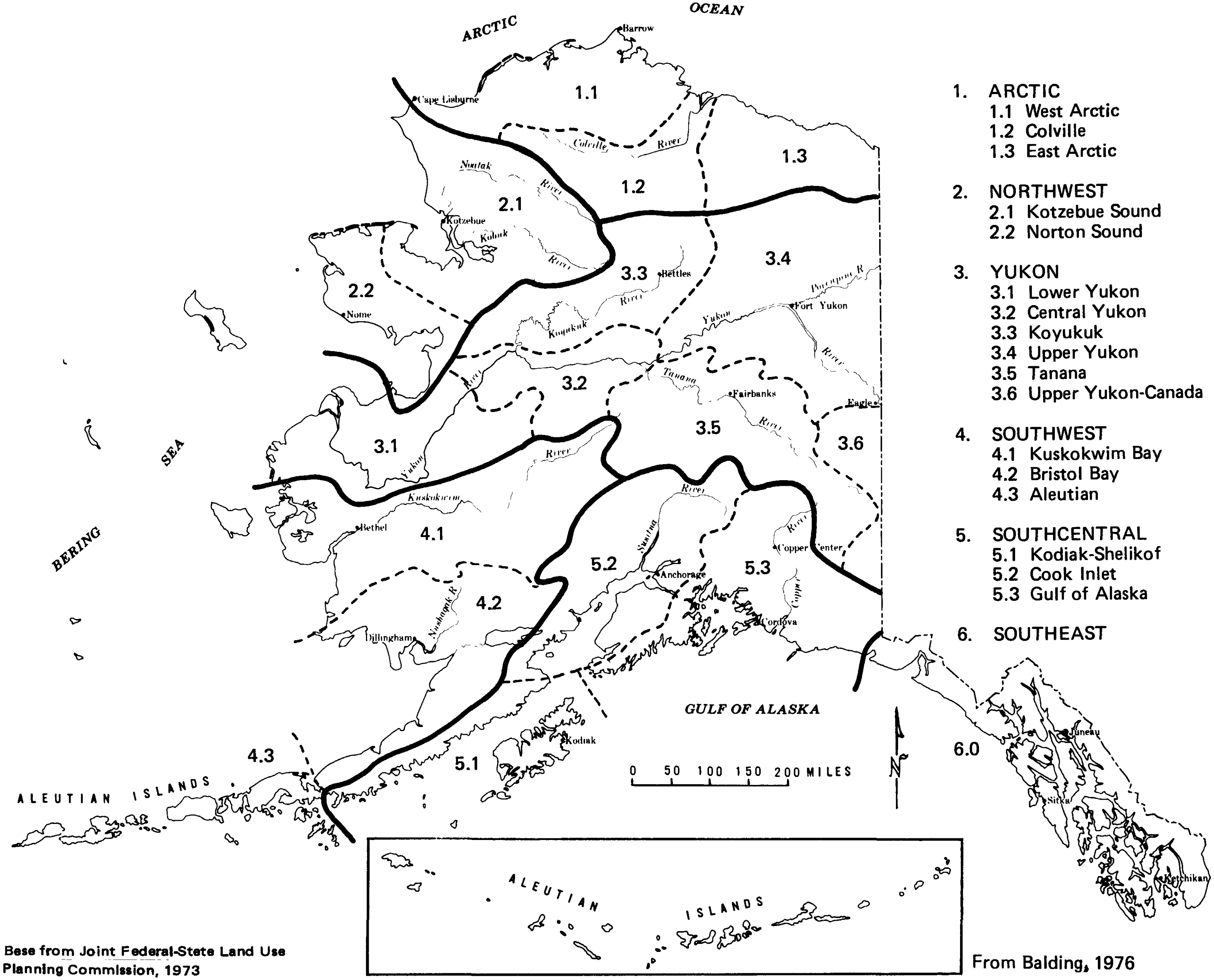
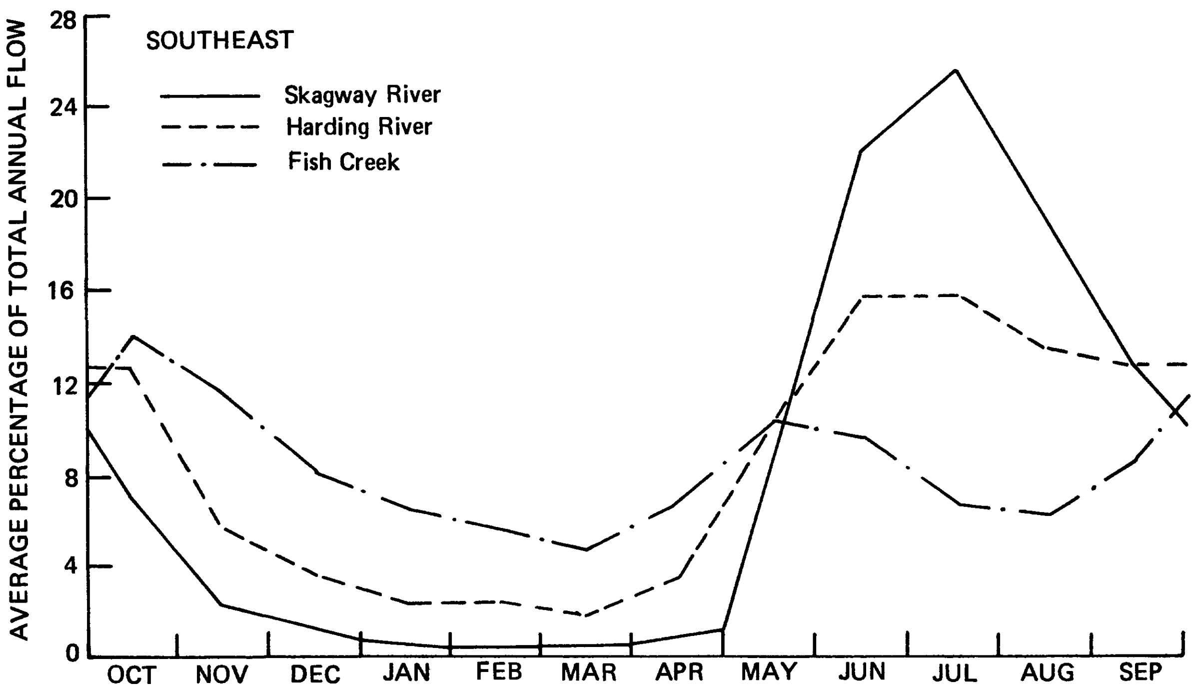


Figure 4.--Hydrologic subregions and subareas of Alaska.



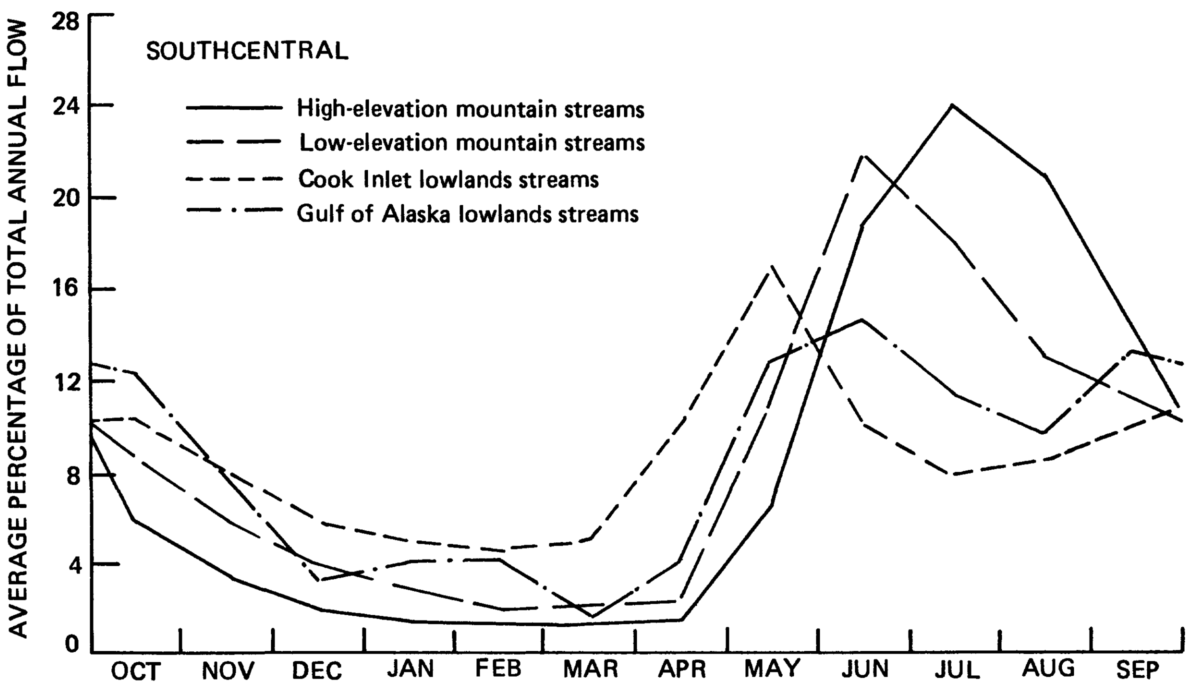


Figure 5.--Monthly contribution to mean annual streamflow for Southeast and Southcentral streams.

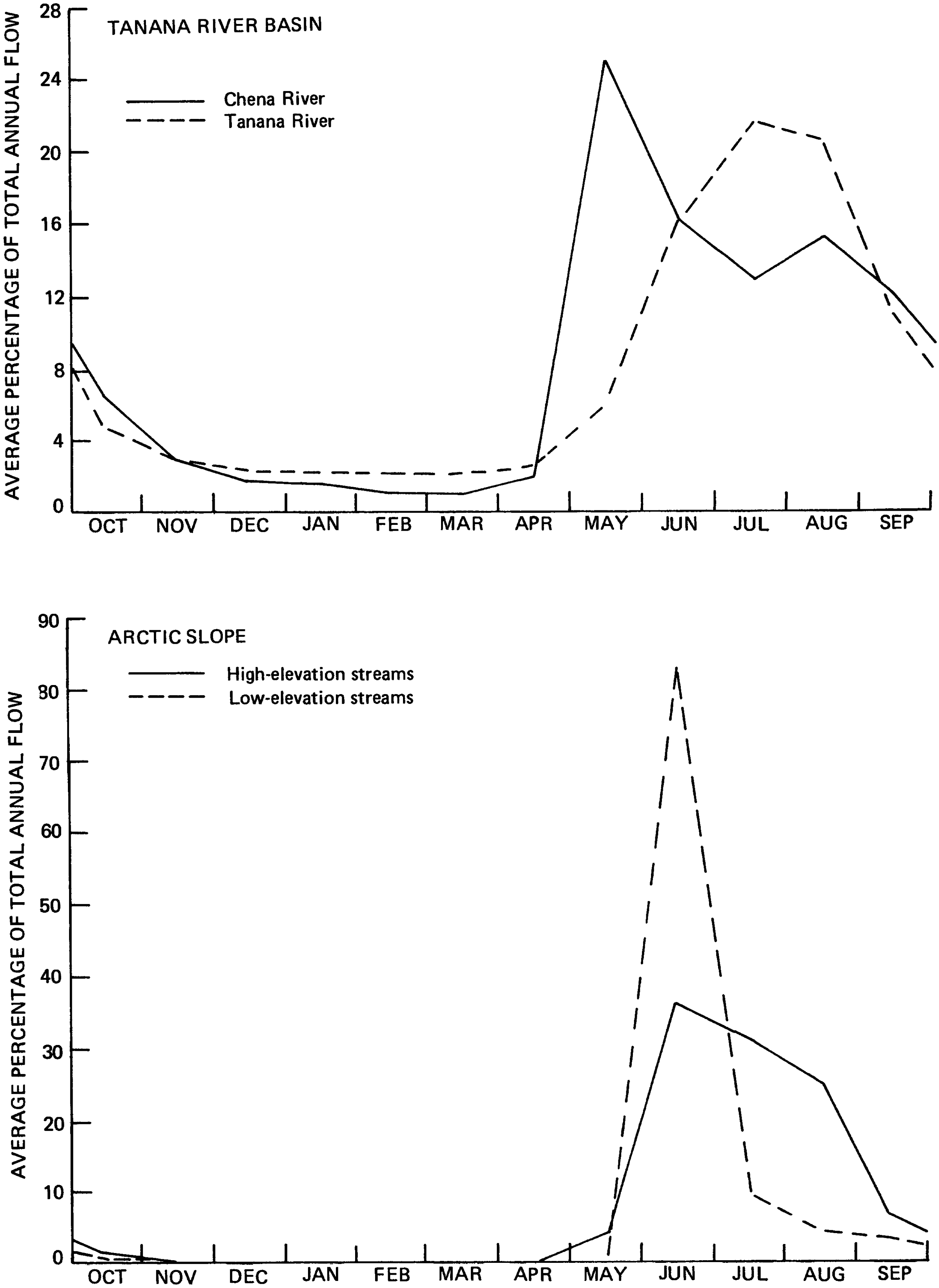


Figure 6.--Monthly contribution to mean annual streamflow for Tanana River basin and Arctic Slope streams.

of the three or more distinct types of seasonal hydrographs for the Tanana subarea are illustrated (the other types are not shown because of insufficient data for classification). The Tanana River is the major river of the subarea and its runoff is primarily controlled by glaciers and snowmelt in the Alaska Range to the south. The Chena River is a major northern tributary to the Tanana River. Its winter flows are reduced by the severe winter temperatures; however, groundwater inflow is sufficient to sustain some flow. The larger flow volumes occur because of spring snowmelt runoff from the relatively low elevations of the Chena River basin. Occasionally, widespread summer rains may cause large floods. The generalized seasonal hydrographs for two distinct types of runoff in the Arctic Slope subregion are based on short streamflow records at only five gaging stations. Snowmelt occurs in June at lower elevation near the Arctic Ocean. Prolonged snowmelt runoff occurs in basins with higher elevations and with large ranges in basin elevations. Also, summer rains contribute more to streamflow in high elevation basins than in low elevation basins.

In most of the other areas of the state, not enough data are available to develop representative generalized seasonal hydrographs. In order to obtain enough data to prepare this type of streamflow information and to provide more detailed analysis of streamflow characteristics throughout the state, the streamflow network must expand into those areas with sparse stream-gaging records.

Before network modification or expansion of any significant scope is undertaken, the streamflow data already collected need to be evaluated and analyzed. Gaps in knowledge of streamflow characteristics throughout the state can then be identified and prospective gaging station locations on certain types of streams can be specified. The last formal review of the network was reported in "A Proposed Streamflow Data Program in Alaska" (Childers, 1970). One method commonly used to generalize regional streamflow characteristics is to relate flow characteristics of gaged basins to the physical and climatic characteristics that cause variations of streamflow within the basins in the region (Thomas and Benson, 1970). This method was used by Childers (1970) to compute statewide regression equations for streamflow characteristics which can be used to estimate streamflow characteristics at ungaged sites. However, these equations were not very reliable because of the limited number of records available. In 1970, there were only 63 Alaska stations (with 10 or more years of daily streamflow record) available for analysis and subsequent preparation of statewide regression equations to calculate streamflow characteristics. Twenty-nine of the records used in Childers' analysis were from streams in southeastern Alaska and the other 34 were in western Alaska. At present, 136 records are available for analysis, 48 in the Southeast and 88 in the rest of Alaska. For those areas of the state with sufficient data, this larger number of records allows preparation of regional regression equations for determining streamflow characteristics at ungaged sites (Bruce Parks, U.S. Geological Survey, written commun., 1983).

In the derivation of regression equations for regionalized streamflow characteristics, Parks found that the most significant basin characteristic generally was drainage area; the second most significant characteristic was mean annual precipitation. The latest available statewide map of mean annual precipitation (Wise, 1977) needs to be updated to consider more recent precipitation data and to use runoff values as a guide. These additional data along with snow-course data would improve the reliability of the proposed map, particularly at higher elevations because most of the precipitation data are from climatic stations at lower elevations. Revision of the statewide mean annual precipitation map should be a multiagency effort.

The proposed statewide assessment of streamflow data should suggest methods to increase the knowledge of surface-water hydrology throughout the state. One of the more obvious suggestions would be to add gaging stations in areas of the state where data are sparse or nonexistent. Examination of table 2 shows several hydrologic subareas that definitely fit the above criteria. At least one long-term representative stream gage should be installed and operated in each of the following subareas:

Lower Yukon subarea in Yukon subregion
Central Yukon subarea in Yukon subregion
Uppper Yukon-Canada subarea in Yukon subregion
Colville subarea in Arctic subregion.

There is a streamgaging station in both the Lower Yukon and in the Upper Yukon-Canada subareas; however, their streamflow records are not representative of their respective subareas. These stations are Yukon River at Pilot Station (15565447), near the mouth of the river just upstream from its distributary delta, and King Creek near Dome Creek (15344000), which was just installed in spring 1983 and has a drainage area of only 5.99 mi^2. The three discontinued stations in the Central Yukon subarea listed in table 2 were at two sites on the Yukon River, upstream and downstream from the Koyukuk River (the major tributary to the Yukon River in this subarea), and on the Melozitna River, a large northside tributary to the Yukon River. The need for data from the Colville subarea might best be served by a gaging station on the Colville River just downstream from Anaktuvuk River, the penultimate major tributary upstream from the mouth. Low flows cannot be measured nearer the mouth due to insufficient stream velocity.

USES, FUNDING, AND AVAILABILITY OF CONTINUOUS STREAMFLOW DATA

The relevance of a stream-gaging station is defined by the uses made of the data obtained from the gage. Data uses identified by the USGS, nationwide, have been categorized into nine classes. The sources of funding for each gaging station and the frequency at which data are provided to the users were also compiled. This information for each continuous gaging station is presented in table 3, which is replete with footnotes to expand the information conveyed. The entry of an asterisk in the table indicates "yes" and no additional qualifier is required.

Data-Use Classes

The following definitions were used to categorize each known use of streamflow data for each continuous stream gage.

Regional Hydrology

Stations in this category are those useful in developing regionally transferable information about the relation between streamflow and basin characteristics. For data to be useful in defining regional hydrology, a streamflow record must be largely unaffected by manmade diversion, storage, and regulation throughout the year.

Ninety-one stations in the current network are classified in the regional hydrology data-use class. Some of these stations are special cases in that they are designated benchmark, index, or NASQAN (National Stream-Quality Accounting Network) stations. There is one hydrologic benchmark station in Alaska, Talkeetna River near Talkeetna (15292700), which serves as an indicator of hydrologic conditions in a watershed relatively free of man's influence. Seventeen long-term index stations, located in different regions of the state, are identified in table 3. NASQAN stations are included in this category because seven of the nine stations are on major rivers near the mouth. Streamflow information obtained at these stations together with streamflow data collected upstream at other stations along the main stem or at principal tributaries can be used to estimate streamflow characteristics at other points in the basin. The two remaining NASQAN stations are representative of their area and are considered index stations. Another reason for including the NASQAN stations in this category is because it is anticipated that they will have long-term records. Two other major rivers with gaging stations near the mouth, Kvichak River at Igiugig (15300500) and Kobuk River near Kiana (15744500) are included. Three major rivers with streamflow out of Canada into Alaska that have gaging stations near the border, are also included. They are the Stikine, Yukon, and Porcupine Rivers.

In the current Alaska stream-gaging network, streamflow at three stations can be affected by flood-control regulation at the recently constructed Moose Creek Dam on the Chena River. During extreme flood events, water will be diverted from the Chena River into the Tanana River upstream from Fairbanks. During lesser flood events, water will be temporarily stored upstream from the dam, thereby reducing flood peaks in the Chena River. The stations affected are:

Tanana River at Fairbanks (15485500)
Chena River below Moose Creek Dam (15493700)
Chena River at Fairbanks (15514000)

Additionally, three stations have diversions throughout the year that affect the streamflow record. These diversions are measured and accounted for when the streamflow record is published. These stations are:

Main Bay Creek near Port Nellie Juan (15237020)
Kenai River at Cooper Landing (15258000)
Ship Creek near Anchorage (15276000)

Knowing which streamflow characteristics are affected and when, and with proper adjustments to the streamflow record, records from these six stations are still useful in developing regionally transferable information about the relationship between streamflow and basin characteristics of climate, physiography, topography, and vegetation.

All the other stations in the Alaska network could be classified under regional hydrology. However, some of these stations are not identified as such in table 3 for various reasons. Six of these stations (all in urban areas) are considered short-term special purpose stations and four additional stations are affected by varying degrees of urbanization. Three stations near Homer, Upper Bradley River (15238990), Bradley River (15239000), and Bradley River near tidewater (15239070), are not included because undefined variations in drainage have occurred over the past 13 years as a result of shifts in the direction of outflow from the terminus of Nuka Glacier. Also, four stations that have or will have changes in streamflow because of the Terror Lake Hydropower Project, currently under construction, are not included. Tanana River at Fairbanks (15485500) is not included as ungaged flow in Salchaket Slough bypasses the gage. Daily discharge hydrographs at Salmon Creek near Juneau (15051008) are affected by intermittent operation of a hydropower plant, utilizing temporary storage upstream in Salmon Creek Reservoir; therefore, this station is not included as a regional hydrology station.

One of the purposes of operating a regional streamflow network is to enable the calculation of streamflow characteristics at sites on ungaged streams. A method used to make these computations is the use of regional regression equations of streamflow relative to basin characteristics. However, at least 10 years of streamflow data are desirable before a station is included in a regional regression analyses. Several stations in the current network with less than 10 years of record should be continued in operation to obtain at least 10 years of record. Streamflow information from these stations would help develop regional regression equations for areas where streamflow data are sparse or would include sites with types of basin characteristics not previously sampled. Some of these stations were established with the concept that at least 10 years of streamflow data would be collected in order to help develop regional relations of streamflow and basin characteristics. Twenty sites are designated in table 3 as "Regional Streamflow Statistics Stations."

The locations of stream gages that provide selected information about regional hydrology are shown in figure 7.

Hydrologic Systems

Stations that can be used for accounting, that is, to define current hydrologic conditions and to document changes in hydrologic conditions because of changes in the hydrologic system, are designated as hydrologic systems stations. Forty stations are included in this classification. They include: stations with diversion or regulation, which are those six previously catalogued; stations useful for defining the interactions of water systems, such as surface- and ground-water systems; and stations with changing streamflow characteristics, such as in urban areas. These "urban area" stations (not including four short-term stations in the Anchorage urban runoff study) are:

Lemon Creek near mouth near Juneau (15052009)
Little Rabbit Creek above Goldenview Drive at Anchorage (15273095)
North Fork Campbell Creek near Anchorage (15274300)
Campbell Creek near Spenard (15274600)
Chester Creek at Arctic Boulevard at Anchorage (15275100)
Peters Creek near Birchwood (15277410)

The benchmark, index, and NASQAN stations are included in the hydrologic systems category because they account for current and long-term conditions of their systems. The two stations near the mouth of major rivers (the Kvichak and Kobuk Rivers) are also included. Kenai River at Soldotna (15266300) is included in this

Table 3. -- Data use table

STATION NAME	IDENTIFIERS: MAP INDEX NUMBER	IDENTIFIERS: STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	DATA USE: HYDROLOGIC SYSTEMS	DATA USE: LEGAL OBLIGATIONS	DATA USE: PLANNING & DESIGN	DATA USE: PROJECT OPERATION	DATA USE: HYDROLOGIC FORECASTS	DATA USE: WATER-QUALITY MONITORING	DATA USE: RESEARCH	DATA USE: OTHER	FUNDING: FEDERAL PROGRAM	FUNDING: OFA PROGRAM	FUNDING: CO-OP PROGRAM	FUNDING: OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
SOUTHEAST ALASKA																
White Creek near Ketchikan	1	15011870	*						1	1				2		A
Keta River near Ketchikan	2	15011880	*						1	1				2		A T
Blossom River near Ketchikan	3	15011894	*						1	1				2		A
Harding River near Wrangell	4	15022000	3	3								*				A
Goat Creek near Wrangell	5	15024750	*			4						5	5			A
Stikine River near Wrangell	6	15024800	6 7	6 7		8		9	7			*				A T
Farragut River near Petersburg	7	15283000	10									*				A T
Salmon Creek above diversion near Juneau	8	15051008									11			12		A
Lemon Creek near mouth near Juneau	9	15052009		13						13				12		A
Mendenhall River near Auke Bay	10	15052500	*					9 14						12		A T
Skagway River at Skagway	11	15056100	3 7	3 7				9	7			*				A O
Klehini River near Klukwan	12	15056560	10						15	15				12		A
Upper Mahoney Lake outlet near Ketchikan	13	15067900	*			4						5	5			A
Fish Creek near Ketchikan	14	15072000	3	3								*				A
Black Bear Lake outlet near Klawock	15	15081580	*			4								16		A
Reynolds Creek below Lake Mellen near Hydaburg	16	15081995	*			4								12		A
Perkins Creek near Metlakatla	17	15083500	10						17				18			A

1. Proposed molybdenum mine-Quartz Hill, U.S. Borax.
2. Alaska Department of Environmental Conservation.
3. Long-term index gaging station.
4. Potential hydropower site.
5. U.S. Corps of Engineers (includes A&E funds from federal program).
6. International gaging station.
7. NASQAN station.
8. Proposed hydropower development upstream by British Columbia Hydro and Power Authority.
9. Flood forecasting - U.S. National Weather Service.
10. Regional stream-flow statistics station.
11. Adjudication of water rights.
12. Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys.
13. Effects of gravel removal.
14. Seasonal streamflow forecasting - U.S. National Weather Service.
15. Bald eagle research project.
16. Alaska Power Authority.
17. Hydrologic data collected for U.S. Forest Service for land management purposes.
18. U.S. Forest Service.

* Yes, no further comment needed.
A Annual data report.
O Observer.
T Telemetry.

Table 3. -- Continued

STATION NAME	IDENTIFIERS: MAP INDEX NUMBER	IDENTIFIERS: STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	DATA USE: HYDROLOGIC SYSTEMS	DATA USE: LEGAL OBLIGATIONS	DATA USE: PLANNING & DESIGN	DATA USE: PROJECT OPERATION	DATA USE: HYDROLOGIC FORECASTS	DATA USE: WATER-QUALITY MONITORING	DATA USE: RESEARCH	DATA USE: OTHER	FUNDING: FEDERAL PROGRAM	FUNDING: OFA PROGRAM	FUNDING: CO-OP PROGRAM	FUNDING: OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
SOUTHEAST ALASKA																
Old Tom Creek near Kasaan	18	15085100	*						17				18			A
Hamilton Creek near Kake	19	15087570	10									*				A
Rocky Pass Creek near Point Baker	20	15087590	10						17				18			A
Indian River near Sitka	21	15087690	10								11					A T
Greens Creek near Juneau	22	15101500	10						19	19			18			A
Kadashan River above Hook Creek near Tenakee	23	15106920	*						17	20			18			A
Tonalite Creek near Tenakee	24	15106980	*						17	20			18			A
SOUTH-CENTRAL ALASKA																
Copper River near Chitina	25	15212000	7	7					7			*				A
Power Creek near Cordova	26	15216000	3	3		4						5	5			A
Main Bay Creek near Port Nellie Juan	27	15237020	*	21										22		A
Barbara Creek near Seldovia	28	15238820	*											23		A
Upper Bradley River near Homer	29	15238990				24			24					16		A
Bradley River near Homer	30	15239000				24			24					16		A
Bradley River tributary near Homer	31	15239050	10			24								16		A
Bradley River near tidewater near Homer	32	15239070				24								16		A
Anchor River near Anchor Point	33	15239900	3	3				9						12		A O
Ninilchik River at Ninilchik	34	15241600	*										25			A

3. Long-term index gaging station.
4. Potential hydropower site.
5. U.S. Corps of Engineers (includes A&E funds from federal program).
7. NASQAN station.
9. Flood forecasting - U.S. National Weather Service.
10. Regional stream-flow statistics station.
11. Adjudication of water rights.
12. Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys.
16. Alaska Power Authority.
17. Hydrologic data collected for U.S. Forest Service for land management purposes.
18. U.S. Forest Service.
19. Proposed underground mine - Greens Creek project, Noranda Mining, Inc..
20. Research study area for effects of logging - U.S. Forest Service.
21. Fish hatchery (water diverted from stream).
22. Alaska Department of Fish and Game.
23. Kenai Peninsula Borough.
24. Proposed Bradley Lake Hydropower Project.
25. U.S. Corps of Engineers.

* Yes.
A Annual data report.
O Observer.
T Telemetry.

Table 3. -- Continued

STATION NAME	IDENTIFIERS		DATA USE									FUNDING				FREQUENCY OF DATA AVAILABILITY
	MAP INDEX NUMBER	STATION NUMBER	REGIONAL HYDROLOGY	HYDROLOGIC SYSTEMS	LEGAL OBLIGATIONS	PLANNING & DESIGN	PROJECT OPERATION	HYDROLOGIC FORECASTS	WATER-QUALITY MONITORING	RESEARCH	OTHER	FEDERAL PROGRAM	OFA PROGRAM	CO-OP PROGRAM	OTHER NON-FEDERAL	
SOUTH-CENTRAL ALASKA--Continued																
Kenai River at Cooper Landing	35	15258000	3	3 26				9						12		A T P
Kenai River at Soldotna	36	15266300	*	27				9 14				5	5			A O
Resurrection Creek near Hope	37	15267900	*								17		18			A
Sixmile Creek near Hope	38	15271000	10								17		18			A T
Little Rabbit Creek above Goldenview Drive at Anchorage	39	15273095		27						27				28		A
North Fork Campbell Creek near Anchorage	40	15274300		29										28		A
Campbell Creek near Spenard	41	15274600		30										28		A
South Branch South Fork Chester Creek near 20th Avenue at Anchorage	42	15274798							31	31				28		A
South Branch South Fork Chester Creek tributary near Baxter Road	43	15274820							31	31				28		A
North Fork Chester Creek tributary near 20th Avenue at Anchorage	44	15275035							31	31				28		A
Chester Creek tributary near 36th Avenue at Anchorage	45	15275055							31	31				28		A
Chester Creek at Arctic Boulevard at Anchorage	46	15275100		30					31	31		5	5			A
Ship Creek near Anchorage	47	15276000	*	32			32	9 14						28		A T
Peters Creek near Birchwood	48	15277410		27								5	5			A
Knik River near Palmer	49	15281000	*										25			A
Little Susitna River near Palmer	50	15290000	3	3				9 14				*				A T P
Susitna River near Denali	51	15291000	*			33			33						16	A
Maclaren River near Paxson	52	15291200	*			33									16	A

3. Long-term index gaging station.
5. U.S. Corps of Engineers (includes A&E funds from federal program).
9. Flood forecasting - U.S. National Weather Service.
10. Regional stream-flow statistics station.
12. Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys.
14. Seasonal streamflow forecasting - U.S. National Weather Service.
16. Alaska Power Authority.
17. Hydrologic data collected for U.S. Forest Service for land management purposes.
18. U.S. Forest Service.
25. U.S. Corps of Engineers.
26. Includes water from Cooper Lake hydropower plant diverted into Kenai Lake.
27. Developing area.
28. Municipality of Anchorage.
29. Downstream from Municipality of Anchorage water-supply well field.
30. Downstream of developed urban area.
31. Urban runoff study.
32. At water-supply diversion dam, monthly streamflow summary includes diversion upstream from gage.
33. Proposed Susitna Hydroelectric Project.

* Yes.
A Annual data report.
O Observer.
P Periodic provisional discharge data.
T Telemetry.

Table 3. -- Continued

STATION NAME	IDENTIFIERS: MAP INDEX NUMBER	IDENTIFIERS: STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	DATA USE: HYDROLOGIC SYSTEMS	DATA USE: LEGAL OBLIGATIONS	DATA USE: PLANNING & DESIGN	DATA USE: PROJECT OPERATION	DATA USE: HYDROLOGIC FORECASTS	DATA USE: WATER-QUALITY MONITORING	DATA USE: RESEARCH	DATA USE: OTHER	FUNDING: FEDERAL PROGRAM	FUNDING: OFA PROGRAM	FUNDING: CO-OP PROGRAM	FUNDING: OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
SOUTH-CENTRAL ALASKA--Continued																
Susitna River near Cantwell	53	15291500	*			33			33						16	A T
Susitna River at Gold Creek	54	15292000	3	3		33		9 14	33					16		A T
Chulitna River near Talkeetna	55	15292400	*			33			33						16	A
Talkeetna River near Talkeetna	56	15292700	34	34		33			33 34			*				A
Susitna River at Sunshine	57	15292780	*			33		9	33						16	A T
Willow Creek near Willow	58	15294005	10						35					12		A
Deception Creek near Willow	59	15294010	10						35					12		A
Deshka River near Willow	60	15294100	10											12		A
Yentna River near Susitna Station	61	15294345	*			33		9	33					16		A T
Susitna River at Susitna Station	62	15294350	7	7		33			7 33					16		A
Capps Creek below N Capps Creek near Tyonek	63	15294410	10							36				12		A
Chuitna River near Tyonek	64	15294450	10							36				12		A
Paint River near Kamishak	65	15294900	*			37								22		A
Terror River near Kodiak	66	15295600				38									16	A
Terror River at mouth near Kodiak	67	15295700				38			38						16	A
Larsen Bay Creek near Larsen Bay	68	15296480	*			4									16	A
Hidden Basin Creek near Port Lions	69	15297100	*			38									16	A
Hidden Basin Creek near mouth near Kodiak	70	15297110	*			38									16	A
Myrtle Creek near Kodiak	71	15297200	3	3								*				A
Falls Creek near Port Lions	72	15297482				38									16	A
Kizhuyak River near Port Lions	73	15297485				38			38						16	A

3. Long-term index gaging station.
4. Potential hydropower site.
7. NASQAN station.
9. Flood forecasting - U.S. National Weather Service.
10. Regional stream-flow statistics station.
12. Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys.
14. Seasonal streamflow forecasting - U.S. National Weather Service.
16. Alaska Power Authority.
22. Alaska Department of Fish and Game.
33. Proposed Susitna Hydroelectric Project.
34. Hydrologic benchmark station.
35. Hydrologic data collected for Alaska Department of Natural Resources for land management purposes.
36. Potential coal mining area.
37. Proposed fish ladder.
38. Terror Lake Hydropower Project (under construction).

* Yes.
A Annual data report.
T Telemetry.

Table 3. -- Continued

STATION NAME	IDENTIFIERS: MAP INDEX NUMBER	IDENTIFIERS: STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	DATA USE: HYDROLOGIC SYSTEMS	DATA USE: LEGAL OBLIGATIONS	DATA USE: PLANNING & DESIGN	DATA USE: PROJECT OPERATION	DATA USE: HYDROLOGIC FORECASTS	DATA USE: WATER-QUALITY MONITORING	DATA USE: RESEARCH	DATA USE: OTHER	FUNDING: FEDERAL PROGRAM	FUNDING: OFA PROGRAM	FUNDING: CO-OP PROGRAM	FUNDING: OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
SOUTHWEST ALASKA																
Whiskey Bills Creek near Sand Point	74	15297602	*			39								40		A
Humboldt Creek at Sand Point	75	15297603	*			39								40		A
Russell Creek near Cold Bay	76	15297610	*				21							22		A
Eskimo Creek at King Salmon	77	15297900	10			41								42		A
Tazimina River near Nondalton	78	15299900	*			4			4						16	A
Newhalen River near Iliamna	79	15300000	*			4									16	A
Kvichak River at Igiugig	80	15300500	43	43								*				A
Nuyakuk River near Dillingham	81	15302000	3	3										12		A
Nushagak River at Ekwok	82	15302500	7	7					7			*				A
Snake River near Dillingham	83	15303150	*											12		A
Kuskokwim River at Crooked Creek	84	15304000	7	7				9	7			5	5			A O
Kisarlik River near Akiak	85	15304200	10			4								16		A
YUKON ALASKA																
King Creek near Dome Creek	86	15344000	10			41								42		A
Yukon River at Eagle	87	15356000	6	6				9 14				*			44	A O
Porcupine River at Old Crow, Yukon Territory	88	15388950	6	6								*			44	A
Yukon River near Stevens Village	89	15453500	*					9				5	5			A T
Hess Creek near Livengood	90	15457800	10											12		A
Tanana River near Tanacross	91	15476000	*					9						12		A
Phelan Creek near Paxson	92	15478040	*							45				12		A

3. Long-term index gaging station.
4. Potential hydropower site.
5. U.S. Corps of Engineers (includes A&E funds from federal program).
6. International gaging station.
7. NASQAN station.
9. Flood forecasting - U.S. National Weather Service.
10. Regional stream-flow statistics station.
12. Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys.
14. Seasonal streamflow forecasting - U.S. National Weather Service.
16. Alaska Power Authority.
21. Fish hatchery (water diverted from stream).
22. Alaska Department of Fish and Game.
39. Design of water-supply system.
40. City of Sand Point.
41. Small streams program.
42. Alaska Department of Transportation and Public Facilities.
43. Near mouth of large river.
44. Operated jointly with Water Survey of Canada.
45. Glacier studies.

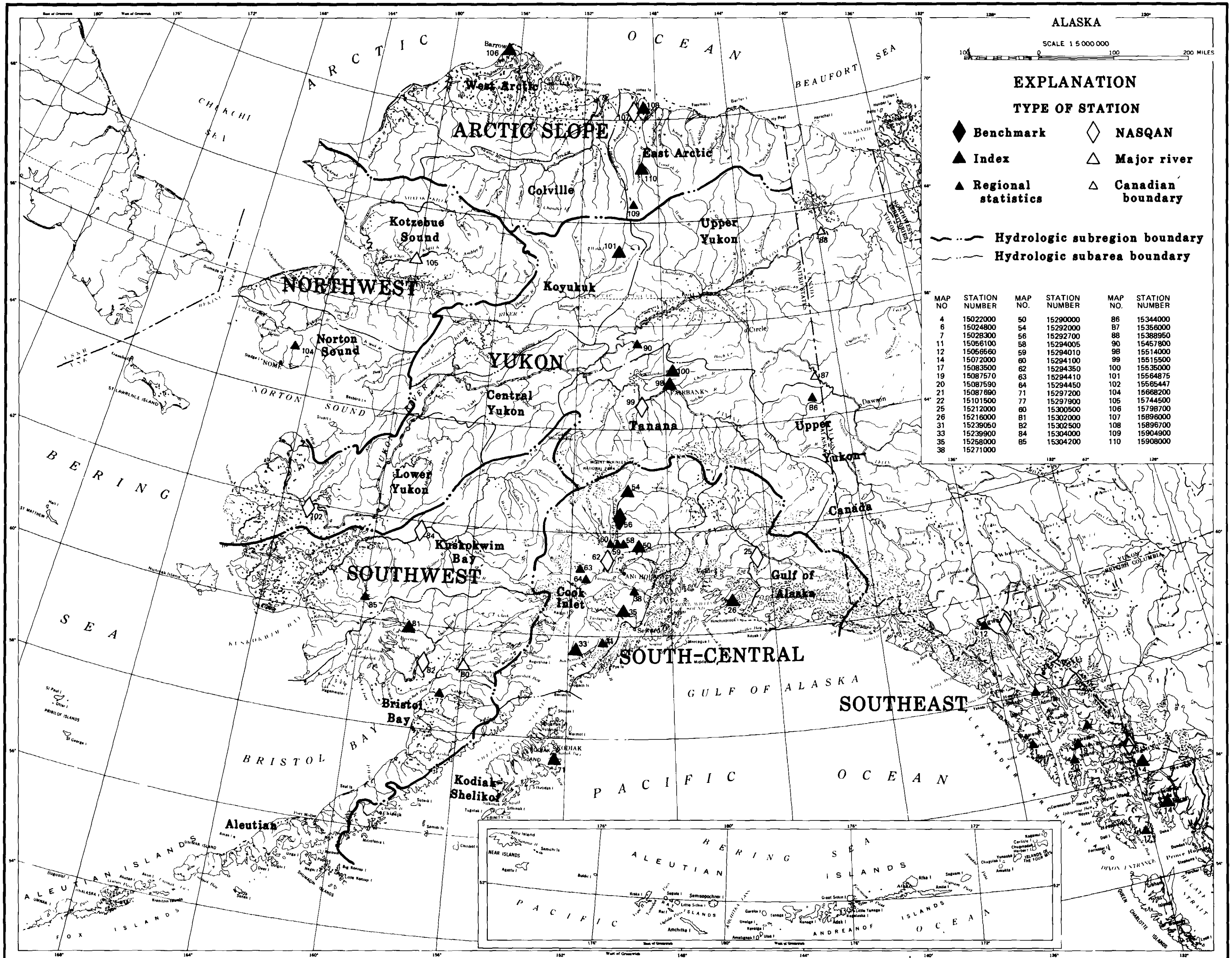
* Yes.
A Annual data report.
O Observer.
T Telemetry.

Table 3. -- Continued

STATION NAME	IDENTIFIERS: MAP INDEX NUMBER	IDENTIFIERS: STATION NUMBER	DATA USE: REGIONAL HYDROLOGY	DATA USE: HYDROLOGIC SYSTEMS	DATA USE: LEGAL OBLIGATIONS	DATA USE: PLANNING & DESIGN	DATA USE: PROJECT OPERATION	DATA USE: HYDROLOGIC FORECASTS	DATA USE: WATER-QUALITY MONITORING	DATA USE: RESEARCH	DATA USE: OTHER	FUNDING: FEDERAL PROGRAM	FUNDING: OFA PROGRAM	FUNDING: CO-OP PROGRAM	FUNDING: OTHER NON-FEDERAL	FREQUENCY OF DATA AVAILABILITY
YUKON ALASKA--Continued																
Salcha River near Salchaket	93	15484000	*				46	9 14					25			A T
Tanana River at Fairbanks	94	15485500		47			46						25			A
Chena River near Two Rivers	95	15493000	*				46	9					25			A T
Chena River below Moose Creek Dam	96	15493700	*	47			46						25			A T
Little Chena River near Fairbanks	97	15511000	*				46	9					25			A T
Chena River at Fairbanks	98	15514000	3	3 47			46	9 14					25			A P O
Tanana River at Nenana	99	15515500	7	7			46	9 14	7				25			A T P
Caribou Creek near Chatanika	100	15535000	3	3						48				12		A
Middle Fork Koyukuk River near Wiseman	101	15564875	3	3										12		A
Yukon River at Pilot Station	102	15565447	7	7				9	7			*				A O
NORTHWEST ALASKA																
Snake River near Nome	103	15621000	*										25			A
Crater Creek near Nome	104	15668200	10			41								42		A
Kobuk River near Kiana	105	15744500	43	43										12		A
ARCTIC SLOPE ALASKA																
Nunavak Creek near Barrow	106	15798700	3	3								*				A
Kuparuk River near Deadhorse	107	15896000	3 7	3 7					7			*				A
Putuligayuk River near Deadhorse	108	15896700	3	3										12		A
Atigun River tributary near Pump Station 4	109	15904900	10			41								42		A
Sagavanirktok River near Pump Station 3	110	15908000	3	3										12		A

3. Long-term index gaging station.
7. NASQAN station.
9. Flood forecasting - U.S. National Weather Service.
10. Regional stream-flow statistics station.
12. Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys.
14. U.S. National Weather Service.
25. U.S. Corps of Engineers.
41. Small streams program.
42. Alaska Department of Transportation and Public Facilities.
43. Near mouth of large river.
46. Chena River Flood-Control Project.
47. Potential diversion from Chena River into Tanana River.
48. Interagency Watershed Research basin.

* Yes.
A Annual data report.
O Observer.
P Periodic provisional discharge data.
T Telemetry.



MAP NO	STATION NUMBER	MAP NO.	STATION NUMBER	MAP NO.	STATION NUMBER
4	15022000	50	15290000	86	15344000
6	15024800	54	15292000	B7	15356000
7	1502B300	56	15292700	88	15388950
11	15056100	58	15294005	90	15457800
12	15056560	59	15294010	9B	15514000
14	15072000	60	15294100	99	15515500
17	15083500	62	15294350	100	15535000
19	15087570	63	15294410	101	15564875
20	15087590	64	15294450	102	15565447
21	15087690	71	15297200	104	15668200
22	15101500	77	15297900	105	15744500
25	15212000	60	15300500	106	1579B700
26	15216000	B1	15302000	107	15B96000
31	15239050	B2	15302500	108	15896700
33	15239900	84	15304000	109	15904900
35	15258000	B5	15304200	110	15908000
38	15271000				

Base from U.S. Geological Survey Alaska Map A

Figure 7. -- Location of selected regional hydrology stream gages.

data-use category as it is near the mouth of a river whose basin is undergoing development. Three gaging stations on major rivers flowing out of Canada into Alaska provide data for the proper management by both countries of potentially conflicting uses of the rivers' resources. These "International Gaging Stations" are:

Stikine River near Wrangell, Alaska (15024800)
Yukon River at Eagle, Alaska (15356000)
Porcupine River at Old Crow, Yukon Territory (15388950)

Legal Obligations

Some stations provide records of flows for the verification or enforcement of existing treaties, compacts, and decrees. The legal obligation category contains only those stations that the Geological Survey is required to operate to satisfy a legal responsibility. None of the stations in the Alaska streamflow program come under this data-use classification.

Planning and Design

Gaging stations in this data-use category are used for planning and designing a specific project (for example, a dam, water-supply diversion, hydropower plant, or waste-treatment facility) or group of structures. Currently, there are 36 stations in this category.

Twenty-nine of these stations are being operated to obtain streamflow data for hydropower investigations. Investigations range from sites where only preliminary studies have been made or are in a preliminary phase, to submittal of a request for licensing and development from the Federal Energy Regulatory Commission (FERC). For example, eight stations are on streams with good hydropower potential. These stations are:

Goat Creek near Wrangell (15024750)
Upper Mahoney Lake outlet near Ketchikan (15067900)
Reynolds Creek below Lake Mellen near Hydaburg (15081995)
Power Creek near Cordova (15216000)
Larsen Bay Creek near Larsen Bay (15296480)
Tazimina River near Nondalton (15299900)
Newhalen River near Iliamna (15300000)
Kisarlik River near Akiak (15304200)

Another station, Black Bear Lake outlet near Klawock (15081580), is at a site where a license from FERC has been requested by the Alaska Power Authority (APA). Active hydropower studies have been carried out by British Columbia Hydropower and Power Authority in Canada for several proposed dams on the Stikine and Iskut Rivers. The gaging station on the Stikine River (15024800) is downstream from potential hydropower development.

Preparation of a license request for the proposed Bradley Lake Hydropower Project, requires hydrologic information from the following stations:

Upper Bradley River near Homer (15238990)
Bradley River near Homer (15239000)
Bradley River tributary near Homer (15239050)
Bradley River near tidewater near Homer (15239070)

A license from FERC is being sought by APA for the proposed Susitna Hydropower Project. Nine stations are being used to directly provide planning and design information. The nine stations are:

Susitna River near Denali (15291000)
Maclaren River near Paxson (15291200)
Susitna River near Cantwell (15291500)
Susitna River at Gold Creek (15292000)
Chulitna River near Talkeetna (15292400)
Talkeetna River near Talkeetna (15292700)
Susitna River at Sunshine (15292780)
Yentna River near Susitna Station (15294345)
Susitna River at Susitna Station (15294350)

Talkeetna River is also a benchmark station and Susitna River at Susitna Station is a NASQAN station. Three stations on small streams near Willow, Willow Creek (15294005), Deception Creek (15294010), and Deshka River (15294100), indirectly provide streamflow information relative to the Susitna Project; however, they are not included in this data-use class.

Construction is under way at the Terror Lake Hydropower Project. However, the six stations established to provide data for this project are still being shown in table 3 as planning and design stations until construction is complete. These stations are:

Terror River near Kodiak (15295600)
Terror River at mouth near Kodiak (15295700)
Hidden Basin Creek near Port Lions (15297100)
Hidden Basin Creek near mouth near Kodiak (15297110)
Falls Creek near Port Lions (15297482)
Kizhuyak River near Port Lions (15297485)

Four stations are being operated, in cooperation with the Alaska Department of Transportation and Public Facilities, to obtain regional planning and design information on small streams in remote and otherwise ungaged areas. They are:

Eskimo Creek at King Salmon (15297900)
King Creek near Dome Creek (15344000)
Crater Creek near Nome (15668200)
Atigun River tributary near Pump Station 4 (15904900)

Two stations, Whiskey Bills Creek (15297602) and Humboldt Creek (15297603), have recently been established (1983) to obtain water-supply information on Popof Island for the City of Sand Point. Another new station, Paint River near Kamishak (15294900), is being operated to obtain design and operational data for a proposed fish ladder.

Project Operation

Gaging stations in this category are used, on an ongoing basis, to assist water managers in making operational decisions such as reservoir releases, hydropower operations, or diversions. Project-operation use generally implies that the data are routinely available to the operators on a rapid-reporting basis. Seven of the stations in this data-use class provide data to the Corps of Engineers for operation of the Chena Lakes Flood-Control Project near Fairbanks. Six of these sites have telemetry equipment for use in providing data in flood situations. Another station in this class, Ship Creek (15276000), provides information needed to operate the Municipality of Anchorage water-supply system; the water-treatment plant operator reads the gage daily. There also is telephonic telemetry at this site.

Hydrologic Forecasts

Gaging stations in this category are regularly used to provide information for hydrologic forecasting. These might be flood forecasts for a specific river reach, or periodic (daily, weekly, monthly, or seasonal) flow-volume forecasts for a specific site or region. The hydrologic forecast use generally implies that the data are routinely available to the forecasters on a rapid-reporting basis. On large streams, data may only be needed every few days.

The hydrologic forecast category includes 21 stations used for flood forecasting by the U.S. National Weather Service (NWS). Periodic flow-volume forecasts also are prepared by NWS at 9 of these 21 sites during the open-water season. Telemetry equipment is available at 13 of the sites and observers are used at the 8 sites without telemetry. Three sites with telemetry equipment also have observers. One of the observer sites, Yukon River at Pilot Station (15565447), has an observer only during the ice breakup period.

Water-Quality Monitoring

Gaging stations where regular water-quality or sediment-transport monitoring is being conducted are designated as water-quality-monitoring sites. Concurrent streamflow data contribute to the utility of the water-quality or sediment data or is essential to its interpretation.

Thirty-eight stations are included in this category. One such station in the program is a designated benchmark station and nine are NASQAN stations. Water-quality samples from benchmark stations are used as an index to water-quality characteristics of streams that have been and probably will continue to be relatively free of man's influence. NASQAN stations are part of a nationwide network designed to assess water-quality trends of major or representative streams on a regional basis (fig. 7).

Water-quality information is collected for the U.S. Forest Service at five stations in Southeast Alaska. Additionally, water-quality data are being collected at four other stations in Southeast Alaska to assess potential impacts of two mines being developed.

Water-quality data are being collected at 13 stations in areas where the Alaska Power Authority is studying potential or proposed hydropower developments or is constructing hydropower projects. Water-temperature data are collected at 11 of the 13 sites. Water-chemistry or sediment data are being collected at eight stations (which are included in the 13 sites) for analysis to determine the potential effects of the proposed hydropower development in the Susitna River basin.

Water-quality data collection and analysis are integral parts of urban runoff studies and the five stations in Chester Creek basin in Anchorage are listed in table 3 under this category. Additionally, water-quality data are collected at Klehini River near Klukwan (15056560) in an investigation of bald eagle habitat. Also, water-quality data are collected for the Division of Geological and Geophysical Surveys (DGGS) of the Alaska Department of Natural Resources at two stations near Willow, Willow Creek (15294005) and Deception Creek (15294010).

Research

Gaging stations in this category are operated for a particular research or water-investigations study. Typically, they are only operated for a few years.

Seventeen stations in the Alaska network are used in support of water-investigations studies both by the Geological Survey and other agencies. For example, five stations in the Chester Creek basin are operated to provide data for an urban runoff study. Streamflow data from the Klehini River gaging stations are being used in a Geological Survey investigation of ground/surface-water interactions. Another station, Little Rabbit Creek above Goldenview Drive (15273095), is operated to provide data for a study of a rapidly developing area in Anchorage. Data from Phelan Creek near Paxson (15478040) are used in studying Gulkana Glacier.

Three stations near Ketchikan, White Creek (15011870), Keta River (15011880), and Blossom River (15011894), provide data for permitting activities on Forest Service land at a proposed molybdenum mine being developed by U.S. Borax. Another station, Greens Creek near Juneau (15101500), provides data on the effects of development by Noranda Mining, Inc. of an underground mine for zinc, lead, copper, silver, and gold. Two stations, Capps Creek (15294410) and Chuitna River (15294450), provide data in a proposed coal mining area near Tyonek. Data from Lemon Creek near mouth near Juneau (15052009) are used for analysis of the effects of gravel removal from the streambed. Two other stations, Kadashan River (15106920) and Tonalite Creek (15106980), provide data for the Forest Service in its investigation of the effects of logging in the Kadashan River basin near Tenakee. Caribou Creek near Chatanika (15535000) is operated in an interagency watershed research basin in a sub-arctic environment.

Other

In addition to the eight data-use classes described above, Salmon Creek near Juneau (15051008) and Indian River near Sitka (15087690), are operated to obtain data for use in the adjudication of water rights. Streamflow data collected at Ship Creek near Anchorage (15276000) conceivably could be used for the adjudication of water rights; however, it was decided that for the station the proper data-use classification is Project Operation. Two stations near Hope, Resurrection Creek (15267900) and Sixmile Creek (15271000), are operated for the Forest Service to provide data for land management.

Funding

The four sources of funding for the streamflow-data program are:

1. Federal program.--Funds that have been directly allocated by Congress to the USGS. "A&E" (Army Engineer) funds used to provide partial funding at some stations, where the U.S. Corps of Engineers and the Geological Survey have joint interests, are included.
2. Other Federal Agency (OFA) program.--Funds that have been transferred to the USGS by other Federal agencies.
3. Coop program.--Funds that come jointly from USGS cooperative-designated funding and from a non-Federal cooperating agency.
4. Other non-Federal.--Funds that are provided entirely by a non-Federal agency. Funding for some stations established for planning and design purposes was not matched by USGS cooperative funds because of a shortage of cooperative funds. The Water Survey of Canada and the Geological Survey jointly operate two gaging stations; however, separate funds are used in their respective efforts.

In all four categories, the identified sources of funding pertain only to the collection of streamflow data. Sources of funding for other activities at the site, particularly the collection of water-quality samples or daily water temperature data, are not necessarily the same as those identified herein for three gaging stations out of the 110 stations in table 3.

Eleven entities currently are contributing funds to the Alaska streamgaging program.

Frequency of Data Availability

Frequency of data availability refers to the times at which the streamflow data may be furnished to the users. In this category, three distinct possibilities exist. Data can be furnished by direct-access telemetry equipment for immediate use, by periodic release of provisional data, or annually in Water Data Report for Alaska (U.S. Geological Survey, 1982). These three categories are designated T, P, and A, respectively, in table 3. In the current Alaska program, data for all 110 stations are or will be made available in the annual reports; data from 12 stations with telemetry currently being operated by USGS can be made available on a real-time basis. The National Weather Service (NWS) and Corps of Engineers have installed and operate telemetry equipment at seven gaging stations in the Chena River Flood Control Project. Additionally, NWS operates telemetry equipment at two of the USGS gaging stations in its flood-forecasting network; it also has observers at six USGS stations without telemetry. These six sites are designated by an "O" in table 3. Provisional discharge data are computed monthly for the four stations used in the Survey's Water Resources Review. Provisional data for many stations are provided on request to cooperators or their consultants.

Network Management

An important aspect of network management is the identification of gaging stations at which the data have adequately fulfilled the purpose for operating the station. Another related aspect of management is the assigning of priorities to stations in a network, based on the relative value of additional data from the current stream gages, so that the most useful information can be obtained at a given funding level or reduced funding levels. Funding sometimes can be obtained from another source to continue operating a station if further need for the data exists, whether for the original purpose or for some previously undefined purpose or need.

The Alaska District of the Geological Survey periodically re-examines the need for additional streamflow data at a site. This examination is made particularly after a short-term project utilizing the data has been completed, whenever funding levels remain static or decrease, after the first 5 years of data collection, and again after the first 10 years of data collection. The 5-year criterion is arbitrary in that after 5 years of operation, the Geological Survey considers sufficient data have been collected to publish values of mean annual discharge. Also, 5 years of record are sufficient to identify the general seasonal pattern of streamflow. Occasionally, a station might have such unstable hydraulic conditions that a satisfactory stage-discharge relation cannot be developed and it might not be worthwhile collecting additional data of low reliability. (If it is worthwhile collecting further data, remedial actions should be taken such as locating a more suitable hydraulic control and relocating the gage; if a more suitable site cannot be found, funding to obtain additional measurements throughout the year should be made available.) Similarly, the 10-year criterion is arbitrary as the USGS considers at least 10 years of record necessary to use the resultant streamflow characteristics in any regional analysis. Of course, the additional data collected after this 10-year point should be periodically re-examined to determine if more valuable streamflow information can be obtained by collecting data at another gaging station. The methodology of these examinations is somewhat cursory, informal, and subjective.

Two station records will reach the 10-year point at the end of the 1983 water year on September 30, 1983. These stations are Peters Creek near Birchwood (15277410) and Snake River near Dillingham (15303150). Because of static funding levels and because it has served its original purpose, the USGS and the Corps of Engineers have decided to discontinue funding for Peters Creek at the end of the current water year (1983). Increasing residential development is occurring within the flatter areas of the basin near the gage. However, development is relatively minor and the 10 years of collected record can be used in regional hydrologic analysis, which was the original purpose for installing the gage. The station on Snake River will be terminated at the end of the water year as further data collection will add little to regional hydrologic analysis. Barbara Creek near Seldovia (15238820), which has 11 years of record, will be continued on a year-to-year basis as there is continuing interest in streamflow data from the area because of potential development.

A review of the data-use and funding information presented in table 3 indicates that 18 stations are operated to support hydrologic studies. However, 11 of these stations also have regional hydrology applications. Of the remaining seven stations that are being operated to support hydrologic studies, only the five stations in Anchorage on Chester Creek and tributaries, which are used in urban runoff studies, have a short-term project with a defined ending date. Data collection is scheduled to end in 1984 for the urban runoff study. It was decided that three (15274820, 15275035, 15275055) of these five stations will be terminated at the end of the current project. The basin of the upstream station on South Branch South Fork Chester Creek (15274798) is virtually undeveloped. Although streamflow data from the station would have little transfer value, it would continue to furnish site-specific information to help understand the hydrologic system of Chester Creek basin. It is suggested that further analysis be made in 1984 when the current study ends, to determine whether it would be worthwhile continuing operation of the gage. Because of static funding levels, the agency currently funding Chester Creek at Arctic Boulevard at Anchorage (15275100) has placed a low priority on continued funding of this station. It is suggested that an alternative source of funding be found for this station and operation continue, if the present funding is terminated, because of the need to understand the effects of urban development on the hydrologic system of Chester Creek.

A study on a bald eagle habitat area in Southeast Alaska is scheduled to end in 1984. Because the station used in this study, Klehini River near Klukwan (15056560), provides data useful for defining regional hydrology, the cooperating agency has agreed to continue funding the station. Another station in Southeast Alaska, White Creek near Ketchikan (15011870) was discontinued September 30, 1983, because of decreased funding.

Based on the short-term nature of the hydrologic study of the urban runoff in Chester Creek, the stream gages on the tributaries to Chester Creek are not included for analysis in the following sections of the report. Another, perhaps more pertinent reason for not including them, is that measurements are not scheduled periodically but are made in response to runoff events such as snowmelt and rainstorms.

However, the three stations, White Creek near Ketchikan (15011870), Peters Creek near Birchwood (15277410), and Snake River near Dillingham (15303150), being discontinued after September 30, 1983 are included in the following sections of the report. Because of the continually changing stream-gaging network, it was decided to analyze the network that existed as of September 30, 1983.

Conclusions

Many areas in Alaska have sparse or no streamflow data. It is suggested that this situation be remedied by measures discussed earlier in this report and listed below:

1. Prepare a report detailing an expansion of streamflow data collection network in the state. This effort would involve the following steps:
   a. Analyze the available streamflow data to update the prior network assessment by Childers (1970)
   b. Update the annual precipitation map of Alaska as an interagency effort. This map is essential to computation of multiple-regression equations relating streamflow characteristics to basin characteristics.
   c. Make specific suggestions for areal reconnaissance studies, low-flow and peak-flow partial-record sites, and stream-gaging sites.
2. Install and operate a gaging station in each of four subareas of the state (Lower Yukon, Central Yukon, Upper Yukon-Canada, and Colville) as potential long-term index stations, even before reports on a comprehensive network assessment and on proposed network expansion are completed.
3. Continue with the periodic examination of the stream-gaging network to insure the most effective use of funding and manpower in adding to Alaska's streamflow information.

ALTERNATIVE METHODS OF DEVELOPING STREAMFLOW INFORMATION

The second step of the analysis of the stream-gaging program is to investigate alternative methods of providing daily streamflow information in lieu of operating continuous-record gaging stations. The objective of the analysis is to identify gaging stations where alternative technology, such as flow-routing or statistical methods, will provide information about daily mean streamflow in a more cost-effective manner than operating a continuous stream gage. No guidelines exist concerning suitable accuracies for particular uses of the data; therefore, judgment is required in deciding whether the accuracy of the estimated daily flows is suitable for the intended purpose. The uses of the data from a station will help identify those stations where alternative methods should be examined. For example, stations for which flood hydrographs are required in a real-time sense, such as hydrologic forecasts and project operation, are not candidates for alternative methods. The primary candidates for alternative methods are stations that are operated upstream or downstream of other stations on the same stream. Estimated streamflow at these sites may be of acceptable accuracy because of the high redundancy of flow information between sites. Gaging stations in similar watersheds, which are within the same physiographic and climatic area, also may have potential for alternative methods.

All stations in the current Alaska stream-gaging program were categorized as to their potential utilization of alternative methods and selected methods were applied at six stations. The categorization of gaging stations and the application of the specific methods are described in subsequent sections of this report. This section briefly describes the two alternative methods considered in the Alaska analysis and documents why these specific methods were chosen.

Desirable attributes of a proposed method are that (1) it should be computer oriented and easy to apply, (2) it should have an available interface with the USGS WATSTORE Daily Values File (Hutchinson, 1975), and (3) it should be technically sound and generally acceptable to the hydrologic community. The desirability of the first attribute above is obvious. Secondly, the interface with the WATSTORE Daily Values File is needed to easily develop and calibrate the proposed alternative method. Lastly, the alternative method selected for analysis must be technically sound or it will not be able to provide data of suitable accuracy. The above selection criteria were used to examine two methods--a flow-routing model and a simple-regression analysis.

Description of Flow-Routing Model

Hydrologic flow-routing methods utilize the law of conservation of mass and the relationship between the storage in a reach and the outflow from the reach. The hydraulics of the system are not considered. The method usually requires only a few parameters and treats the reach in a lumped sense without subdivision. The input usually consists of discharge hydrographs for the upstream and the downstream ends of the reach.

The Kenai, Susitna, Yukon, Chena, and Tanana Rivers are the only streams in the Alaska network that have two or more active gaging stations. However, these stations are not candidates for alternative methods because the data collected at most of the stations are used for hydrologic forecasts or project operation. This method could be examined later at several stations, presently used for planning and design data for the proposed Susitna Hydroelectric Project, when a sufficient length of record is obtained at the newer sites with only a short length of record. More specific details and examples of streamflow routing are given in the prototype Maine report (Fontaine and others, 1983).

Description of Regression Analysis

Simple- and multiple-regression techniques can also be utilized to estimate daily flow records. Regression equations can be computed that relate daily flows (or their logarithms) at a single station to daily flows at a combination of upstream, downstream, and/or tributary stations. Unlike the flow-routing method, this statistical method is not limited to downstream stations where an upstream station exists on the same stream. The independent variables in the regression analysis can be daily streamflow at stations in different watersheds, or from stations on downstream and tributary watersheds. The regression-analysis method has many of the same attributes as the flow-routing method in that it is easy to apply, provides indices of accuracy, and is generally accepted as a good method of estimating streamflow. The theory and assumptions of regression analysis are described in several textbooks such as Draper and Smith (1966) and Kleinbaum and Kupper (1978). The application of regression analysis to hydrologic problems is described and illustrated by Riggs (1973) and by Thomas and Benson (1970).

A simple linear regression model of the following form was developed for estimating daily mean discharge in Alaska:

$$Q_d = a + b\,Q_i \qquad (1)$$

where

- Q_d is the daily mean discharge at dependent station (dependent variable),
- Q_i is the daily mean discharge at nearby base station (independent variable),
- a is a constant, and
- b is a coefficient.

An equation is developed for the paired stations using observed values of daily mean discharges retrieved from the WATSTORE Daily Values File. The values of Q_i may be discharges observed on the same day as the values of Q_d, or may be for a previous or following day, depending upon various factors such as comparative drainage areas, storm paths, or altitudes of gage or basin, etc. If the two stations whose discharges are being compared are on the same stream system, flow events at the upstream station usually will precede the equivalent flow event at the downstream station. The constant and the coefficient are determined as a result of the regression analysis.

Similar regression equations can be developed to relate logarithmic values of the observed daily discharges at the two stations. The logarithmic model is similar in form to the prior equation and can be expressed as follows:

$$\text{Log}\,(Q_d) = \text{Log}\,(d) + e\,\text{Log}\,(Q_i) \qquad (2)$$

where

- Q_d and Q_i are the same as previously explained,
- d is a regression constant, and
- e is a regression coefficient.

The above equation is more commonly expressed as an exponential equation as follows:

$$Q_d = d(Q_i)^e.$$

Once the equations are derived for paired stations, discharges at the dependent station can be estimated based on observed discharges at the independent station. The application of simple linear-regression techniques to six drainage basins in Alaska is described in a subsequent section of this report.

Selection of Gaging Stations Using Regression Procedures as an Alternative Method

Examination of the data uses given in table 3 helped to identify several stations at which it might be appropriate to use and test regression procedures as an alternative method to provide daily discharge values. Further studies reduced the prospective stations to four. Discharges from only two stations were used to provide the independent variables for simulating the discharges at the four dependent stations. However, these four station pairs had somewhat similar seasonal flow characteristics. Therefore, another station pair with different seasonal characteristics was added to test the method. Still another station pair was added to test the method when a "lag" correction is required because the response time is different at the dependent and independent stations. These six station pairs and the period of record used in the analysis are:

Dependent station	Independent station	Period analyzed
Goat Creek near Wrangell (15024750)	Harding River near Wrangell (15022000)	10/1/76 to 9/30/82
Farragut River near Wrangell (15028300)	Harding River near Wrangell (15022000)	10/1/77 to 9/30/82
Mendenhall River near Auke Bay (15052500)	Skagway River at Skagway (15056100)	10/1/65 to 9/30/82
Barbara Creek near Seldovia (15238820)	Anchor River near Anchor Point (15239900)	10/1/72 to 10/10/73 and 9/1/78 to 9/30/81
Ninilchik River at Ninilchik (15241600)	Anchor River near Anchor Point (15239900)	7/1/65 to 10/10/73 and 9/1/78 to 9/30/81
Snake River near Dillingham (15303150)	Nuyakuk River near Dillingham (15302000)	10/1/73 to 9/30/82

These six pairs do not have adjoining drainage basins for the dependent and independent stations.

Regression Analysis Results

Simple regression techniques (using observed and log-transformed discharge values) were applied to the six selected station pairs. The daily streamflow record for each station considered for simulation (the dependent variable) was regressed against the daily streamflow record at the other station (independent variable) during a given period of record. "Best fit" linear regression equations were computed and used to provide an estimated daily streamflow record that was compared to the observed streamflow record. The percent difference between the simulated and actual record for each day was calculated. The results of the regression analysis for each site are summarized in table 4.

The coefficients of determination (R^2), which are a measure of how well the models fit for the periods of record analyzed, ranged from 0.354 for the linear regression equation for estimating discharges for Barbara Creek to 0.929 for the logarithmic regression equation for estimating Farragut River discharges. R^2 was found to be higher for the logarithmically transformed discharge models. However, a problem exists when logarithmic transforms are used to derive a regression equation for streamflow. In the process of changing discharges to their logarithmic values to calculate a regression equation and then changing the simulated logarithmic discharges back to cubic feet per second, a bias is introduced. This bias results because low flows are slightly overestimated and high flows are underestimated to a greater degree. An index of this bias can be determined by dividing the mean of the observed discharges by the mean of the simulated discharges for the period of concurrent record that was analyzed. This value is shown in table 4 as a "bias correction" and ranged from 1.01 to 1.19 for the analysis made in this study.

Table 4. -- Results of regression modeling of mean daily streamflow at selected gage sites in Alaska

[R^2, coefficient of determination; C. V., coefficient of variation; S. E., standard error of estimate]

Daily discharge model Dependent station versus independent station	Dependent variable Q_d	Values used in regression equations				R^2	C. V. (percent)	S. E. (percent)		Q_d within limits shown of actual flow			Bias correction
		a	b	d	e			(+)	(-)	5%	10%	25%	
Goat Creek versus Harding River	Q_G	-46	0.335			0.485	122			--	--	--	
				0.140	1.08	.884		48	32	--	--	--	1.11
Farragut River versus Harding River	Q_F	193	1.97			.802	43			10	19	47	
				2.40	.99	.929		33	25	14	28	66	1.03
	Q_{F1}	67	1.93			.876	49			7	14	52	
				2.03	1.01	.939		27	21	8	23	73	1.01
	Q_{F2}	40	1.81			.859	34			17	43	74	
				3.59	.89	.898		24	19	21	38	78	1.03
	Q_{F3}	57	1.91			.643	38			12	21	65	
				3.38	.91	.781		32	24	9	32	71	1.04
	Q_{F4}	115	1.67			.830	29			13	33	66	
				4.10	.88	.863		28	22	17	37	75	1.03
	Q_{F5}	186	1.61			.802	16			26	48	88	
				4.00	.88	.829		16	14	29	48	88	1.01
	Q_{F6}	205	1.88			.661	16			28	49	91	
				4.67	.88	.686		16	14	28	49	93	1.01
	Q_{F7}	956	1.56			.447	26			20	43	78	
				27.5	.65	.481		23	19	26	44	78	1.02
	Q_{F8}	990	1.83			.728	22			23	42	82	
				20.0	.72	.743		20	17	24	48	83	1.02
	Q_{F9}	443	1.91			.779	34			17	35	68	
				8.94	.81	.816		29	22	13	27	69	1.04
	Q_{F10}	697	1.72			.773	39			8	19	44	
				3.48	.94	.884		32	24	27	39	68	1.01
	Q_{F11}	332	1.67			.532	78			17	37	73	
				3.59	.92	.802		42	29	19	31	73	1.07
	Q_{F12}	193	1.18			.717	39			9	19	55	
				9.13	.72	.711		36	27	15	32	69	1.05
						Error summary for year using monthly equations				16	33	70	
										20	37	77	1.03
Mendenhall River versus Skagway River	Q_M	320	1.40			.610	80			--	--	--	
				2.32	.97	.897		72	42	--	--	--	1.06
Barbara Creek versus Anchor River	Q_B	60	.235			.354	73			--	--	--	
				1.56	.77	.453		91	48	--	--	--	1.19
Ninilchik River versus Anchor River	Q_N	54	.245			.510	54			--	--	--	
				5.76	.55	.696		35	26	--	--	--	1.07

Basic equations:

Linear $Q_d = a + b\, Q_i$

Logarithmic $Q_d = d\, (Q_i)^e$

where Q_d is the dependent variable: the simulated daily discharge, in cubic feet per second, at the station for which discharges for any given day are being determined;

Q_i is the independent variable: the actual daily discharge, in cubic feet per second, at the station being used to provide base discharge values for any given day;

a is the constant and b is the coefficient;

d is the regression constant and e is the regression coefficient;

where additionally

Q_{dn} is the dependent variable for any given month where n=1 is January, n=11 is November, and so forth;

for example,

Q_{F1} is the simulated daily discharge at Farragut River near Wrangell for any given day in January, provided there is a discharge value for that day at Harding River near Wrangell.

Table 4. -- Continued

Daily discharge model Dependent station versus independent station	Dependent variable Q_d	Values used in regression equations a	b	d	e	R^2	C. V. (percent)	S. E. (percent) (+)	(-)	Q_d within limits shown of actual flow 5%	10%	25%	Bias correction
Snake River versus Nuyakuk River	Q_S	184	0.053			0.582	49			9	17	44	
				1.03	0.71	.678		50	33	10	20	47	1.09
NOTE.--A lag correction of 3 days is applied to Nuyakuk discharge values	Q_{S1}	-164	.177			.438	40			6	10	34	
				.042	1.11	.286		48	33	10	13	44	1.09
	Q_{S2}	60	.078			.186	38			19	31	57	
				2.15	.60	.161		44	31	18	28	60	1.07
	Q_{S3}	-102	.181			.504	36			7	15	30	
				.032	1.17	.495		40	29	8	18	42	1.07
	Q_{S4}	-43	.158			.474	34			17	27	57	
				.033	1.18	.692		28	22	11	24	56	1.04
	Q_{S5}	225	.096			.622	39			11	19	42	
				.175	.97	.769		45	31	12	29	58	1.03
	Q_{S6}	660	.037			.154	34			16	24	48	
				52.2	.32	.089		41	29	14	24	49	1.06
	Q_{S7}	20	.046			.616	26			14	26	65	
				.024	1.07	.635		30	23	18	27	67	1.03
	Q_{S8}	37	.050			.603	40			12	17	43	
				.055	.99	.577		45	31	15	30	51	1.07
	Q_{S9}	-108	.092			.671	33			6	11	60	
				.035	1.08	.534		39	28	7	20	59	1.06
	Q_{S10}	68	.075			.683	21			24	37	67	
				.100	.98	.694		24	19	19	38	70	1.02
	Q_{S11}	-13	.108			.567	30			6	15	52	
				.123	.98	.522		33	25	7	13	51	1.04
	Q_{S12}	-159	.156			.639	32			16	25	39	
				.0030	1.43	.548		43	30	15	25	36	1.06
						Error summary for year using monthly equations				13	22	49	
										13	24	54	1.05

Basic equations:

Linear $Q_S = 184 + 0.053\ Q_N$

Logarithmic $Q_S = 1.03\ Q_N^{0.71}$

where for example, the simulated daily discharge during any September day at Snake River near Dillingham can be determined using the following equations:

$Q_{S9} = -108 + 0.092\ Q_{N9}$

$Q_{S9} = 0.035\ (Q_{N9})^{1.08}$

Hardison (1969) discusses some common methods of measuring the variability of the differences between the estimated and the observed discharge values. The statistics are the standard error of estimate (S.E.) for the logarithmic regressions and the coefficient of variation (C.V.) of the linear regressions. (Discharge values can be simulated with a greater degree of confidence if these values are low. About two-thirds of the estimated discharges are within the S.E. and C.V. limits of the actual discharges.)

These statistics are computed in the units used in the regression. However, for comparative purposes they were converted to percent as shown in table 4. Standard error of estimate (S.E.) for the regression using the logarithmic transform is computed in absolute, (+) or (-), log units. When these departures from the regression equation are converted to percent, the values are different for the positive standard error than for the negative standard error. For example, if S.E. = 0.12 log units, the positive departure would be +31.8 percent and the negative departure would be -24.1 percent (Hardison, 1969, table 2). Discharge units are used in the linear regression analysis and the S.E. is in the same units. To convert to percent, S.E. is divided by the mean of the discharge values and S.E. is expressed as a percentage of the mean. However, it is simpler to compute standard deviation, and standard deviation divided by the mean is the coefficient of variation (C.V.). C.V. can easily be converted to percent. For very large sample sizes, S.E. and C.V. for the departures from the linear regression equation are almost the same.

Relative judgments of the regression analysis results can be made by examining the values of R^2 and C.V. (or S.E.). An arbitrary rule of judgment is that when R^2 is less than 0.5, the model is unreliable. Using the above criteria, the equations for estimating the Barbara Creek discharge based on concurrent Anchor River discharge should be used only with reservation.

The other regression equations varied in the quality of their results. However, the equations for estimating discharge for Farragut River gave the best overall results. A very noticeable seasonal trend in the differences between estimated and actual discharges exists because of overestimation of discharge in low-flow winter months and underestimation of higher flows in summer and early fall. Therefore, it was decided to calculate regression equations for each month. The results were analyzed using another type of error summary to compare the differences between the estimated and observed discharges. If a linear equation is applied throughout the year, 19 percent of the estimated flows are within 10 percent of the observed flows. When the 12 monthly linear equations are used to estimate discharges, 33 percent of the estimated flows are within 10 percent of the observed flows. When the logarithmic versions of the regression equations are used, 28 percent of the estimated values are within 10 percent of the actual values if one overall equation is used and 37 percent are within the 10 percent limit when 12 monthly equations are used. Similar statistics are also shown in table 4 for 5 and 25 percent limits and for each individual month. The improvement in results through the year, using the monthly equations instead of using equations covering the whole year, is shown in table 4. The estimated discharges, for the linear and logarithmic models using a single overall equation and also the monthly equations, are compared in figure 8 with the actual discharges in August and September 1982.

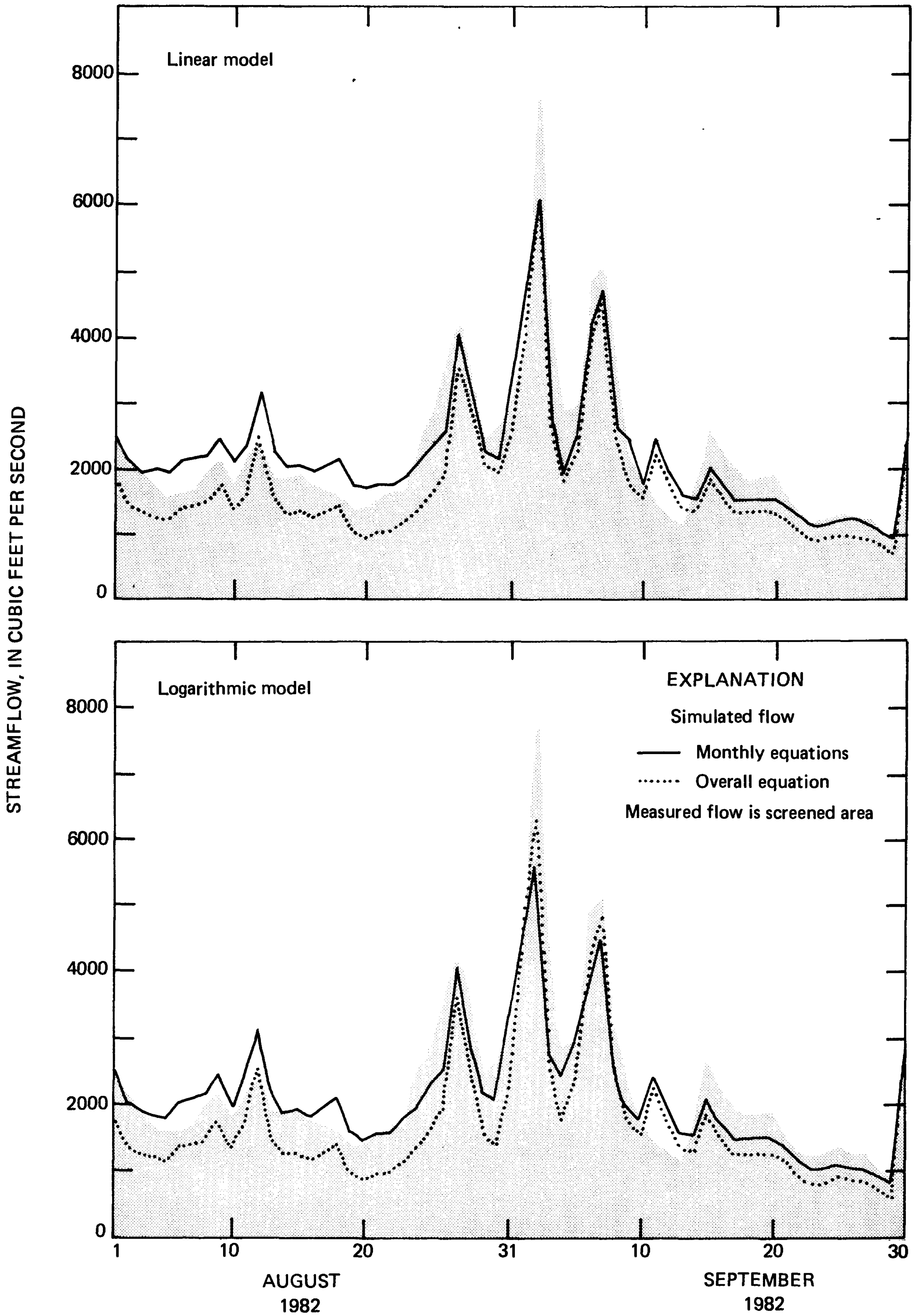


Figure 8.--Daily discharge hydrograph at Farragut River near Wrangell.

Computations were also made for a station pair near Dillingham, Snake River (15303150) and Nuyakuk River (15302000), with a difference in response times to climatic influences or events. The best correlation throughout the year between discharges at the two stations occurs when a 3-day lag correction is applied to the discharge at the base station, Nuyakuk River. Flows at the Snake River gage that occur in response to climatic influences on a given day or over a short period of time generally occur or start 3 days later at the gage on the Nuyakuk. The principal reasons for this delay are because the Nuyakuk drainage area is about 13 times larger than the Snake River drainage and because the mean altitude of the Nuyakuk basin is twice as high as that of the Snake River basin. Twenty-eight percent of the Snake River basin area is a large lake upstream from the gage; 14 percent of the area of Nuyakuk basin consists of several lakes.

Monthly regression equations were calculated using this 3-day lag throughout the year. For example, if the logarithmic equations for September and October are used to estimate discharges at the Snake River gage on September 30 and October 1, 1977, the simulated Snake River discharges would be 412 and 489 ft^3/s, respectively (based on Nuyakuk River discharges on October 3 and 4 of 5,880 ft^3/s and 5,820 ft^3/s). The estimated values compare with the observed discharges of 398 and 367 ft^3/s, respectively.

The results of the analysis by months are mixed. For example, R^2's are low for January, February, and June. Because of seasonal differences in flow at the gages on Snake River and Nuyakuk River during these months, the correlation between daily discharges is very poor. The correlation in June is poor because the snow-melt runoff in the lower altitude (mean elevation = 550 ft) Snake River basin begins several days earlier, peaks earlier, and occurs during a shorter period than in the higher altitude (mean elevation = 1,100 ft) Nuyakuk basin. The explanation for the poor correlations in January and February is more complex. Because both stations are located just downstream from large lakes, it is not uncommon for open-water flows to occur at the gages in mid-winter when the winter temperatures have been mild and pre-freezeup flows greater than usual. However, these mid-winter open-flow events may not occur concurrently at both gage sites, and they might not have been recorded at both stations in the past. Only about 46 percent of simulated daily flows are within 25 percent of the observed flows using the two overall regression equations for the period analyzed. When the monthly equations are used, this percentage for the year improves slightly with about 52 percent of the estimated flows within the 25 percent limits.

In examining the results of the use of monthly regression equations, three problems present themselves. First, the dependent station might have better correlations in discharge with different base stations during different months. Secondly, the use of different lag times for each month might provide better discharge correlations than using the same lag time throughout. Finally, there is not always a smooth transition between simulated discharges at the end of a month and at the beginning of the next month.

The generally unsatisfactory results presented in table 4 show that an alternative method of providing discharge values at a previously gaged site by using simple regression models is not comparable in accuracy with daily discharge values provided by continued operation of the gaging station. The results of the development of the models were insufficient to justify the effort of model "checking." These checking methods include splitting the sample into calibration and verification periods, examining the results to see whether the loss in variance between the estimated and observed discharges is significant, and examining the regression constant and coefficient to see if they are significantly different from zero (Fontaine and others, 1983, p. 24).

Table 6, which is explained and introduced later in the report, demonstrates that the only two stations at which it might be worthwhile to further examine simple regression techniques as an alternative method would be a station pair near Ketchikan, White Creek and Keta River (White Creek is tributary to Keta River) and another station pair near Tenakee, Kadashan River and Tonalite Creek (which adjoin each other).

Conclusions

Based on the preceding analysis, it is suggested that no further effort be expended for developing regression equations as an alternative method of determining discharge, particularly at sites in non-adjacent drainage basins. In summary, regression techniques do not provide a satisfactory alternative method of calculating mean daily discharges as compared to continued operation of a gaging station. Therefore, all the stations considered in this section will be included in the next step of the analysis.

COST-EFFECTIVE RESOURCE ALLOCATION

Introduction to Kalman-Filtering for Cost-Effective Resource Allocation (K-CERA)

In a study of the cost-effectiveness of a network of stream gages operated to determine water consumption in the Lower Colorado River Basin, a set of techniques called K-CERA were developed (Moss and Gilroy, 1980). Because of the water-balance nature of that study, the measure of effectiveness of the network was chosen to minimize the sum of variances of errors (in cubic feet per second) in estimating the annual mean discharges at each site in the network. This measure of effectiveness tends to concentrate stream-gaging resources on the larger streams where potential errors are greatest. While such a tendency is appropriate for a water-balance network, in the broader context of the multitude of uses of the streamflow data collected in the USGS's Streamflow Information Program, this tendency causes undue concentration on larger streams. Therefore, the original version of K-CERA was modified to include as optional measures of effectiveness the sums of the variances of errors (either as cubic feet per second or as percentage) in estimating the annual mean discharge or the average instantaneous discharge. The use of percentage errors does not unduly weight streamflow information from large streams to the detriment of records on small streams. Since instantaneous discharge is the basic variable from which all other streamflow information is derived, this study used the K-CERA techniques with the sums of the variances in the percentage errors of the instantaneous discharges at most of the continuously gaged sites in the Alaska stream-gaging program as the measure of the effectiveness of the data-collection activity.

The original version of K-CERA also did not account for error contributed by missing stage or other correlative data used to compute streamflow data. The probabilities of missing correlative data increase as the period between service visits to a stream gage increases. A procedure for dealing with the missing record has been developed and was incorporated into this study.

Brief descriptions of the mathematical program used to optimize cost-effectiveness of the data-collection activities and of the application of Kalman filtering (Gelb, 1974) to the determination of the accuracy of a stream-gaging record are presented below. For more details on either the theory or the applications of K-CERA, see Moss and Gilroy (1980) and Gilroy and Moss (1981).

Description of Mathematical Program

The program, called "The Traveling Hydrographer," attempts to allocate, among the stream gages in a network, a predefined budget for the collection of streamflow data so that the field operation is the most cost-effective possible. The measure of effectiveness is discussed above. The set of decisions available to the network manager is the frequency of use (number of times per year) for each of a number of routes that may be used to service the stream gages and to make discharge measurements. The range of options within the program is from zero usage to daily usage for each route. A route is defined as a set of one or more stream gages and the lowest cost of round-trip travel that the hydrographer can take from his base of operations to each of the gages. (An average cost of travel to cover the route and the average cost of servicing each stream gage visited along the way is used.) The first step in this part of the analysis is to define the set of practical routes. This set of routes frequently will have round-trip visits to an individual stream gage and back to the base of operations so that the individual requirements at a stream gage can be considered independently of all other gages.

Another step in this part of the analysis is the determination of any special requirements for visits to each of the gages for such things as necessary periodic maintenance, rejuvenation of recording equipment, or required periodic sampling of water-quality data. Such special requirements are considered inviolable constraints in determining the minimum number of visits to each gage.

The final step is to use all of the above to determine the number of times, N_i, that the i^{th} route for i = 1, 2, ..., NR, where NR is the number of practical routes, is used during a year such that (1) the budget for the network is not exceeded, (2) the minimum number of visits to each station is made, and (3) the total uncertainty in the network is minimized. Figure 9 represents this step in the form of a mathematical program. Figure 10 presents a tabular layout of the problem. Each of the NR routes is represented by a row of the table and each of the stations is represented by a column. The zero-one matrix, (ω_{ij}), defines the routes in terms of the stations that comprise it. A value of one in row i and

$$\underset{\underline{N}}{\text{Minimize}}\ V = \sum_{j=1}^{MG} \phi_j\ (M_j)$$

$V \equiv$ total uncertainty in the network

$\underline{N} \equiv$ vector of annual number times each route was used

$MG \equiv$ number of gages in the network

$M_j \equiv$ annual number of visits to station j

$\phi_j \equiv$ function relating number of visits to uncertainty at station j

Such that

Budget $\geq T_c \equiv$ total cost of operating the network

$$T_c = F_c + \sum_{j=1}^{MG} \alpha_j M_j + \sum_{i=1}^{NR} \beta_i N_i$$

$F_c \equiv$ fixed cost

$\alpha_j \equiv$ unit cost of visit to station j

$NR \equiv$ number of practical routes chosen

$\beta_i \equiv$ travel cost for route i

$N_i \equiv$ annual number times route i is used (an element of $\underline{N}$)

and such that

$$M_j \geq \lambda_j$$

$\lambda_j \equiv$ minimum number of annual visits to station j

Figure 9.--Mathematical-programing form of the optimization of the routing of hydrographers.

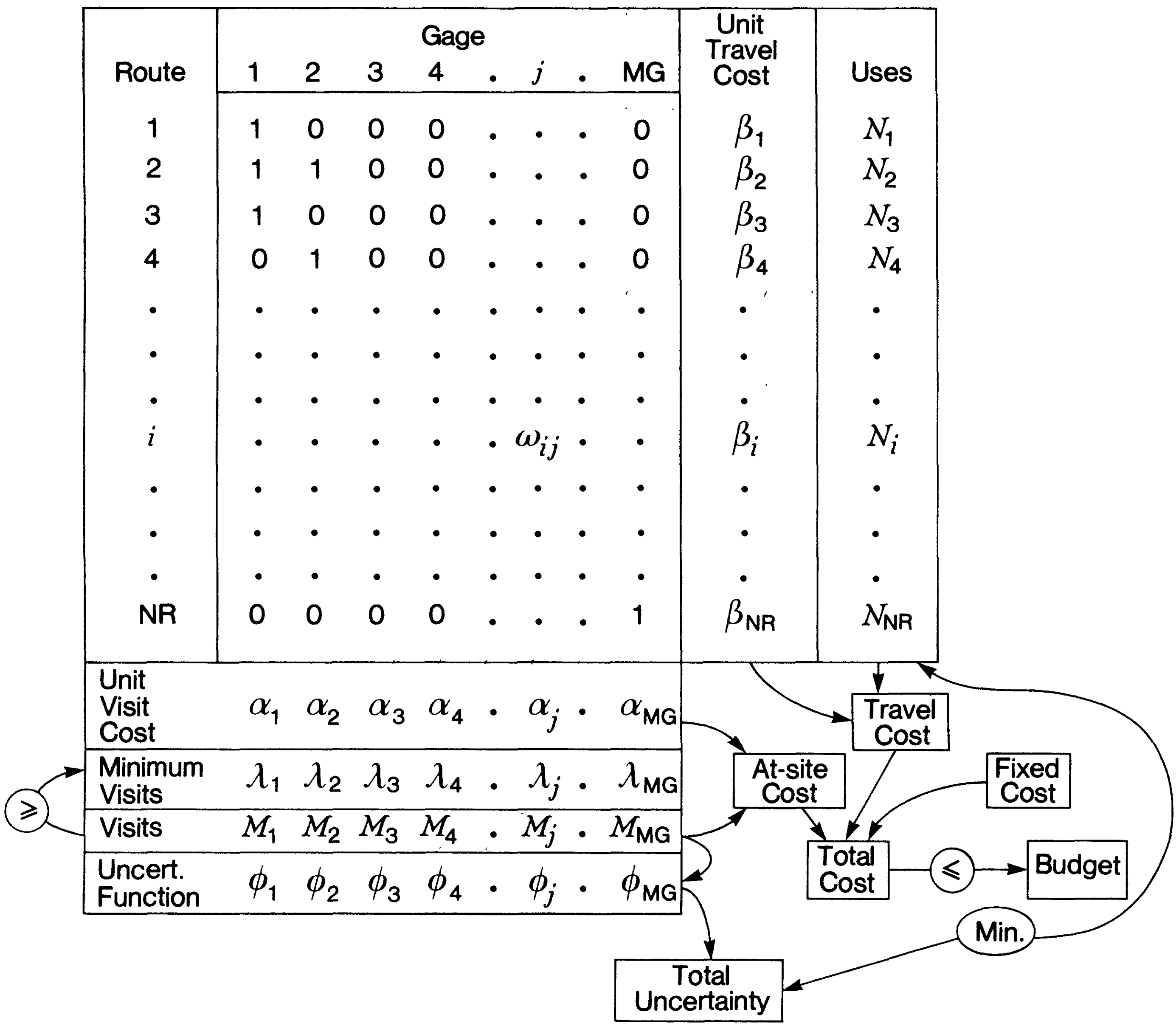


Figure 10.--Tabular form of the optimization of the routing of hydrographers.

column j indicates that gaging stations j will be visited in route i; a value of zero indicates that it will not. The unit travel costs, β_i, are the per-trip costs of the hydrographers's traveltime and any related per diem and operation, maintenance, and rental costs of vehicles. The sum of the products of β_i and N_i for i = 1, 2, ..., NR is the total travel costs associated with the set of decisions $\underline{N} = (N_1, N_2, \ldots, N_{NR})$.

The unit-visit cost, α_j, is comprised of the average service and maintenance costs incurred on a visit to the station plus the average cost of making a discharge measurement. The set of minimum visit constraints is denoted by the row, λ_y, j = 1, 2, ..., MG, where MG is the number of stream gages. The row of integers M_j, j = 1, 2, ..., MG specifies the number of visits to each stations. M_j is the sum of the products of ω_{ij} and N_i for all i and must equal or exceed λ_j for all j if $\underline{N}$ is to be a feasible solution to the decision problem.

The total cost expended at the stations is equal to the sum of the products of α_j and M_j for all j. The cost of record computation, documentation, and publication is assumed to be influenced negligibly by the number of visits to the station and is included along with the overhead in the fixed cost of operating the network. The total cost of operating the network equals the sum of the travel costs, the at-site costs, and the fixed cost, and must be less than or equal to the available budget.

The total uncertainty in the estimates of discharges at the MG stations is determined by summing the uncertainty functions, ϕ_j, evaluated at the value of M_j from the row above it, for j = 1, 2, ..., MG.

As Moss and Gilroy (1980) pointed out, the steepest descent search used to solve this mathematical program does not guarantee a true optimum solution. However, the locally optimum set of values for $\underline{N}$ obtained with this technique specifies an efficient strategy for operating the network, which may be the true optimum strategy. The true optimum cannot be guaranteed without testing all undominated, feasible strategies.

Description of Uncertainty Functions

As noted earlier, uncertainty in streamflow records is measured in this study as the average relative variance of estimation of instantaneous discharges. The accuracy of a streamflow estimate depends on how that estimate was obtained. Three situations are considered in this study: (1) streamflow is estimated from measured discharge and correlative data using a stage-discharge relation (rating curve), (2) the streamflow record is reconstructed using secondary data at nearby stations because primary correlative data are missing, and (3) primary and secondary data are unavailable for estimating streamflow. The variances of the errors of the estimates of flow that would be employed in each situation were weighted by the fraction of time each situation is expected to occur. Thus the average relative variance would be

$$\bar{V} = \varepsilon_f V_f + \varepsilon_r V_r + \varepsilon_e V_e$$

with (3)

$$1 = \varepsilon_f + \varepsilon_r + \varepsilon_e$$

where

- $\bar{V}$ is the average relative variance of the errors of streamflow estimates,
- ε_f is the fraction of time that the primary recorders are functioning,
- V_f is the relative variance of the errors of flow estimates from primary recorders,
- ε_r is the fraction of time that secondary data are available to reconstruct streamflow records given that the primary data are missing,
- V_r is the relative variance of the errors of estimation of flows reconstructed from secondary data,
- ε_e is the fraction of time that primary and secondary data are not available to compute streamflow records, and
- V_e is the relative error variance of the third situation.

The fractions of time that each source of error is relevant are functions of the frequencies at which the recording equipment is serviced.

The time τ since the last service visit until failure of the recorder or recorders at the primary site is assumed to have a negative-exponential probability distribution truncated at the next service time; the distribution's probability density function is

$$f(\tau) = ke^{-k\tau}/(1-e^{-ks}) \qquad (4)$$

where

- k is the failure rate in units of $(\text{day})^{-1}$,
- e is the base of natural logarithms, and
- s is the interval between visits to the site in days.

It is assumed that, if a recorder fails, it continues to malfunction until the next service visit. As a result,

$$\varepsilon_f = (1-e^{-ks})/(ks) \qquad (5)$$

(Fontaine and others, 1983, eq. 21).

The fraction of time ε_e that no records exist at either the primary or secondary sites can also be derived assuming that the time between failures at both sites are independent and have negative exponential distributions with the same rate constant. It then follows that

$$\varepsilon_e = 1 - [2(1-e^{-ks}) + 0.5(1-e^{-2ks})]/(ks)$$

(Fontaine and others, 1983, eqs. 23 and 25).

Finally, the fraction of time ε_r that records are reconstructed based on data from a secondary site is determined by the equation

$$\varepsilon_r = 1 - \varepsilon_f - \varepsilon_e. \tag{6}$$

$$= [(1-e^{-ks}) + 0.5(1-e^{-2ks})]/(ks)$$

The relative variance, V_f, of the error derived from primary record computation is determined by analyzing a time series of residuals that are the differences between the logarithms of measured discharge and the rating curve discharge. The rating curve discharge is determined from a relationship between discharge and some correlative data, such as water-surface elevation at the gaging station. The measured discharge is the discharge determined by field observations of depths, widths, and velocities. Let $q_T(t)$ be the true instantaneous discharge at time t and let $q_R(t)$ be the value that would be estimated using the rating curve. Then

$$x(t) = \ln q_T(t) - \ln q_R(t) = \ln [q_T(t)/q_R(t)] \tag{7}$$

is the instantaneous difference between the logarithms of the true discharge and the rating curve discharge.

In computing estimates of streamflow, the rating curve may be continually adjusted on the basis of periodic measurements of discharge. This adjustment process results in an estimate, $q_c(t)$, that is a better estimate of the stream's discharge at time t. The difference between the variable $\hat{x}(t)$, which is defined

$$\hat{x}(t) = \ln q_c(t) - \ln q_R(t) \tag{8}$$

and x(t) is the error in the streamflow record at time t. The variance of this difference over time is the desired estimate of V_f.

Unfortunately, the true instantaneous discharge, $q_T(t)$, cannot be determined and thus x(t) and the difference, $\hat{x}(t) - x(t)$, cannot be determined as well. However, the statistical properties of $\hat{x}(t) - x(t)$, particularly its variance, can be inferred from the available discharge measurements. Let the observed residuals of measured discharge from the rating curve be z(t) so that

$$z(t) = x(t) + v(t) = \ln q_m(t) - \ln q_R(t) \tag{9}$$

where

v(t) is the measurement error, and

$\ln q_m(t)$ is the logarithm of the measured discharge equal to $\ln q_T(t)$ plus v(t).

In the Kalman-filter analysis, the z(t) time series was analyzed to determine three site-specific parameters. The Kalman filter used in this study assumes that the time resuduals x(t) arise from a continuous first-order Markovian process that has a Gaussian (normal) probability distribution with zero mean and variance (subsequently referred to as process variance) equal to p. A second important parameter is β, the reciprocal of the correlation time of the Markovian process giving rise to x(t); the correlation between $x(t_1)$ and $x(t_2)$ is $\exp[-\beta|t_1-t_2|]$. Fontaine and others (1983) also define q, the constant value of the spectral density function of the white noise which drives the Gauss-Markov x-process. The parameters, p, q, and β are related by

$$Var[x(t)] = p = q/(2\beta) \tag{10}$$

The variance of the observed residuals z(t) is

$$Var[z(t)] = p + r \tag{11}$$

where r is the variance of the measurement error v(t). The three parameters, p, β, and r, are computed by analyzing the statistical properties of the z(t) time series. These three site-specific parameters are needed to define this component of the uncertainty relationship. The Kalman filter utilizes these three parameters to determine the average relative variance of the errors of estimation of discharges as a function of the number of discharge measurements per year (Moss and Gilroy, 1980).

If the recorder at the primary site fails and there are no concurrent data at other sites that can be used to reconstruct the missing record at the primary site, there are at least two ways of estimating discharges at the primary site. A recession curve could be applied from the time of recorder stoppage until the gage was once again functioning or the expected value of discharge for the period of missing data could be used as an estimate. The expected-value approach is used in this study to estimate V_e, the relative error variance during periods of no concurrent data at nearby stations. If the expected value is used to estimate discharge, the value that is used should be the expected value of discharge at the time of year of the missing record because of the seasonality of the streamflow processes. The variance of streamflow, which also is a seasonally varying parameter, is an estimate of the error variance that results from using the expected value as an estimate. Thus the coefficient of variation squared $(C_v)^2$ is an estimate of the required relative error variance V_e. Because C_v varies seasonally and the times of failures cannot be anticipated, a seasonally averaged value of C_v is used:

$$\overline{C}_v = \left[\frac{1}{365}\sum_{i=1}^{365}\left(\frac{\sigma_i}{\mu_i}\right)^2\right]^{1/2} \tag{12}$$

where

σ_i is the standard deviation of daily discharges for the i^{th} day of the year,

μ_i is the expected value of discharge on the i^{th} day of the year, and

$(\overline{C}_v)^2$ is used as an estimate of V_e.

The variance V_r of the relative error during periods of reconstructed streamflow records is estimated on the basis of correlation between records at the primary site and records from other gaged nearby sites. The correlation coefficient

ρ_c between the streamflows with seasonal trends removed at the site of interest and detrended streamflows at the other sites is a measure of the goodness of their linear relationship. The fraction of the variance of streamflow at the primary site that is explained by data from the other sites is equal to ρ_c^2. Thus, the relative error variance of flow estimates at the primary site obtained from secondary information will be

$$V_r = (1-\rho_c^2)\ \overline{C}_v^2 \qquad (13)$$

Because errors in streamflow estimates arise from three different sources with widely varying precisions, the resultant distribution of those errors may differ significantly from a normal or log-normal distribution. This lack of normality causes difficulty in interpretation of the resulting average estimation variance. When primary and secondary data are unavailable, the relative error variance V_e may be very large. This could yield correspondingly large values of $\overline{V}$ in equation (3) even if the probability that primary and secondary information are not available, ε_e, is quite small.

A new parameter, the equivalent Gaussian spread (EGS), is introduced here to assist in interpreting the results of the analyses. If it is assumed that the various errors arising from the three situations represented in equation (3) are log-normally distributed, the value of EGS was determined by the probability statement that

$$\text{Probability}\ [e^{-EGS} \leq (q_c(t)\ /\ q_T(t)) \leq e^{+EGS}] = 0.683 \qquad (14)$$

Thus, if the residuals $\ln q_c(t) - \ln q_T(t)$ were normally distributed, $(EGS)^2$ would be their variance. Here EGS is reported in units of percent because EGS is defined so that nearly two-thirds of the errors in instantaneous streamflow data will be within plus or minus EGS percent of the reported values.

The Application of K-CERA in Alaska

There are 110 stream gages in the Alaska surface-water program as of September 1983. In the first part of this analysis, four stations on Chester Creek tributaries (being studied in an urban runoff project in Anchorage) were excluded from further analysis. The station numbers are 15274798, 15274820, 15275035, and 15275055. Seven stations installed since June 1, 1983 are also excluded from this part of the analysis, as not enough data or information were available to estimate the factors needed for K-CERA analysis. These stations are:

Bradley River near tidewater near Homer (15239070)
Paint River near Kamishak (15294900)
Hidden Basin Creek near mouth near Kodiak (15297110)
Whiskey Bills Creek near Sand Point (15297602)
Humboldt Creek at Sand Point (15297603)
King Creek near Dome Creek (15344000)
Phelan Creek near Paxson (15478040)

Additionally, the discharge record for Porcupine River at Old Crow, Yukon Territory (15388950), furnished by the Water Survey of Canada is not included.

Therefore, it was decided to analyze the network that existed before June 1, 1983. Excluding the stations mentioned above, 98 stream gages were subjected to the K-CERA analysis with the results that are described below. These 98 stations include three stations discontinued on October 1, 1983: White Creek near Ketchikan (15011870), Peters Creek near Birchwood (15277410), and Snake River near Dillingham (15303150).

Definition of Parts of Year not Analyzed by K-CERA Techniques

Application of K-CERA analysis in Alaska was complicated because the techniques previously developed depend upon the existence of a stage-discharge relationship. In most of Alaska, no stage record is available for the colder parts of the year. The stations with stage record throughout the year have insufficient data to develop backwater stage-discharge ratings for the winter such as were used in the prototype report (Fontaine and others, 1983). Therefore, it is not possible to compute uncertainty functions during the colder parts of the year when no stage record is available or when the gage height is affected by backwater from ice. In Alaska, streamflow during this period is lower than during the rest of the year and the lowest flows generally occur in late winter or spring prior to ice breakup.

It was assumed that not being able to determine the errors in the computation of discharges during this period (and consequently not being able to include these errors in the K-CERA analysis) would have little effect on the validity of the study of cost-effectiveness of the stream-gaging program in Alaska.

The amount of flow during these "winter" periods and the length of the "winter" were determined for several gaging stations. The period designated as "winter" in this report is the time period at a gaging station during which K-CERA techniques cannot be applied because the current techniques require stage-discharge ratings. The length of this period ranges from zero days at a few stations in areas with strong maritime climatic influences to a period extending from early September to mid-June for the few stations near the Arctic Coast.

Some stations at low altitudes near the ocean have very short periods of stage record affected by backwater from ice. These stations are influenced by the maritime climatic conditions that prevail during the winter in Southeast Alaska and along the Gulf of Alaska in South-Central Alaska. Backwater from ice usually occurs sporadically; it may not occur in some years or may occur several times during the year during short separated periods. Minor increases in altitude of the station or in the distance from the ocean can result in an increased length of the period of backwater caused by ice. Stream-gaging stations located near the outlets of large lakes usually have shorter "winter" periods than other nearby stations not located near lake outlets; outflow from the lake tends to keep the streams ice-free for some distance downstream from the lake.

The length of period designated as "winter" also depends on the operating conditions at the gaging station. If a stilling well is used, a relatively short period might occur when the stage record is affected by backwater from ice. Next, the water in the well freezes and the recorder does not register any changes in stage occurring in the stream (regardless of whether open-water flow occurs or if the stage is affected by backwater from ice). After breakup occurs in the spring the stilling well may remain frozen during a period of open-water flow conditions. All of the periods during which these conditions occur are combined to determine the "winter" period.

At other stations, the recorder float may be removed and recorder stopped prior to freezing of the water in the well. When temperatures become warm enough to prevent ice formation in the well, the remaining ice is removed from the well, the float reinstalled, and the recorder started. At stations where a pressure manometer (bubble gage) is used to register stage, the orifice might be removed prior to freezeup and not reinstalled until after breakup, when the danger of losing the orifice because of floating ice is past. This time between the stoppage of the recorder prior to freezeup and starting the recorder after breakup is included in the "winter" period.

In essence, the length of the "winter" period varies from gage to gage and is that period during which an open-water stage-discharge rating cannot be used (sometimes because the gage is not in operation). It is not necessarily confined to the period when there is ice in the channel and it does not necessarily include all periods during which open-water flow occurs. The duration of the "winter" period depends upon the type of equipment at the gage, physical conditions at the gage, and operating practices and requirements.

At stations that have been in operation for several years, the average streamflow during the "winter" period can be estimated as a percentage of the total annual flow by using a cumulative monthly hydrograph, the average length of the "winter" period, and the average beginning and end of the "winter" period. Figure 11 shows the results for three representative stations. However, this method does not work with the many stations in northern Alaska at which a high percentage of their total annual flow occurs during the period when the ice breaks up and shortly thereafter. At these stations, the flow in every "winter" was determined from the actual discharge records for every year during the period of record; then the percentage of "winter" flow was computed by summing the flows in "winter" for each complete water year and dividing by the total flow for those water years. This procedure was necessary for eight stations. The results showed that Caribou Creek near Chatanika (15535000) has the highest percentage of flow in "winter" (50 percent) and Putuligayuk River near Deadhorse (15896700) has the longest "winter" period (as shown in figure 12).

The results of this analysis are presented in table 5 for 70 stations at which mean annual flow values were determined and shown in table 1. The results of this analysis to determine "winter" flows are further summarized in figure 13 by histograms of the percent of annual flow that occurs during the "winter" period and the length of the "winter" period. On the average for these 70 stations, 15.7 percent of the flow occurs during the "winter" period and the length of the "winter" period is 147 days.

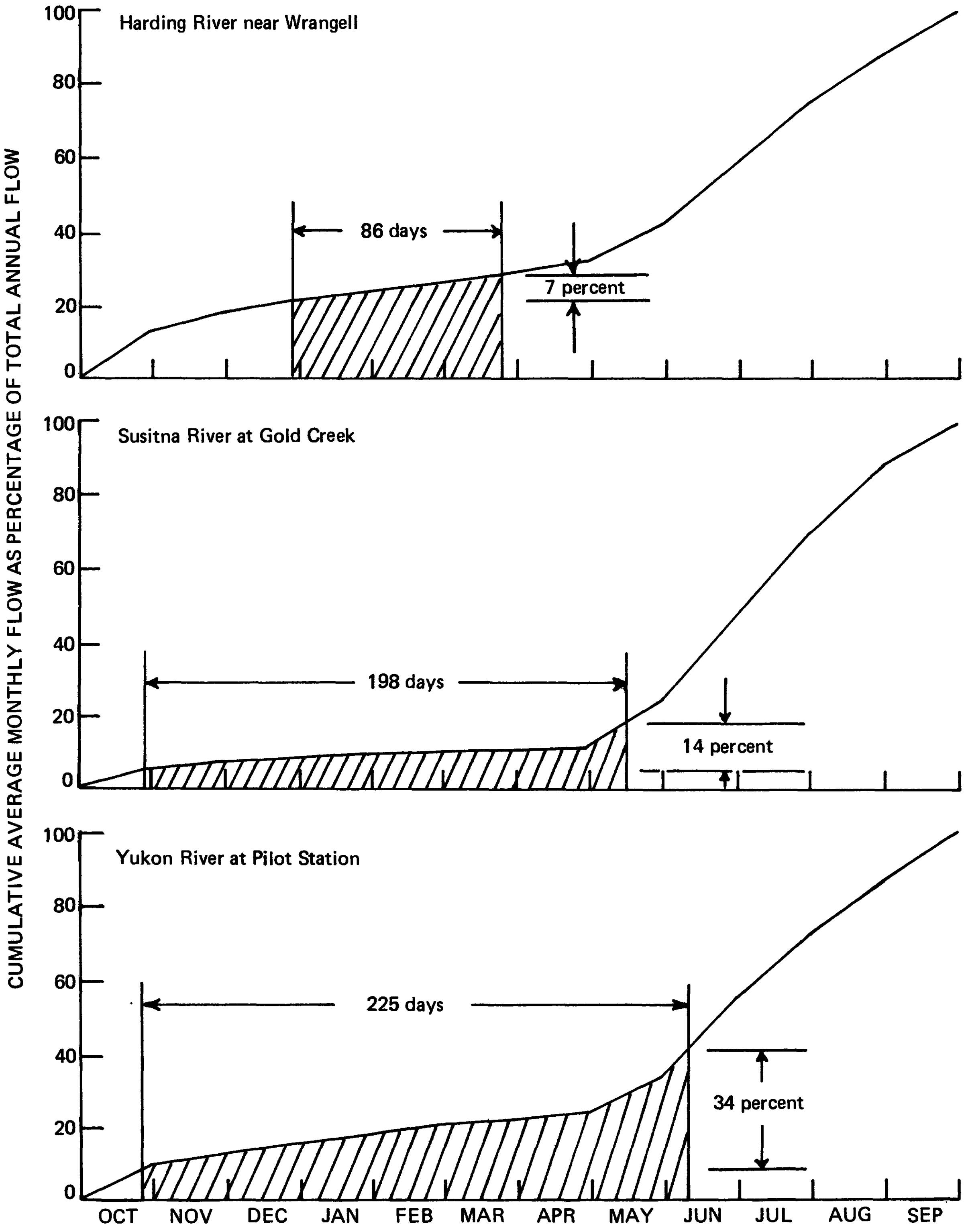


Figure 11.--Determination of "winter" flow and length of "winter" period at three representative stations in Alaska.

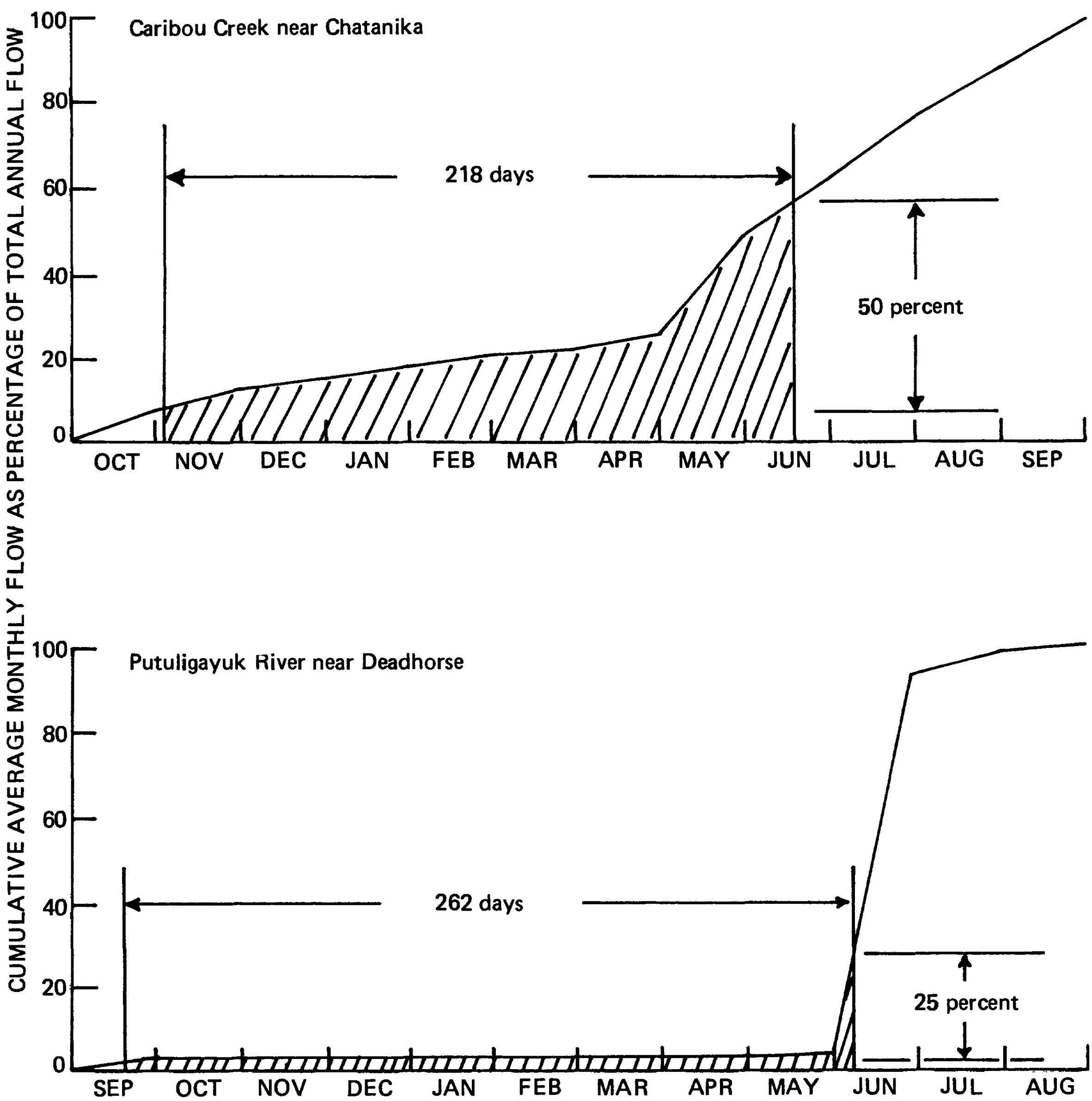


Figure 12.--Extremes in amount of "winter" flow and in length of "winter" period.

Table 5.--Determination of "winter" period discharges and length of "winter" period at selected stream-gaging stations in Alaska

Station number	Station name	"Winter" period: Fraction of annual flow (percent)	"Winter" period: Length of period (days)
	SOUTHEAST ALASKA		
15011870	White Creek near Ketchikan	5	42
15011880	Keta River near Ketchikan	3	28
15022000	Harding River near Wrangell	7	86
15024750	Goat Creek near Wrangell	8	111
15024800	Stikine River near Wrangell	6	119
15028300	Farragut River near Petersburg	4	50
15052500	Mendenhall River near Auke Bay	1	54
15056100	Skagway River at Skagway	1	70
15067900	Upper Mahoney Lake outlet near Ketchikan	11	78
15072000	Fish Creek near Ketchikan	2	10
15083500	Perkins Creek near Metlakatla	6	21
15085100	Old Tom Creek near Kasaan	11	42
15087570	Hamilton Creek near Kake	26	110
15087590	Rocky Pass Creek near Point Baker	16	63
15106920	Kadashan River above Hook Creek near Tenakee	6	40
15106980	Tonalite Creek near Tenakee	11	78
	SOUTH-CENTRAL ALASKA		
15212000	Copper River near Chitina	18	229
15216000	Power Creek near Cordova	6	78
15238820	Barbara Creek near Seldovia	11	87
15239000	Bradley River near Homer	< 1[a]	5[a]
15239900	Anchor River near Anchor Point	22	147
15241600	Ninilchik River at Ninilchik	38	160
15258000	Kenai River at Cooper Landing	1	17
15266300	Kenai River at Soldotna	10	116
15267900	Resurrection Creek near Hope	15	153
15274300	North Fork Campbell Creek near Anchorage	18	161
15274600	Campbell Creek near Spenard	21	176
15275100	Chester Creek at Arctic Blvd. at Anchorage	25	130
15276000	Ship Creek near Anchorage	11	162
15277410	Peters Creek near Birchwood	8	91
15281000	Knik River near Palmer	6	142
15290000	Little Susitna River near Palmer	6	134
15291000	Susitna River near Denali	10	226
15291200	Maclaren River near Paxson	14	232
15291500	Susitna River near Cantwell	16	222
15292000	Susitna River at Gold Creek	14	198

< [a] Adjusted to reflect present location of gage.
Less than.

Table 5.--Continued

Station number	Station name	"Winter" period: Fraction of annual flow (percent)	"Winter" period: Length of period (days)
	SOUTH-CENTRAL ALASKA--Continued		
15292400	Chulitna River near Talkeetna	13	214
15292700	Talkeetna River near Talkeetna	15	208
15294350	Susitna River at Susitna Station	15	196
15294450	Chuitna River near Tyonek	16	162
15295600	Terror River near Kodiak	11	153
15295700	Terror River at mouth near Kodiak	1	19
15297200	Myrtle Creek near Kodiak	25	87
	SOUTHWEST ALASKA		
15297900	Eskimo Creek at King Salmon	30	153
15300000	Newhalen River near Iliamna	22	215
15300500	Kvichak River at Igiugig	16	109
15302000	Nuyakuk River near Dillingham	12	99
15302500	Nushagak River at Ekwok	18	178
15303150	Snake River near Dillingham	22	150
15304000	Kuskokwim River at Crooked Creek	41	240
	YUKON ALASKA		
15356000	Yukon River at Eagle	25	219
15453500	Yukon River near Stevens Village	25	204
15457800	Hess Creek near Livengood	25	230
15476000	Tanana River near Tanacross	19	192
15484000	Salcha River near Salchaket	15	179
15485500	Tanana River at Fairbanks	17	182
15493000	Chena River near Two Rivers	12	172
15511000	Little Chena River near Fairbanks	13	180
15514000	Chena River at Fairbanks	13	172
15515500	Tanana River at Nenana	16	179
15535000	Caribou Creek near Chatanika	50	218
15564875	Middle Fork Koyukuk River near Wiseman	9	234
15565447	Yukon River at Pilot Station	34	225
	NORTHWEST ALASKA		
15621000	Snake River near Nome	31	225
15668200	Crater Creek near Nome	21	238
15744500	Kobuk River near Kiana	38	218
	ARCTIC SLOPE ALASKA		
15798700	Nunavak Creek near Barrow	25	234
15896000	Kuparuk River near Deadhorse	22	225
15896700	Putuligayuk River near Deadhorse	25	262
15904900	Atigun River tributary near Pump Station 4	11	237

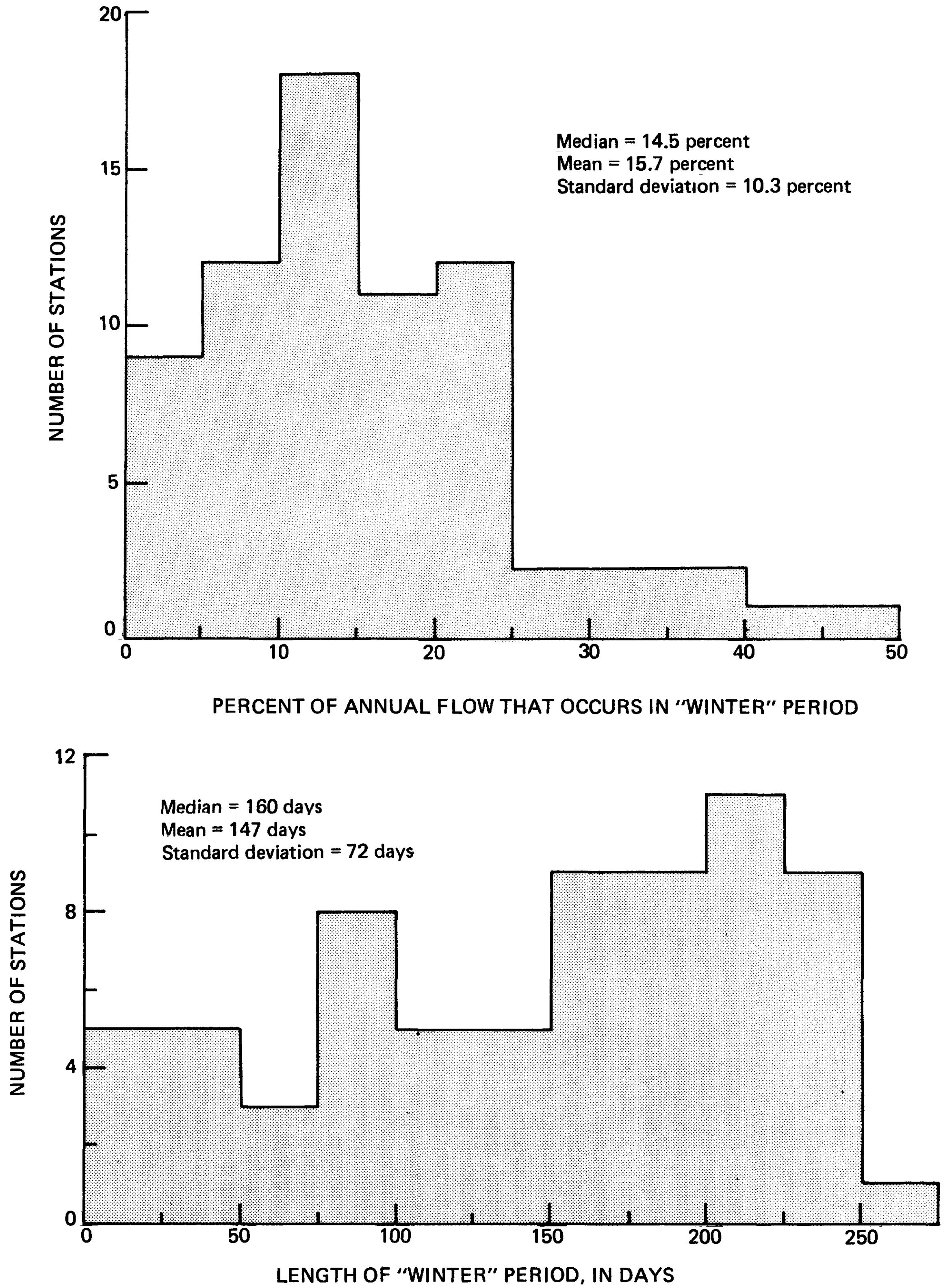


Figure 13.--Summary of "winter" period statistics. Based on 70 stations shown in table 5.

Definition of Missing Record Probabilities

As was described earlier, the statistical characteristics of missing stage or other correlative data for computation of streamflow records can be defined by a single parameter, the value of k in the negative exponential probability distribution of times to failure of the equipment. In the representation of f_T as given in equation 4, the average time to failure is 1/k. The value of 1/k will vary from site to site depending on the type of equipment at the site and upon its exposure to natural elements and vandalism. The value of 1/k can be changed by advances in the technology of data collection and recording.

The analysis of missing record for the open-water periods is complex in Alaska. Four stations do not (or did not) have recording equipment but relied on observers to collect stage record during their period of operation. Other stations may have had stage recorders sometimes during their period of operation but relied on gage observers during other periods, or both stage record and observers were used at the same time. To estimate 1/k in Alaska, past records were examined to determine the average length of missing record at each station. The periods analyzed at most stations were the open-water periods during the 8 water years 1975-82. However, other periods were analyzed for nine stations that had interrupted record during 1975-82, and shorter periods of record were analyzed for those stations that began after October 1, 1974, or that had significant changes in type of recording equipment or location of gage during the 1975-82 period.

Percent of missing record was estimated for stations which have been in operation for only a few years (some only over one season) and also for recently installed gaging stations at which little gage-height record was available for examination. This estimate necessarily had to be subjective and based on short periods of available record, type of gage, climate, and amount of lost record at nearby gages. During the varying periods of time examined for the individual gages, the average amount of lost record in Alaska was slightly more than 10 percent. [In Southeast Alaska, where it is common practice to use both a digital and an analog (strip-chart) recorder at stations, the amount of lost record was only 8 percent.]

The general policy in the past few years has been to visit stations about every 2 months during the open-water season. However, the frequency of station visits during the periods of time examined varied from year to year and from site to site depending on operational policies, amount of funding and manpower available, runoff conditions, and differing durations of the open-water season throughout the state. Some stations had a higher visit frequency because of special studies requiring collection of sediment, water-quality, or low-flow data. Because of this variability, past records (where available) were used as a guide to the amount of lost record at a given station. These values are listed later in table 6.

The amount of lost record ranged from zero at Ninilchik River at Ninilchik (15241600), where there has been a very reliable gage-height observer to 30 percent of the open-water portions of a 3-year record at Capps Creek below North Capps Creek near Tyonek (15294410). The loss of record at the latter site was due primarily to a small landslide area, upstream from the gage, that periodically dumps silt into the stream which covers the orifice of the manometer (bubble-gage).

The amount of record lost at each station was computed disregarding the method used to obtain stage data -- whether from a stage-recorder alone, from a digital recorder with an auxiliary analog recorder, from a combination of a stage recorder and periodic observations by an observer, by once- or twice-daily observations of stage, or even by a combination of a stage recorder and telemetry. This qualification is made because the theoretical adjustment for lost record is based on the operation of a stage recorder. However, the preponderance of available stage data collected at stations in the Alaska network is from a single stage recorder. No adjustments were applied where the method of collecting stage data was by the other methods listed above.

The past records (usually for the 8-year period, 1975-82) were also used to determine the average number of measurements at each station during the open-water periods of the year. These numbers are shown later in table 6. This number is used in the computer program to determine τ and s for use in equations 4, 5 and 6 for each station.

Definition of Cross-Correlation Coefficient and Coefficient of Variation

To compute the values of V_e and V_r of the needed uncertainty functions, daily streamflow records were retrieved for each of the 98 stations for the last 30 years or the part of the last 30 years for which daily streamflow values are stored in WATSTORE (Hutchinson, 1975). For the 81 stream gages with 3 or more complete water years of data in WATSTORE, the value of C_v was computed and various options, based on combinations of other stream gages, were explored to determine the maximum ρ_c. For the 17 stations that had less than 3 water years of data, values of C_v and ρ_c were estimated.

The range of C_v values in general were comparable with those found for Maine (Fontaine and others, 1983). However, there are some exceptions. For example, the lowest value of C_v, 20.6 percent, occurred at Yukon River at Pilot Station (15565447), which is just upstream from the mouth. Streams in the Alaska network with the larger mean annual flows usually have the lower C_v values. The highest C_v value was 149 percent at Nunavak Creek near Barrow (15798700). The highest C_v values computed were for streams on the coastal plain of the Arctic Slope subregion. Most of the total annual flow in these streams occurs during a short period of ice breakup and shortly afterward; long periods of no-flow occur each winter. (See figure 12 for hydrograph of Putuligayuk River.) In fact, the computer program used to determine C_v and the concomitant value of ρ_c had to be modified to determine values of C_v and ρ_c for four stations with long periods of no-flow during the "winter" period of every year. In the previous section on "Description of Uncertainty Functions", equation 10 was applied for a time period of a full year (or 365 days). In the modified version of the equation, the time period used to compute C_v consists only of those days throughout the year which have 3 or more years of discharge values (other than zero) stored in WATSTORE. This period ranged from 116 days at Nunavak Creek to 149 days at Atigun River tributary near Pump Station 4 (15904900). Similarly, only those days with flow at both the primary site and the secondary site were used in the determination of the correlation coefficient, ρ_c.

A variety of combinations of auxiliary records from one to three nearby base stations were tried to obtain the maximum cross-correlation coefficient for each primary station. In almost all cases, a combination of streamflow records from two auxiliary stations resulted in the highest ρ_c values for a station. Therefore, two auxiliary stations (with 3 or more years of record) are shown in table 6 for each station. The station shown first in the table as a source for reconstructed records is the auxiliary station with the highest single station cross-correlation coefficient. The best cross-correlation coefficient, 0.916 was at Tonalite Creek near Tenakee (15106980) using auxiliary records from nearby stations on Kadashan River and Greens Creek. The correlation with the record at Kadashan River alone was almost as good. The basins of Kadashan River and Tonalite Creek have a common drainage divide. The lowest correlation coefficients ranging from 0.121 to 0.203 were for the stations on the Arctic Slope.

Many of the station numbers shown in table 6 have a term "Lag x" underneath them; the daily flows are shown as lagged in an upstream (negative lag) or downstream (positive lag) direction. For example, the daily flows of Yukon River near Stevens Village (15453500) generally reflect flows that occurred 4 days earlier at the upstream station on the Yukon River at Eagle (15356000). Therefore, in determining the maximum ρ_c for the station near Stevens Village, the auxiliary records for the station at Eagle would be used and a "Lag -4" is shown under the station number for the site at Eagle. This concept can also be applied to station records at sites that are near each other but not on the same stream or that do not have adjacent drainage basins. An example of applying lag was presented earlier, in the discussion of alternative methods, using streamflow records from Snake and Nuyakuk Rivers near Dillingham for two stations on different streams.

Table 6 lists the four parameters necessary to compute the variances, V_r and V_e, of the error sources at each station when the primary recorder is not functioning. These four parameters are the percent of missing record, number of measurements, coefficient of variation (C_v), and the cross-correlation coefficient (ρ_c). Subjective estimates of C_v and ρ_c were made for the 17 stations that had less than 3 complete water years of record and they were based on values used for nearby stations and general knowledge of the areas and streams.

Kalman-Filter Definiton of Variance

The determination of V_f for each of the 98 stream gages required the execution of three distinct steps: (1) long-term rating analysis and computation of residuals of measured discharges from the long-term rating, (2) time-series analysis of the residuals to determine the input parameters of the Kalman-filter analysis of streamflow records, and (3) computation of the error variance, V_f, as a function of the time-series parameters, the discharge-measurement-error variance, and the frequency of discharge measurement. "Winter" period records, which were discussed previously, were not used in the Kalman-filter analysis.

Adequate definition of the long-term rating function is dependent on having a sufficient number of discharge measurements with their corresponding gage heights collected at a gage site with the same or similar control conditions over a number of years. These conditions were met at 70 out of the 98 sites analyzed in this section of the report.

A rating function for the 70 stations was developed of the form:

$$LQM = B1 + B3 * LOG(GHT - B2) \quad (15)$$

in which

- LQM is the logarithmic (base e) value of the measured discharge,
- GHT is the recorded gage height corresponding to the measured discharge,
- B1 is the logarithm (base e) of discharge for a flow depth of 1 ft,
- B2 is the gage height of zero flow, and
- B3 is the slope of the rating curve expressed as the change in LQM per unit change in LOG(GHT-B2).

The equation for the rating curve is more commonly expressed in terms of an exponential equation:

Table 6. – Statistics of missing record and record reconstruction

Station number	Percent missing record 1/	No. of measurements 1/	C_v 2/	ρ_c 3/	Source of reconstructed records	
		SOUTHEAST ALASKA				
15011870	7	5	84.2	0.887	15011880	15072000 Lag 1
15011880	6	5	82.0	.894	15011870	15024750
15011894*	6	4	100	.77		
15022000	10	3	85.2	.807	15024750	15072000 Lag 1
15024750	12	3	77.1	.797	15028300	15011880
15024800	7	9	50.3	.80	Upstream Canadian discharge records.	
15028300	15	4	67.3	.786	15024750	15011880
15051008*	5	4	80	.70		
15052009*	5	4	80	.70		
15052500	5	4	79.5	.795	15056100	15028300
15056100	5	4	81.3	.701	15052500	15028300
15056560*	8	6	90	.70		
15067900	10	3	97.3	.702	15011870 Lag 1	15072000
15072000	5	4	88.5	.792	15085100 Lag -1	15011870 Lag -1
15081580*	5	5	100	.65		
15081995*	5	6	100	.65		
15083500	5	6	104	.621	15085100	15072000 Lag 1
15085100	9	4	97.8	.765	15072000 Lag 1	15083500
15087570	10	3	110	.743	15087590	15083500 Lag -1
15087590	5	4	117	.736	15087570	15083500
15087690*	3	8	100	.70		
15101500	3	5	64.9	.742	15028300	15106980
15106920	8	6	91.4	.908	15106980	15101500
15106980	8	5	96.1	.916	15106920	15101500
		SOUTH-CENTRAL ALASKA				
15212000	20	5	33.5	.582	15476000 Lag 2	15281000 Lag -1
15216000	8	6	81.4	.542	15258000 Lag 3	15238820
15237020*	12	6	80	.55		
15238820	13	7	70.8	.773	15239000	15239900
15238990	15	3	69.7	.608	15239050	15239000 Lag 1
15239000	10	2	80.0	.783	15258000 Lag 2	15238820
15239050	6	4	47.5	.663	15238990 Lag 1	15239000
15239900	2	10	65.2	.828	15241600	15238820
15241600	0	6	52.1	.739	15239900	15238820
15258000	5	4	53.3	.897	15266300 Lag 2	15239000 Lag -2
15266300	1	3	47.0	.870	15258000 Lag -2	15281000 Lag -4
15267900	10	7	45.2	.701	15271000	15276000
15271000	7	7	40.4	.742	15267900	15276000
15273095*	8	6	50	.65		
15274300	7	10	43.4	.692	15274600	15276000
15274600	8	10	48.8	.812	15276000	15274300
15275100	2	15	43.8	.753	15274600 Lag 1	15274300
15276000	8	7	55.9	.823	15274600	15267900
15277410	3	9	33.6	.638	15276000	15267900
15281000	3	6	58.5	.690	15266300 Lag 4	15239000
15290000	6	6	51.1	.657	15294005	15276000 Lag 1
15291000	5	4	40.8	.707	15291500 Lag 1	15291200
15291200	10	4	42.0	.746	15291500 Lag 1	15291000
15291500	10	4	40.7	.848	15292000	15291200 Lag -1
15292000	5	4	35.8	.837	15291500	15291200
15292400	10	5	30.7	.704	15291000	15292700
15292700	5	5	36.7	.703	15294005	15292000
15297780*	5	5	32	.70		
15294005	4	9	48.3	.767	15294010	15294100 Lag 1
15294010	8	9	74.5	.871	15294100 Lag 1	15294005
		SOUTH-CENTRAL ALASKA--Continued				
15294100	10	4	59.4	.850	15294010 Lag -1	15294005 Lag -1
15294345*	10	3	32	.60		
15294350	20	4	30.4	.700	15292700 Lag -1	15292000 Lag -1
15294410	30	5	54.4	.658	15294450	15239900
15294450	3	4	66.6	.598	15294410	15239900
15295600	8	4	84.4	.839	15295700	15297200
15295700	8	6	71.5	.842	15295600	15297200
15296480*	4	4	130	.50		
15297100*	10	4	100	.65		
15297200	4	8	121	.578	15295700	15295600
15297482*	15	4	100	.65		
15297485*	15	7	80	.75		
		SOUTHWEST ALASKA				
15297610*	20	11	120	.40		
15297900	8	5	63.9	.568	15294410 Lag -1	15239900 Lag -1
15299900*	5	5	40	.75		
15300000	8	3	29.6	.523	15302000	15258000 Lag -2
15300500	20	1	26.9	.496	15258000 Lag -5	15302000 Lag -5
15302000	20	1	34.2	.709	15304200 Lag -3	15300000
15302500	5	3	31.5	.491	15304000 Lag 2	15294350 Lag -3
15303150	8	4	50.6	.690	15302000 Lag 3	
15304000	18	2	39.4	.647	15302500 Lag -2	15300000 Lag 2
15304200	5	2	51.8	.625	15302000 Lag 3	15302500 Lag 2
		YUKON ALASKA				
15356000	1	1	29.5	.693	15453500 Lag 4	15476000 Lag -1
15453500	20	2	23.1	.640	15356000 Lag -4	15565447 Lag 5
15457800	5	4	133	.556	15535000 Lag -1	15493000
15476000	10	3	24.0	.634	15212000 Lag -2	15485500
15484000	3	4	63.4	.795	15514000 Lag 1	15493000
15485500	10	8	24.0	.710	15515500	15476000
15493000	4	4	58.0	.821	15514000 Lag 1	15484000
15493700	8	3	41.3	.568	15493000 Lag -1	15514000
15511000	2	4	67.5	.760	15514000 Lag 1	15493000
15514000	8	5	59.3	.820	15493000 Lag -1	15484000 Lag -1
15515500	2	3	25.8	.717	15485500	15514000
15535000	10	3	69.8	.637	15514000 Lag 2	15457800 Lag 1
15564875	10	3	109	.408	15744500 Lag 5	15621000 Lag -2
15565447	25	3	20.6	.562	15515500 Lag -5	15453500 Lag -5
		NORTHWEST ALASKA				
15621000	5	4	83.2	.631	15744500 Lag 4	15668200
15668200	10	3	91.7	.424	15744500 Lag 2	15621000
15744500	10	3	48.1	.636	15621000 Lag -4	15564875 Lag -5
		ARCTIC SLOPE ALASKA				
15798700	15	6	149	.167	15896700 Lag -3	See note
15896000	2	4	120	.203	15896700 Lag 3	See note
15896700	10	4	136	.203	15896000 Lag -3	See note
15904900	3	3	66.5	.121	15564875 Lag 1	See note
15908000*	10	4	100	.20		

* Less than 3 years of data available. Estimates of C_v and ρ_c subjective. Average missing record and measurements estimated from available information.

1/Average for open-water season, based on analysis of past station operation.

2/C_v is the coefficient of variation.

3/ρ_c is the cross-correlation coefficient.

NOTE.-- A different method was used to compute C_v and ρ_c for the last four stations. See text for explanation of method.

$$Q = [\text{Antilog}(B1)] \times (GHT - B2)^{B3} \quad (16)$$

in which

Q	is the discharge in cubic feet per second,
GHT	is any assumed gage height, in feet, for which a discharge is desired; and
B1, B2, and B3	are as previously described and are determined individually for each site from several discharge measurements.

Minor adjustments were made in developing the long-term rating for individual stations. For example, two rating equations were developed for Anchor River near Anchor Point (15239900). One rating was used for gage heights below 3.75 ft:

$$Q = 1.58\ (GHT + 0.19)^{4.49} \quad (17)$$

and another for above 3.75 ft:

$$Q = 124\ (GHT - 1.09)^{1.82} \quad (18)$$

The cause for the break in the rating can be explained by physical conditions at the gage. At lower stages, flow is within the channel and the control is a gravel bar downstream. At higher stages, the control changes to channel control and the stage-discharge relation is further complicated by super-elevation effects of a channel bend just downstream and the start of overbank flow.

Two equations were also developed for seven stations where a distinct change in control occurred during a short definable period either because of man's efforts or a minor relocation of the gage site. This adjustment was made only for those stations that otherwise would have had only a few measurements available for the analysis of the rating curve. For example, two equations were developed using the 32 measurements available for the rating analysis at Middle Fork Koyukuk River near Wiseman (15564875). The gage was located on the left bank prior to July 23, 1976, when it was moved 0.3 mi downstream to a mid-span pier on the downstream side of a newly constructed bridge. There were 20 open-water measurements available at the prior site and 12 at the latter site.

At several other sites, the gage has recently been moved and not enough measurements were available to develop a rating equation for the present site. However, one of the intermediate objectives of the Kalman filtering process is the definition of a time series of residuals (the difference between measured and rating curve discharge) to help determine the variance, V_f. The variance was computed for the prior site (if enough measurements were available to determine a long-term rating equation). If there were no significant differences in channel or control conditions at the two sites, V_f for the prior site was assumed to apply to the present site. For example, following relocation of the gage on Anchor River, not enough measurements were available to define V_f at the new site. Therefore, measurements made when the gage was at its former site were used to help determine a V_f value to use for the new site.

Table 7 demonstrates the computation of residuals at Sixmile Creek near Hope (15271000) for input into the later computation of V_f. Residuals and discharges are shown in both cubic feet per second (ft^3/s) and in logarithmic (base e) units for illustrative purposes. In reality, only the logarithmic values were used for further computations. The time series of residuals is used to compute sample estimates of $\underline{q}$ and β, two of the three parameters required to compute V_f, by determining a best fit autocovariance function to the time series of residuals.

Measurement variance, the third parameter, was determined for each station (with sufficient measurements) by using a sample of the discharge measurements. Carter and Anderson (1963) evaluated the accuracy of current meter measurements. An illustration in their article presents the general relation between the standard deviation of the total error in measured discharge and the number of stations (verticals) taken in the cross section for both the 0.6 method and the 0.2 and 0.8 method using a velocity observation time of 45 seconds (fig. 14). The original illustration was modified by adding a "lattice" to cover the usual range of verticals observed. Discharge measurements made by standard Geological Survey practice conform to the observation time of about 45 seconds and to the use of the 0.6 or the 0.2 and 0.8 method (rule). The "0.6 method" means that the current velocity at a vertical was determined by positioning the current meter at six-tenths of the total depth and determining the average velocity over the requisite 45 seconds. The 0.2 and 0.8 method is similar except that the current velocities are obtained at the 0.2 and 0.8 depths and are averaged to determine the mean current velocity in the vertical.

Ten to 12 open-water discharge measurements were selected for each station over the range of discharges and the period of time used in computing the rating curve. For the number of observed verticals and the method (or methods) used, a percent error was determined from figure 14. Each discharge measurement is subjectively rated as good, fair, or poor by the person measuring. A multiplier, or weight, of 1.0 was arbitrarily applied to "good" measurements, 1.2 to "fair" measurements, and 1.5 to "poor" measurements. This multiplier was used with the previously determined measurement errors from figure 14, to determine the error for a particular discharge measurement. The resultant discharge measurement errors were averaged for the 10 or 12 discharge measurements sampled. Measurement errors ranged from 2.5 percent at three large rivers with good measuring conditions to 5.4 percent at two small streams with poor measuring conditions. Those sites measured mostly by wading the stream had the higher measurement errors, because the 0.6 method is used for streams that are not deep enough to use the 0.2 and 0.8 method.

As discussed earlier, $\underline{q}$ and β can be expressed as the process variance of the residuals from the rating curve and the 1-day autocorrelation coefficient of these residuals. Table 8 presents a summary of the autocovariance analysis. The measurement error in percent is also shown, as well as the length of open-water period for which the autocovariance analysis applies at each station. Measurement variance is computed from the measurement error by the formula:

$$r = \log_e \left[1 + \left(\frac{V(t)}{100} \right)^2 \right] \qquad (19)$$

where measurement error, V(t), is in percent and measurement variance, r, is in logarithmic units (base e).

Figure 15 is a presentation of the fit of the covariance functions for Sixmile Creek. The points plotted on the illustration can be derived from data listed in table 7. The lag, in days, is the time between two consecutive discharge measurements. The covariance is the product of the two residuals of each two consecutive measurements. (The covariance plot only covers the measurements with a lag time of less than 60 days.) The quantitative significance of the curve shown cannot be demonstrated without delving further into the theories of the Kalman-filter analysis (Moss and Gilroy, 1980). However, suffice it to restate that computation of the autocovariance function is an intermediate step in the computation of $\underline{q}$ and β, required to compute V_f.

A non-quantitative significance can be deduced from graphs for individual stations, similar to figure 15. If the preponderance of the covariance values are positive in sign, the 1-day autocorrelation coefficient, RHO, usually is high. The higher the RHO value the greater the decrease in V_f resulting from incremental increases in the measurement frequency. (This will be demonstrated later in the discussion and in figure 17.) RHO is an index of the "memory" or "persistence" of the measurements made at a station. If RHO is very low, the sign (positive or negative) of the residuals of consecutive measurements varies unpredictably. Therefore, a "shift curve" to the base rating curve developed by plotting residuals (in percent, or more commonly, as the difference between the actual gage height and an effective gage height) versus gage height or versus time between measurements is less reliable than a "shift curve" from a station where the sign of the residuals of consecutive measurements tends to remain the same. In the latter case, RHO values are high. The Geological Survey uses "shift curves" as a standard method in the computation of daily discharges during open-water periods.

The autocovariance parameters (table 8) and data from the statistics of missing record (table 6) are used jointly to define uncertainty functions for each gaging station. The uncertainty functions give the relationship of total error variance to the number of visits and discharge measurements. Typical examples of uncertainty functions are given in figure 16 for several stations at which a measurement is usually made during each visit and the effects of missing record were used to compute the curves.

Various factors affect the standard error in streamflow records at a station. The two stations chosen to demonstrate (fig. 17) the effects of some of these factors were Sixmile Creek near Hope (15271000), and Bradley River near Homer (15239000). Both stations have similar standard errors of about 5 percent when assumptions are made that only one measurement is made and no gage-height record is lost during the open-water period. However, RHO for Bradley River is 0.539 and for Sixmile Creek it is 0.988. As the number of measurements increases to 36 at Bradley River, the

Table 7.--Residual data for Sixmile Creek near Hope

Observation number	Measurement number	Date	Measured discharge		Residual	
			(ft^3/s)	(base e)	(ft^3/s)	(base e)
1	15	May 29, 1980	1,920	7.37584	-93	-0.13434
2	16	June 19, 1980	3,150	8.055116	51	0.01629
3	17	July 8, 1980	4,940	8.50512	197	0.04060
4	18	Aug. 5, 1980	2,350	7.76217	-172	-0.07068
5	19	Sept. 10, 1980	1,000	6.90776	-121	-0.11449
6	20	Nov. 19, 1980	531	6.27476	-27	-0.04985
7	22	Feb. 3, 1981	526	6.26530	55	0.11008
8	25	Mar. 24, 1981	226	5.42053	18	0.08325
9	26	May 4, 1981	646	6.47080	60	0.09826
10	27	June 9, 1981	2,550	7.84385	181	0.07359
11	28	July 23, 1981	2,890	7.96901	223	0.08045
12	29	Sept. 15, 1981	920	6.82437	-48	-0.05107
13	30	Nov. 3, 1981	435	6.07535	2	0.00354
14	33	Apr. 14, 1982	130	4.86753	-5	-0.03849
15	34	Apr. 30, 1982	182	5.20401	-7	-0.03512
16	35	Aug. 12, 1982	1,040	6.94698	9	0.00877
17	36	Oct. 5, 1982	657	6.48768	43	0.06804
18	37	Dec. 8, 1982	311	5.73979	-29	-0.08883

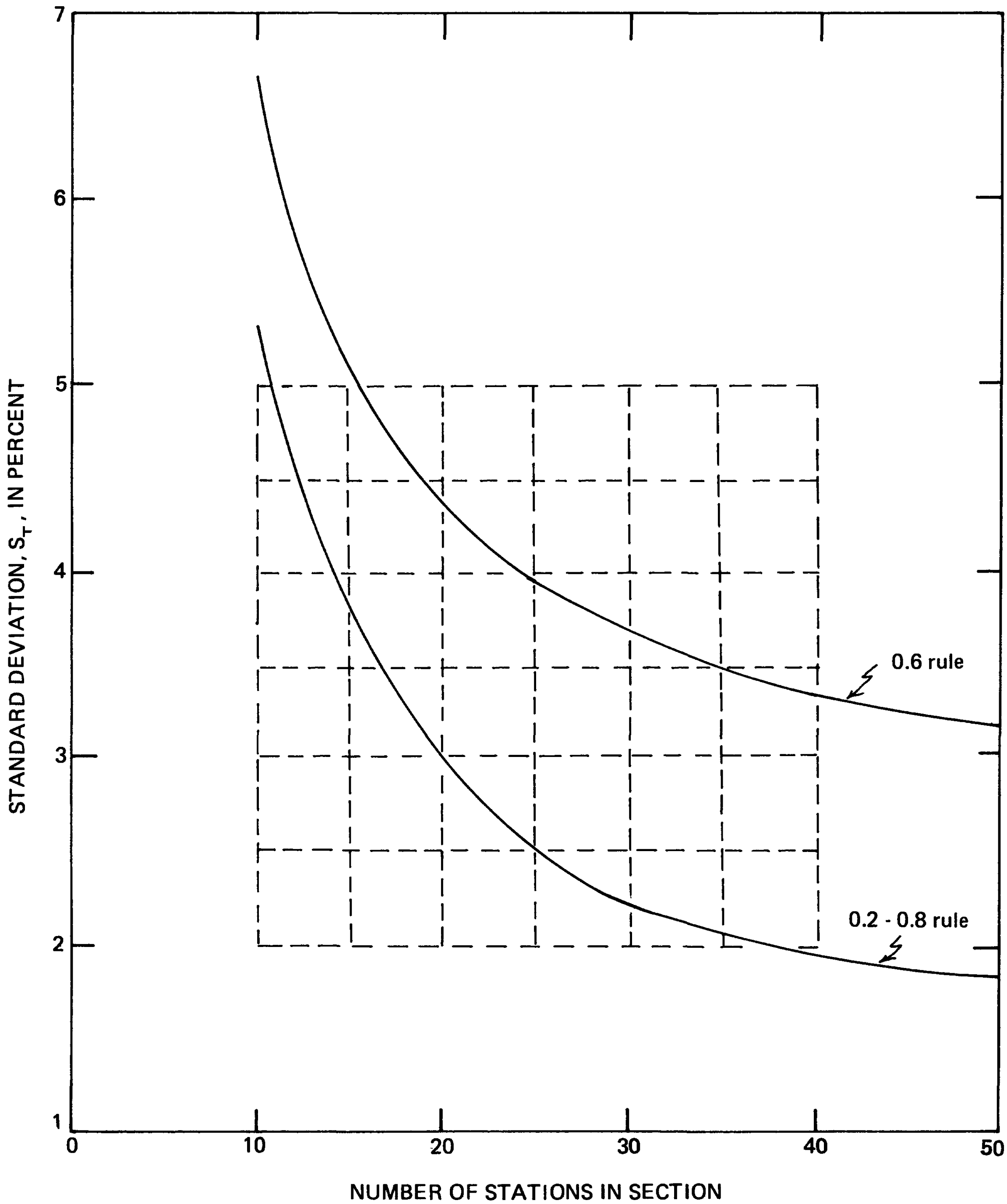


Figure 14.--Standard deviation of total error of discharge measurement. Modified from Carter and Anderson, 1963.

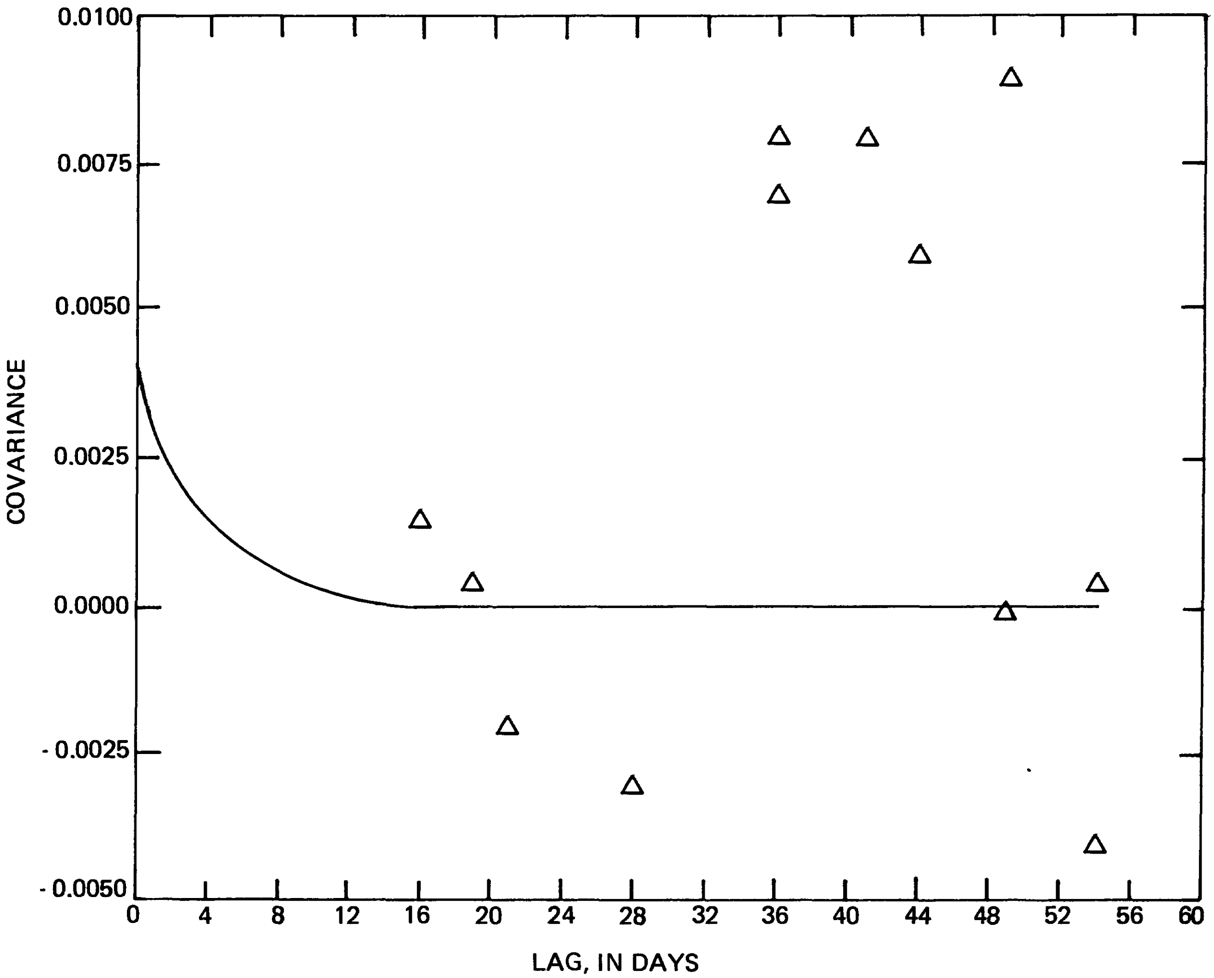


Figure 15.--Autocovariance function for Sixmile Creek near Hope.

Table 8. -- Summary of the autocovariance analysis

Station number	Station name	RHO#	Measurement error (percent)	Measurement variance (log base e)²	Process variance (log base e)²	Length of period (days)
	SOUTHEAST ALASKA					
15011870	White Creek near Ketchikan	0.981	4.4	0.00193	0.04326	323
15011880	Keta River near Ketchikan	.992	3.6	.00129	.01170	337
15011894	Blossom River near Ketchikan*	.95	a4.1	.0017	.03	339
15022000	Harding River near Wrangell	.976	3.2	.00102	.00872	279
15024750	Goat Creek near Wrangell	.654	4.2	.00176	.00482	254
15024800	Stikine River near Wrangell	.915	3.7	.00137	.00443	246
15028300	Farragut River near Petersburg	.994	2.6	.00067	.00227	315
15051008	Salmon Creek above diversion near Juneau*	.95	a4.0	.0015	.02	300
15052009	Lemon Creek near mouth near Juneau*	.95	a4.8	.0022	.03	300
15052500	Mendenhall River near Auke Bay	.953	3.6	.00129	.01113	311
15056100	Skagway River at Skagway	.541	4.0	.00160	.13824	295
15056560	Klehini River near Klukwan*	.95	a3.6	.0013	.10	310
15067900	Upper Mahoney Lake outlet near Ketchikan	.759	4.4	.00193	.05316	287
15072000	Fish Creek near Ketchikan	.759	3.3	.00109	.00313	355
15081580	Black Bear Lake outlet near Klawock	.838	4.1	.00168	.00175	360
15081995	Reynolds Creek below Lake Mellen near Hydaburg*	.95	a4.0	.0015	.02	360
15083500	Perkins Creek near Metlakatla	.937	4.5	.00202	.00795	344
15085100	Old Tom Creek near Kasaan	.977	4.3	.00185	.02495	323
15087570	Hamilton Creek near Kake	.859	4.1	.00168	.02079	255
15087590	Rocky Pass Creek near Point Baker	.963	4.9	.00240	.00414	302
15087690	Indian River near Sitka*	.95	a3.8	.0014	.10	365
15101500	Greens Creek near Juneau	.921	4.3	.00185	.03347	296
15106920	Kadashan River above Hook Creek near Tenakee*	.95	a4.5	.0020	.03	325
15106980	Tonalite Creek near Tenakee	.965	4.2	.00176	.02123	287
	SOUTH-CENTRAL ALASKA					
15212000	Copper River near Chitina	.983	2.7	.00073	.01052	136
15216000	Power Creek near Cordova	.745	4.2	.00176	.00182	287
15237020	Main Bay Creek near Port Nellie Juan*	.95	---	.002	.02	352
15238820	Barbara Creek near Seldovia	.558	4.6	.00211	.00580	278
15238990	Upper Bradley River near Homer*	.95	a4.7	.0022	.03	157
15239000	Bradley River near Homer	.539	3.8	.00144	.00247	360
15239050	Bradley River tributary near Homer*	.95	a4.8	.0023	.04	226
15239900	Anchor River near Anchor Point	.994	4.5	.00202	.01355	218
15241600	Ninilchik River at Ninilchik	.961	4.1	.00168	.00655	205
15258000	Kenai River at Cooper Landing	.987	2.5	.00062	.00379	348
15266300	Kenai River at Soldotna	.584	2.6	.00067	.00067	249
15267900	Resurrection Creek near Hope	.959	4.5	.00202	.01385	212
15271000	Sixmile Creek near Hope	.988	3.7	.00137	.00349	250
15273095	Little Rabbit Creek above Goldenview Drive* at Anchorage	.95	---	.002	.03	195
15274300	North Fork Campbell Creek near Anchorage	.946	4.2	.00176	.00301	204
15274600	Campbell Creek near Spenard	.958	4.0	.00160	.00624	189
15275100	Chester Creek at Arctic Boulevard at Anchorage	.956	4.3	.00185	.00579	235
15276000	Ship Creek near Anchorage*	.95	---	.002	.01	203
15277410	Peters Creek near Birchwood*	.95	4.5	.0020	.06	274
15281000	Knik River near Palmer	.728	2.6	.00067	.01117	223
15290000	Little Susitna River near Palmer	.725	4.2	.00176	.00850	231
15291000	Susitna River near Denali	.971	3.5	.00122	.01859	139
15291200	Maclaren River near Paxson	.964	2.9	.00084	.00470	133
15291500	Susitna River near Cantwell	.000	3.4	.00116	.00278	143
15292000	Susitna River at Gold Creek	.981	2.6	.00067	.00122	167
15292400	Chulitna River near Talkeetna	.898	2.8	.00078	.00192	151
15292700	Talkeetna River near Talkeetna	.958	2.7	.00073	.00774	157
15292780	Susitna River at Sunshine*	.95	---	.001	.01	170
15294005	Willow Creek near Willow*	.95	---	.002	.02	195
15294010	Deception Creek near Willow	.989	3.9	.00152	.02010	193
15294100	Deshka River near Willow	.000	4.0	.00160	.00051	175
15294345	Yentna River near Susitna Station*	.95	---	.001	.01	180
15294350	Susitna River at Susitna Station	.473	3.0	.00090	.00137	169
15294410	Capps Creek below North Capps Creek near Tyonek	.976	4.4	.00193	.02339	184
15294450	Chuitna River near Tyonek	.000	3.7	.00137	.00250	203
15295600	Terror River near Kodiak*	.95	---	.002	.02	212
15295700	Terror River at mouth near Kodiak*	.95	---	.002	.03	346
15296480	Larsen Bay Creek near Larsen Bay *	.95	---	.002	.06	200
15297100	Hidden Basin Creek near Port Lions*	.95	---	.002	.06	170
15297200	Myrtle Creek near Kodiak	.978	4.2	.00176	.02556	278
15297482	Falls Creek near Port Lions*	.95	---	.002	.08	161
15297485	Kizhuyak River near Port Lions*	.95	---	.002	.10	365

One day autocorrelation coefficient.
* Data insufficient for autocovariance analysis; values shown are estimates.
a Estimated from a small sample of discharge measurement notes.

Table 8. -- Continued

Station number	Station name	RHO#	Measurement error (percent)	Measurement variance (log base e)²	Process variance (log base e)²	Length of period (days)
	SOUTHWEST ALASKA					
15297610	Russell Creek near Cold Bay*	0.95	---	0.002	0.02	270
15297900	Eskimo Creek at King Salmon*	.95	4.8	.0023	.08	212
15299900	Tazimina River near Nondalton*	.95	---	.002	.01	201
15300000	Newhalen River near Iliamna	.771	2.5	b0.00040	b0.00015	150
15300500	Kvichak River at Igiugig	.992	3.0	.00090	.00024	256
15302000	Nuyakuk River near Dillingham	.953	2.5	.00062	.00070	266
15302500	Nushagak River at Ekwok	.991	3.0	.00090	.00033	187
15303150	Snake River near Dillingham	.976	4.1	.00168	.00373	215
15304000	Kuskokwim River at Crooked Creek	.943	3.0	.00090	.00062	125
15304200	Kisarlik River near Akiak*	.95	---	.002	.02	186
	YUKON ALASKA					
15356000	Yukon River at Eagle	.961	2.6	.00067	.00093	146
15453500	Yukon River near Stevens Village	.775	2.9	b0.00022	b0.00004	161
15457800	Hess Creek near Livengood	.967	3.5	.00122	.07640	135
15476000	Tanana River near Tanacross	.981	2.7	.00073	.00059	173
15484000	Salcha River near Salchaket	.527	2.7	.00073	.01385	186
15485500	Tanana River at Fairbanks	.969	3.0	.00090	.007	183
15493000	Chena River near Two Rivers	.971	3.5	.00122	.01329	193
15493700	Chena River below Moose Creek Dam*	.95	---	.001	.02	195
15511000	Little Chena River near Fairbanks	.645	3.1	.00096	.00957	185
15514000	Chena River at Fairbanks	.963	2.6	.00067	.00340	193
15515500	Tanana River at Nenana	.920	3.1	.00096	.00346	186
15535000	Caribou Creek near Chatanika	.989	5.4	.00291	.10408	147
15564875	Middle Fork Koyukuk River near Wiseman	.970	3.4	.00116	.04716	131
15565447	Yukon River at Pilot Station	.827	3.2	.00102	.00155	140
	NORTHWEST ALASKA					
15621000	Snake River near Nome	.981	3.7	.00137	.00369	140
15668200	Crater Creek near Nome	.939	4.2	.00176	.01802	127
15744500	Kobuk River near Kiana	.978	3.1	.00096	.00342	147
	ARCTIC SLOPE ALASKA					
15798700	Nunavak Creek near Barrow	.811	5.4	.00291	.12709	131
15896000	Kuparuk River near Deadhorse	.992	3.2	.00102	.02730	140
15896700	Putuligayuk River near Deadhorse	.938	4.1	.00168	.33400	103
15904900	Atigun River tributary near Pump Station 4	.732	4.8	.00230	.00951	128
15908000	Sagavanirktok River near Pump Station 3*	.95	---	.001	.05	130

\# One day autocorrelation coefficient.
* Data insufficient for autocovariance analysis; values shown are estimates.
b Adjusted (lowered) measurement variance because the variance of discharge rating curve was less than estimated measurement variance.

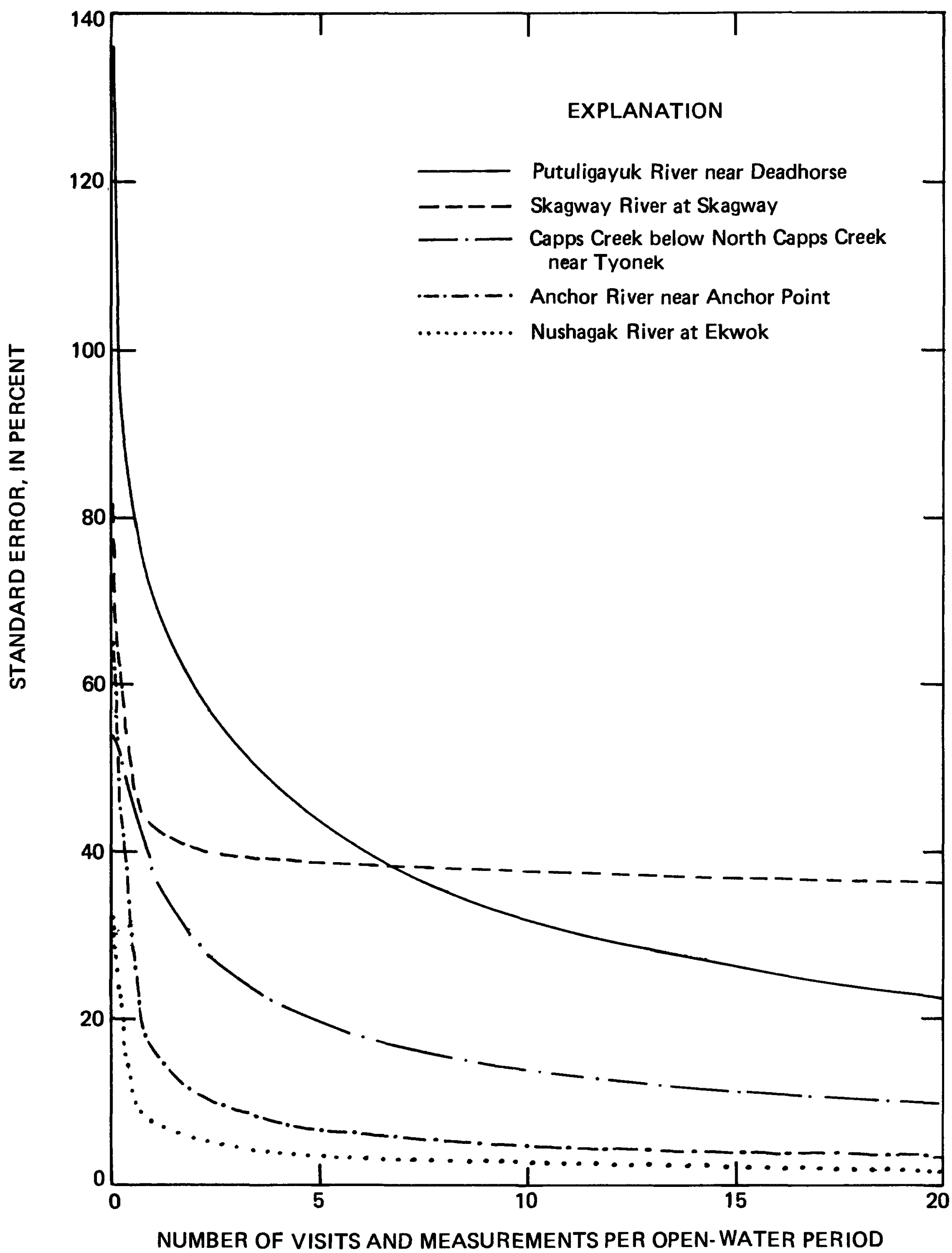


Figure 16.--Typical uncertainty functions for selected stations.

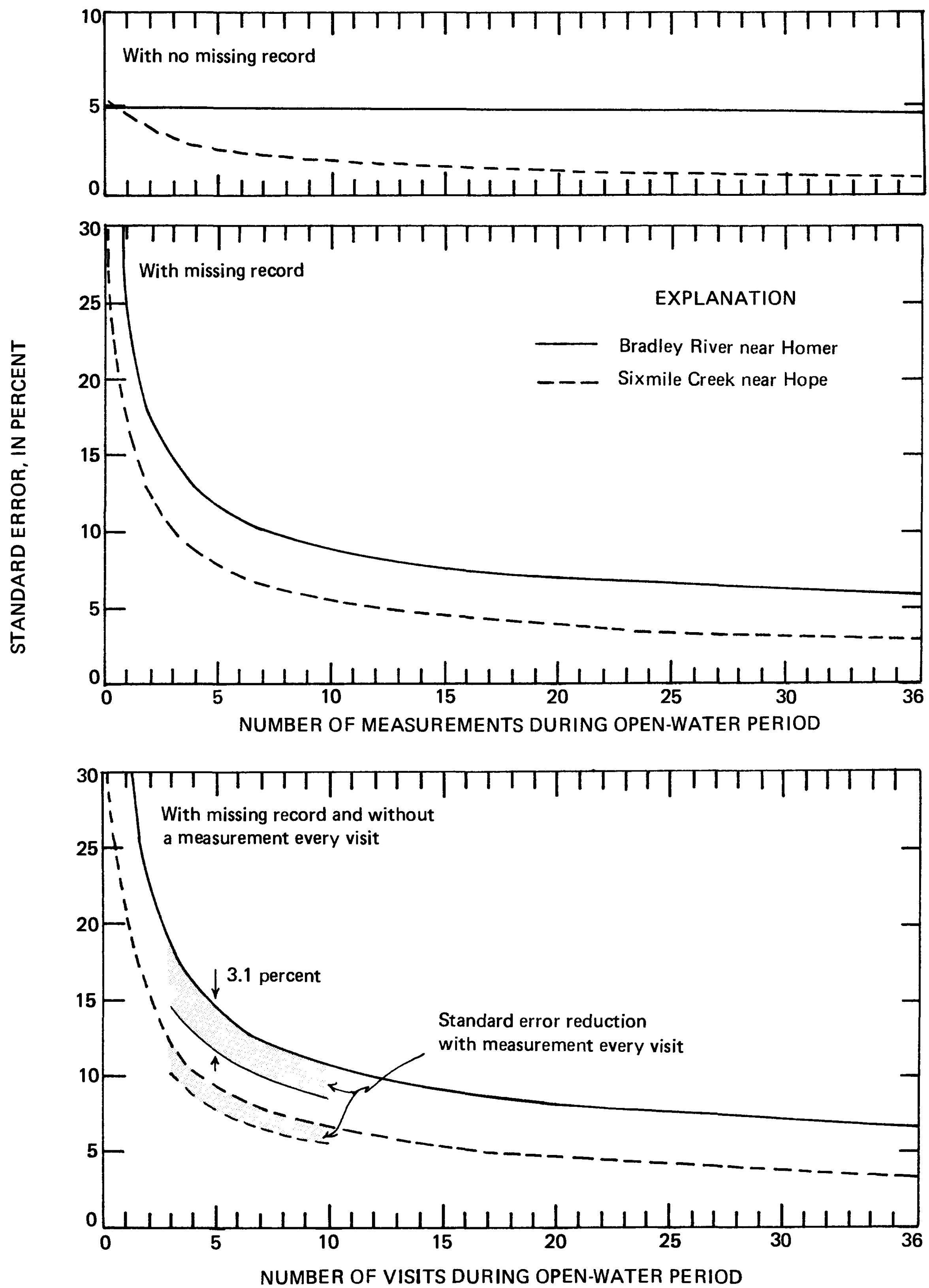


Figure 17.--Factors affecting uncertainty functions.

standard error decreases to 4.6 percent during the 360-day open-water period. As the number of measurements at Sixmile Creek increases to 36, during the 250-day open-water period, the standard error decreases to 1.1 percent. (The differences in the length of the open-water period do not affect the basic concepts in figure 17.)

The effect of lost record is also demonstrated for the two stations. Based on the amount of missing gage-height records in the past few years, Bradley River had an average lost record of 10 percent and Sixmile Creek had an average lost record of 7 percent. Separate curves are shown for each station which combine the errors due to lost record with the error for the time that open-water rating relationship was used. (See equation 3.)

Both of these sets of curves presume that a measurement is made every time the station is visited. Based on the past history of the stations, the probability of measuring the discharge during a visit was 61 and 70 percent for Bradley River and Sixmile Creek, respectively. The uncertainty function at each station was replotted using the number of visits during the open-water period as the independent variable (instead of number of measurements). For example, if the Bradley River gage were visited five times during the year and discharge measured three times, the standard error would be 14.7 percent. If it was measured at each of the five visits, standard error would be reduced to 11.6 percent. (See lower graph, figure 17).

Definition of Routes and Costs

The use of the program, called "The Traveling Hydrographer," has been previously discussed under "Description of Mathematical Program". In Alaska, 82 feasible routes were selected to service all the 98 stream gages studied in this section of the report. These routes include: (1) those used under current-operating practice, (2) similar routes exclusive of the crest-stage gages or periodic measurement sites included in the above routes, and (3) routes to visit smaller groups of stations (or a key individual station). More frequent visits to these latter stations would be cost-effective in reducing the total error for the Alaska stream-gaging network. The routes and the stations visited on each are summarized in table 9.

The practical routes in Alaska are to a large extent controlled by the mode of transportation, and its cost relative to other modes, used in servicing the gages included in the route. Two examples are given for illustration. Route number 1 is serviced during the spring through fall by flying commercially from Juneau to Ketchikan, by floatplane from Ketchikan to the Quartz Hill mine camp (visiting station number 15072000 enroute), and visiting and servicing the remaining three stations by use of a helicopter stationed at Quartz Hill. During the winter, when the Quartz Hill mine camp is closed, different arrangements have to be made for servicing the gages from Ketchikan. Route number 3 stations are serviced by flying commercially from Juneau to Petersburg, and then using various transportation modes: helicopter, floatplane, automobile, and chartered boat. The chartered boat is used for inter-island travel out of Petersburg during fall and winter periods when the weather is marginal for flying to the sites.

Other factors also must be considered in route design and the cost of using these routes in Alaska. In most cases, a helicopter or floatplane cannot be chartered without having to pay a minimum usage charge (commonly, either 3 or 4 hours of actual flying time per day) and there usually is a charge for the aircraft waiting on the ground while the gage is being visited. For those Alaskan stations along a highway in South-central, Yukon, and Arctic Slope, there are no alternative road systems to use. The extent of the territory covered by the offices at Juneau, Anchorage, and Fairbanks is determined by the travel modes and costs of travel necessary to visit the gaging stations. Only one group of stations (and crest-stage gage stations) could practically be serviced from either Anchorage or Fairbanks. This group includes three stations in the upper Susitna basin. The other stations on the Susitna River and its tributaries are operated out of Anchorage (and records computed in Anchorage) so it was decided to continue operation of these three stations from Anchorage. Most trips require two persons for safety reasons or because two people are required to make boat measurements of discharge. Also, the time spent on the ground at a station is reduced by using two people when aircraft are used. Floatplanes are not always usable or available throughout the year. In winter, a ski-equipped plane or helicopter may be required. When the route involves the use of aircraft, projected costs must include a contingency for bad weather for those times when flying to the site is not possible.

In addition to continuous-record gaging stations, a specific route may also include crest-stage gages and periodic measurement sites that must be visited a minimum number of times a year. The only other activity that imposes a minimum visit criterion is the quarterly water-quality sampling required at most NASQAN stations. Visits are required six times a year at two of the nine NASQAN sites. The routes which include crest-stage gages or periodic measurement sites are shown in table 9.

Unit-visit costs of non-continuous discharge-record sites are not included in "The Traveling Hydrographer". However, travel costs to these types of sites are included with the travel costs to the daily-record stations in the unit-route costs.

The route costs of the 82 routes used in the analysis were determined. Fixed costs to operate a gage typically include: equipment rental, batteries, a pro-rated cost for replacing measuring and recording equipment, data processing and storage, computer charges, maintenance, and miscellaneous supplies. Most of the fixed cost for a station is the salaries of the people involved in the analysis, computation, review, and publication of the discharge records; this cost was computed based on past experience. A pro-rated contingency cost may or may not be included in the fixed cost depending on the relative ease of visiting a station, the mode of travel to a station, the type of station, how well the upper (or lower) end of the rating is defined, or whether indirect measurements of discharge might be required. In the Alaska version of "The Traveling Hydrographer," the costs during the "winter" period of travel to a station and measuring discharge (and servicing the recorder, if it is operating) were treated as a fixed cost. The number of "winter" visits is based on current practices and may range from zero to three visits.

Table 9.--Summary of the routes that may be used to visit stream-gaging stations in Alaska

Route number	Stations serviced on the route						
	SOUTHEAST ALASKA						
1	15011870	15011880	15011894	15072000			
2	15067900	15081580	15081995	15083500	15085100		
3	15022000	15028300	15087570	15087590			
4	15024750	15024800					
5	15106920	15106980					
6	15051008						
7	15052009						
8	15052500						
9	15056100						
10	15056560						
11	15087690						
12	15101500						
13*	15011870						
14*	15011894						
15*	15024800						
16*	15028300						
17*	15067900						
18*	15072000						
19*	15081580						
20*	15081995						
21*	15083500						
22*	15085100						
23*	15087570						
24*	15087590						
25*	15106920						
26*	15106980						
	SOUTH-CENTRAL ALASKA						
27	15297100	15295600	15295700	15297482	15297485	15296480	15297200
	1-CSG	3-PM					
28	15292400	15291200	15291000	15291500	15212000	14-CSG	
29	15238820	15238990	15239000	15239050	15239900	15241600	15266300
	15258000	15267900	15271000	7-CSG			
30	15281000	15290000	15294005	15294010	6-CSG		

* Extra routes to visit stations with large uncertainty functions.
CSG Crest-stage gage site.
PM Periodic measurement site.

Table 9.--Continued

Route number	Stations serviced on the route						
				SOUTH-CENTRAL ALASKA			
31	15275100	15274600	15273095	15274300	15276000	15277410	2-PM
32	15292000	15292780	15292700				
33	15294410	15294450					
34	15294100	15294345	15294350				
35	15216000	15237020					
36#	15297100	15295600	15295700	15297482	15297485	15296480	15297200
37#	15292400	15291200	15291000	15291500	15292400	15212000	
38#	15238820	15238990	15239000	15239050	15239900	15241600	15266300
	15258000	15267900	15271000				
39#	15281000	15290000	15294005	15294010			
40#	15275100	15274600	15273095	15274300	15276000	15277410	
41*	1521200						
42*	15237020						
43*	15238820						
44*	15238990						
45*	15238990	15239000	15239050				
46*	15273095						
47*	15277410						
48*	15294410						
49*	15296480						
50*	15297100						
51*	15297200						
52*	15297482						
53*	15297485						
54+	15290000						
				SOUTHWEST ALASKA			
55	15304200	15302000	15303150	15302500	15297900	15300500	15299900
	15300000	3-CSG					
56	15297610						
57	15304000	15565447a					
58#	15304200	15302000	15303150	15302500	15297900	15300500	15299900
	15300000						
59*	15297900						

* Extra routes to visit stations with large uncertainty functions.
\# Routes previously shown, deleted crest-stage gage and periodic measurement sites.
\+ Station measured more frequently for monthly Water Resources Review.
CSG Crest-stage gage site.
PM Periodic measurement site.
a In Yukon Alaska subregion.

Table 9.--Continued

Route number	Stations serviced on the route						
				YUKON ALASKA			
60	15457800	15453500	15564875	15904900b	15908000b	11-CSG	b2-CSG
61	15457800	15453500	15564875	11-CSG			
62	15476000	15356000	23-CSG				
63	15493000	15511000	1-CSG				
64	15484000						
65	15485500						
66	15493700						
67	15514000						
68	15515500						
69	15535000						
70#	15457800	15453500	15564875	15904900b	15908000b		
71#	15476000	15356000					
72#	15493000	15511000					
73*	15457800	15564875					
				NORTHWEST ALASKA			
74	15621000	15668200	5-CSG				
75	15744500						
76#	15621000	15668200					
				ARCTIC SLOPE ALASKA			
77	15798700	15896000	15896700	15908000	15904900	2-CSG	
78	15798700	15896000	15896700				
79#	15798700	15896000	15896700	15908000	15904900		
80*	15798700						
81*	15896700						
82*	15908000						

* Extra routes to visit stations with large uncertainty functions.
\# Routes previously shown, deleted crest-stage gage and periodic measurement sites.
CSG Crest-stage gage site.
b In Arctic Slope subregion.

The use of abbreviations, such as "14-CSG" and "3-PM", means that number of crest-stage gages and periodic measurement sites, respectively, are visited on a particular route.

K-CERA Results

The "Traveling Hydrographer Program" utilizes the uncertainty functions along with the appropriate cost data and route definitions to compute the most cost-effective way of operating the stream-gaging program. In this application, the first step was to simulate current operating practice and determine the total uncertainty associated with it. To accomplish this, the number of visits being made to each stream gage and the specific routes that are being used to make these visits are fixed.

In Alaska, current practice is to make about six visits per year to most stations; generally, four of the six visits are made during the open-water period and two during the "winter" period. However, there are exceptions to the above visit frequency mainly because of variations in the length of the open-water season at individual stations. For example, stations along the Gulf of Alaska and on Kodiak Island, which have a maritime climate, are measured more frequently than stations farther inland. Experience has shown that the stage-discharge rating curves for these stations are not as stable as the ratings for other stations. Also, stations in the immediate Anchorage vicinity are visited more frequently. Discharge measurements are not necessarily made each time a station is visited. A few stations with long-term stable ratings may be measured only once or twice a year (table 6). Discharge at other stations is usually measured during every visit, especially at those stations in operation for only a short time period or those with unstable ratings. The probability of measuring during a visit is given in table 10 for each station.

Table 10 gives the standard error at each station using current practice. The average standard error of estimation for the total network under current operating practices during the open-water period is 18.4 percent, which is plotted as a point in figure 18.

The next step was to modify the number of visits during the open-water period at each station within the Alaska network to determine more cost-effective methods of managing the network (table 10 and fig. 18). The solid line in figure 18 represents the minimum level of average uncertainty that can be obtained for a given budget using existing instrumentation and technology. The line was defined by several runs of the "Traveling Hydrographer Program" using different budgets. Constraints on the operations other than budget are described below.

To determine the minimum number of times each stations must be visited, consideration was given only to the physical limitations of the method used to record data. The effect of visitation frequency on the accuracy of the data and amount of lost record is taken into account in the uncertainty analysis. In Alaska, at least three open-water visits per year are required at most gaging stations. This value was based on limitations of the batteries used to drive recording equipment, capacities of the uptake spools on digital recorders, and, to a lesser extent, the need to check gas pressures at bubble-gage sites and to replace the tanks of nitrogen. The above limitations impose a requirement that stations must be visited at least every 3 months during open-water periods.

Table 10.--Selected results of K-CERA analysis for stream-gaging stations in Alaska

Identification	Station statistics* IDAYS FD PI	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] Number of visits per open-water period to site — Current operation*	Budget, in thousands of 1983 dollars — 1,381	1,440	1,539	2,000	2,500
Average per station**	---	18.4	19.8	18.2	16.8	13.9	11.9
SOUTHEAST							
15011870 White C nr Ketchikan	323 7 98	16.2 [14.2] 5-s 1-w	17.6 [15.6] 4	17.6 [15.6] 4	17.6 [15.6] 4	15.0 [13.2] 6	12.6 [10.9] 9
15011880 Keta R nr Ketchikan	337 6 95	9.2 [4.8] 6-s 0-w	10.0 [5.3] 5	10.0 [5.3] 5	10.0 [5.3] 5	8.6 [4.4] 7	7.2 [3.7] 10
15011894 Blossom R nr Ketchikan	339 6 95	18.8 [15.1] 6-s 0-w	19.9 [15.7] 5	19.9 [15.7] 5	19.9 [15.7] 5	17.9 [14.5] 7	15.9 [13.1] 10
15022000 Harding R nr Wrangell	279 10 90	12.6 [6.8] 5-s 1-w	13.9 [7.5] 4	13.9 [7.5] 4	13.9 [7.5] 4	11.6 [6.4] 6	10.2 [5.6] 8
15024750 Goat C nr Wrangell	254 12 90	13.5 [7.4] 4-s 2-w	15.0 [7.6] 3	15.0 [7.6] 3	15.0 [7.6] 3	13.5 [7.4] 4	11.8 [7.1] 6
15024800 Stikine R nr Wrangell	246 7 100	11.2 [6.8] 4-s 2-w	12.4 [7.3] 3	12.4 [7.3] 3	12.4 [7.3] 3	11.2 [6.8] 4	9.7 [6.3] 6
15028300 Farragut R nr Petersburg	315 15 100	13.3 [2.2] 5-s 1-w	14.8 [2.6] 4	14.8 [2.6] 4	14.8 [2.6] 4	12.2 [2.0] 6	10.7 [1.7] 8

*See footnotes at end of table.
**Square root of average station variance for the network after adjustment for varying lengths of open-water period at individual stations. Referred to in text as average standard error of estimate or average standard error.

Table 10.--Continued

Identification	Station statistics* IDAYS FD PI	Current operation*	1,381	1,440	1,539	2,000	2,500
		Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] Number of visits per open-water period to site					
			Budget, in thousands of 1983 dollars				
SOUTHEAST--Continued							
15051008 Salmon C ab div nr Juneau	300 5 100	15.6 [12.3] 5-s 1-w	16.7 [12.9] 4	15.6 [12.3] 5	12.2 [10.0] 10	9.4 [7.8] 19	7.9 [6.6] 27
15052009 Lemon C nr mouth nr Juneau	300 5 100	17.7 [15.0] 5-s 1-w	18.8 [15.7] 4	16.7 [14.4] 6	13.5 [11.8] 11	10.3 [9.1] 21	8.6 [7.6] 31
15052500 Mendenhall R nr Auke Bay	311 5 93	12.6 [9.3] 5-s 1-w	13.5 [9.7] 4	13.5 [9.7] 4	11.2 [8.5] 7	8.5 [6.7] 14	7.5 [5.9] 19
15056100 Skagway R at Skagway	295 5 98	38.8 [38.4] 5-s 1-w	39.1 [38.7] 4	39.1 [38.7] 4	38.8 [38.4] 5	35.0 [34.9] 32	27.2 [27.2] 106
15056560 Klehini R nr Klukwan	310 8 95	31.8 [28.9] 5-s 1-w	33.6 [30.4] 4	25.0 [22.8] 11	20.4 [18.5] 18	15.4 [13.9] 33	13.2 [11.8] 45
15067900 Upper Mahoney Lk outlet nr Ketchikan	287 10 90	26.9 [23.7] 5-s 1-w	28.0 [24.1] 4	28.0 [24.1] 4	26.9 [23.7] 5	25.1 [22.9] 8	23.7 [22.1] 12
15072000 Fish C nr Ketchikan	355 5 85	15.5 [6.0] 6-s 0-w	16.7 [6.1] 5	16.7 [6.1] 5	16.7 [6.1] 5	14.5 [5.9] 7	12.5 [5.7] 10
15081580 Black Bear Lk outlet nr Klawock	360 5 100	15.9 [4.2] 6-s 0-w	17.3 [4.3] 5	17.3 [4.3] 5	15.9 [4.2] 6	13.2 [4.0] 9	11.2 [3.9] 13

*See footnotes at end of table.

Table 10.--Continued

Identification	Station statistics* IDAYS FD PI	Current operation*	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] Number of visits per open-water period to site — Budget, in thousands of 1983 dollars: 1,381	1,440	1,539	2,000	2,500
SOUTHEAST--Continued							
15081995 Reynolds C blw Lk Mellen nr Hydaburg	360 5 100	20.4 [12.5] 6-s 0-w	22.0 [13.1] 5	22.0 [13.1] 5	20.4 [12.5] 6	17.4 [11.2] 9	14.9 [9.8] 13
15083500 Perkins C nr Metlakatla	344 5 96	19.3 [8.3] 6-s 0-w	20.9 [8.6] 5	20.8 [8.6] 5	19.3 [8.3] 6	16.2 [7.5] 9	13.8 [6.7] 13
15085100 Old Tom C nr Kasaan	323 9 100	19.3 [11.8] 5-s 1-w	21.2 [12.8] 4	21.2 [12.8] 4	19.3 [11.8] 5	15.7 [9.6] 8	13.0 [7.9] 12
15087570 Hamilton C nr Kake	255 10 94	21.8 [14.7] 4-s 2-w	23.9 [15.2] 3	23.9 [15.2] 3	23.9 [15.2] 3	20.4 [14.3] 5	18.5 [13.7] 7
15087590 Rocky Pass C nr Point Baker	302 5 90	15.3 [5.4] 5-s 1-w	16.9 [5.7] 4	16.9 [5.7] 4	16.9 [5.7] 4	14.0 [5.1] 6	12.3 [4.7] 8
15087690 Indian R nr Sitka	365 3 100	29.9 [27.7] 6-s 0-w	31.2 [28.8] 5	28.7 [26.6] 7	25.7 [24.0] 10	18.9 [17.6] 22	16.1 [15.0] 31
15101500 Greens C nr Juneau	296 3 90	17.8 [17.0] 5-s 1-w	18.4 [17.4] 4	18.4 [17.4] 4	18.4 [17.4] 4	17.3 [16.6] 6	13.9 [13.5] 15
15106920 Kadashan R abv Hook C nr Tenakee	325 8 90	18.1 [16.0] 5-s 1-w	19.1 [16.8] 4	19.1 [16.8] 4	19.1 [16.8] 4	15.9 [14.2] 8	13.9 [12.5] 12

*See footnotes at end of table.

Table 10.--Continued

Identification	Station statistics* IDAYS FD PI	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] Number of visits per open-water period to site: Current operation*	Budget, in thousands of 1983 dollars: 1,381	1,440	1,539	2,000	2,500
SOUTHEAST--Continued							
15106980 Tonalite C nr Tenakee	287 8 100	14.3 [11.8] 5-s 1-w	15.4 [12.6] 4	15.4 [12.6] 4	15.4 [12.6] 4	12.0 [9.9] 8	10.1 [8.3] 12
SOUTH-CENTRAL							
15212000 Copper R nr Chitina	136 20 83	10.0 [5.9] 4-s 2-w	11.4 [6.9] 3	11.4 [7.0] 3	11.4 [6.9] 3	10.0 [5.9] 4	10.0 [5.9] 4
15216000 Power C nr Cordova	287 8 93	17.7 [4.5] 6-s 1-w	19.3 [4.6] 5	19.3 [4.6] 5	15.6 [4.4] 8	13.0 [4.2] 12	10.8 [4.0] 18
15237020 Main Bay C nr Port Nellie Juan	352 12 94	23.9 [13.1] 7-s 0-w	25.4 [13.8] 6	23.9 [13.1] 7	20.6 [11.5] 10	16.3 [9.3] 17	13.7 [7.8] 25
15238820 Barbara C nr Seldovia	278 13 98	18.2 [9.0] 5-s 1-w	19.8 [9.4] 4	18.2 [9.0] 5	16.0 [8.5] 7	12.9 [7.8] 13	11.6 [7.6] 18
15238990 Upper Bradley R nr Homer	157 15 95	18.1 [14.0] 4-s 1-w	20.0 [15.3] 3	20.0 [15.3] 3	18.1 [14.0] 4	15.5 [12.2] 6	13.0 [10.3] 9
15239000 Bradley R nr Homer	360 10 61	10.5 [5.2] 6-s 0-w	11.2 [5.2] 5	11.2 [5.2] 5	10.5 [5.2] 6	9.4 [5.1] 8	8.4 [5.0] 11
15239050 Bradley R trib nr Homer	226 6 100	17.7 [17.0] 4-s 2-w	18.8 [18.0] 3	18.8 [18.0] 3	17.7 [17.0] 4	15.8 [15.2] 6	13.8 [13.3] 9

*See footnotes at end of table.

Table 10.--Continued

Identification	Station statistics* IDAYS FD PI	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] Number of visits per open-water period to site: Current operation*	Budget, in thousands of 1983 dollars: 1,381	1,440	1,539	2,000	2,500
SOUTH-CENTRAL--Continued							
15239900 Anchor R nr Anchor Point	218 2 100	7.5 [4.4] 4-s 2-w	8.6 [5.1] 3	8.6 [5.1] 3	7.5 [4.4] 4	6.2 [3.6] 6	5.1 [3.0] 9
15241600 Ninilchik R at Ninilchik	205 0 91	6.3 [6.3] 4-s 1-w	6.7 [6.7] 3	6.7 [6.7] 3	6.3 [6.3] 4	5.6 [5.6] 6	4.8 [4.8] 9
15258000 Kenai R at Cooper Landing	348 5 42	5.8 [4.3] 6-s 0-w	6.2 [4.5] 5	6.2 [4.5] 5	5.8 [4.3] 6	5.2 [3.9] 8	4.5 [3.4] 11
15266300 Kenai R at Soldotna	249 1 55	3.1 [2.6] 4-s 2-w	3.2 [2.6] 3	3.2 [2.6] 3	3.1 [2.6] 4	2.9 [2.6] 6	2.8 [2.6] 9
15267900 Resurrection C nr Hope	212 10 95	13.0 [9.4] 4-s 2-w	14.4 [10.3] 3	14.4 [10.3] 3	13.0 [9.4] 4	11.2 [8.1] 6	9.4 [6.8] 9
15271000 Sixmile C nr Hope	250 7 70	8.5 [3.7] 4-s 2-w	9.6 [4.3] 3	9.6 [4.3] 3	8.5 [3.7] 4	7.0 [3.1] 6	5.8 [2.5] 9
15273095 L Rabbit C abv Goldenview Dr at Anchorage	195 8 92	15.7 [14.0] 5-s 4-w	16.8 [14.9] 4	15.7 [14.0] 5	13.3 [11.9] 8	10.9 [9.7] 13	9.0 [8.0] 20
15274300 NF Campbell C nr Anchorage	204 7 100	9.7 [4.7] 5-s 4-w	10.6 [5.1] 4	9.7 [4.7] 5	9.7 [4.7] 5	6.8 [3.5] 11	5.9 [3.1] 15

*See footnotes at end of table.

Table 10.--Continued

Identification	Station statistics* IDAYS FD PI	Current operation*	1,381	1,440	1,539	2,000	2,500
		Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] Number of visits per open-water period to site					
			Budget, in thousands of 1983 dollars				
SOUTH-CENTRAL--Continued							
15274600 Campbell C nr Spenard	189 8 96	9.9 [6.2] 5-s 4-w	10.8 [6.8] 4	9.9 [6.2] 5	9.9 [6.2] 5	7.0 [4.5] 11	6.1 [3.9] 15
15275100 Chester C at Arctic Blvd at Anchorage	235 2 100	7.5 [5.7] 6-s 3-w	8.0 [6.1] 5	7.5 [5.7] 6	7.5 [5.7] 6	5.7 [4.4] 12	5.0 [3.9] 16
15276000 Ship C nr Anchorage	203 8 98	10.9 [8.2] 5-s 3-w	11.8 [8.8] 4	10.9 [8.2] 5	10.9 [8.2] 5	8.0 [6.1] 11	7.0 [5.3] 15
15277410 Peters C nr Birchwood	274 3 98	19.7 [19.6] 6-s 2-w	20.5 [20.5] 5	19.7 [19.6] 6	15.8 [15.7] 12	12.2 [12.1] 22	10.5 [10.4] 30
15281000 Knik R nr Palmer	223 3 97	12.4 [10.6] 4-s 2-w	13.0 [10.8] 3	13.0 [10.8] 3	13.0 [10.8] 3	11.6 [10.4] 6	10.9 [10.0] 9
15290000 L Susitna R nr Palmer	231 6 82	11.0 [9.1] 8-s 4-w	11.2 [9.2] 7	11.2 [9.2] 7	11.2 [9.2] 7	11.0 [9.1] 8	10.1 [8.8] 12
15291000 Susitna R nr Denali	139 5 100	9.0 [8.3] 4-s 2-w	10.1 [9.3] 3	10.1 [9.3] 3	10.1 [9.3] 3	9.0 [8.3] 4	9.0 [8.3] 4
15291200 Maclaren R nr Paxson	133 10 100	8.0 [6.2] 4-s 2-w	8.6 [6.4] 3	8.6 [6.4] 3	8.6 [6.4] 3	8.0 [6.2] 4	8.0 [6.2] 4

*See footnotes at end of table.

Table 10.--Continued

Identification	Station statistics* IDAYS FD PI	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] Number of visits per open-water period to site: Current operation*	Budget, in thousands of 1983 dollars: 1,381	1,440	1,539	2,000	2,500
SOUTH-CENTRAL--Continued							
15291500 Susitna R nr Cantwell	143 10 100	6.4 [5.0] 4-s 2-w	6.8 [5.1] 3	6.8 [5.1] 3	6.8 [5.1] 3	6.4 [5.0] 4	6.4 [5.0] 4
15292000 Susitna R at Gold Creek	167 5 94	3.5 [1.9] 4-s 2-w	4.0 [2.1] 3	4.0 [2.1] 3	4.0 [2.1] 3	3.5 [1.9] 4	3.5 [1.9] 4
15292400 Chulitna R nr Talkeetna	151 10 93	6.1 [3.8] 4-s 2-w	6.8 [3.9] 3	6.8 [3.9] 3	6.8 [3.9] 3	6.1 [3.8] 4	6.1 [3.8] 4
15292700 Talkeetna R nr Talkeetna	157 5 100	7.1 [5.9] 4-s 2-w	7.9 [6.5] 3	7.9 [6.5] 3	7.9 [6.5] 3	7.1 [5.9] 4	7.1 [5.9] 4
15292780 Susitna R at Sunshine	170 5 83	8.2 [7.5] 4-s 2-w	8.9 [8.0] 3	8.9 [8.0] 3	8.9 [8.0] 3	8.2 [7.5] 4	8.2 [7.5] 4
15294005 Willow C nr Willow	195 4 100	12.1 [10.8] 4-s 2-w	13.1 [11.5] 3	13.1 [11.5] 3	13.1 [11.5] 3	10.6 [9.5] 6	9.1 [8.1] 9
15294010 Deception C nr Willow	193 8 100	12.6 [6.5] 4-s 2-w	14.3 [7.7] 3	14.3 [7.7] 3	14.3 [7.7] 3	10.4 [5.2] 6	8.6 [4.2] 9
15294100 Deshka R nr Willow	175 10 100	7.3 [2.2] 4-s 2-w	8.3 [2.2] 3	8.3 [2.2] 3	8.3 [2.2] 3	7.3 [2.2] 4	6.6 [2.2] 9

*See footnotes at end of table.

Table 10.--Continued

Identification	Station statistics* IDAYS FD PI	Current operation*	Budget, in thousands of 1983 dollars 1,381	1,440	1,539	2,000	2,500
		Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] Number of visits per open-water period to site					
SOUTH-CENTRAL--Continued							
15294345 Yentna R nr Susitna Station	180 10 95	9.3 [8.2] 4-s 2-w	10.0 [8.8] 3	10.0 [8.8] 3	10.0 [8.8] 3	9.3 [8.2] 4	8.6 [7.7] 5
15294350 Susitna R at Susitna Station	169 20 100	7.7 [4.1] 4-s 2-w	8.6 [4.3] 3	8.6 [4.3] 3	8.6 [4.3] 3	7.7 [4.1] 4	7.1 [4.0] 5
15294410 Capps C below N Capps C nr Tyonek	184 30 100	20.1 [11.1] 4-s 2-w	22.4 [13.3] 3	22.4 [13.3] 3	22.4 [13.3] 3	18.3 [9.7] 5	14.9 [7.4] 8
15294450 Chuitna R nr Tyonek	203 3 100	8.5 [5.1] 4-s 2-w	9.4 [5.1] 3	9.4 [5.1] 3	9.4 [5.1] 3	8.5 [5.1] 4	8.5 [5.1] 4
15295600 Terror R nr Kodiak	212 8 98	15.1 [12.2] 4-s 3-w	16.5 [13.0] 3	14.0 [11.2] 5	13.1 [10.8] 6	10.0 [8.3] 12	8.1 [6.8] 19
15295700 Terror R at mouth nr Kodiak	346 8 100	16.7 [14.7] 7-s 0-w	17.5 [15.3] 6	16.0 [14.1] 8	15.4 [13.6] 9	12.8 [11.3] 15	10.9 [9.6] 22
15296480 Larsen Bay C nr Larsen Bay	200 4 100	25.8 [20.3] 4-s 3-w	28.3 [21.7] 3	23.8 [19.0] 5	23.3 [18.0] 6	16.6 [13.7] 12	13.4 [11.0] 19
15297100 Hidden Basin C nr Port Lions	170 10 100	24.9 [20.0] 4-s 3-w	27.5 [21.7] 3	23.0 [18.5] 5	21.4 [17.3] 6	15.9 [12.8] 12	12.7 [10.3] 19

*See footnotes at end of table.

Table 10.--Continued

Identification	Station statistics* IDAYS FD PI	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] Number of visits per open-water period to site Current operation*	Budget, in thousands of 1983 dollars 1,381	1,440	1,539	2,000	2,500
SOUTH-CENTRAL--Continued							
15297200 Myrtle C nr Kodiak	278 4 100	22.3 [10.9] 6-s 1-w	24.3 [11.9] 5	20.8 [10.2] 7	16.7 [8.2] 11	13.2 [6.4] 18	11.2 [5.5] 25
15297482 Falls C nr Port Lions	161 15 90	29.4 [23.9] 4-s 3-w	32.4 [26.0] 3	27.2 [22.1] 5	25.4 [20.7] 6	18.9 [15.3] 12	15.2 [12.2] 19
15297485 Kizhuyak R nr Port Lions	365 15 100	31.5 [28.6] 7-s 0-w	32.8 [29.9] 6	30.3 [27.5] 8	29.2 [26.4] 9	24.4 [21.7] 15	20.8 [18.3] 22
SOUTHWEST							
15297610 Russell C nr Cold Bay	270 20 100	60.8 [19.7] 5-s 2-w	66.1 [24.6] 4	53.2 [15.3] 7	45.8 [12.2] 10	34.3 [8.4] 19	29.1 [6.9] 27
15297900 Eskimo C at King Salmon	212 8 100	25.9 [24.2] 4-s 2-w	27.8 [25.9] 3	24.3 [22.8] 5	20.7 [19.3] 8	15.4 [14.3] 16	13.3 [12.3] 22
15299900 Tazimina R nr Nondalton	201 5 95	9.4 [8.4] 4-s 2-w	10.2 [9.0] 3	10.2 [9.0] 3	10.2 [9.0] 3	9.4 [8.4] 4	8.8 [7.9] 5
15300000 Newhalen R nr Iliamna	150 8 50	4.2 [1.2] 4-s 2-w	4.8 [1.3] 3	4.8 [1.3] 3	4.8 [1.3] 3	4.2 [1.2] 4	3.8 [1.2] 5
15300500 Kvichak R at Igiugig	256 20 28	4.8 [1.2] 4-s 2-w	5.5 [1.3] 3	5.5 [1.3] 3	5.5 [1.3] 3	4.8 [1.2] 4	4.3 [1.1] 5

*See footnotes at end of table.

Table 10.--Continued

Identification	Station statistics* IDAYS FD PI	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] Number of visits per open-water period to site					
		Current operation*	Budget, in thousands of 1983 dollars				
			1,381	1,440	1,539	2,000	2,500
SOUTHWEST--Continued							
15302000 Nuyakuk R nr Dillingham	266 20 32	5.5 [2.6] 4-s 2-w	6.1 [2.7] 3	6.1 [2.7] 3	6.1 [2.7] 3	5.5 [2.6] 4	5.0 [2.6] 5
15302500 Nushagak R at Ekwok	187 5 100	3.9 [0.8] 4-s 2-w	4.5 [0.9] 3	4.5 [0.9] 3	4.5 [0.9] 3	3.9 [0.8] 4	3.5 [0.7] 5
15303150 Snake R nr Dillingham	215 8 97	9.0 [4.4] 4-s 2-w	10.2 [4.9] 3	10.2 [4.9] 3	10.2 [4.9] 3	9.0 [4.4] 4	8.1 [4.0] 5
15304000 Kuskokwim R at Crooked Creek	125 18 72	5.9 [2.1] 4-s 1-w	6.7 [2.3] 3	6.7 [2.3] 3	6.7 [2.3] 3	5.9 [2.1] 4	5.9 [2.1] 4
15304200 Kisarlik R nr Akiak	186 5 60	13.1 [12.5] 4-s 2-w	13.8 [13.0] 3	13.8 [13.0] 3	13.8 [13.0] 3	13.1 [12.5] 4	12.5 [12.0] 5
YUKON							
15356000 Yukon R at Eagle	146 1 43	2.7 [2.6] 4-s 2-w	2.8 [2.7] 3	2.8 [2.7] 3	2.8 [2.7] 3	2.7 [2.6] 4	2.7 [2.6] 4
15453500 Yukon R nr Stevens Village	161 20 53	4.0 [0.7] 4-s 2-w	4.6 [0.7] 3	4.6 [0.7] 3	4.6 [0.7] 3	3.3 [0.6] 6	2.7 [0.6] 9
15457800 Hess C nr Livengood	135 5 89	23.4 [18.4] 4-s 2-w	26.3 [20.1] 3	26.3 [20.1] 3	23.4 [18.4] 4	18.2 [14.4] 7	16.1 [12.7] 9

*See footnotes at end of table.

Table 10.--Continued

Identification	Station statistics* IDAYS FD PI	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] Number of visits per open-water period to site: Current operation*	Budget, in thousands of 1983 dollars: 1,381	1,440	1,539	2,000	2,500
YUKON--Continued							
15476000 Tanana R nr Tanacross	173 10 70	3.9 [1.7] 4-s 2-w	4.5 [1.8] 3	4.5 [1.8] 3	4.5 [1.8] 3	3.9 [1.7] 4	3.9 [1.7] 4
15484000 Salcha R nr Salchaket	186 3 70	12.5 [11.8] 4-s 2-w	12.8 [11.9] 3	12.8 [11.9] 3	12.8 [11.9] 3	12.5 [11.8] 4	12.5 [11.8] 4
15485500 Tanana R at Fairbanks	183 10 90	7.8 [6.5] 4-s 2-w	8.6 [7.2] 3	8.6 [7.2] 3	8.6 [7.2] 3	7.8 [6.5] 4	7.1 [5.9] 5
15493000 Chena R nr Two Rivers	193 4 55	10.4 [9.5] 4-s 2-w	11.2 [10.1] 3	11.2 [10.1] 3	10.4 [9.5] 4	7.9 [7.3] 9	6.3 [5.9] 15
15493700 Chena R blw Moose Creek Dam	195 8 50	13.9 [13.1] 4-s 2-w	14.6 [13.6] 3	14.6 [13.6] 3	14.6 [13.6] 3	11.3 [10.8] 10	9.6 [9.2] 16
15511000 L Chena R nr Fairbanks	185 2 90	10.5 [9.7] 4-s 2-w	10.9 [9.8] 3	10.9 [9.8] 3	10.5 [9.7] 4	9.8 [9.4] 9	9.2 [9.0] 15
15514000 Chena R at Fairbanks	193 8 90	8.9 [4.7] 4-s 2-w	10.1 [5.3] 3	8.9 [4.7] 4	8.1 [4.4] 5	5.9 [3.3] 10	4.9 [2.7] 15
15515500 Tanana R at Nenana	186 2 60	5.6 [5.5] 4-s 2-w	5.8 [5.6] 3	5.8 [5.6] 3	5.8 [5.6] 3	5.6 [5.5] 4	5.6 [5.5] 4

*See footnotes at end of table.

Table 10.--Continued

Identification	Station statistics* IDAYS FD PI	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] Number of visits per open-water period to site: Current operation*	Budget, in thousands of 1983 dollars: 1,381	1,440	1,539	2,000	2,500
YUKON--Continued							
15535000 Caribou C nr Chatanika	147 10 88	16.4 [14.0] 4-s 2-w	18.8 [16.3] 3	18.8 [16.3] 3	14.7 [12.4] 5	11.7 [9.6] 8	10.0 [8.3] 11
15564875 MF Koyukuk R nr Wiseman	131 10 85	21.5 [14.2] 4-s 2-w	24.4 [16.0] 3	24.4 [16.0] 3	21.5 [14.2] 4	16.6 [11.0] 7	14.7 [9.7] 9
15565447 Yukon R at Pilot Station	140 25 89	6.0 [4.0] 4-s 1-w	6.6 [4.2] 3	6.6 [4.2] 3	6.6 [4.2] 3	6.0 [4.0] 4	6.0 [4.0] 4
NORTHWEST							
15621000 Snake R nr Nome	140 5 100	9.6 [3.2] 4-s 1-w	11.0 [3.6] 3	11.0 [3.6] 3	11.0 [3.6] 3	9.6 [3.2] 4	8.6 [2.9] 5
15668200 Crater C nr Nome	127 10 95	17.0 [10.6] 4-s 1-w	19.1 [11.5] 3	19.1 [11.5] 3	19.1 [11.5] 3	17.0 [10.6] 4	15.5 [9.9] 5
15744500 Kobuk R nr Kiana	147 10 85	7.4 [3.6] 4-s 2-w	8.5 [4.1] 3	8.5 [4.1] 3	8.5 [4.1] 3	7.4 [3.6] 4	7.4 [3.6] 4
ARCTIC SLOPE							
15798700 Nunavak C nr Barrow	131 15 97	54.7 [37.3] a4-s a2-w	58.8 [39.2] 3	43.2 [32.6] 8	37.6 [29.4] 12	29.2 [23.4] 23	25.3 [20.3] 32

*See footnotes at end of table.

Table 10.--Continued

Identification	Station statistics* IDAYS FD PI	Current operation*	Budget, in thousands of 1983 dollars 1,381	1,440	1,539	2,000	2,500
		Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] Number of visits per open-water period to site					
ARCTIC SLOPE--Continued							
15896000 Kuparuk R nr Deadhorse	140 2 100	11.7 [5.5] a4-s a2-w	13.4 [6.3] 3	13.4 [6.3] 3	13.4 [6.3] 3	10.4 [4.9] 5	8.8 [4.2] 7
15896700 Putuligayuk R nr Deadhorse	103 10 100	47.7 [43.6] a4-s a2-w	52.8 [48.2] 3	40.5 [36.9] 6	32.0 [29.0] 10	25.3 [22.8] 16	21.6 [19.3] 22
15904900 Atigun R trib nr Pump Station 4	128 3 95	11.0 [9.4] 4-s 2-w	11.6 [9.5] 3	11.6 [9.5] 3	11.6 [9.5] 3	10.2 [9.1] 6	9.6 [8.8] 9
15908000 Sagavanirktok R nr Pump Station 3	130 10 100	24.5 [16.7] 4-s 2-w	27.6 [18.4] 3	27.6 [18.4] 3	27.6 [18.4] 3	20.6 [14.2] 6	17.1 [11.8] 9

* See footnotes listed below.
IDAYS Open-water period, in days.
FD Lost record, in percent.
PI Probability of measuring during visit, in percent.
s Open-water measurements.
w "Winter" measurements.
a Adjusted and approximate. These values are not strictly true values. A hydrographer is usually stationed near the site for a period, generally ranging from 5 to 14 days, from just before ice breakup until backwater from ice ceases. One or more "winter" measurements and one or more open-water measurements may be obtained during this limited time period.

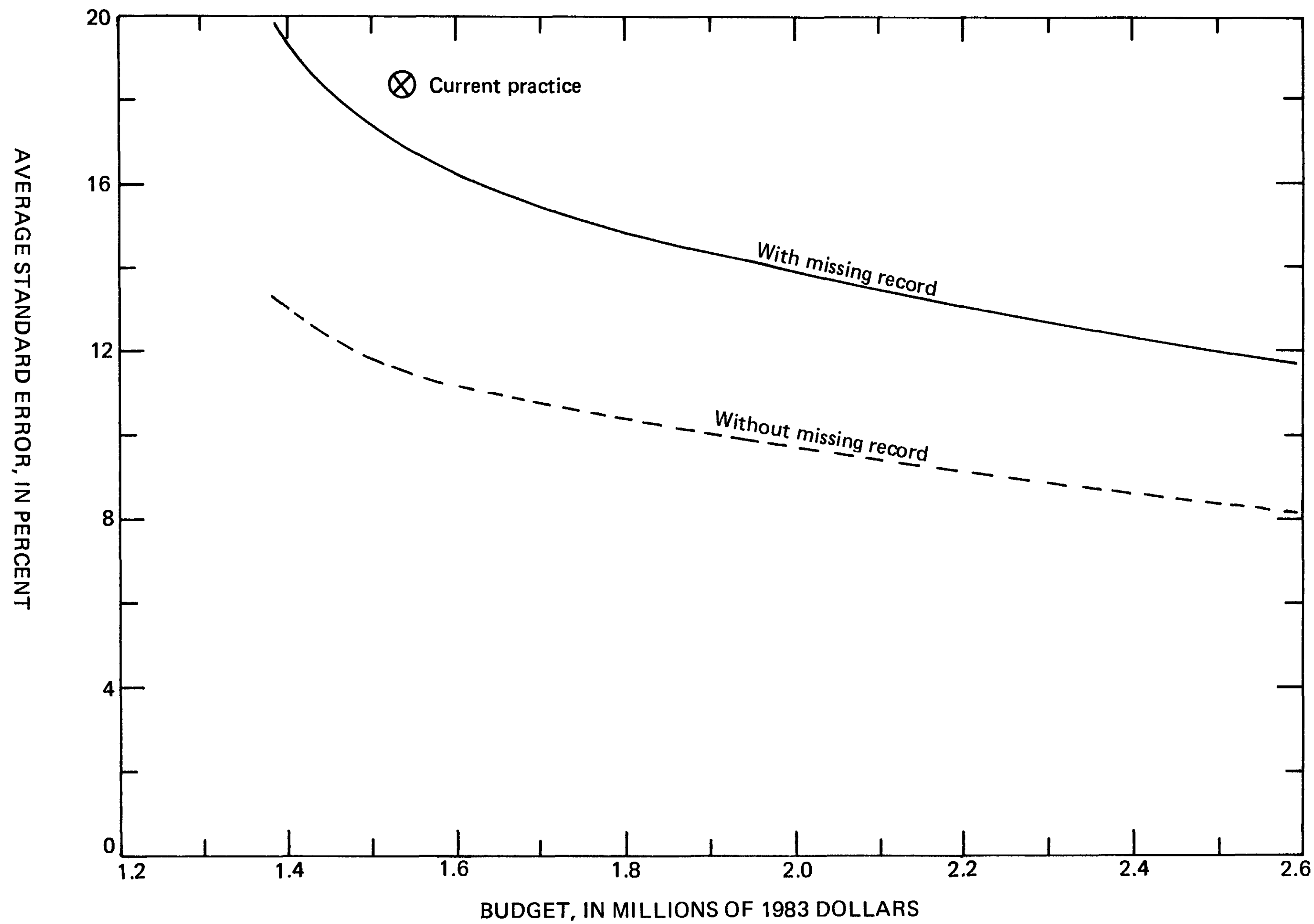


Figure 18.--Temporal average standard error for stream-gaging program.

In the interior parts of Alaska, stations need to be visited during breakup, or as soon thereafter as possible, to re-start recorders and to ensure that gaging-station equipment is operating. These stations need to be visited during the freezeup period to prevent damage to the gage-height sensing and recording equipment. At least one visit is needed between ice breakup and freezeup because the average length of the open-water period is about 160 days for a typical gaging station in interior Alaska.

Minimum visit requirements should also reflect the need to visit stations for special reasons such as water-quality sampling. In Alaska, the only criterion about frequency of water-quality sampling is that samples must be collected quarterly at most NASQAN stations. The frequency of visits under current practice conforms to this policy. As of June 1983, 74 crest-stage gages were being operated in Alaska. Current practice is to visit these sites four times a year. (All visits are during ice-free conditions.) Similarly, the three periodic measurement sites on Kodiak Island are visited four times a year during open water. Six periodic measurements during open water (besides three others during the "winter" period) are made at two sites in Anchorage.

Considering the constraints on visit frequency mentioned above, a minimum visit frequency of one less open-water visit per year than current practice was used in "The Traveling Hydrographer." At the same time, the required visits to the crest-stage gages and periodic measurement sites were reduced by one visit per year.

It should be emphasized that figure 18 and table 10 are based on various assumptions (as stated at various points throughout this section of the report) concerning both the time series of shifts (residuals) to the stage-discharge relationship and the methods of record reconstruction. Where a choice of assumptions was available, the assumption was chosen that would not underestimate the magnitude of the error variances. (In other words, the standard error of determining discharges for most stations, especially where several assumptions were required for the analysis, is probably slightly overestimated.)

It can be seen that current policies result in an average standard error of estimate of streamflow of 18.4 percent. These policies require a budget of $1,539,000 (1983 dollars) to operate the 98-station stream-gaging network that was analyzed. (It does not include the cost of operating the 12 stations not included in "The Traveling Hydrographer" analysis or the cost of operating the 74 crest-stage gages and the 6 periodic measurement sites.) The range of standard error is from a low of 2.7 percent at Yukon River at Eagle (15356000) to a high value of 60.8 percent assumed at the short-term station on Russell Creek near Cold Bay (15297610). It is possible to obtain about the same average standard error (18.2 percent) with a budget of $1,440,000, about $100,000 lower, by decreasing the number of open-water visits per year by one at stations with low uncertainty values. However, stations with higher uncertainties would be visited more often during open-water than under current practice. This policy and budget change would result in a slight increase in standard error at Yukon River at Eagle to 2.8 percent and a decrease in standard error at Russell Creek to 53.2 percent. (However, the number of open-water visits to Russell Creek would increase to seven from the current five.)

Conclusions

As a result of the K-CERA analysis, the following suggestions are made:

1. The scheduling of field activities in the stream-gaging program should be altered to reduce the current average standard error of estimate of open-water streamflow records which is 18.4 percent.
2. The probabilities of missing record should be reduced by increased use of local gage observers, increased satellite relay of data, upgrading of equipment, and development of alternative strategies to supplement gage-height record.
3. The funding for stations with accuracies that are not acceptable for the intended use of the data should be renegotiated with the data users.
4. The K-CERA analysis should be rerun to include new stations when sufficient information about the streamflow characteristics at the new sites has been obtained.
5. A method should be developed to determine standard errors of streamflow records computed for "winter" periods in Alaska. Alternate, improved, or new methods should be developed and evaluated as to their cost-effectiveness in improving streamflow records for the "winter" period. For the present, "winter" measurements should be made at least at the frequency shown as current practice in table 10.

SUMMARY

Currently (September 1983), there are 110 continuous stream gages being operated in Alaska at a cost of about $1,700,000. Eleven separate sources of funding contribute to this program. Many uses are made of these data; six separate uses were identified for data from a single gage. In spite of the cost and size of this program, there are insufficient streamflow data to provide valid estimates of streamflow characteristics in more than half of western Alaska. An analysis needs to be made to summarize the available data and suggest sites to be added to the current streamflow network. New long-term gaging stations are suggested in four areas of the state. These actions should be undertaken as funds become available.

In an analysis of the uses that are made of the data, two stations with insufficient reason to continue their operation were identified and were discontinued. Another station was discontinued because of loss of funding. Three other stations were identified as having uses specific only to short-term studies; it was decided that these stations would be deactivated at the end of the data-collection phases of the studies. The remaining 104 stations should be maintained in the program for the foreseeable future.

Operating the current network of 110 stations requires a budget of about $1,700,000 per year. However, for the purposes of this report, only 98 stations were included in the analysis of cost-effectiveness. This 98-station network requires a yearly budget of $1,539,000 to operate. It was shown that the overall level of accuracy of the streamflow records at the 98 sites could be maintained with a budget of $1,440,000, if present operating practices (and individual station costs) were altered to visit some stations at different frequencies than currently. This change would result in some increases and decreases in the accuracy of records at

It would also be possible to reduce the average standard error of estimate of streamflow at the stations in the network while maintaining the same budget of $1,539,000. In this case, the average would decrease to 16.8 percent. The range of standard error would be 2.8 and 45.8 percent at Yukon River at Eagle and Russell Creek near Cold Bay, respectively. (The visits would increase to 10 for Russell Creek. A measurement is obtained at every visit at Russell Creek and about once every two or three visits to the station at Eagle.)

A minimum budget of $1,381,000 is required to operate the 98-station program with one less visit per year required at each station during open-water than at present. A budget less than this does not permit proper service and maintenance of the gages and recorders and also would not provide for the three minimum required visits to the crest-stage gages and required visits to periodic measurement sites. At the minimum budget, the average standard error is 19.8 percent. The minimum standard error of 2.8 percent would still occur at the Eagle station and the maximum standard error would be 66.1 percent at Russell Creek.

Two other budgets were analyzed, $2,000,000 and $2,500,000. These budgets use the current practice as the lower limit on number of visits at all gages and the periodic measurement sites. The larger budget would increase the present costs by 62 percent and decrease the average standard error to 11.9 percent, a decrease of 35 percent from current operational policies. The extremes of standard error would be 2.7 percent at Eagle and 29.1 percent at Russell Creek (27 visits during open-water). Thus, it is apparent that significant improvements in accuracy of streamflow records can be obtained if larger budgets become available.

In practice, the larger budgets would also be used to increase the number of "winter" measurements. The budget of $2,500,000, as used in "The Traveling Hydrographer," considers only increases in open-water measurements. If an average of two "winter" visits was added for every station with significant lengths of "winter" period, the budget would be slightly more than $3,000,000.

Another analysis was made using the assumption that no gage-height record was lost because of less than perfect instrumentation. The curve, labeled "without missing record" on figure 18, shows the average standard errors of estimating streamflow that could be obtained if perfectly reliable systems were available to record gage heights during the open-water period. For the minimal operating budget of $1,381,000, the effects are the greatest for less than perfect instrumentation; average standard error increases from 13.4 percent (assuming no missing record) to 19.8 percent (with missing record). Using the present less-than-perfect equipment, the current budget would have to be increased by about $580,000 to attain a standard error of 13.4 percent.

At the other budgetary extreme of $2,500,000, under which the stations would be visited more frequently and the reliability of equipment should be less sensitive, the average standard error increased from 8.4 percent for ideal equipment to 11.9 percent for the current systems of recording and sensing hydrologic data. Thus, improved equipment can have a very positive impact on streamflow uncertainties throughout the range of operational budgets that could possibly be anticipated for the stream-gaging program in Alaska.

individual sites. It is suggested as far as feasible, that the scheduling of visits to these stations be altered. Cost-effective techniques to reduce the missing gage-height data at gaging stations should be utilized. Studies should be made to determine standard errors of "winter" discharge records and to develop optimum methods of data collection and record analysis during the "winter."

The analysis of cost-effective methods of providing and improving streamflow records should be a continuing effort. Future studies will be required because of changes in demands for streamflow information with subsequent addition and deletion of stream gages. Such changes will impact the operation of other stations in the program both because of the interdependence among stations of the information that is generated (data redundancy) and because of the interdependence of the costs per station to collect the data from which the information is derived.

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