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SEASONAL, FREQUENCY AND DURATIONAL ASPECTS OF STREAMFLOW IN SOUTHEAST AND COASTAL ALASKA

FINAL REPORT

by

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16. Abstract

The design of culverts for fish passage and other purposes is improved with information on magnitude, duration and frequency of streamflow at various times of the year. A prior report (Ashton and Carlson, 1984) addressed the problem for 33 gaging stations in southcentral, western, interior, and arctic Alaska. This report includes watersheds in the southeast, the southcentral and the Aleutian regions of Alaska. Like the earlier work, it includes watersheds with drainage areas less than 100 square miles. It aids in the determination of the highest consecutive mean discharge with one, three, seven and 15-day durations, and the lowest consecutive mean discharge with three, seven, 15 and 30-day durations. Streamflow was analyzed during four seasons: spring, April 1 to June 30; summer, July 1 to September 30; fall, October 1 to December 31; and winter, January 1 to March 31. The lognormal distribution was used to estimate flows at recurrence intervals of 1.5, 2, 5, 10 and 20 years. Multiple regression equations were developed to predict flows from ungaged watersheds. Significant basin and climatic characteristics for high flows and low flows included drainage area, mean annual precipitation, mean minimum January temperature, and percent of drainage area with forest cover and lake cover. This information provides the engineer and designer with a method to estimate flows on a basis other than instantaneous peak flow.

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IMPLEMENTATION STATEMENT

In the past, resource agencies have required engineers to design fish passage structures according to the instantaneous mean annual discharge ($Q_{2.33}$). This policy is based on the assumption that the peaks of discharge and fish migration upstream coincide at about the same time. Past fish passage studies have shown that this seldom happens and, therefore, the assumption is conservative. In response to this assumption, several authors (Ashton and Carlson, 1984; Arctic Hydrologic Consultants, 1985; Tilsworth and Travis, 1987) advocate using duration flows for designing culverts. By utilizing the average flow rate for a specific time period instead of the higher instantaneous peak flow, engineers can design smaller cost-effective structures that still offer efficient fish passage during most of the open water period. Any delay periods that the upstream migrating fish may incur while negotiating the structure would be directly related to the duration flow period that the engineer used to design the structure. An acceptable delay period for a particular crossing would have to be decided between the developer and the permitting agency defore the design process could begin.

During the spring of 1987, the University of Alaska-Fairbanks will study the effects of delaying upstream migrating Arctic grayling on spawning by delaying fish at a highway culvert. The purpose of the study is to determine if grayling can be delayed for varying periods of time behind highway structures without harming the fish population. If the study shows that grayling may be delayed for a specific period of time, then highway engineers could design fish passage structures using lower discharge rates than those which are currently used, and thus permit more conservative sizing of highway drainage structures.

Based on the results of this study and with coordination between the Alaska Department of Fish and Game and the Department of Transportation and Public Facilities, mutually acceptable flow duration periods will be determined. The methodology presented in Dr. Carlson's report will then be used to calculate these flow periods.

Mike Travis, Project Manager
Research Section

FORWARD

This report follows another report entitled, "Determination of Seasonal, Frequency and Durational Aspects of Streamflow with Regard to Fish Passage Through Roadway Drainage Structures" by William Ashton and Robert Carlson (Report No. AK-RD-85-06, Alaska Department of Transportation and Public Facilities, Fairbanks, Alaska). It presents additional information on southeast and coastal Alaska. The report has been reviewed in draft form by the following agencies:

Alaska Department of Transportation and Public Facilities
Alaska Department of Fish and Game

Significant comments by these agencies were incorporated into the final draft. Comments that merely gave a difference of opinion or recommended a different way of presenting the information may not be reflected in the final copy. Copies of these comments may be obtained by writing to the project manager:

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We thank the commenting agencies and the individuals involved for their interest in this report and their efforts to improve upon and implement the work. This manuscript constitutes the completion report for Water Research Center project number I85.28.

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INTRODUCTION

Proper design of stream crossings by transportation routes is critical for maintaining the habitat near the crossing. In particular, the designers must be aware of the impact of culvert placement on fish passage. Four criteria are important to the design of culverts for fish passage: the hydrologic flow regime of the stream; the hydraulic properties of the culvert; the swimming abilities of the fish species; and the time of year of fish migration through the crossing reach. The Alaska Department of Transportation and Public Facilities has sponsored a series of research projects that have addressed problems associated with these criteria. Reports which have been issued as the result of this work include Wellen and Kane (1983), Ashton and Carlson (1984), and Tilsworth and Travis (1987). This report addresses the criteria of hydrologic flow regime and migration season.

Often the flow regime is addressed only through the specification of the peak annual flow with recurrence interval of approximately two years, depending on the particular frequency distribution being used to describe this expected statistical variation of the flow. In addition to this two-variable frequency specification, it is also important to determine the magnitude and frequency of flows of various durations at different seasons of the year. The frequency is important to understanding the risk or possibility of a given flow being exceeded. A flow's duration at a particular magnitude provides the time that the normal migration of a fish species may be delayed. The season of year indicates whether a particular flow will occur during a critical period of fish passage. By providing a more detailed four-variable representation of the flow regime instead of the commonly used mean annual instantaneous flood (frequency depends on distribution used), culverts can be designed for fish passage with a greater degree of confidence. The previous study (Ashton and Carlson, 1984) presented the necessary background and special literature of this problem with particular reference to southcentral, interior, northern and western Alaska. The many stations of southeast Alaska, coastal southcentral Alaska and the Aleutian chain were not addressed. For a discussion of literature on the effects of highway culverts on fish passage in northern latitudes, the reader is referred to the previous study and to Ashton (1983). For convenience, the bibliography on the fish passage literature from Ashton and Carlson (1984) is included in the appendix of this report.

OBJECTIVE

This study analyzes existing streamflow data from watersheds smaller than 100 mi^2 in the southeast, the coastal southcentral and the Aleutian regions of Alaska. It develops the capability for predicting the magnitude and frequency of high and low flows for specific durations and periods of the year, thus providing a four-variable specification of high and low flow for a given area. It also uses standard regression techniques to enable the designer to calculate an approximate flow estimate of basins which do not have nearby stream gaging stations. Using these methods, a designer can estimate flow and frequency of a stream for a critical time of year and duration on a given stream.

LITERATURE REVIEW

Previous workers at the University of Alaska-Fairbanks (Ashton, 1983; and Janowicz, 1983) directed their attention toward flood frequency estimation and, in the former case, concerns of fish passage. These two theses each contain over 40 references, with Janowicz concentrating on instantaneous flood frequency estimation and Ashton concentrating on flow important to fish passage. The two include many references that relate to the problems at hand. Some portions of Ashton (1983) are included in Ashton and Carlson (1984). Five main references in this study include these three, Lamke (1979) and Ott Water Engineers (1979).

Lamke (1979) developed a series of multiple regression equations for design flood estimates for selected return periods. Two delineated regions of Alaska are the southcentral region of Alaska and the remainder of the state. This report has become a standard for flood frequency estimation in Alaska and used data up to 1975.

Ashton's thesis (1983) concentrated on the flow regime of the Little Tonsina River in Alaska at a specific site. It illustrated the use of the flow analysis method developed by Ashton and Carlson (1984). It particularly concentrated on the determination of critical discharge, duration and frequency for design of culverts for fish passage. Ashton and Carlson analyzed streamflow records from 33 gaging stations in southcentral, interior, western and arctic Alaska. They included records up to 1982 for watersheds smaller than 100 mi^2, and they determined flow magnitude for a variety of durations, frequencies and seasons for both high and low flows. Multiple linear regression equations were used to predict flows for ungaged watersheds. This report forms the basis of the present report.

Janowicz (1983) developed a technique for determining peak design flows of ungaged watersheds in Alaska. The state was separated into three hydrologic units, and four theoretical probability distributions were fitted to samples of streamflow data. The two-parameter log normal distribution fit the sample data better than other methods. Some auxiliary curves and relationships were developed as an aid to using Janowicz's results for the three regions. No particular attempt was made to provide a regression-type relationship of the model parameters for estimation in ungaged regions such as Lamke (1979) and Ashton and Carlson (1984) did.

The Ott Water Engineers report (1979) presents a set of equations and related information which can be used to estimate various characteristics of streamflow in ungaged watersheds. The regression equations relate precipitation and physiographic watershed characteristics to streamflow characteristics. A variety of streamflow characteristics may be estimated for a variety of stream development purposes. The report presents a useful addition to the current study and presents a particularly good background of characteristics for many watersheds in southeast Alaska. The present study uses additional streamflow records that became available since the time of the study by Ott Water Engineers.

METHODS

Streamflow stations used in this report follow the criteria of locations in southeast or coastal Alaska, 100 mi^2 or less, five or more years of continuous streamflow records, 20% or less of the basin covered by glaciers and no regulation of streamflow. Lamke (1986) of the U.S. Geological Survey was consulted about the stations used in his report, and new stations were added as appropriate. A list of streamflow stations, drainage areas and the years of record are shown in Table 9.

Periods of zero flow are replaced with a very low flow value. The year is divided into four periods: spring, April 1 to June 30; summer, July 1 to September 39; fall, October 1 to December 31; and winter, January 1 to March 31. For each period, computations determined the highest consecutive mean discharge with durations of one, three, seven and 15 days, and the lowest consecutive mean discharge with a duration of three, seven, 15 and 30 days.

Predicted discharge values are computed from a lognormal frequency distribution. Previous work by Ashton and Carlson (1984) and Janowicz (1983) showed this distribution to be the most useful for areas with little data. Each of the distributions was fitted using the maximum likelihood or method of moments, which are equivalent for the lognormal distribution. If the results are plotted as a comparison to the calculated distribution, a Bloom plotting distribution should be used. To predict flows from ungaged basins, a multiple linear regression technique (SPSS, 1986) was used to relate physical and climatic characteristics of the gaged basins to the flow as estimated from the lognormal distribution. Calculated flows were extracted for both the high and low flows with recurrence intervals of 1.25, 2, 5, 10 and 20 years. Recurrence intervals greater than 20 years are not considered because most of the problems associated with fish passage in culverts occur at medium to low recurrence interval flows. The regression equation has the following form for each period.

$$Q = a\, A^{b}\, B^{c}\, C^{d}\, D^{e} E^{f} \qquad (1)$$

where

Q = dependent variable, the discharge for a specific duration, return period and season, ft^3/sec,

a = regression constant,

b,c,d,e and f = regression coefficients for the independent variables,

A,B,C,D and E = independent variables representing basin and climatic characteristics.

The independent variables for the study are:

A = basin area, mi^2

B = lake area, % of total

C = forest area, % of total

D = annual precipitation, inches

E = January mean minimum temperature, (°F+30).

Regression analysis was carried out on a VAX 785 computer using the SPSS statistics program (SPSS, 1986). A step-wise regression option was used. A maximum of five independent variables were considered for each equation. A variable was included if it explained a significant (5% level) amount of residual variation and increased the R^2 by at least 5%. The program automatically examines each variable in the equation building process to see whether additional parameters could be added or removed from the equation. Variables considered in the regression analyses included the drainage area, mean annual precipitation, percentage of drainage area covered by forests or lakes, and mean minimum January temperature. Other parameters normally included did not prove to be significant factors in the previous study (Ashton and Carlson, 1984). The basin and climatic characteristics were obtained from Lamke (1979), and additional information was furnished by the U.S. Geological Survey's basin characteristics file (Lamke, 1987). These basin characteristics are listed in Table 9.

RESULTS

The product of this flow analysis allows a drainage designer the freedom to consider a greater variety of flow frequency variables. The results are presented in a series of tables (1 through 8) which give the regression coefficients with respect to: spring, summer, fall and winter seasons; one, three, seven and 15 days duration for high flows; three, seven, 15 and 31 days duration for low flows; and one, two, five, 10 and 20 year return periods. The standard error of estimate is given for each flow value. These errors, of course, are quite high and emphasize that flow estimates should be made from a variety of sources to check these values and to provide more reliability for final design. The greatest value of the regression estimation is to easily assess a variety of design configurations at the preliminary stage.

Information relating to the gage locations and estimates of precipitation and the January mean minimum temperature are shown in Figures 1 through 5.

TABLE 1. Regression constants for estimating maximum flows of one day duration for various return periods and seasons.

Flow designation	Regression constants						Standard Error	
	a *(x10^{-4})	b	c	d	e	f	+%	-%
Q20MAX1-1	15.8*	0.798	---	---	0.802	1.846	89	47
Q20MAX1-2	11.48	0.734	---	---	0.497	---	89	47
Q20MAX1-3	8.46	0.917	---	---	0.536	---	65	39
Q20MAX1-4	3.62	0.909	-0.152	---	0.809	---	53	35
Q10MAX1-1	5.07*	0.780	---	---	0.810	2.046	84	46
Q10MAX1-2	6.48	0.776	---	---	0.552	---	62	38
Q10MAX1-3	5.31	0.926	---	---	0.589	---	63	38
Q10MAX1-4	2.42	0.914	-0.140	---	0.855	---	48	33
Q5MAX1-1	1.59*	0.761	---	---	0.818	2.256	82	45
Q5MAX1-2	3.97	0.820	---	---	0.610	---	62	38
Q5MAX1-3	3.25	0.936	---	---	0.644	---	62	38
Q5MAX1-4	1.58	0.918	-0.127	---	0.902	---	45	31
Q2MAX1-1	0.142*	0.721	---	---	0.836	2.686	90	47
Q2MAX1-2	1.30	0.909	---	---	0.728	---	45	31
Q2MAX1-3	1.19	0.955	---	---	0.758	---	67	40
Q2MAX1-4	0.658	0.930	-0.102	---	0.999	---	41	29
Q1MAX1-1	0.0128*	0.853	---	---	0.853	3.11	113	53
Q1MAX1-2	0.426	0.998	---	---	0.846	---	46	32
Q1MAX1-3	0.434	0.974	---	---	0.872	---	80	44
Q1MAX1-4	0.273	0.941	-0.076	---	1.096	---	42	30

Flow designation explanation: Example Q20MN7-1
20 - refers to return period years (1 is 1.25 years)
MN(MAX) - refers to low flows or high flows
7 - refers to duration, days
-1 - refers to season: (1) 1 Jan-31 Mar; (2) 1 Apr-30 June; (3) 1 July-30 Sept; (4) 1 Oct-31 Dec

TABLE 2. Regression constants for estimating maximum flows of three days duration for various return periods and seasons.

Flow designation	Regression constants						Standard Error	
	a *(x10^{-4})	b	c	d	e	f	+%	-%
Q20MAX3-1	38.6*	0.843	---	---	0.794	1.525	82	45
Q20MAX3-2	5.14	0.818	---	-0.129	0.664	---	62	38
Q20MAX3-3	3.14	0.983	---	---	0.623	---	63	39
Q20MAX3-4	2.20	0.947	---	---	0.771	---	49	33
Q10MAX3-1	13.1*	0.825	---	---	0.804	1.719	76	43
Q10MAX3-2	3.23	0.885	---	-0.116	0.703	---	55	35
Q10MAX3-3	2.25	0.988	---	---	0.654	---	62	38
Q10MAX3-4	1.54	0.953	---	---	0.881	---	45	31
Q5MAX3-1	4.18*	0.806	---	---	0.814	1.922	76	43
Q5MAX3-2	1.98	0.895	---	-0.102	0.743	---	49	33
Q5MAX3-3	1.59	0.993	---	---	0.687	---	62	38
Q5MAX3-4	1.06	0.958	---	---	0.853	---	41	29
Q2MAX3-1	0.406*	0.766	---	---	0.834	2.339	85	46
Q2MAX3-2	0.872	0.955	---	---	0.741	---	44	31
Q2MAX3-3	0.773	1.004	---	---	0.756	---	68	40
Q2MAX3-4	0.497	0.970	---	---	0.940	---	36	27
Q1MAX3-1	0.151*	0.702	0.214	0.167	0.4902	2.534	97	49
Q1MAX3-2	0.296	1.044	---	---	0.858	---	47	32
Q1MAX3-3	0.377	1.014	---	---	0.824	---	81	45
Q1MAX3-4	0.232	0.981	---	---	1.026	---	36	27

Flow designation explanation: Example Q20MN7-1
20 - refers to return period years (1 is 1.25 years)
MN(MAX) - refers to low flows or high flows
7 - refers to duration, days
-1 - refers to season: (1) 1 Jan-31 Mar; (2) 1 Apr-30 June; (3) 1 July-30 Sept; (4) 1 Oct-31 Dec

TABLE 3. Regression constants for estimating maximum flows of seven days duration for various return periods and seasons.

Flow designation	Regression constants						Standard Error	
	a *(x10^{-4})	b	c	d	e	f	+%	-%
Q20MAX7-1	52.9*	0.859	---	---	0.802	1.341	72	42
Q20MAX7-2	3.82	0.869	---	---	0.667	-0.156	57	36
Q20MAX7-3	2.63	0.961	---	---	0.787	---	60	38
Q20MAX7-4	1.35	0.961	---	---	0.787	---	41	29
Q10MAX7-1	2.07*	0.843	---	---	0.807	1.506	71	42
Q10MAX7-2	2.39	0.905	---	-0.142	0.704	---	51	34
Q10MAX7-3	1.86	1.017	---	---	0.601	---	61	38
Q10MAX7-4	0.97	0.965	---	---	0.825	---	39	28
Q5MAX7-1	7.75*	0.828	---	---	0.812	1.678	72	42
Q5MAX7-2	1.47	0.942	---	-0.128	0.748	---	47	32
Q5MAX7-3	1.29	1.024	---	---	0.640	---	62	38
Q5MAX7-4	0.68	0.969	---	---	0.865	---	37	27
Q2MAX7-1	1.22*	0.809	0.144	---	0.775	1.995	78	44
Q2MAX7-2	0.538	1.019	---	-0.099	0.840	---	41	30
Q2MAX7-3	65.1	1.042	---	---	0.728	-1.169	67	40
Q2MAX7-4	0.335	0.978	---	---	0.948	---	36	26
Q1MAX7-1	0.175*	0.784	0.208	---	0.765	2.333	93	48
Q1MAX7-2	0.235	1.0753	---	---	0.849	---	49	33
Q1MAX7-3	61.55	1.055	---	---	0.809	-1.352	79	44
Q1MAX7-4	0.165	0.988	---	---	1.030	---	37	27

Flow designation explanation: Example Q20MN7-1

20 - refers to return period years (1 is 1.25 years)

MN(MAX) - refers to low flows or high flows

7 - refers to duration, days

-1 - refers to season: (1) 1 Jan-31 Mar; (2) 1 Apr-30 June; (3) 1 July-30 Sept; (4) 1 Oct-31 Dec

TABLE 4. Regression constants for estimating maximum flows of 15 days duration for various return periods and seasons.

Flow designation	Regression constants						Standard Error	
	a *(x10^{-4})	b	c	d	e	f	+%	-%
Q20MAX15-1	0.858	0.858	---	---	0.789	---	71	41
Q20MAX15-2	2.51	0.903	---	-0.144	0.678		54	35
Q20MAX15-3	1.89	1.030	---	---	0.554	---	63	39
Q20MAX15-4	0.795	0.977	---	---	0.824	---	37	27
Q10MAX15-1	44.1*	0.841	---	---	0.783	1.258	68	41
Q10MAX15-2	1.61	0.936	---	-0.136	0.722	---	49	33
Q10MAX15-3	130.7	1.040	---	---	0.591	-1.136	61	38
Q10MAX15-4	0.601	0.978	---	---	0.853	---	36	26
Q5MAX15-1	17.5*	0.829	---	---	0.784	1.423	33	42
Q5MAX15-2	1.00	0.970	---	-0.127	0.769	---	47	32
Q5MAX15-3	135.4	1.047	---	---	0.623	-1.224	63	38
Q5MAX15-4	0.447	0.980	---	---	0.885	---	35	26
Q2MAX15-1	3.21*	0.819	0.163	---	0.731	1.719	75	43
Q2MAX15-2	0.384	1.041	---	-0.109	0.865	---	46	32
Q2MAX15-3	58.8	1.100	---	-0.139	0.848	-1.265	66	40
Q2MAX15-4	0.244	0.983	---	---	0.950	---	35	26
Q1MAX15-1	0.526*	0.800	0.229	---	0.711	2.040	88	47
Q1MAX15-2	0.185	1.086	---	---	0.857	---	55	35
Q1MAX15-3	52.9	1.122	---	-0.166	0.944	-1.416	76	43
Q1MAX15-4	0.133	0.986	---	---	1.014	---	37	27

Flow designation explanation: Example Q20MN7-1
20 - refers to return period years (1 is 1.25 years)
MN(MAX) - refers to low flows or high flows
7 - refers to duration, days
-1 - refers to season: (1) 1 Jan-31 Mar; (2) 1 Apr-30 June; (3) 1 July-30 Sept; (4) 1 Oct-31 Dec

TABLE 5. Regression constants for estimating minimum flows of three days duration for various return periods and seasons.

Flow designation	Regression constants a	b	c	d	e	f	Standard Error +%	-%
Q20MN3-1	0.310	0.992	0.307	---	---	---	105	51
Q20MN3-2	0.0339	0.994	0.283	---	0.597	---	122	55
Q20MN3-3	427.9	1.302	---	-0.469	0.935	-2.381	152	60
Q20MN3-4	0.4772	1.021	0.249	---	---	---	103	51
Q10MN3-1	0.372	0.997	0.302	---	---	---	95	49
Q10MN3-2	0.0332	0.950	0.266	---	0.645	---	116	54
Q10MN3-3	603.0	1.301	---	-0.453	0.942	-2.445	142	59
Q10MN3-4	0.111	0.985	0.228	---	0.372	---	97	47
Q5MN3-1	0.452	1.003	0.299	---	---	---	86	46
Q5MN3-2	0.0326	0.955	0.248	---	0.695	---	92	48
Q5MN3-3	865.2	1.300	---	-0.436	0.949	-2.513	132	57
Q5MN3-4	0.109	0.991	0.224	---	0.419	---	80	44
Q2MN3-1	0.113	0.962	0.270	---	0.408	---	68	40
Q2MN3-2	0.0312	0.967	0.211	---	0.798	---	71	41
Q2MN3-3	1808.	1.297	---	-0.401	0.965	-2.652	120	55
Q2MN3-4	9.69	1.004	0.214	---	0.516	---	66	40
Q1MN3-1	0.107	0.960	0.257	---	0.510	---	59	37
Q1MN3-2	0.030	0.979	0.174	---	0.901	---	62	38
Q1MN3-3	3785.7	1.295	---	-0.367	0.980	-2.791	117	54
Q1MN3-4	6.05	1.021	0.207	---	0.619	-1.033	58	37

Flow designation explanation: Example Q20MN7-1
20 - refers to return period years (1 is 1.25 years)
MN(MAX) - refers to low flows or high flows
7 - refers to duration, days
-1 - refers to season: (1) 1 Jan-31 Mar; (2) 1 Apr-30 June; (3) 1 July-30 Sept; (4) 1 Oct-31 Dec

TABLE 6. Regression constants for estimating minimum flows of seven days duration for various return periods and seasons.

Flow designation	Regression constants						Standard Error	
	a	b	c	d	e	f	+%	-%
Q20MN7-1	0.311	1.008	0.308	---	---	---	103	51
Q20MN7-2	0.030	0.956	0.279	---	0.637	---	123	55
Q20MN7-3	458.1	1.340	---	-0.471	0.990	-2.463	161	62
Q20MN7-4	0.0792	1.028	0.243	---	0.413	---	85	49
Q10MN7-1	0.384	1.007	0.302	---	---	---	94	48
Q10MN7-2	0.0296	0.959	0.258	---	0.689	---	107	52
Q10MN7-3	602.4	1.333	---	-0.456	0.993	-2.499	149	60
Q10MN7-4	0.082	1.024	0.235	---	0.452	---	77	43
Q5MN7-1	0.103	0.961	0.279	---	0.352	---	83	45
Q5MN7-2	0.0289	0.963	0.236	---	0.744	---	93	48
Q5MN7-3	804.3	1.326	---	-0.440	0.996	-2.537	138	58
Q5MN7-4	0.084	1.020	0.227	---	0.493	---	70	41
Q2MN7-1	0.112	0.949	0.262	---	0.436	---	68	40
Q2MN7-2	0.0277	0.969	0.190	---	0.855	---	72	42
Q2MN7-3	1450.1	1.311	---	-0.406	1.000	-2.614	123	55
Q2MN7-4	0.0899	1.011	0.211	---	0.577	---	68	40
Q1MN7-1	0.122	0.937	0.244	---	0.519	---	59	37
Q1MN7-2	0.0264	0.976	0.145	---	0.968	---	64	39
Q1MN7-3	2617.6	1.297	---	-0.373	1.006	-2.691	119	54
Q1MN7-4	0.0959	1.202	0.196	---	0.660		54	35

Flow designation explanation: Example Q20MN7-1

20 - refers to return period years (1 is 1.25 years)

MN(MAX) - refers to low flows or high flows

7 - refers to duration, days

-1 - refers to season: (1) 1 Jan-31 Mar; (2) 1 Apr-30 June; (3) 1 July-30 Sept; (4) 1 Oct-31 Dec

TABLE 7. Regression constants for estimating minimum flows of 15 days duration for various return periods and seasons.

Flow designation	Regression constants						Standard Error	
	a	b	c	d	e	f	+%	-%
Q20MN15-1	0.338	0.998	0.338	---	---	---	101	50
Q20MN15-2	0.0184	0.971	0.257	---	0.784	---	115	54
Q20MN15-3	260.1	1.368	---	-0.509	1.133	-2.426	167	62
Q20MN15-4	0.0860	0.985	0.280	---	0.474	---	83	46
Q10MN15-1	0.435	0.996	0.323	---	---	---	93	48
Q10MN15-2	0.0190	0.969	0.235	---	0.831	---	102	50
Q10MN15-3	310.1	1.352	---	-0.479	1.121	-2.424	152	60
Q10MN15-4	0.0871	0.982	0.260	---	0.522	---	76	43
Q5MN15-1	0.989	0.943	0.288	---	0.399	---	81	45
Q5MN15-2	0.0195	0.967	0.211	---	0.880	---	90	47
Q5MN15-3	373.5	1.335	---	-0.447	1.108	-2.421	139	58
Q5MN15-4	0.0884	0.978	0.239	---	0.572	---	70	41
Q2MN15-1	0.112	0.920	0.253	---	0.480	---	68	40
Q2MN15-2	0.0205	0.963	0.163	---	0.981	---	73	42
Q2MN15-3	561.1	1.302	---	-0.382	1.080	-2.416	121	55
Q2MN15-4	0.911	0.970	0.195	---	0.676	---	60	37
Q1MN15-1	0.144	0.913	0.217	---	0.561	---	61	38
Q1MN15-2	0.0217	0.959	0.114	---	1.082	---	68	40
Q1MN15-3	798.7	1.268	---	-0.318	1.054	-2.411	113	53
Q1MN15-4	0.0938	0.961	0.151	---	0.778		57	36

Flow designation explanation: Example Q20MN7-1
- 20 - refers to return period years (1 is 1.25 years)
- MN(MAX) - refers to low flows or high flows
- 7 - refers to duration, days
- -1 - refers to season: (1) 1 Jan-31 Mar; (2) 1 Apr-30 June; (3) 1 July-30 Sept; (4) 1 Oct-31 Dec

TABLE 8. Regression constants for estimating minimum flows of 31 days duration for various return periods and seasons.

Flow designation	Regression constants						Standard Error	
	a *(x10^{-4})	b	c	d	e	f	+%	-%
Q20MN31-1	0.474	0.956	0.391	---	---	---	109	52
Q20MN31-2	0.0459*	0.937	0.164	---	1.025	1.953	103	51
Q20MN31-3	206.0	1.314	---	-0.426	1.195	-2.384	179	64
Q20MN31-4	0.0408	0.976	0.285	---	0.742	---	84	46
Q10MN31-1	0.110	0.901	0.340	---	0.402	---	98	50
Q10MN31-2	0.111*	0.936	0.150	---	1.043	1.766	91	48
Q10MN31-3	221.8	1.297	---	-0.396	1.166	-2.337	158	61
Q10MN31-4	0.0450	0.974	0.260	---	0.773	---	76	43
Q5MN31-1	0.121	0.891	0.306	---	0.453	---	90	47
Q5MN31-2	0.278*	0.936	0.134	---	1.062	1.570	81	45
Q5MN31-3	239.6	1.280	---	-0.365	1.135	-2.287	140	58
Q5MN31-4	0.050	0.972	0.233	---	0.805	---	69	41
Q2MN31-1	0.146	0.870	0.234	---	0.557	---	79	44
Q2MN31-2	1.634*	0.924	---	---	1.134	1.195	67	40
Q2MN31-3	280.6	1.245	---	-0.301	1.072	-2.184	112	53
Q2MN31-4	0.0614	0.968	0.178	---	0.871	---	58	37
Q1MN31-1	0.175	0.849	0.163	---	0.662	---	76	43
Q1MN31-2	0.0257	0.930	---	---	1.167	---	59	37
Q1MN31-3	328.3	1.209	---	-0.237	1.009	-2.082	97	49
Q1MN31-4	0.0757	0.964	0.122	---	0.937	---	53	35

Flow designation explanation: Example Q20MN7-1

20 - refers to return period years (1 is 1.25 years)

MN(MAX) - refers to low flows or high flows

7 - refers to duration, days

-1 - refers to season: (1) 1 Jan-31 Mar; (2) 1 Apr-30 June; (3) 1 July-30 Sept; (4) 1 Oct-31 Dec

TABLE 9. Streamflow station basin information.

Station No.	Description	Period of record	Area (mi^2)	Lake area (%)	Forest area (%)	Annual precipitation (in)	January mean minimum temperature (°F + 30)
15010000	Davis R nr Hyder	1930-40	80.00	1	27	160	58
15011500	Red R nr Metlakatla	1963-78	45.30	1	65	160	59
15012000	Winstanley C nr Ketchikan	1936-38, 47-75	15.50	2	85	140	59
15015600	Klahini R nr Bell Island	1967-73	58.00	3	50	150	58
15020100	Tyee C at mouth nr Wrangell	1963-69	16.10	5	46	160	57
15022000	Harding R nr Wrangell	1951-	67.40	1	41	150	57
15024750	Goat Creek nr Wrangell	1976-	17.30	7	32	140	56
15026000	Cascade C nr Petersburg	1917-28, 46-73	23.00	5	23	80	55
15030000	Sweetheart Falls C nr Juneau	1915-17, 18-27	36.30	10	7	80	51
15040000	Dorothy C nr Juneau	1915-24,26-33,51-73	15.20	16	14	80	51
15044000	Carlson C nr Juneau	1951-61	24.30	1	67	120	53
15048000	Sheep C nr Juneau	1911-13,16-20,46-73	4.57	1	45	120	53
15050000	Gold C at Juneau	1916-20, 46-82	9.76	1	30	120	53
15052800	Montana C nr Auke Bay	1965-75	15.50	1	65	80	55
15053800	Lake C at Auke Bay	1963-73	2.50	1	71	80	55
15054000	Auke C nr Auke Bay	1947-50, 62-75	3.96	9	49	70	55
15058000	Purple Lk outlet nr Metlakatla	1947-56	6.67	38	63	150	59
15059500	Whipple C nr Ward Cove	1968-80	5.29	1	100	100	59
15060000	Perseverance C nr Wacker	1931-39, 46-69	2.81	12	92	150	59
15062000	Ward C nr Wacker	1948-58	14.00	8	92	150	59
15064000	Ketchikan C at Ketchikan	1909-12,15-19,64-67	13.50	10	82	150	59
15066000	Beaver Falls C nr Ketchikan	1917,20-25,27-32	5.80	10	70	150	59

TABLE 9. (Continued)

Station No.	Description	Period of record	Area (mi^2)	Lake area (%)	Forest area (%)	Annual precipitation (in)	January mean minimum temperature (°F + 30)
15067900	Upper Mahoney Lake nr Ketchikan	1977-	2.03	7	1	200	59
15068000	Mahoney C nr Ketchikan	1920-33,47-58,77-81	5.70	10	80	160	59
15070000	Falls C nr Ketchikan	1916-26,27-33,46-59	36.50	7	62	160	59
15072000	Fish C nr Ketchikan	1915-36, 38-	32.10	20	73	160	59
15074000	Ella C nr Ketchikan	1927-38, 47-58	19.70	17	67	160	59
15076000	Manzanita C nr Ketchikan	1927-37, 47-67	33.90	13	69	160	59
15078000	Grace C nr Ketchikan	1927-37, 63-69	30.20	11	68	160	59
15080000	Orchard C nr Bell Island	1915-27	59.00	4	69	160	59
15081500	Staney C nr Craig	1964-81	51.60	2	96	90	59
15081800	NB Trocadero C nr Hydaburg	1967-73	17.40	1	96	160	63
15083500	Perkins C nr Metlakatla	1976-	3.38	1	82	120	63
15085100	Old Tom C nr Kassan	1949-	5.90	9	86	150	61
15085600	Indian C nr Hollis	1949-64	8.82	1	78	150	61
15085700	Harris C nr Hollis	1949-64	28.70	1	85	150	61
15085800	Maybeso C nr Hollis	1949-63	15.10	1	89	150	61
15086500	Neck C nr Point Baker	1960-67	17.00	12	82	90	59
15086600	Big C nr Point Baker	1963-81	11.20	10	86	90	59
15087545	Municipal Watershed C nr Petersburg	1978-	2.20	1	98	80	56
15087570	Hamilton C nr Kake	1976-	65.00	1	92	80	57
15087590	Rocky Pass C nr Point Baker	1976-	3.27	3	99	80	58
15087610	Nakwasina R nr Sitka	1976-82	31.90	3	33	170	59

TABLE 9. (Continued)

Station No.	Description	Period of record	Area (mi^2)	Lake area (%)	Forest area (%)	Annual precipitation (in)	January mean minimum temperature (°F + 30)
15088000	Sawmill C nr Sitka	1920-22,28-42,45-57	39.00	4	24	160	59
15092000	Maksoutof R nr Pt Alexander	1951-56	26.00	16	36	160	59
15093400	Sashin C nr Big Port Walter	1965-73,74-80	3.72	8	22	250	61
15094000	Deer Lk Outlet nr Port Alexander	1951-67	7.41	22	39	280	58
15098000	Baranof R nr Baranof	1915-28,57-74	32.00	10	61	200	61
15100000	Takatz C nr Baranof	1951-69	17.50	8	44	200	61
15101500	Greens C nr Juneau	1978-	22.80	2	65	50	54
15102000	Hasselborg C nr Angoon	1951-68	56.20	12	69	80	55
15106940	Hook C AB TR nr Tenakee	1967-80	4.48	1	100	160	57
15106960	Hook C nr Tenakee	1960-80	8.00	1	100	160	57
15106980	Tonalite C nr Tenakee	1968-	14.50	1	89	160	57
15107000	Kadashan R nr Tenakee	1964-79	37.70	1	94	160	57
15107920	Indian R nr Tenakee	1975-82	12.90	1	74	160	56
15108000	Pavlof R nr Tenakee	1957-81	24.30	2	91	120	55
15109000	Fish C nr Auke Bay	1958-78	13.60	1	73	70	55
15195000	Dick C nr Cordova	1970-81	7.95	1	64	140	47
15219000	WF Olsen Bay C nr Cordova	1964-81	4.78	1	44	140	47
15238600	Spruce C nr Seward	1967-79	9.26	1	23	80	43
15238820	Barbara C nr Seldovia	1972-	20.70	1	7	40	51
15295600	Terror R nr Kodiak	1962-68, 78-	15.00	4	9	60	53
15296550	Upper Thumb R nr Larsen Bay	1974-82	18.80	1	4	60	52

TABLE 9. (Continued)

Station No.	Description	Period of record	Area (mi^2)	Lake area (%)	Forest area (%)	Annual precipitation (in)	January mean minimum temperature (°F + 30)
15297200	Myrtle C nr Kodiak	1963-	4.74	1	1	80	55
15297655	Clevenger C on Amchitka Is	1968-74	0.28	8	1	36	59
15297680	Bridge C on Amchitka Is	1967-74	3.03	36	1	36	59
15297690	White Alice C on Amchitka Is	1968-74	0.79	3	1	36	59

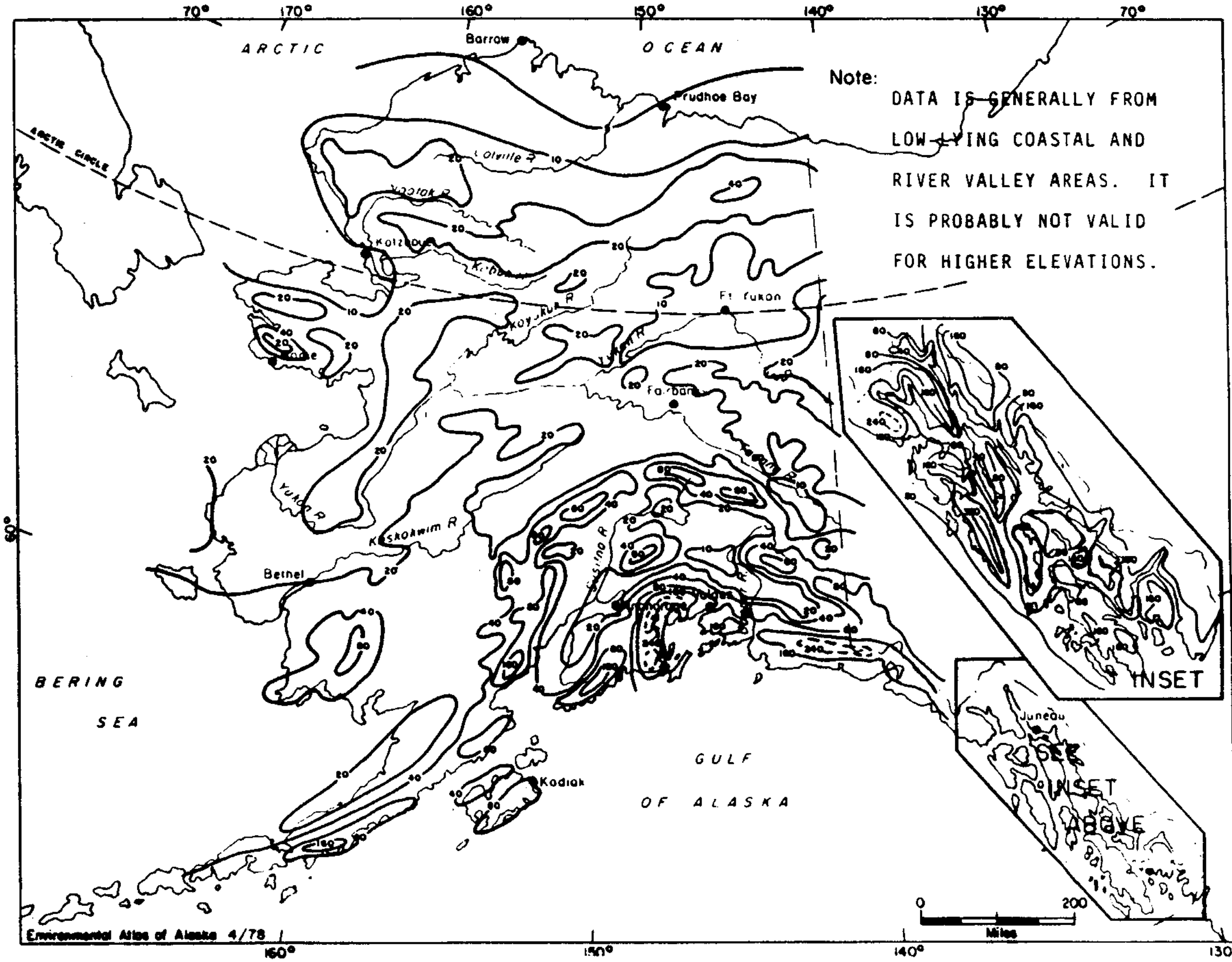

Figure 1. Mean annual precipitation (from Hartman and Johnson, 1978).

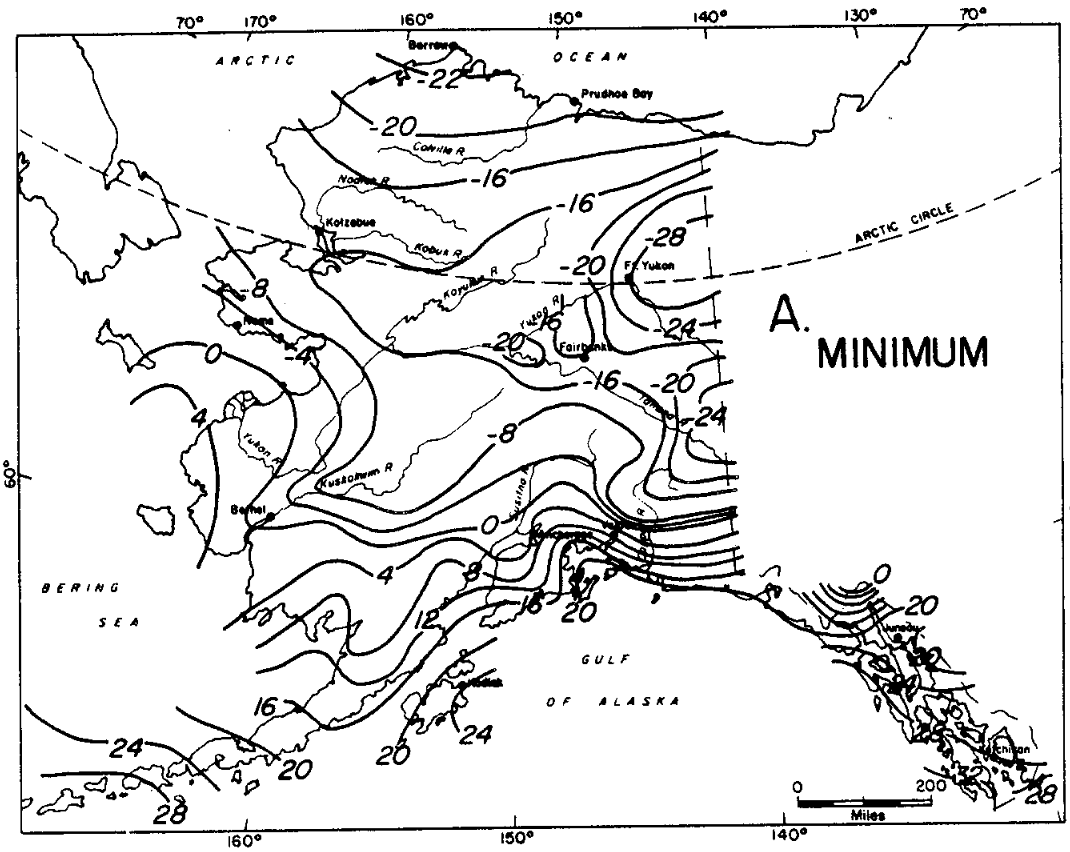

Figure 2. Mean minimum January temperature (from Hartman and Johnson, 1978).

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APPENDIX A

EXAMPLE COMPUTATION

The first step for the designer is to choose the appropriate flow criteria. For example, a regional fisheries biologist may feel that for a small creek near Petersburg a 1-day duration, 1.25-year return period spring maximum flow and a 7-day duration, 10-year return period fall minimum flow are appropriate trial design flows for the fish population in question.

From available information such as Figures 1 and 2 and USGS maps, the basin parameters are determined to be

(B)	Drainage area	-	30 sq mi
(C)	Lake area	-	10%
(D)	Forest area	-	45%
(E)	Annual precipitation	-	90 inches
(F)	January mean minimum temperature	-	58 (°F+30)

For the high flow value, Table 1 gives the appropriate flow designation as Q1MAX1-2 and the regression constants are

a	-	0.426
b	-	0.998
c	-	0
d	-	0
e	-	0.846
f	-	0

Therefore, the appropriate estimation equation is

$$Q = .426(30)^{.998}(90)^{.846}$$
$$= 537 \text{ cfs}$$

The upper and lower standard error limits are 784 cfs and 365 cfs.

For the low flow value, Table 6 gives the appropriate flow designation as Q10MN7-4 and the regression constants are

a - 0.082

b - 1.024

c - 0.235

d - 0

e - 0.452

f - 0

Again, the appropriate estimating equation is

$$Q = 0.082(30)^{1.024}(10)^{.235}(90)^{.452}$$
$$= 35 \text{ cfs}$$

The upper and lower standard error limits are 62 cfs and 20 cfs.

APPENDIX B

ESTIMATION FOR OTHER THAN SPECIFIED RETURN PERIODS

The choice of 1.25, 2, 5, 10 and 20 years as reference recurrence intervals is based on convenience of interpolation and follows a common standard. The 2-year value is the median annual flow and is close to the mean annual flow, depending on the theoretical distribution which best fits a sample distribution. Some common theoretical flow frequency distributions and their predicted mean flow frequencies follow: normal, 2 years; log-normal, 2.51 years; Gumbel, 2.33 years; and log-Pearson Type III, 2.53 years. The log-normal and the log-Pearson Type III values are based on a skew equal to 1.0. Thus, the 2-year flow is approximately equal to the mean flow, although it is somewhat smaller. If a designer believes he or she knows the theoretical distribution parameters well enough to specify the return period of the mean flow, the appropriate value can be interpolated between the 2- and 5-year value.

The flow for a specified return period such as 2.33 can also be easily calculated from the two calculation equations for 2 and 5 years

$$\ln[Q(2.0)] = \overline{x}$$

$$\ln[Q(5.0)] = \overline{x} + 0.84\sigma$$

where $\overline{x}$ and σ are the mean and standard deviation of the flow.

When solved for $\bar{x}$ and σ, the following relationships result.

$$\bar{x} = \ln[Q(2.0)] \qquad \text{(B-1)}$$

$$\sigma = \frac{\ln[Q(5.0)] - \bar{x}}{0.84} \qquad \text{(B-2)}$$

Now for ln[Q(2.33)], the appropriate calculation equation is

$$\ln\,[Q(2.33)] = \bar{x} + 0.18\sigma \qquad \text{(B-3)}$$

and for ln[Q(2.5)]

$$\ln[Q(2.5)] = \bar{x} + 0.25\sigma \qquad \text{(B-4)}$$

Thus, for estimated flow values at 2.0 and 5.0 years, the equations B-1, B-2 and B-3 or B-4 can be solved in sequence.