DETERMINATION OF SEASONAL, FREQUENCY AND DURATIONAL ASPECTS OF STREAMFLOW WITH REGARD TO FISH PASSAGE THROUGH ROADWAY DRAINAGE STRUCTURES

FINAL REPORT

by

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FORWARD

This report has been reviewed in draft form by the following agencies:

State of Alaska Department of Transportation
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Alaska Department of Fish and Game
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The most significant commments by these agencies were incorporated into the final report. Comments that merely gave a difference of opinion or recommended a different way of presenting the information were considered, but may not be reflected in the final text. Copies of comments may be obtained by writing to the project manager below:

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ABSTRACT

Optimal design of culverts for fish passage for each stream crossing requires the magnitude, duration, frequency and seasonal relationship of the flow and the timing of fish movement. Although previous studies have measured fish swimming abilities and culvert water velocity profiles, there are limited studies in northern regions of the hydrologic relationship among magnitude, duration, frequency and season of discharge for the design of culverts for fish passage. We analyzed streamflow records from 33 gaging stations in southcentral, western, interior, and arctic Alaska (from watersheds with a drainage area less than 100 mi^2 each) to determine the highest consecutive mean discharge with one-, three-, seven- and fifteen-day durations, and the lowest consecutive mean discharge with three-, seven-, fourteen- and thirty-day durations. Streamflow during three seasons were analyzed: spring, April 1 to June 30; summer, July 1 to August 31; and fall, September 1 to November 30. The lognormal distribution, using the Blom plotting position formula, was used to estimate flows at recurrence intervals of 1.25, 2, 5, 10 and 20 years. Multiple linear regression equations were developed to predict flows from ungaged watersheds. Significant basin and climatic characteristics for high flows were drainage area, mean annual precipitation and percent of the drainage basin with forest cover. Significant characteristics at low flows were drainage area, mean minimum January temperature, mean annual precipitation and percent of drainage basin covered by forests. This report provides the culvert designer with equations to predict flows, other than the instantaneous peak flow, for use in designing culverts for fish passage. Two example problems are given to show the application of these equations.

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1.0 INTRODUCTION

1.1 Description of Problem

Proper location, design and construction of highway culverts are critical in maintaining fisheries habitat upstream of road crossings. Road locators, designers and construction inspectors must be aware of the impact of culvert placement on fish passage. Four criteria must be considered for effective and practical design of hydraulic structures, primarily culverts, for fish passage. These criteria are: the flow regime of the stream; the hydraulic properties of the culvert (i.e., shape, roughness or length); the swimming abilities of the fish species and age classes present; and the time of year of fish migration in the stream.

Understanding the flow regime is important for determining the relationship among the frequency, duration, season and magnitude of flow. The frequency is important to understanding the risk or probability that a given magnitude of flow will occur. The duration of time for which a given magnitude of flow is exceeded provides the time a fish species might be delayed in its normal migration. The time of year of the flow indicates whether a given magnitude flow will occur during a critical period in the life stage of a fish species. By providing a more detailed representation of the flow regime than the highest annual instantaneous discharge, culverts can be designed for fish passage using the predicted flow during periods of probable fish passage.

Development of arctic oil and gas resources in the United States and Canada has provided an impetus to study the effects of highway culverts on fish passage in northern latitudes (Dryden and Jessop, 1974; MacPhee and Watts, 1976; Katopodis et al., 1978; and Elliott, 1982). These studies focused on the blockage effect of high water velocities in culverts on upstream migration (Dryden and Jessop, 1974; Elliott, 1982), the identification of delay time as an important design criterion (Dryden and Stein, 1975) and the effect of low flows in streams blocking fall out-migration

(Elliott, 1982). Delay of spawnable fishes can cause them to spawn at less suitable spawning sites (affecting spawning success), and can cause stress which may lead to physical damage. The higher stress levels can make them more vulnerable to disease and predation (Dryden and Stein, 1975).

1.2 Objective of Study

The objective of this study was to analyze existing streamflow data from watersheds smaller than 100 mi^2 in south central, western, interior and arctic Alaska and develop methods to predict the magnitude and frequency of high and low flows for specific durations and periods of the year. Using these methods the design flow (for fish passage) can be predicted knowing the critical period of the year and duration of tolerable delay of the design fish for a given stream.

2.0 LITERATURE REVIEW

2.1 Summary of Fish Passage Culvert Design Methods

There are various methods of fish passage culvert design (Kay and Lewis, 1970; Gebhards and Fisher, 1972; Watts, 1974; Dryden and Stein, 1975; Evans, 1977; Katopodis, 1977; Dane, 1978; U.S. Forest Service, 1979; State Pipeline Coordinator Office, 1982). Dane (1978), in an extensive review of the fish passage culvert literature, defines two terms describing the hydrologic limits for fish passage. The first, "critical migration delay," is the maximum time period a fish, or group of fish, can be delayed without causing harm. Harm includes causing fish to spawn at unsuitable sites, stressing the fish so they become more susceptible to disease, and blocking off suitable spawning and rearing habitat. The second term, "critical migration discharge," is the maximum discharge at which fish are able to migrate through the culvert. Ashton (1983) expands this definition to include the maximum discharge for a given culvert location, depending on the age class and species of the slowest swimming fish in the stream. For Alaska, specific age classes and species are considered for design standards (Anon., 1980). A third critical culvert design parameter is the timing of the peak fish migration with-respect-to the timing of the peak discharge. Arctic grayling (*Thymallus arcticus*), for example, migrate during high spring flows, but it is unknown whether they move upstream at the spring instantaneous peak discharge or the rising limb of the hydrograph.

For anadromous fish in California, Kay and Lewis (1970) define the Critical Migration Discharge as, "that discharge which (is) equalled or exceeded 10% of the period October through April." However, they do not address Critical Migration Delay or overlap of peak migration and peak discharge. For Idaho streams, Gebhards and Fisher (1972) recommend a two-day Critical Migration Delay for determining the Critical Migration Discharge. During studies for the development of the Mackenzie pipeline, three field studies quantified fish passage problems (Dryden and Jessop, 1974; Engel, 1974; and Katopodis et al., 1978). A set of design recommendations (Dryden and Stein, 1975) and a method for designing culverts for fish passage (Katopodis, 1977) were developed from these studies.

Dryden and Stein (1975), based on the work of Dryden and Jessop (1974), define the Critical Migration Delay and Critical Migration Discharge.

> It is recommended that a 7-day impassable period should not be exceeded more than once in the design period of 50 years. A 3-day impassable period should not be exceeded during the average annual flood, defined as a flood having a recurrence interval of 2.33 years. The 7-day delay discharge is that discharge being represented on the design flood (generally a 1 in 50-year recurrence interval) hydrograph by a straight line projected between both limbs of the hydrograph and parallel to the time axis for a period of 7 days. The 3-day delay discharge is represented on the average annual flood hydrograph and encompasses a time period of 3 days. For culvert designs to satisfy these criteria, neither the 7-day nor the 3-day delay discharges should exceed the critical fish migration discharge.

Later Dryden and Stein add that "the distance to spawning beds must be considered." The closer the culvert is to the spawning areas the shorter the delay fish can tolerate. They do not, however, say how to determine what the shorter delay period should be. This method assumes the designer has actual streamflow data on the stream for which they are designing.

For culvert design on ungaged watersheds along the Mackenzie Highway, Katopodis (1977) developed regression coefficients for predicting fish passage discharges. Katopodis uses the delay times defined by Dryden and Stein (1975). Katopodis found in practice, for basins smaller than 830 mi^2, that the mean annual flood defines the upper limit of the Critical Migration Discharge.

Two governmental agencies in Alaska, the U.S. Forest Service (USFS) and the State of Alaska Office of the Pipeline Coordinator (SPCO), have developed fish passage culvert design methods. The USFS design guide is primarily for southeast Alaska, an area influenced by a maritime climate, with high fall and spring flows, and low summer flows. The primary design fish in southeast Alaska is the slow swimming (relative to salmon) Dolly Varden (Salvelinus malma). Dolly Varden spawning migrations occur from July through October, and peak in September (Armstrong, 1965). Design requirements for fish passage culverts along the Alaskan Northwest Natural Gas Transportation System (ANNGTS) require fish passage at the mean annual flood (SPCO, 1982). For ungaged basins in the pipeline corridor, flood frequency regression equations are used to predict the mean annual flood (SPCO, 1981).

Low flows are critical to fish movements during spawning migrations and out-migrations (Saltzman and Koski, n.d.; Metsker, 1970; and USFS, 1979). Elliott (1982), in an extensive study of culverts along the trans-Alaska oil pipeline, identified late August and September as a critical low-flow period. In southeast Alaska, the USFS uses a design discharge of the lowest seven-day flow that occurs once in five years (USFS, 1979). The water must be deep enough during low flows to submerge the largest fish using the structure -- 8 to 10 inches for salmon and steelhead (Metsker, 1970).

2.2 Selection of Design Fish and Design Discharge

More than 12 families of fish inhabit Alaskan streams. The period of the year critical for fish passage varies with each species, with geographic location and with year-to-year variations of fish migration in a given stream. Fish swimming abilities vary with species and age class. Therefore, culvert design must accommodate the smallest and slowest swimming fish (Watts, 1974; Tack and Fisher, 1977). The smallest and slowest swimming fish considered for culvert design is called the design fish.

The selection of an appropriate flow frequency, duration and season for a given fish passage site must be made by the culvert designer with due consideration for the engineering criteria and advice from the regional fisheries biologist. Although general guidelines may be promulgated, each site presents its specific problems which must be addressed in order to obtain an efficient design. The prediction equations in this report may be used in a variety of design procedures. We have presented two examples each for high and low flows to aid in understanding the application of these equations. These are:

high flow - one and three day duration with a two-year return period,

low flow - seven day duration with five- and ten-year return periods.

These flows are only examples and do not imply or suggest criteria for a specific site.

3.0 METHODS

Streamflow data used in this report are from continuously recording U.S. Geological Survey gaging stations in the hydrologically similar area (Area II) defined by Lamke (1979). Stations within this region were deleted from further consideration if the basin area was greater than 100 mi^2, 20% or more of the basin area was covered by glaciers, the streamflow was regulated, or there were less than five years of record as of November 1981. Aleutian Island stations, although within Lamke's region definition, were deleted from consideration. Outliers, discharge values which deviate from the general trend, and stations with periods of zero flow are treated as described in Kite (1977). Three periods of the year were selected for streamflow analysis: spring, April 1 to June 30; summer, July 1 to August 31; and fall, September 1 to November 30. For each period, we computed the highest consecutive mean discharge with durations of one, three, seven and fifteen days, and the lowest consecutive mean discharge with a duration of three, seven, fourteen and thirty days.

Predicted discharge values were computed using a Canadian flood frequency program (Condie et al., 1976). Four frequency distributions are available with this program: Gumbel (Extreme Value Type I), lognormal, three-parameter lognormal, and the log-Pearson Type III. Each of the distributions uses the maximum likelihood method of fitting. In the event a true solution is not found by this method, a moment fit is used. Condie et al. revised the program in 1981 to replace the Weibull plotting position formula with a generalized plotting position formula developed by Adamowski (1981).

Two-parameter distributions, such as the Gumbel and lognormal distributions, can provide more sensible results for gaging stations with short periods of record, as is the case for many Alaskan stations, than a three-parameter distribution, such as the three-parameter lognormal and log-Pearson Type III distributions (Flood Studies Report, 1975). For streamflow data analysis, the lognormal distribution was selected because it provides a closer fit of the data than other 2-parameter distributions (Flood Studies Report, 1975). The generalized plotting position formula developed by Adamowski was replaced by the Blom plotting position formula, which was considered the appropriate plotting position formula for the lognormal distribution (Cunnane, 1978).

To predict flows from ungaged basins, multiple linear regression techniques were used to relate physical and climatic characteristics of the gaged basin to its flow estimated using the lognormal distribution. Multiple linear regression equations were developed to predict high flows and low flows with recurrence intervals of 1.25, 2, 5, 10 and 20 years. Recurrence intervals greater than 20 years were not considered because most of the problems associated with fish passage through culverts occur at low recurrence interval flows. Equations were developed for each of the spring, summer and fall periods. The regression equations have the form:

$$Q = a\ A^b\ B^c\ C^d\ D^e \qquad (1)$$

where

Q	= dependent variable, the discharge for a specific duration and return period,
a	= regression constant,
b, c, d and e	= regression coefficients for the independent variables,
A, B, C and D	= independent variables, basin and climatic characteristics.

Regression equations were computed using an Hewlett-Packard 9845 stepwise regression program. Due to limited data, a maximum of three independent variables was considered for each equation. A variable was included in the equation if it explained a significant (5% level) amount of residual variation and increased the R^2 by at least 5%. At each step of the equation-building process, each variable was examined to determine if it could be removed. Variables considered in the regression analyses were: drainage area; mean annual precipitation; percentage of drainage basin covered by forests, glaciers and lakes; main channel slope; stream length; mean basin elevation; mean minimum January temperature; 2-year, 24 hour precipitation intensity; and mean annual snowfall. Basin and climatic characteristics were obtained from Lamke (1979) or the U.S. Geological Survey's basin characteristics file (available through the Anchorage District office).

4.0 RESULTS

4.1 High Flows

Thirty-three gaging stations met the criteria of basin size, percent of drainage area as glaciers, and length of record (Figure 1 and Table 1). The flow data used in the regression analysis are presented in Tables A1 to A6. For high flow, the basin and climatic characteristics found significant are: drainage area, mean annual precipitation, and percent forest cover for spring and summer; and drainage area and mean annual precipitation for fall. High flows are predicted for ungaged basins using equation 2.

$$Q(m, n, q) = a\, A^{b}\, P^{c}\, (F+1)^{e} \qquad (2)$$

where:

Q(m, n, q)	= dependent variable, the highest consecutive mean discharge for the mth period, where s is spring, su is summer, and f is fall, the nth duration where 1 is one day and 3 is three days, ft^3/s, and the qth return period,
a	= regression constant,
b, c,and e	= regression coefficients for the independent variables (basin and climatic characteristics),
A	= drainage area, mi^2,
P	= mean annual precipitation, inches,
F	= percentage of drainage basin covered by forests, expressed as a whole number.

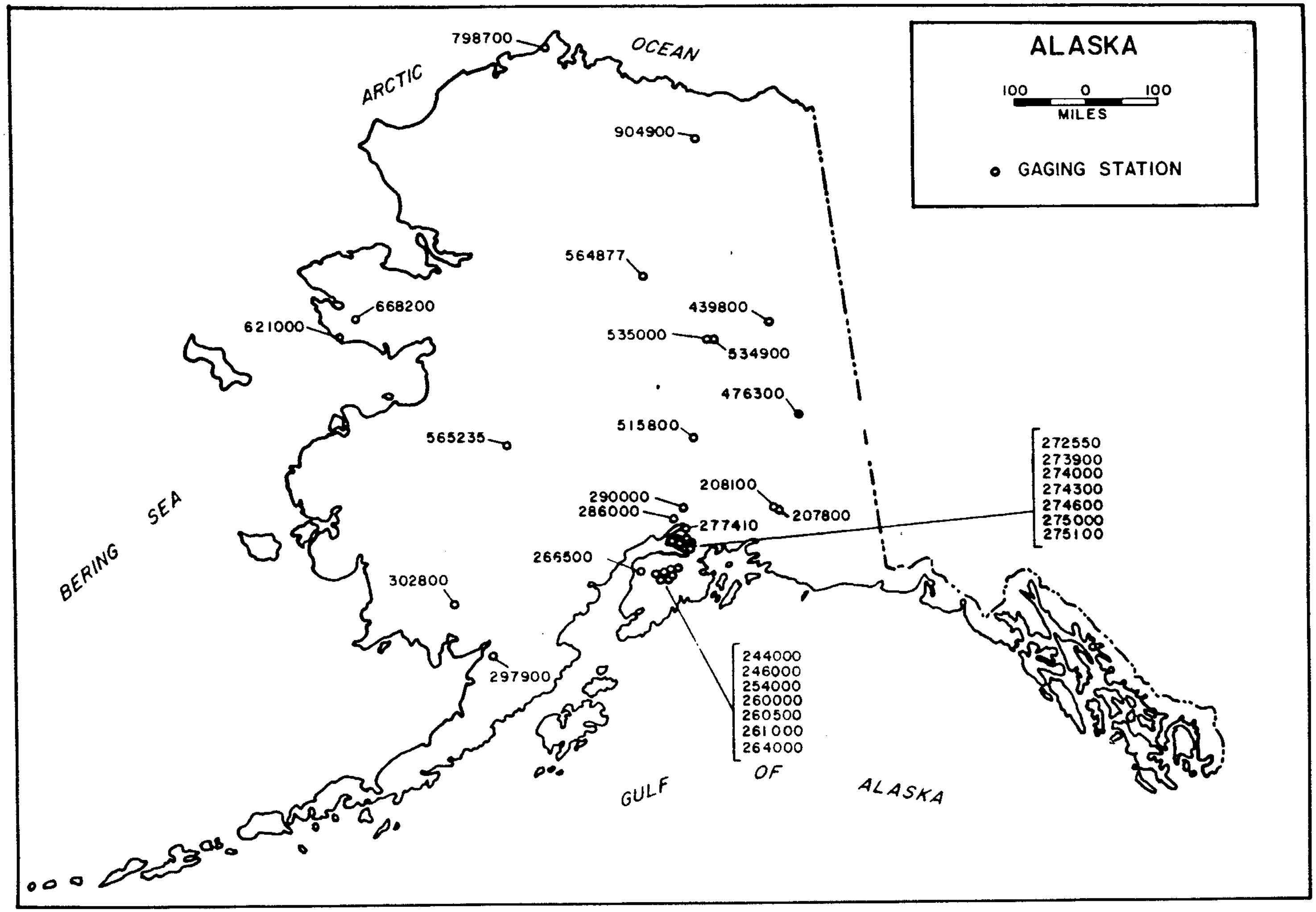

Figure 1. Location map of gaging stations used in this report.

TABLE 1. Basin and climatic characteristics of selected gaging stations.

Station No.	Station Name	Location Latitude (degrees)	Location Longitude (degrees)	Drainage Area (mi^2)	Main Channel Slope (ft/mi)	Stream Length (mi)	Mean Basin Elevation (ft)	Area of lakes and ponds (percent)	Area of forests (percent)	Area of Glacier (percent)	Mean Annual Precipitation (in)	Precipitation Intensity (in)	Mean Annual Snowfall (in)	Mean Minimum January Temperature (°F)
15207800	Little Tonsina River near Tonsina	61.48	145.15	22.7	449	5.7	3,320	1	51	0	17	2.50	50	0
15208100	Squirrel Creek at Tonsina	61.67	145.17	70.5	119	17.9	3,100	4	58	0	11	1.50	49	-10
15244000	Ptarmigan Creek at Lawing	60.41	149.36	32.6	220	14.6	2,800	6	46	12	90	5.00	90	10
15246000	Grant Creek near Moose Pass	60.46	149.35	44.2	150	12.8	2,900	10	20	18	90	5.00	90	10
15254000	Crescent Cr near Cooper Landing	60.50	149.68	31.7	136	14.7	2,700	13	38	0	50	4.00	110	8
15260000	Cooper Creek near Cooper Landing	60.43	149.82	31.8	194	9.9	2,400	16	44	6	60	3.00	110	8
15260500	Stetson Creek near Cooper Landing	60.44	149.85	8.6	459	4.8	3,200	0	47	0	50	3.00	110	8
15261000	Cooper Creek at mouth near Cooper Landing	60.47	149.87	48.0	74.1	13.5	2,500	10	49	4	50	3.00	110	8
15264000	Russian River near Cooper Landing	60.45	149.98	61.8	116	23.5	2,100	4	51	12	70	3.00	180	10
15266500	Beaver Creek near Kenai	60.56	151.12	51.0	4.75	13.5	140	15	67	0	20	1.50	60	6
15272550	Glacier Creek at Girdwood	60.94	149.16	62.0	455	11.0	2,610	0	28	11	80	4.00	160	10
15273900	SF Campell Creek at canyon mouth near Anchorage	61.15	149.72	25.2	255	9.2	2,760	1	8	0	24	1.50	80	6
15274000	SF Campell Creek near Anchorage	61.17	149.77	30.4	246	11.5	2,530	1	26	0	22	1.50	80	6
15274300	NF Campell Creek near Anchorage	61.17	149.76	13.4	389	10.6	2,670	2	30	0	22	1.50	80	6
15274600	Campbell Creek near Spenard	61.14	149.92	69.7	162	19.2	1,680	1	46	0	20	1.50	70	6
15275000	Chester Creek at Anchorage	61.20	149.84	20.0	226	11.4	800	1	61	0	18	1.50	70	6
15275100	Chester Creek at Arctic Blvd at Anchorage	61.21	145.90	27.2	169	12.8	780	1	59	0	17	1.50	70	6
15277410	Peters Creek near Birchwood	61.42	149.49	87.8	133	21.0	3,150	0	23	2	35	1.50	80	6
15286000	Cottonwood Creek near Wasilla	61.57	149.41	28.5	44.0	11.4	500	6	85	0	20	1.50	55	5
15290000	Little Susitna River near Palmer	61.71	149.23	61.9	187	14.9	3,700	0	16	5	50	1.50	50	4
15297900	Eskimo Creek at King Salmon	58.69	156.67	16.1	18.2	7.3	140	5	14	0	20	1.50	40	8
15302800	Grant Lake Outlet near Aleknagik	59.80	158.55	34.3	82.7	9.0	876	12	52	0	40	2.00	80	6
15439800	Boulder Creek near Central	65.57	144.89	31.3	155	12.4	2,570	0	73	0	15	1.20	50	-24
15476300	Berry Creek near Dot Lake	63.69	144.36	65.1	223	19.1	3,200	1	40	5	18	2.00	30	-14
15515800	Seattle Creek near Cantwell	63.33	148.25	36.2	169	10.2	3,400	2	6	0	20	1.50	,300	-6
15534900	Poker Creek near Chatanika	65.16	147.48	23.1	130	9.75	1,710	0	91	0	18	1.25	90	-18
15535000	Caribou Creek near Chatanika	65.15	147.55	9.19	229	3.5	1,640	0	97	0	18	1.20	90	-18
15564877	Wiseman Creek at Wiseman	67.41	150.11	49.2	171	14.0	2,930	0	3	0	18	1.50	75	-17
15565235	Ophir Creek near Takotna	63.15	156.52	6.19	79	6.4	1,070	0	86	0	20	1.50	90	-8
15621000	Snake River near Nome	64.56	165.51	85.7	19.6	19.5	632	0	4	0	30	1.50	70	-6
15668200	Crater Creek near Nome	64.93	164.87	21.9	145	9.2	1,620	1	3	0	40	1.50	100	-7
15798700	Nunavak Creek near Barrow	71.26	156.78	2.79	13.0	2.5	40	22	0	0	4.0	0.50	24	-23
15904900	Antigun River tributary near pump station 4	68.77	149.31	32.6	210	10.2	5,100	0	0	4	20	1.00	35	-16

The regression constants and coefficients, with their associated standard error of estimate, are given in Tables A7 to A9. The regression constants and coefficients for the design examples, with their associated standard error of estimate, are given in Table 2. The reliability of the regression equations are expressed by the standard error of estimate. The standard error may be used to construct an interval in which approximately two-thirds of the values of the predicted characteristic are expected to fall. An equation with a standard error of positive 25 percent and negative 20 percent, for example, would have approximately two-thirds of the flows of the specified duration, and return period, at an ungaged site lie between 125 percent (100 + 25) and 80 percent (100-20) of the predicted value.

Drainage area and percent forest cover are computed from the latest U.S. Geological Survey topographic maps. Basin characteristics are defined as follows:

Drainage area: in square miles, is the total drainage area upstream from the measurement site. The area is measured in a horizontal plane and is enclosed by a drainage divide.

Area of lakes and ponds: in percent, is the percentage of the total drainage area occupied by lakes and ponds.

Area of forests: in percent, is the percentage of the total drainage area shown as forested (usually with a green overprint) on the topographic maps.

Mean annual precipitation: in inches, as determined from an isohyetal map (Figure 2) using the grid-sampling method.

Mean minimum January temperature: in degrees F, as determined from an isothermal map (Figure 3) using grid-sampling method.

TABLE 2. Regression constants and coefficients for predicting high and low flows for selected durations and return periods.

Equation Number	Dependent Variable Q(m,n,q)	Regression Constant a	Regression Coefficients b	c	d	e	Percent Standard Error +	-
			High flows with 2-year return period					
2a	Q(s, 1, 2)	2.712	0.812	0.831	--	-0.396	25	20
2b	Q(s, 3, 2)	2.010	0.822	0.874	--	-0.393	24	19
2c	Q(su, 1, 2)	0.300	0.916	1.233	--	-0.373	21	17
2d	Q(su, 3, 2)	0.234	0.900	1.273	--	-0.359	20	17
2e	Q(f, 1, 2)	0.0744	0.773	1.331	--	--	21	17
2f	Q(f, 3, 2)	0.0632	0.783	1.336	--	--	21	17
			Low flows with 5-year return period					
3a	Q(s, 7, 5)	0.0131	0.487	--	1.366	--	23	19
3b	Q(su, 7, 5)	0.0272	0.729	1.302	--	--	30	23
3c	Q(f, 7, 5)	0.00962	0.594	--	1.528	--	23	19
			Low flows with 10-year return period					
3d	Q(s, 7, 10)	0.0147	0.452	--	1.331	--	23	19
3e	Q(su, 7, 10)	0.0252	0.716	1.292	--	--	32	24
3f	Q(f, 7, 10)	0.0106	0.575	--	1.478	--	23	19

NOTE: When using Equations 2a and 2b for streams in the Anchorage bowl (the area between Rabbit Creek on the south and Peters Creek on the north) multiply result by 0.6 to get the spring 1- and 3-day high flow. When using Equations 2a and 2b for streams in Yukon River drainage multiply result by 1.4 to get the spring 1- and 3-day high flow. When using Equations 3b and 3e for streams in the Anchorage bowl multiply result by 1.4 to get the summer 7-day 5 and 10-year low flows. When using Equations 3b and 3e for streams in Yukon River drainage, multiply result by 0.6 to get the summer 7-day, 5-year and 10-year low flows.

4.2 Low Flows

Basin and climatic characteristics found significant for low flows are: drainage area, mean minimum January temperature, percent forest cover and percent lakes for spring; drainage area and mean annual precipitation for summer; and drainage area and mean minimum January temperature for fall. Low flows are predicted for ungaged basins using equation 3.

$$Q(m, n, q) = a\, A^{b}\, P^{c}\, (T + 30)^{d}\, (F+1)^{e}\, (L + 1)^{f} - 1 \qquad (3)$$

where:

Q(m, n, q)	= dependent variable, the lowest consecutive mean discharge for the mth period, where s is spring, su is summer, and f is fall, the nth duration where 7 is seven days, ft^3/s, and the qth return period,
a	= regression constant,
b, c, d, e and f	= regression coefficients for the independent variables (basin and climatic characteristics),
A	= drainage area, mi^2,
P	= mean annual precipitation, inches,
T	= mean minimum January temperature, °F,
F	= percentage of drainage basin covered by forests, expressed as a whole number,
L	= percentage of drainage basin occupied by lakes and ponds, expressed as a whole number.

The regression constants and coefficients, with their associated standard error of estimate, are given in Tables A10 to A12. The regression constants and coefficients for the design examples with their associated standard error of estimate, are given in Table 2. See above for a discussion of standard error.

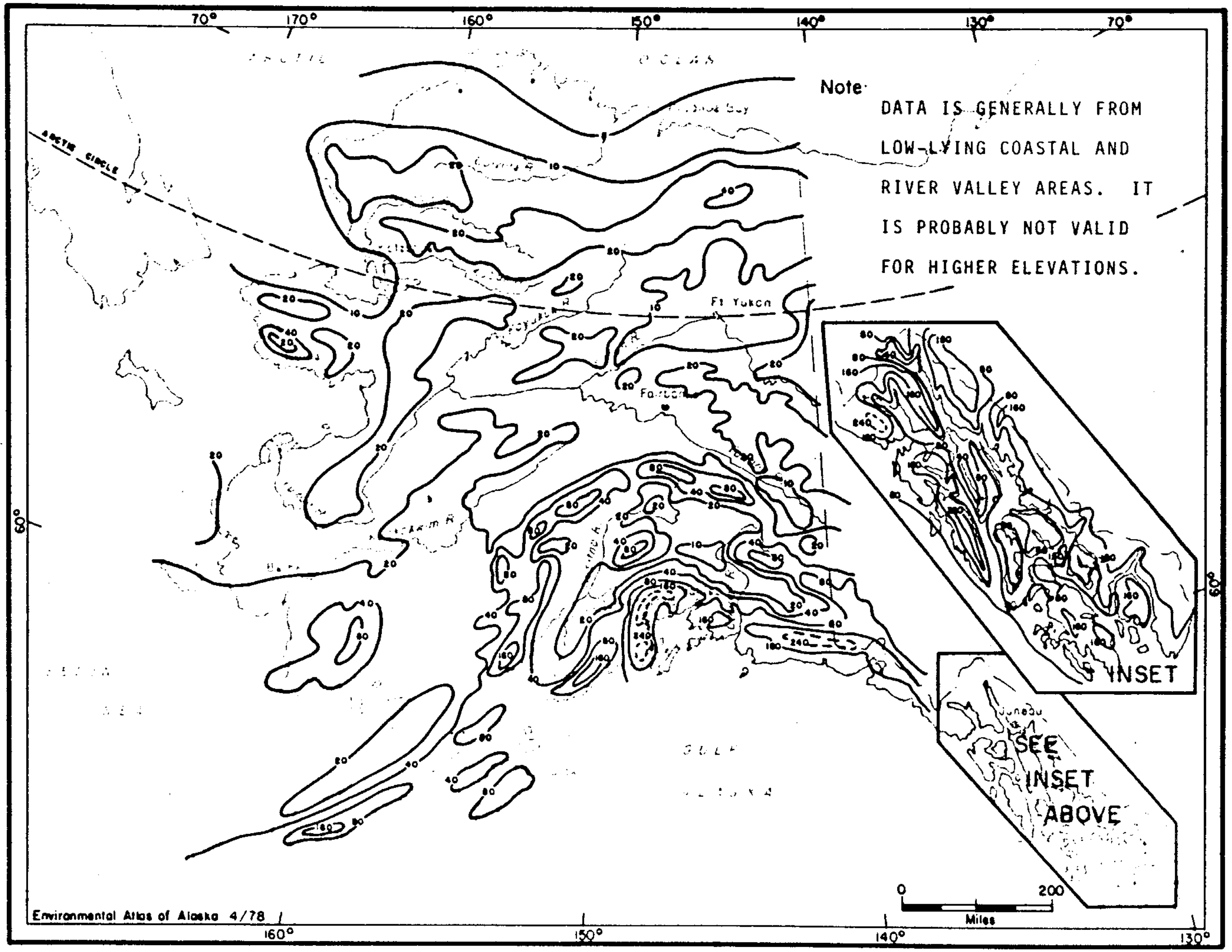

Figure 2. Mean annual precipitation for Alaska (from Hartman and Johnson, 1978).

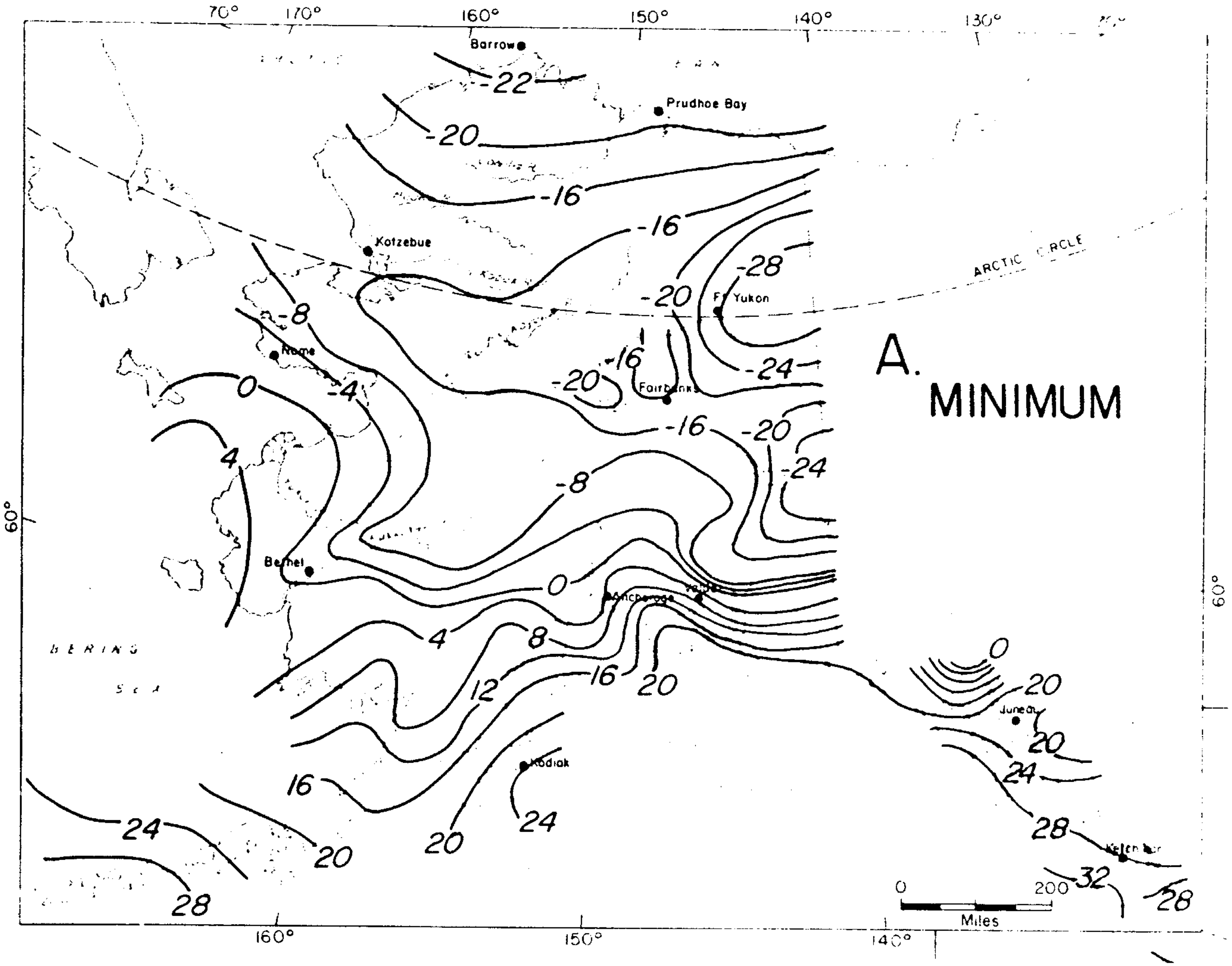

Figure 3. Mean minimum January temperatures for Alaska (from Hartman and Johnson, 1978).

For some combinations of basin and climatic characteristics the low flows are negative; this is considered as a zero flow.

5.0 DISCUSSION

5.1 Prediction of Design Flows

The regionalization of single station data presented in this report provides a method to predict high and low flows for drainage basins smaller than 100 mi^2 in south central, western, interior, and arctic Alaska. This report provides the culvert designer with a means to predict flows for use in designing culverts for fish passage during the spring, summer and fall of the year. The designer can make a reasonable prediction of the design flow (for fish passage) given the season of the year, whether high flow or low flow is of concern, and the duration of interest.

Optimal fish passage culvert design requires for each crossing site a design hydrograph and the relationship between timing of fish migration and flood discharges for the fish passage period(s) (Katopodis, 1977). For most streams, however, no yearly records of discharge are available. Also, the dates of occurrence of fish migrations vary with species, geographic location and year-to-year variation of fish migration for the same stream. An additional complicating factor includes the proximity of the culvert site to spawning grounds. For instance, the length of time a fish may be delayed in its upstream migration is believed to be longer if the spawning grounds are several miles upstream instead of immediately upstream of a highway crossing (Dryden and Stein, 1975). During periods of low flow, outmigrating fish may be trapped upstream of a culvert if the water depth is insufficient for fish passage. Previous fish passage culvert design methods have used the annual instantaneous peak discharge, with different frequencies of occurrence, for the design discharge (Watts, 1974; Katopodis, 1977; SPCO, 1982). Using this report, the designer can predict flows other than the annual instantaneous peak discharge for use in designing culverts for fish passage.

5.2 Design Examples

The following example problems are provided to illustrate the application of equations 2 and 3 (see Table 2). The streams used in these examples are hypothetical with the input data (drainage area, season of interest, mean annual precipitation, etc.) selected to illustrate selected applications of this report. For a description on how to determine the basin characteristics see Section 4.1 High Flows. For each crossing site, the designer must obtain from the regional fisheries biologist information regarding the design fish, whether high flow or low flow is of concern, the critical fish passage period (i.e., spring, summer or fall), and the tolerable delay (i.e., one, three, seven, fifteen or thirty days). For streams in the Anchorage bowl (the area between Rabbit Creek on the south and Peters Creek on the north), these equations tend to overestimate the spring high flows and underestimate the summer low flows. When using Equations 2a and 2b to predict the spring high flows in the Anchorage bowl, multiply the result by 0.6. When using Equations 3b and 3e to predict the summer low flows in the Anchorage bowl, multiply the result by 1.4. For streams in the Yukon River drainage, these equations tend to underestimate the spring high flows and overestimate the summer low flows. When using Equations 2a and 2b to predict the spring high flows in the Yukon River drainage, multiply the result by 1.4. When using Equations 3b and 3e to predict the summer low flows in the Yukon River drainage, multiply the result by 0.6.

Example 1.

For creek X near Coldfoot on the Dalton Highway the regional fisheries biologist has recommended using the 1-day duration, 2-year return period spring high flow and the 7-day duration, 10-year return period fall low flow for the fish passage design flows.

From U.S. Geological Survey maps,

the drainage area is 23.4 mi^2

the percent drainage area as forest is 4%

From Figure 2

the mean annual precipitation is 19 inches

From Figure 3

the mean minimum January temperature is -18°F

For high flows: to compute the spring 1-day duration, 2-year return period flow use equation 2a (see Table 2).

Equation 2a

$$Q(s, 1) = (1.4)\ 2.712A^{0.812}\ P^{0.831}\ (F+1)^{-0.396}$$

$$Q(s, 1) = (1.4)\ 2.712\ (23.4)^{0.812}\ (19)^{0.831}\ (4+1)^{-0.396}$$

$$Q(s, 1) = 300\ ft^3/s$$

For low flows: to compute the fall 7-day, 10-year return period flow use equation 3f (see Table 2).

Equation 3f

$$Q(f, 7) = (0.0106\ A^{0.575}\ (T+30)^{1.478}) - 1$$

$$Q(f, 7) = (0.0106\ (23.4)^{0.575}\ (-18+30)^{1.478}) - 1$$

$$Q(f, 7) = 1.6\ ft^3/s$$

For this stream the fish passage design discharges are 300 ft^3/s for high flows and 1.6 ft^3/s for low flows.

Example 2.

For creek Y near Wasilla on the Parks Highway the regional fisheries biologist has recommended using the 3-day duration, 2-year return period spring and summer high flows and the 7-day duration, 5-year return period summer and fall low flows for the fish passage design flows.

From U.S. Geological Survey maps,

the drainage area is	11.5 mi^2
the percent drainage area as forest is	67%

From Figure 2

the mean annual precipitation is	25 inches

From Figure 3

the mean minimum January temperature is	0°F

For high flows: to compute the spring 3-day duration, 2-year return period flow use equation 2b (see Table 2).

Equation 2b

$$Q(s, 3) = 2.010\ A^{0.822}\ P^{0.874}\ (F+1)^{-0.393}$$

$$Q(s, 3) = 2.010\ (11.5)^{0.822}\ (25)^{0.874}\ (67+1)^{-0.393}$$

$$Q(s, 3) = 48\ ft^3/s$$

To compute the summer 3-day, 2-year return period flow use equation 2d (see Table 2).

Equation 2d

$$Q(su, 3) = 0.234\ A^{0.900}\ P^{1.273}\ (F+1)^{-0.359}$$

$$Q(su, 3) = 0.234\ (11.5)^{0.900}\ (25)^{1.273}\ (67+1)^{-0.359}$$

$$Q(su, 3) = 28\ ft^3/s$$

For low flows: to compute the summer 7-day, 5-year return period flow use equation 3b (see Table 2).

Equation 3b

$$Q(su, 7) = (0.0272\ A^{0.729}\ P^{1.302}) - 1$$

$$Q(su, 7) = (0.0272\ (11.5)^{0.729}\ (25)^{1.302}) - 1$$

$$Q(su, 7) = 9.7\ ft^3/s$$

To compute the fall 7-day, 5-year return period flow use equation 3c (see Table 2).

Equation 3c

$$Q(f, 7) = (0.00962\ A^{0.594}\ (T+30)^{1.528}) - 1$$

$$Q(f, 7) = (0.00962\ (11.5)^{0.594}\ (0+30)^{1.528}) - 1$$

$$Q(f, 7) = 6.4\ ft^3/s$$

For streams with two critical fish passage periods select the highest high flow and the lowest low flow for the fish passage design discharge. For this stream the fish passage design discharges are 48 ft^3/s for high flows and 6.4 ft^3/s for low flows.

6.0 SUMMARY

For the design of culverts for fish passage Watts (1974) recommends use of the probable discharge at the time of fish migration. Since the timing of fish migrations vary with species and geographic location, the method to predict the discharge during periods of fish migration must account for these different periods of migration. We provide example problems showing the application of the equations presented in Tables A7 to A12 for the design of culverts for fish passage. Using this report the designer can predict high and low flows given the season of the year, flow duration and return period of interest.

This regionalization provides reasonable estimates for drainage basins with the following limitations: the basin area should be less than 100 mi^2; the percentage of the basin covered by glaciers should be less than 20%; for some combination of basin characteristics, the predicted one-day spring flows can exceed flows predicted using Lamke's equations; and these equations are not usable for basins in southeastern Alaska, Kodiak Island, the Aleutian Islands and streams draining directly into Prince William Sound. Reliability of the high and low flow prediction equations is less certain in areas of the state with no stations than the areas with relatively numerous stations. In those stationless areas, we recommend culvert designers use field measurements and/or nearby gaging stations to check the predicted values, and adjust the predicted value accordingly. We recommend these equations be recomputed periodically as new data become available.

Practical and efficient design of culverts for fish passage is an interdisciplinary problem including engineering, hydraulic, economic and fishery considerations. Factors important for the design of fish passage culverts, besides the design flows presented herein, include: culvert length; consideration of aufeis; the swimming speeds of the slowest swimming fish species and age class present in the stream; proper placement of the culvert in the stream channel; and most importantly, field changes in the culvert design which include fish passage considerations. Subsequent steps in the design of culverts for fish passage are computing the average velocity in the culvert using the fish passage design discharge and comparing that velocity with an accepted fish swimming velocity. These additional design factors are discussed in numerous publications and reports. Four publications are listed below in order of recommended reading. The culvert designer is highly encouraged to read at least one of them prior to design of culverts for fish passage.

A Review and Resolution of Fish Passage Problems at Culvert Sites in British Columbia by B.G. Dane, 1978. Technical Report No. 810,

126 pp. Habitat Protection Division, Dept. of Fisheries and Environment, Fisheries and Marine Service, Vancouver, B.C. CANADA

Design of Culverts for Fish Passage by C. Katopodis. 1977. In Proceedings of the Third National Hydrotechnical Conference, pp. 949-971. Quebec, CANADA

Design of Culvert Fishways by F.J. Watts, 1974, 62 pp. Water Resources Research Institute, University of Idaho, Moscow, Idaho.

Guidelines for the Protection of the Fish Resources of the Northwest Territories During Highway Construction and Operation by R.L. Dryden and J.N. Stein, 1975. Technical Report No. CEN/T-75-1, 32 pp. Resource Impact Division, Central Region, Dept. of Environment, Fisheries and Marine Service, Winnipeg, Manitoba, CANADA

7.0 IMPLEMENTATION

(Prepared by Alaska Department of Transportation and Public Facilities)

The research represented by this report was contracted to the University of Alaska-Fairbanks (UAF) by the Alaska Department of Transportation and Public Facilities (DOTPF). It was funded by the Federal Highway Administration as part of the Highway Planning and Research program. The work was conducted to form a rational approach to the design of drainage structures for fish passage.

Additional research regarding physical characteristics of culverts, velocity profiles at various flows, and effects of upstream and downstream conditions is underway by separate contract with UAF and a report is due on the work. It will help answer questions about water velocity and other impediments that a fish actually encounters while entering and passing through a culvert. This research may lead to culvert design improvements that enable fish passage without resorting to over-large drainage structures.

DOTPF Statewide Research recommends that the research findings in this report on seasonal, frequency and durational aspects of streamflow be implemented by the Department as follows:

1. Upon publication of this report, culvert designers will use the low prediction methods given herein. Existing methods should also be used to compute flows for comparison purposes. Where substantial differences in design flow result, decisions should be made by the designer on a case-by-case basis considering all information available.

2. After implementation of the fish passage research on drainage structures in 1984, a reasonable time period will be allowed to gain experience with both aspects of improved fish passage design. In 1986 or 1987, the Department will review the implementation experience and evaluate the flow equations contained herein using new data generated during the interim. In the interim, flow prediction equations for southeast Alaska and Kodiak will also be developed, and the Department can work toward establishing final design methods in cooperation with the regulatory agencies.

The Department currently uses the mean annual flood (Q 2.33) to design for fish passage. Hydrologically, this is essentially the same as the 1-day duration, 2-year return period flow that is specified in this report. Based on draft report comments by the Alaska Department of Fish and Game, we will continue to adhere to the mean annual flood criteria as the basic guide for culvert design. Delay priods will only be used on a case by case basis where they are considered appropriate by both the culvert designer and regional fish biologist.

The Department will continue to work toward resolution of fish passage issues by a program of cooperative research and information exchange with Alaska Department of Fish and Game and other interested agencies. Proven concepts will be implemented to the extent feasible.

Our goal is to provide a biologically acceptable level of fish passage at least cost to the public. This can only be accomplished when more is known about fish swimming ability, hydraulics of culverts and the impact of delays during spawning on fish propagation. Because of the flow variability inherent in nature, statistical methods will need to be used for arriving at reasonable solutions.

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9.0 APPENDIX

9.1 General

Regression equations developed for a range of flow durations and return periods, are provided so the culvert designer has the option to use different flow durations and/or return periods. The regional regression equations presented in Tables A7 to A12 provide reasonable estimates for drainage basins with the following limitations: the basin area should be less than 100 mi^2; the percentage of the basin covered by glaciers should be less than 20%; for some combination of basin characteristics, the predicted 1-day spring flows can exceed flows predicted using Lamke's equation; and these equations are not usable for basins in southeastern Alaska, Kodiak Island, the Aleutian Islands and streams draining directly into Prince William Sound. Reliability of the regionalization is less certain in areas of the state with no stations than the areas with relatively numerous stations. In those stationless areas, we recommend culvert designers use field measurements and/or nearby gaging stations to check the predicted values, and adjust the predicted value accordingly. As additional data become available from existing and recently installed stations, we recommend these equations be revised.

9.2 High Flows

The high flow equations presented in Tables A7 to A9 have the same form as Equation 2, are used in the same manner as explained in Section 5.2 Design Examples and are subject to the same limitations.

The regression equation developed for the fall 7-day duration 20-year return period high flow gave fall 7-day, 20-year high flows lower than fall 7-day, 10-year high flows for basins with high percent forest cover. The equation given in Table A9 has a higher standard error but is more reliable for a range of basin characteristics. The original equation has a = 0.292, b = 0.718, c = 1.465, e = 0.295, and a positive standard error = 18 and a negative standard error = 15.

9.3 Low Flows

The low flow equations presented in Tables A10 to A12 have the same form as Equation 3, are used in the same manner as explained in Section 5.2 Design Examples and are subject to the same limitations. For some combinations of basin characteristics, the spring period equations predict higher return period flows to be greater than lower return period flows.

TABLE A1. Spring period (April 1 to June 30) high flow magnitudes, in cubic feet per second, for selected durations and return periods for the gaging stations selected.

FLOW DURATION

STATION NUMBER	1 DAY RETURN PERIOD (YEARS) 1.25	2	5	10	20	3 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20
15207800	85.2	113.0	149.0	173.0	195.0	74.1	103.0	142.0	169.0	194.0
15208100	144.0	226.0	355.0	449.0	546.0	122.0	198.0	321.0	413.0	509.0
15244000	256.0	369.0	530.0	640.0	748.0	242.0	350.0	506.0	613.0	719.0
15246000	477.0	701.0	1030.0	1260.0	1490.0	447.0	661.0	979.0	1200.0	1420.0
15254000	196.0	264.0	356.0	416.0	472.0	192.0	257.0	345.0	403.0	457.0
15260000	203.0	283.0	394.0	469.0	541.0	199.0	278.0	385.0	457.0	528.0
15260500	102.0	127.0	159.0	179.0	197.0	96.3	120.0	149.0	167.0	183.0
15261000	194.0	322.0	536.0	700.0	872.0	181.0	301.0	502.0	655.0	816.0
15264000	255.0	392.0	604.0	757.0	912.0	249.0	380.0	580.0	723.0	868.0
15266500	63.2	122.0	236.0	334.0	443.0	62.1	115.0	213.0	294.0	383.0
15272550	750.0	1010.0	1370.0	1600.0	1820.0	698.0	915.0	1200.0	1380.0	1550.0
15273900	119.0	145.0	178.0	197.0	215.0	109.0	134.0	165.0	185.0	202.0
15274000	99.2	145.0	213.0	261.0	307.0	93.6	134.0	190.0	229.0	267.0
15274300	41.4	50.4	61.4	68.0	74.0	38.8	47.1	57.1	63.2	68.6
15274600	156.0	193.0	239.0	267.0	293.0	147.0	180.0	222.0	247.0	270.0
15275000	19.7	29.3	43.5	53.6	63.5	18.6	26.8	38.6	46.7	54.7
15275100	25.7	37.1	53.6	64.9	76.1	23.0	32.5	45.9	55.1	63.9
15277410	252.0	332.0	439.0	507.0	572.0	240.0	315.0	413.0	476.0	536.0
15286000	16.9	19.7	23.1	25.0	26.8	16.7	19.5	22.9	24.9	26.6
15290000	815.0	1120.0	1530.0	1800.0	2060.0	734.0	1040.0	1470.0	1760.0	2040.0
15297900	23.5	41.3	72.5	97.3	124.0	22.1	38.2	65.9	87.7	111.0
15302800	296.0	436.0	643.0	787.0	931.0	288.0	422.0	618.0	755.0	890.0
15439800	95.6	145.0	221.0	274.0	329.0	81.2	117.0	169.0	204.0	239.0
15476300	238.0	407.0	696.0	920.0	1160.0	191.0	302.0	477.0	605.0	737.0
15515800	259.0	437.0	736.0	967.0	1210.0	244.0	391.0	626.0	802.0	983.0
15534900	46.2	82.5	147.0	200.0	256.0	42.1	73.1	127.0	169.0	215.0
15535000	28.4	41.8	61.4	75.1	88.7	20.5	32.6	51.8	66.0	80.6
15564877	197.0	300.0	457.0	569.0	682.0	187.0	260.0	363.0	432.0	498.0
15565235	15.3	41.3	112.0	188.0	289.0	12.4	29.7	70.8	112.0	162.0
15621000	1560.0	2080.0	2770.0	3220.0	3650.0	1240.0	1720.0	2400.0	2850.0	3280.0
15668200	405.0	583.0	838.0	1010.0	1180.0	351.0	463.0	610.0	706.0	795.0
15798700	15.9	28.4	50.7	68.7	88.2	14.1	24.5	42.4	56.6	71.8
15904900	183.0	267.0	389.0	475.0	559.0	152.0	227.0	337.0	414.0	491.0

FLOW DURATION

STATION NUMBER	7 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20	15 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20
15207800	64.1	92.7	134.0	163.0	191.0	56.8	84.5	126.0	155.0	184.0
15208100	103.0	168.0	274.0	353.0	436.0	85.1	135.0	216.0	275.0	336.0
15244000	225.0	320.0	455.0	546.0	636.0	206.0	280.0	380.0	446.0	509.0
15246000	415.0	596.0	855.0	1030.0	1210.0	384.0	520.0	703.0	823.0	937.0
15254000	182.0	241.0	320.0	370.0	417.0	170.0	220.0	286.0	328.0	366.0
15260000	192.0	262.0	357.0	419.0	479.0	184.0	240.0	313.0	360.0	404.0
15260500	84.4	106.0	133.0	150.0	165.0	73.7	93.5	119.0	134.0	149.0
15261000	161.0	272.0	461.0	607.0	761.0	144.0	248.0	426.0	566.0	715.0
15264000	239.0	351.0	517.0	632.0	746.0	223.0	311.0	433.0	514.0	593.0
15266500	58.2	103.0	183.0	246.0	315.0	52.6	86.2	141.0	183.0	226.0
15272550	623.0	797.0	993.0	1120.0	1240.0	565.0	693.0	849.0	944.0	1030.0
15273900	97.9	120.0	148.0	164.0	180.0	88.4	107.0	130.0	144.0	157.0
15274000	88.5	122.0	168.0	198.0	228.0	81.2	109.0	146.0	170.0	193.0
15274300	35.1	42.2	50.6	55.7	60.3	30.8	37.8	46.5	51.8	56.6
15274600	133.0	162.0	197.0	219.0	238.0	122.0	148.0	180.0	200.0	218.0
15275000	16.8	24.1	34.4	41.5	48.5	15.7	22.1	31.2	37.4	43.4
15275100	20.9	28.7	39.3	46.4	53.1	19.4	26.0	35.0	40.9	46.4
15277410	224.0	286.0	365.0	414.0	460.0	202.0	256.0	326.0	369.0	409.0
15286000	16.4	19.1	22.2	24.0	25.6	16.2	18.8	21.7	23.5	25.0
15290000	629.0	911.0	1320.0	1600.0	1880.0	533.0	766.0	1100.0	1330.0	1560.0
15297900	19.5	33.3	57.0	75.4	95.0	15.8	27.0	46.1	60.9	76.7
15302800	272.0	398.0	582.0	710.0	836.0	259.0	372.0	533.0	643.0	752.0
15439800	67.9	98.1	142.0	172.0	201.0	56.9	82.2	119.0	144.0	169.0
15476300	142.0	218.0	337.0	423.0	510.0	108.0	169.0	264.0	333.0	403.0
15515800	208.0	333.0	533.0	681.0	834.0	164.0	266.0	433.0	558.0	688.0
15534900	36.2	61.2	104.0	136.0	171.0	30.2	47.7	75.3	95.6	116.0
15535000	14.2	24.5	42.3	56.4	71.4	10.6	18.1	30.9	40.8	51.3
15564877	163.0	220.0	298.0	349.0	397.0	136.0	191.0	268.0	320.0	371.0
15565235	11.4	22.4	43.9	62.4	83.4	10.5	17.9	30.8	40.8	51.5
15621000	988.0	1430.0	2070.0	2510.0	2950.0	803.0	1170.0	1700.0	2060.0	2420.0
15668200	287.0	359.0	448.0	503.0	554.0	219.0	282.0	362.0	413.0	460.0
15798700	11.4	19.4	32.8	43.3	54.4	7.9	12.8	20.8	26.8	33.1
15904900	127.0	184.0	267.0	325.0	381.0	103.0	147.0	211.0	255.0	298.0

TABLE A2. Summer period (July 1 to August 31) high flow magnitudes, in cubic feet per second, for selected durations and return periods for the gaging stations selected.

STATION NUMBER	1 DAY, RETURN PERIOD (YEARS) 1.25	2	5	10	20	3 DAYS, RETURN PERIOD (YEARS) 1.25	2	5	10	20
15207800	80.5	108.0	144.0	168.0	191.0	70.1	97.6	136.0	161.0	186.0
15208100	39.4	61.0	94.4	118.0	143.0	35.2	54.1	83.3	104.0	126.0
15244000	326.0	400.0	492.0	548.0	599.0	313.0	380.0	462.0	512.0	556.0
15246000	623.0	759.0	925.0	1030.0	1120.0	594.0	706.0	839.0	918.0	989.0
15254000	153.0	210.0	287.0	338.0	387.0	149.0	202.0	274.0	321.0	366.0
15260000	181.0	259.0	369.0	445.0	519.0	180.0	253.0	356.0	426.0	493.0
15260500	60.6	74.0	90.2	100.0	109.0	58.5	69.9	83.5	91.6	98.9
15261000	114.0	206.0	372.0	506.0	653.0	108.0	198.0	363.0	497.0	645.0
15264000	163.0	246.0	371.0	459.0	548.0	162.0	236.0	344.0	419.0	493.0
15266500	20.1	28.8	41.2	49.6	57.9	18.9	27.2	39.1	47.3	55.3
15272550	770.0	1080.0	1520.0	1810.0	2090.0	737.0	957.0	1240.0	1420.0	1590.0
15273900	111.0	158.0	226.0	273.0	318.0	102.0	142.0	198.0	235.0	271.0
15274000	104.0	139.0	186.0	217.0	246.0	93.3	121.0	157.0	180.0	202.0
15274300	39.8	54.2	73.9	86.9	99.3	38.0	51.1	68.6	80.1	91.0
15274600	149.0	205.0	283.0	335.0	385.0	139.0	189.0	256.0	300.0	342.0
15275000	18.7	27.1	39.4	48.0	56.3	16.6	24.1	34.8	42.2	49.5
15275100	27.6	39.5	56.5	68.1	79.5	24.2	33.4	46.3	54.8	63.0
15277410	312.0	455.0	664.0	809.0	952.0	300.0	430.0	616.0	743.0	867.0
15286000	16.5	26.1	41.4	52.7	64.2	16.2	25.6	40.5	51.4	62.7
15290000	748.0	1210.0	1960.0	2520.0	3110.0	645.0	1020.0	1600.0	2030.0	2470.0
15297900	16.1	23.4	33.9	41.1	48.3	15.3	22.3	32.4	39.4	46.3
15302800	148.0	231.0	360.0	455.0	551.0	152.0	218.0	312.0	376.0	439.0
15439800	28.9	67.1	156.0	242.0	347.0	23.1	51.0	113.0	171.0	240.0
15476300	179.0	230.0	297.0	338.0	378.0	143.0	185.0	240.0	274.0	307.0
15515800	71.1	103.0	148.0	179.0	210.0	61.0	87.5	126.0	152.0	177.0
15534900	19.4	33.5	57.7	76.7	97.1	17.2	26.4	40.5	50.7	61.0
15535000	8.1	16.0	31.7	45.3	60.7	6.5	12.7	24.5	34.6	46.0
15564877	105.0	166.0	264.0	336.0	410.0	79.8	122.0	186.0	232.0	278.0
15565235	6.8	12.1	21.5	29.0	37.2	6.0	10.5	18.3	24.5	31.1
15621000	277.0	573.0	1180.0	1730.0	2360.0	261.0	489.0	916.0	1270.0	1640.0
15668200	258.0	408.0	644.0	818.0	996.0	191.0	290.0	440.0	547.0	655.0
15798700	1.7	3.6	7.8	11.7	16.2	1.5	3.3	7.3	11.0	15.4
15904900	256.0	315.0	388.0	433.0	474.0	217.0	267.0	328.0	365.0	399.0

STATION NUMBER	7 DAYS, RETURN PERIOD (YEARS) 1.25	2	5	10	20	15 DAYS, RETURN PERIOD (YEARS) 1.25	2	5	10	20
15207800	60.5	86.9	125.0	151.0	176.0	54.2	80.8	121.0	149.0	177.0
15208100	30.9	46.3	69.6	86.0	102.0	27.3	39.5	57.2	69.5	81.5
15244000	284.0	349.0	416.0	459.0	498.0	257.0	310.0	374.0	413.0	448.0
15246000	537.0	629.0	737.0	800.0	856.0	489.0	567.0	658.0	712.0	759.0
15254000	142.0	190.0	253.0	294.0	332.0	135.0	176.0	229.0	263.0	292.0
15260000	176.0	242.0	334.0	394.0	453.0	170.0	227.0	303.0	352.0	399.0
15260500	56.0	65.7	77.2	84.0	90.0	51.8	60.4	70.4	76.3	81.5
15261000	101.0	187.0	347.0	479.0	625.0	95.2	176.0	324.0	446.0	581.0
15264000	159.0	219.0	301.0	356.0	409.0	152.0	200.0	263.0	304.0	342.0
15266500	17.7	24.8	34.7	41.4	48.0	16.5	22.5	30.8	36.3	41.6
15272550	684.0	840.0	1030.0	1150.0	1260.0	596.0	725.0	882.0	977.0	1060.0
15273900	89.8	123.0	168.0	198.0	227.0	80.3	109.0	148.0	173.0	199.0
15274000	80.7	103.0	131.0	149.0	166.0	70.6	90.8	117.0	133.0	148.0
15274300	34.8	46.4	61.9	71.9	81.3	32.9	43.7	57.9	67.1	75.8
15274600	126.0	168.0	224.0	260.0	295.0	116.0	153.0	202.0	233.0	262.0
15275000	15.4	21.6	30.1	35.9	41.5	14.4	19.9	27.5	32.5	37.3
15275100	20.8	28.8	40.0	47.5	54.7	18.8	25.9	35.7	42.1	48.4
15277410	281.0	391.0	544.0	647.0	747.0	271.0	369.0	503.0	591.0	676.0
15286000	15.4	23.8	36.8	46.2	55.7	14.2	21.6	32.7	40.7	48.7
15290000	556.0	832.0	1240.0	1540.0	1830.0	480.0	676.0	952.0	1140.0	1320.0
15297900	13.5	19.6	28.4	34.6	40.6	11.7	16.9	24.3	29.4	34.4
15302800	154.0	195.0	246.0	278.0	308.0	138.0	166.0	199.0	219.0	237.0
15439800	17.0	36.5	78.3	117.0	162.0	12.5	26.1	54.7	80.5	111.0
15476300	113.0	142.0	180.0	202.0	224.0	88.7	113.0	144.0	164.0	182.0
15515800	51.0	71.4	100.0	119.0	138.0	43.0	58.8	80.5	94.9	109.0
15534900	14.3	20.9	30.4	36.9	43.4	12.3	18.4	27.6	34.1	40.6
15535000	5.5	10.3	19.1	26.4	34.6	4.6	8.4	15.3	20.9	27.0
15564877	55.6	85.3	131.0	164.0	197.0	37.2	57.9	90.1	114.0	137.0
15565235	5.0	8.4	13.9	18.2	22.7	4.2	7.0	11.7	15.4	19.2
15621000	231.0	401.0	695.0	926.0	1170.0	199.0	324.0	527.0	680.0	840.0
15668200	129.0	209.0	336.0	432.0	531.0	95.0	152.0	244.0	313.0	383.0
15798700	1.3	2.9	6.4	9.7	13.6	1.0	2.1	4.8	7.3	10.4
15904900	185.0	227.0	278.0	309.0	337.0	166.0	194.0	226.0	245.0	263.0

TABLE A3. Fall period (September 1 to November 30) high flow magnitudes, in cubic feet per second, for selected durations and return periods for the gaging stations selected.

STATION NUMBER	FLOW DURATION 1 DAY RETURN PERIOD (YEARS) 1.25	2	5	10	20	3 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20
15207800	39.8	62.6	98.3	124.0	151.0	34.3	53.7	84.0	106.0	129.0
15208100	24.1	30.7	39.0	44.2	49.1	23.0	29.0	36.6	41.3	45.6
15244000	251.0	355.0	503.0	603.0	701.0	236.0	333.0	469.0	562.0	651.0
15246000	431.0	622.0	899.0	1090.0	1280.0	404.0	583.0	842.0	1020.0	1200.0
15254000	109.0	159.0	232.0	283.0	333.0	104.0	151.0	218.0	264.0	310.0
15260000	154.0	209.0	283.0	331.0	377.0	151.0	204.0	276.0	323.0	368.0
15260500	32.2	61.9	119.0	168.0	223.0	31.1	53.7	92.7	123.0	156.0
15261000	43.6	106.0	260.0	415.0	610.0	40.3	98.0	238.0	378.0	555.0
15264000	273.0	474.0	822.0	1100.0	1390.0	264.0	441.0	735.0	960.0	1200.0
15266500	35.8	50.3	70.7	84.5	97.8	34.0	47.8	67.3	80.5	93.2
15272550	581.0	1180.0	2380.0	3440.0	4660.0	486.0	949.0	1850.0	2620.0	3500.0
15273900	66.9	115.0	196.0	260.0	328.0	60.2	96.7	155.0	199.0	244.0
15274000	68.9	104.5	158.0	197.0	236.0	62.8	93.8	140.0	173.0	205.0
15274300	29.6	46.5	73.2	92.7	112.6	26.6	40.9	62.8	78.6	94.6
15274600	118.0	176.0	263.0	324.0	385.0	105.0	154.0	224.0	273.0	321.0
15275000	23.7	34.6	50.5	61.5	72.4	20.7	29.8	43.0	52.0	60.9
15275100	30.9	45.5	67.0	82.0	96.9	25.5	37.0	53.5	64.9	76.2
15277410	206.0	295.0	424.0	512.0	598.0	193.0	266.0	368.0	435.0	500.0
15286000	18.7	25.6	34.9	41.1	47.1	18.5	25.3	34.6	40.7	46.6
15290000	232.0	502.0	1090.0	1620.0	2270.0	209.0	430.0	886.0	1290.0	1760.0
15297900	24.4	34.0	47.5	56.5	65.2	23.4	33.0	46.5	55.6	64.5
15302800	119.0	193.0	314.0	405.0	500.0	118.0	188.0	300.0	383.0	468.0
15439800	8.5	21.8	56.0	91.7	138.0	7.8	19.4	48.1	77.4	114.0
15476300	52.5	75.3	108.0	130.0	152.0	49.8	69.0	95.7	113.0	131.0
15515800	37.0	60.9	100.0	130.0	161.0	34.2	53.7	84.4	107.0	130.0
15534900	16.6	27.6	46.1	60.2	75.0	15.6	24.4	38.2	48.4	58.7
15535000	5.4	10.5	20.3	28.7	38.3	5.1	9.2	16.7	22.8	29.5
15564877	27.5	50.4	92.3	127.0	164.0	25.3	43.8	75.7	101.0	128.0
15565235	4.1	8.9	19.2	28.7	40.1	3.7	7.9	17.0	25.3	35.1
15621000	201.0	435.0	938.0	1400.0	1960.0	186.0	384.0	795.0	1160.0	1590.0
15668200	93.0	212.0	484.0	744.0	1060.0	70.8	161.0	368.0	566.0	807.0
15798700	1.1	2.3	4.7	6.8	9.3	1.0	2.0	3.8	5.3	7.0

STATION NUMBER	FLOW DURATION 7 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20	15 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20
15207800	30.2	45.9	69.7	86.8	104.0	28.3	41.5	61.0	74.5	87.9
15208100	21.8	26.8	33.0	36.8	40.3	21.0	24.9	29.6	32.3	34.8
15244000	203.0	280.0	385.0	455.0	523.0	175.0	234.0	314.0	366.0	414.0
15246000	361.0	495.0	677.0	798.0	914.0	318.0	420.0	556.0	644.0	727.0
15254000	97.6	138.0	195.0	234.0	271.0	89.5	121.0	163.0	190.0	216.0
15260000	140.0	188.0	253.0	295.0	335.0	126.0	166.0	220.0	254.0	286.0
15260500	29.2	45.6	71.4	90.2	109.0	26.1	39.7	60.2	74.9	89.7
15261000	35.7	85.9	206.0	326.0	476.0	32.0	76.5	182.0	287.0	418.0
15264000	242.0	386.0	617.0	789.0	965.0	202.0	300.0	446.0	548.0	650.0
15266500	29.8	42.0	59.2	70.9	82.2	27.7	38.1	52.4	61.9	71.0
15272550	404.0	736.0	1340.0	1830.0	2370.0	338.0	572.0	969.0	1280.0	1600.0
15273900	54.3	82.9	127.0	158.0	190.0	48.7	72.9	109.0	135.0	160.0
15274000	55.2	81.1	119.0	146.0	172.0	49.6	71.8	104.0	126.0	148.0
15274300	23.1	34.4	51.3	63.2	75.0	20.7	31.0	46.3	57.1	67.9
15274600	94.3	134.0	189.0	226.0	263.0	84.1	119.0	168.0	202.0	235.0
15275000	18.6	26.8	38.7	46.9	55.0	17.0	24.6	35.7	43.3	50.9
15275100	22.3	31.3	43.8	52.2	60.3	20.7	28.5	39.4	46.6	53.6
15277410	176.0	224.0	284.0	321.0	356.0	159.0	191.0	230.0	253.0	274.0
15286000	18.0	24.8	34.1	40.3	46.3	17.5	24.2	33.4	39.6	45.6
15290000	187.0	357.0	684.0	961.0	1270.0	162.0	295.0	536.0	733.0	948.0
15297900	21.6	30.1	41.8	49.7	57.3	18.7	26.3	37.0	44.2	51.1
15302800	117.0	174.0	261.0	323.0	384.0	113.0	153.0	209.0	245.0	280.0
15439800	6.8	16.1	38.1	59.7	86.7	5.8	12.8	28.2	42.6	59.9
15476300	47.9	63.4	83.9	97.1	110.0	43.6	57.0	74.4	85.5	96.0
15515800	31.5	47.2	71.0	87.8	105.0	29.0	41.3	58.7	70.5	82.1
15534900	14.7	22.0	32.9	40.6	48.3	13.6	19.7	28.7	34.8	40.9
15535000	4.8	8.1	13.6	17.9	22.3	4.4	6.9	10.9	13.8	16.8
15564877	22.2	36.1	58.6	75.5	93.1	18.5	30.3	49.7	64.3	79.6
15565235	3.3	6.7	13.5	19.4	26.2	3.1	6.0	11.6	16.4	21.7
15621000	170.0	331.0	644.0	912.0	1220.0	155.0	282.0	515.0	705.0	913.0
15668200	56.2	121.0	261.0	389.0	542.0	46.4	98.8	211.0	313.0	433.0
15798700	1.0	1.7	3.0	4.0	5.1	1.0	1.5	2.3	2.9	3.6

TABLE A4. Spring period (April 1 to June 30) low flow magnitudes, in cubic feet per second, for selected durations and return periods for the gaging stations selected.

STATION	FLOW DURATION									
	3 DAYS					7 DAYS				
	RETURN PERIOD (YEARS)					RETURN PERIOD (YEARS)				
NUMBER	1.25	2	5	10	20	1.25	2	5	10	20
15207800	8.7	5.4	3.4	2.6	2.2	8.8	5.5	3.4	2.7	2.2
15208100	14.1	12.0	10.2	9.4	8.8	14.4	12.3	10.4	9.6	9.0
15244000	16.4	13.8	11.6	10.6	9.8	17.9	14.4	11.6	10.3	9.4
15246000	26.2	19.4	14.3	12.2	10.7	26.9	19.7	14.4	12.3	10.7
15254000	24.5	18.5	14.0	12.1	10.7	25.0	18.9	14.3	12.3	10.9
15260000	23.8	16.6	11.5	9.5	8.2	24.0	16.7	11.6	9.6	8.2
15260500	6.1	5.0	4.0	3.6	3.3	6.1	5.2	4.4	4.0	3.7
15261000	24.0	13.8	7.9	5.9	4.6	24.6	13.9	7.8	5.8	4.6
15264000	31.5	26.6	22.4	20.4	19.0	31.8	26.8	22.6	20.7	19.2
15266500	19.3	15.6	12.6	11.3	10.3	19.9	16.1	13.0	11.6	10.6
15272550	39.3	26.7	18.2	14.8	12.6	41.7	27.9	18.7	15.2	12.8
15273900	10.9	9.5	8.3	7.7	7.3	10.9	9.8	8.8	8.4	8.0
15274000	8.7	6.2	4.4	3.7	3.2	8.8	6.3	4.5	3.8	3.3
15274300	5.3	3.8	2.8	2.3	2.0	5.6	4.0	2.8	2.4	2.1
15274600	23.2	16.2	11.3	9.4	8.0	24.6	16.9	11.7	9.6	8.2
15275000	15.3	10.2	6.8	5.5	4.6	16.8	11.2	7.5	6.1	5.1
15275100	16.0	11.9	8.8	7.6	6.6	17.4	12.8	9.5	8.1	7.1
15277410	27.4	24.0	21.1	19.7	18.6	28.0	24.5	21.3	19.9	18.7
15286000	12.7	10.2	8.1	7.2	6.6	13.1	10.6	8.7	7.8	7.1
15290000	20.4	16.3	13.0	11.6	10.5	20.8	16.6	13.2	11.8	10.7
15297900	7.0	6.4	5.8	5.5	5.3	7.3	6.7	6.1	5.9	5.6
15302800	35.0	21.3	13.0	10.0	8.1	35.0	21.3	13.0	10.0	8.1
15439800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15476300	11.7	6.0	3.0	2.1	1.6	12.0	6.1	3.1	2.2	1.6
15515800	10.0	8.6	7.4	6.9	6.4	10.0	8.6	7.4	6.9	6.4
15534900	5.4	2.2	.9	.5	.4	5.7	2.4	1.0	.6	.4
15535000	0.0	0.0	0.0	0.0	0.0	2.1	1.0	.5	.3	.2
15564877	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15565235	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15621000	35.0	17.3	8.5	5.9	4.3	35.1	17.3	8.5	5.9	4.3
15668200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15798700	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15904900	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

STATION	FLOW DURATION									
	14 DAYS					30 DAYS				
	RETURN PERIOD (YEARS)					RETURN PERIOD (YEARS)				
NUMBER	1.25	2	5	10	20	1.25	2	5	10	20
15207800	9.4	5.6	3.4	2.6	2.1	17.3	8.7	4.3	3.0	2.2
15208100	15.2	13.0	11.1	10.2	9.5	20.1	15.9	12.6	11.1	10.1
15244000	20.6	15.9	12.2	10.6	9.5	28.5	20.4	14.6	12.3	10.6
15246000	28.4	20.5	14.8	12.5	10.8	41.0	27.4	18.3	14.9	12.5
15254000	25.6	19.2	14.5	12.5	11.0	32.0	22.5	15.9	13.2	11.4
15260000	24.4	16.9	11.7	9.6	8.2	26.1	18.7	13.4	11.2	9.7
15260500	6.3	5.3	4.5	4.1	3.8	6.5	5.8	5.1	4.8	4.5
15261000	25.7	15.0	8.7	6.5	5.2	30.9	17.9	10.3	7.7	6.1
15264000	33.8	27.9	23.0	20.8	19.2	55.6	38.6	26.8	22.1	18.9
15266500	21.3	17.0	13.6	12.1	10.9	26.0	20.3	15.8	13.9	12.4
15272550	53.9	34.0	21.5	16.9	13.8	88.4	55.8	35.3	27.8	22.8
15273900	11.3	10.4	9.6	9.2	8.9	12.4	11.4	10.4	10.0	9.6
15274000	9.0	6.6	4.9	4.2	3.6	10.6	7.8	5.7	4.9	4.3
15274300	6.2	4.3	3.0	2.5	2.1	7.6	5.5	3.9	3.3	2.9
15274600	28.6	18.8	12.4	9.9	8.3	41.0	26.6	17.3	13.8	11.4
15275000	18.6	12.4	8.3	6.7	5.7	23.8	16.6	11.6	9.6	8.2
15275100	18.0	13.5	10.1	8.7	7.6	19.9	15.9	12.7	11.3	10.3
15277410	28.8	25.1	21.8	20.3	19.1	32.5	27.8	23.8	21.9	20.5
15286000	13.6	11.1	9.1	8.2	7.5	14.6	12.1	10.1	9.2	8.5
15290000	21.7	17.2	13.7	12.1	11.0	25.7	21.2	17.6	15.9	14.6
15297900	7.6	7.0	6.5	6.2	6.0	10.4	8.6	7.1	6.4	5.9
15302800	35.1	21.5	13.1	10.2	8.2	36.4	25.5	17.9	14.9	12.8
15439800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15476300	12.4	6.3	3.3	2.3	1.7	17.2	8.9	4.6	3.3	2.5
15515800	10.1	8.7	7.4	6.9	6.4	10.5	9.2	8.1	7.5	7.1
15534900	6.4	2.7	1.1	.7	.5	7.1	5.0	3.5	2.9	2.5
15535000	2.0	1.1	.6	.4	.3	2.5	1.8	1.3	1.1	.9
15564877	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15565235	0.0	0.0	0.0	0.0	0.0	2.6	.7	.2	.1	0.0
15621000	35.3	17.4	8.6	5.9	4.4	37.9	18.3	8.8	6.0	4.4
15668200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15798700	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15904900	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE A5. Summer period (July 1 to August 31) low flow magnitudes, in cubic feet per second, for selected durations and return periods for the gaging stations selected.

FLOW DURATION

STATION NUMBER	3 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20	7 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20
15207800	36.6	29.6	24.0	21.4	19.6	41.9	33.4	26.6	23.6	21.4
15208100	22.9	19.4	16.4	15.1	14.0	23.9	20.0	16.8	15.3	14.2
15244000	168.0	146.0	127.0	117.0	110.0	184.0	158.0	135.0	125.0	117.0
15246000	334.0	276.0	227.0	206.0	189.0	356.0	301.0	254.0	232.0	216.0
15254000	97.6	77.4	61.5	54.5	49.3	101.0	80.7	64.3	57.1	51.8
15260000	131.0	101.0	77.3	67.3	60.1	140.0	106.0	80.6	69.8	61.9
15260500	32.8	26.1	20.8	18.5	16.8	34.0	27.5	22.3	20.0	18.2
15261000	109.0	58.2	31.0	22.3	17.0	114.0	61.6	33.2	24.0	18.4
15264000	108.0	82.5	62.8	54.4	48.4	117.0	86.8	64.5	55.3	48.6
15266500	17.4	14.3	11.7	10.5	9.7	18.0	14.8	12.2	11.0	10.1
15272550	355.0	266.0	200.0	172.0	152.0	393.0	301.0	230.0	200.0	179.0
15273900	60.8	45.2	33.6	28.8	25.3	64.3	47.2	34.7	29.5	25.8
15274000	49.3	38.9	30.8	27.2	24.6	52.1	41.4	32.8	29.1	26.3
15274300	24.6	17.6	12.7	10.6	9.2	26.2	18.6	13.2	11.0	9.5
15274600	92.4	67.9	49.9	42.5	37.2	97.6	71.7	52.6	44.8	39.2
15275000	21.5	14.9	10.4	8.6	7.3	22.2	15.5	10.8	9.0	7.7
15275100	18.6	14.0	10.5	9.1	8.0	19.5	14.8	11.2	9.7	8.6
15277410	222.0	170.0	130.0	113.0	101.0	237.0	180.0	137.0	119.0	106.0
15286000	20.3	11.9	7.0	5.3	4.2	20.8	12.4	7.3	5.6	4.5
15290000	276.0	208.0	156.0	135.0	119.0	300.0	227.0	171.0	148.0	131.0
15297900	10.0	7.5	5.7	4.9	4.3	10.8	8.0	6.0	5.2	4.5
15302800	75.6	54.5	39.4	33.2	28.8	78.8	56.3	40.2	33.8	29.2
15439800	4.8	2.7	1.5	1.1	.8	5.1	2.9	1.6	1.2	.9
15476300	57.7	47.8	39.5	35.8	33.0	62.8	51.5	42.2	38.1	35.0
15515800	32.7	24.9	19.0	16.5	14.7	34.9	26.5	20.1	17.4	15.4
15534900	11.0	5.7	3.0	2.1	1.6	11.8	6.4	3.5	2.6	2.0
15535000	5.5	3.1	1.7	1.3	1.0	6.0	3.3	1.8	1.3	1.0
15564877	11.7	5.5	2.5	1.7	1.2	12.6	5.9	2.7	1.8	1.3
15565235	5.9	3.1	1.6	1.2	.9	6.1	3.3	1.7	1.3	1.0
15621000	146.0	95.8	62.9	50.5	42.1	154.0	101.0	65.9	52.8	44.0
15668200	88.1	47.6	25.8	18.7	14.3	99.1	51.8	27.1	19.3	14.6
15798700	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15904900	41.2	29.2	20.8	17.4	15.0	51.2	39.3	30.2	26.4	23.5

FLOW DURATION

STATION NUMBER	14 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20	30 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20
15207800	52.3	40.1	30.8	26.8	23.9	64.3	48.4	36.4	31.3	27.7
15208100	25.4	21.1	17.5	15.9	14.7	28.9	23.2	18.7	16.7	15.2
15244000	202.0	173.0	148.0	136.0	127.0	231.0	202.0	177.0	165.0	156.0
15246000	393.0	336.0	287.0	265.0	247.0	453.0	400.0	353.0	330.0	313.0
15254000	110.0	86.0	67.9	59.9	54.0	126.0	97.6	75.6	66.2	59.3
15260000	148.0	112.0	85.2	73.7	65.5	170.0	129.0	97.9	84.7	75.1
15260500	36.4	29.1	23.2	20.6	18.7	42.0	32.6	25.3	22.1	19.8
15261000	127.0	67.1	35.9	25.9	19.8	148.0	78.6	41.8	30.0	22.9
15264000	126.0	92.1	67.3	57.2	50.0	149.0	106.0	75.5	63.3	54.7
15266500	18.8	15.5	12.9	11.7	10.8	19.8	16.4	13.6	12.3	11.4
15272550	493.0	366.0	272.0	233.0	205.0	602.0	446.0	331.0	283.0	248.0
15273900	73.0	52.2	37.2	31.2	27.0	85.0	59.7	41.9	34.8	29.9
15274000	57.1	45.0	35.5	31.4	28.3	69.5	54.6	42.9	37.8	34.1
15274300	29.5	20.7	14.6	12.1	10.4	34.5	24.5	17.3	14.5	12.5
15274600	110.0	79.2	57.2	48.3	42.0	123.0	89.7	65.2	55.2	48.1
15275000	23.0	16.1	11.3	9.4	8.1	24.7	17.4	12.2	10.2	8.7
15275100	21.0	16.1	12.4	10.8	9.6	23.3	17.8	13.6	11.8	10.5
15277410	288.0	213.0	157.0	134.0	117.0	325.0	248.0	190.0	165.0	147.0
15286000	21.7	13.4	8.2	6.4	5.1	23.5	14.8	9.3	7.3	6.0
15290000	356.0	265.0	198.0	169.0	149.0	465.0	339.0	247.0	209.0	182.0
15297900	12.3	8.9	6.5	5.5	4.7	13.8	10.0	7.2	6.1	5.3
15302800	81.3	58.1	41.5	34.8	30.1	97.1	66.3	45.3	37.1	31.5
15439800	6.0	3.4	1.9	1.4	1.1	11.9	5.8	2.9	2.0	1.5
15476300	69.4	58.0	48.5	44.1	40.8	89.1	70.7	56.0	49.6	44.9
15515800	39.9	29.5	21.8	18.7	16.4	46.3	34.2	25.3	21.6	19.0
15534900	13.2	7.9	4.8	3.6	2.9	15.3	11.0	7.9	6.6	5.8
15535000	7.8	4.0	2.1	1.5	1.1	9.0	5.0	2.8	2.1	1.6
15564877	15.0	7.6	3.8	2.7	2.0	25.4	15.2	9.1	7.0	5.6
15565235	6.6	3.5	1.8	1.3	1.0	7.2	3.9	2.1	1.5	1.1
15621000	165.0	109.0	71.7	57.6	48.1	231.0	143.0	87.8	68.2	55.3
15668200	109.0	60.5	33.5	24.6	19.0	131.0	77.7	46.1	35.1	28.0
15798700	.1	0.0	0.0	0.0	0.0	.3	.1	.1	0.0	0.0
15904900	70.5	53.5	40.7	35.2	31.3	101.0	84.9	71.3	65.0	60.3

TABLE A6. Fall period (September 1 to November 30) low flow magnitudes, in cubic feet per second, for selected durations and return periods for the gaging stations selected.

STATION NUMBER	FLOW DURATION 3 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20	7 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20
15207800	14.4	10.5	7.7	6.5	5.7	15.2	10.9	7.9	6.6	5.7
15208100	17.8	14.8	12.2	11.1	10.2	17.9	14.9	12.4	11.2	10.4
15244000	56.8	41.8	30.8	26.2	23.0	59.2	43.1	31.4	26.6	23.2
15246000	83.3	54.6	35.7	28.6	23.9	88.9	57.2	36.8	29.2	24.1
15254000	47.2	37.0	29.0	25.5	23.0	49.0	38.1	29.6	26.0	23.3
15260000	58.1	42.9	31.7	27.0	23.7	60.2	44.1	32.3	27.4	24.0
15260500	8.9	8.4	7.9	7.7	7.5	9.2	8.6	8.1	7.9	7.7
15261000	35.6	20.8	12.2	9.2	7.3	36.1	21.6	12.9	9.8	7.9
15264000	68.8	53.6	41.7	36.6	32.9	72.0	55.9	43.5	38.1	34.2
15266500	17.9	15.4	13.2	12.2	11.4	18.7	15.9	13.6	12.5	11.7
15272550	76.5	52.2	35.6	29.1	24.7	85.0	58.1	39.7	32.5	27.6
15273900	27.6	22.1	17.6	15.6	14.2	29.3	23.7	19.1	17.1	15.5
15274000	26.1	18.1	12.6	10.4	8.9	27.7	19.3	13.4	11.1	9.5
15274300	15.7	9.4	5.6	4.2	3.4	16.0	10.0	6.3	4.9	4.0
15274600	41.2	31.0	23.4	20.1	17.8	43.8	32.8	24.5	21.1	18.6
15275000	17.8	12.3	8.5	7.0	6.0	18.9	13.0	9.0	7.4	6.3
15275100	16.2	11.9	8.7	7.4	6.5	17.2	12.6	9.2	7.8	6.8
15277410	63.5	46.7	34.3	29.2	25.6	68.2	49.6	36.1	30.5	26.6
15286000	17.9	13.2	9.8	8.4	7.4	18.7	13.8	10.2	8.7	7.7
15290000	57.5	44.5	34.5	30.2	27.1	59.5	46.4	36.3	31.9	28.6
15297900	9.0	8.0	7.2	6.7	6.4	9.6	8.3	7.2	6.7	6.3
15302800	70.3	49.3	34.5	28.7	24.6	71.7	50.1	35.0	29.0	24.8
15439800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15476300	15.0	9.4	5.9	4.6	3.7	15.0	9.5	6.0	4.8	3.9
15515800	16.7	12.3	9.1	7.8	6.9	16.7	12.4	9.2	7.9	6.9
15534900	6.7	3.8	2.1	1.6	1.2	6.8	3.9	2.3	1.7	1.3
15535000	3.6	1.7	.8	.6	.4	3.5	1.8	.9	.6	.5
15564877	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15565235	.7	.4	.2	.2	.1	.8	.5	.3	.2	.1
15621000	72.2	51.0	36.1	30.1	25.9	74.1	52.7	37.5	31.4	27.1
15668200	9.0	8.0	7.1	6.7	6.4	9.4	8.6	7.9	7.5	7.2
15798700	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

STATION NUMBER	FLOW DURATION 14 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20	30 DAYS RETURN PERIOD (YEARS) 1.25	2	5	10	20
15207800	17.0	12.0	8.5	7.1	6.1	20.7	14.2	9.8	8.0	6.8
15208100	18.1	15.1	12.6	11.4	10.5	18.9	15.9	13.4	12.2	11.4
15244000	63.4	45.9	33.2	28.0	24.4	94.5	60.9	39.2	31.2	25.8
15246000	103.0	63.9	39.8	31.0	25.3	152.0	86.8	49.4	36.8	28.9
15254000	52.4	40.1	30.7	26.7	23.8	61.9	45.9	34.0	29.1	25.6
15260000	63.8	45.7	32.7	27.5	23.8	78.6	53.4	36.2	29.6	25.0
15260500	10.1	9.5	8.9	8.6	8.4	13.8	12.1	10.6	9.9	9.4
15261000	37.6	23.0	14.0	10.9	8.8	40.6	25.9	16.5	13.0	10.7
15264000	77.0	59.4	45.9	40.1	35.9	91.3	68.5	51.5	44.3	39.2
15266500	19.8	16.9	14.4	13.3	12.4	23.1	20.1	17.4	16.2	15.2
15272550	104.0	70.1	47.5	38.7	32.7	149.0	97.3	63.3	50.6	42.1
15273900	31.5	25.5	20.6	18.5	16.9	35.4	28.6	23.2	20.7	18.9
15274000	29.3	21.4	15.7	13.3	11.7	33.7	25.1	18.6	16.0	14.1
15274300	16.9	10.7	6.8	5.4	4.4	18.8	12.6	8.4	6.8	5.7
15274600	49.3	35.8	26.0	22.0	19.2	60.1	43.1	30.8	25.9	22.4
15275000	20.6	14.0	9.5	7.7	6.5	22.2	15.6	11.0	9.1	7.8
15275100	18.5	13.5	9.8	8.3	7.3	20.3	15.4	11.7	10.1	9.0
15277410	71.3	52.9	39.3	33.6	29.6	79.8	61.5	47.3	41.3	36.9
15286000	19.6	14.9	11.3	9.8	8.7	21.2	16.1	12.2	10.6	9.4
15290000	63.0	49.7	39.1	34.6	31.2	72.6	56.8	44.5	39.1	35.2
15297900	10.3	8.8	7.6	7.0	6.5	11.8	10.2	8.8	8.2	7.7
15302800	74.4	52.1	36.5	30.3	26.0	80.7	58.2	42.0	35.4	30.8
15439800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15476300	14.8	9.8	6.5	5.2	4.4	15.8	11.1	7.8	6.4	5.5
15515800	17.1	12.7	9.5	8.1	7.1	18.4	13.7	10.2	8.8	7.7
15534900	7.0	4.1	2.4	1.8	1.4	8.0	4.8	2.9	2.2	1.8
15535000	3.6	1.9	1.0	.7	.5	4.1	2.3	1.3	1.0	.8
15564877	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15565235	.9	.5	.3	.2	.2	1.4	.7	.4	.3	.2
15621000	78.2	55.7	39.7	33.3	28.8	98.2	68.1	47.2	39.0	33.3
15668200	10.6	9.8	9.0	8.6	8.3	16.1	13.0	10.4	9.3	8.5
15798700	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE A7. Regression constants and coefficients for predicting spring period high flows for selected durations and return periods. The subscripts m, n and q in Q(m,n,q) are: m is the period of the year where s is spring; n is the flow duration in consecutive days, where 1 is one day, 3 is three days, 7 is seven days, and 15 is fifteen days; and q is the return period, 1.25, 2, 5, 10 and 20 years. See note below.

Dependent Variable Q(m,n,q)	Regression Constant a	Regression Coefficients b	c	e	Percent Standard Error +	-
Q(s, 1, 1.25)	1.375	0.855	0.886	-0.412	24	19
Q(s, 1, 2)	2.712	0.812	0.831	-0.396	25	20
Q(s, 1, 5)	5.341	0.768	0.775	-0.380	28	22
Q(s, 1, 10)	7.624	0.745	0.746	-0.372	30	23
Q(s, 1, 20)	10.21	0.727	0.721	-0.365	32	24
Q(s, 3, 1.25)	1.077	0.861	0.923	-0.410	23	19
Q(s, 3, 2)	2.010	0.822	0.874	-0.393	24	19
Q(s, 3, 5)	3.730	0.784	0.824	-0.375	26	21
Q(s, 3, 10)	5.180	0.763	0.798	-0.366	28	22
Q(s, 3, 20)	6.760	0.748	0.776	-0.359	29	22
Q(s, 7, 1.25)	0.794	0.862	0.964	-0.398	22	18
Q(s, 7, 2)	1.435	0.836	0.907	-0.381	23	19
Q(s, 7, 5)	2.580	0.811	0.849	-0.363	25	20
Q(s, 7 10)	3.521	0.797	0.819	-0.354	26	21
Q(s, 7, 20)	4.536	0.786	0.794	-0.347	28	22
Q(s, 15, 1.25)	0.514	0.873	1.010	-0.367	21	17
Q(s, 15, 2)	0.913	0.861	0.947	-0.358	22	18
Q(s, 15, 5)	1.633	0.848	0.881	-0.348	23	19
Q(s, 15, 10)	2.209	0.842	0.847	-0.344	24	19
Q(s, 15, 20)	2.840	0.836	0.819	-0.340	26	21

Note: When using the equations from this table for streams in the Anchorage bowl (the area between Rabbit Creek on the south and Peters Creek on the north), multiply result by 0.6 to get the spring high flows. When using the equations from this table for streams in the Yukon River drainage, multiply result by 1.4 to get the spring high flows.

TABLE A8. Regression constants and coefficients for predicting summer period high flows for selected durations and return periods. The subscripts m, n and q in Q(m,n,q) are: m is the period of the year where su is summer; n is the flow duration in consecutive days, where 1 is one day, 3 is three days, 7 is seven days, and 15 is fifteen days; and q is the return period, 1.25, 2, 5, 10 and 20 years.

Dependent Variable Q(m,n,q)	Regression Constant a	Regression Coefficients b	c	e	Percent Standard Error +	-
Q(su, 1, 1.25)	0.140	0.930	1.329	-0.379	22	18
Q(su, 1, 2)	0.300	0.916	1.233	-0.373	21	17
Q(su, 1, 5)	0.651	0.900	1.135	-0.368	22	18
Q(su, 1, 10)	0.978	0.891	1.085	-0.366	23	19
Q(su, 1, 20)	1.359	0.886	1.042	-0.363	24	19
Q(su, 3, 1.25)	0.105	0.923	1.380	-0.364	22	18
Q(su, 3, 2)	0.234	0.900	1.273	-0.359	20	17
Q(su, 3, 5)	0.525	0.878	1.165	-0.354	20	17
Q(su, 3, 10)	0.797	0.866	1.110	-0.351	21	17
Q(su, 3, 20)	1.124	0.857	1.064	-0.348	22	18
Q(su, 7, 1.25)	0.0761	0.913	1.425	-0.342	22	18
Q(su, 7, 2)	0.177	0.881	1.318	-0.345	20	17
Q(su, 7, 5)	0.408	0.853	1.208	-0.347	20	17
Q(su, 7 10)	0.632	0.836	1.151	-0.348	20	17
Q(su, 7, 20)	0.903	0.824	1.105	-0.349	21	17
Q(su, 15, 1.25)	0.0534	0.913	1.468	-0.319	22	18
Q(su, 15, 2)	0.121	0.879	1.358	-0.314	20	17
Q(su, 15, 5)	0.294	0.837	1.241	-0.314	20	17
Q(su, 15, 10)	0.462	0.816	1.181	-0.313	20	17
Q(su, 15, 20)	0.675	0.799	1.130	-0.313	21	17

TABLE A9. Regression constants and coefficients for predicting fall period high flows for selected durations and return periods. The subscripts m, n and q in Q(m,n,q) are: m is the period of the year where f is fall; n is the flow duration in consecutive days, where 1 is one day, 3 is three days, 7 is seven days, and 15 is fifteen days; and q is the return period, 1.25, 2, 5, 10 and 20 years.

Dependent Variable Q(m,n,q)	Regression Constant a	Regression Coefficients b	c	e	Percent Standard Error +	-
Q(f, 1, 1.25)	0.0392	0.840	1.297	-	22	18
Q(f, 1, 2)	0.0744	0.773	1.331	-	21	17
Q(f, 1, 5)	0.278	0.728	1.460	-0.317	18	15
Q(f, 1, 10)	0.406	0.696	1.487	-0.343	20	17
Q(f, 1, 20)	0.560	0.668	1.509	-0.365	22	18
Q(f, 3, 1.25)	0.0351	0.845	1.301	-	22	18
Q(f, 3, 2)	0.0632	0.783	1.336	-	20	17
Q(f, 3, 5)	0.210	0.744	1.460	-0.293	16	14
Q(f, 3, 10)	0.296	0.715	1.488	-0.316	18	15
Q(f, 3, 20)	0.392	0.692	1.511	-0.335	20	17
Q(f, 7, 1.25)	0.347	0.841	1.278	-	22	18
Q(f, 7, 2)	0.0567	0.794	1.315	-	19	16
Q(f, 7, 5)	0.0946	0.743	1.349	-	20	17
Q(f, 7 10)	0.123	0.718	1.367	-	21	17
Q(f, 7, 20)	0.153	0.698	1.380	-	23	19
Q(f, 15, 1.25)	0.0360	0.833	1.243	-	22	18
Q(f, 15, 2)	0.0556	0.793	1.279	-	20	17
Q(f, 15, 5)	0.0871	0.750	1.314	-	19	16
Q(f, 15, 10)	0.111	0.728	1.331	-	20	17
Q(f, 15, 20)	0.137	0.707	1.342	-	21	17

TABLE A10. Regression constants and coefficients for predicting spring period low flows for selected durations and return periods. The subscripts m, n and q in Q(m,n,q) are: m is the period of the year where s is spring; n is the flow duration in consecutive days, where 3 is three days, 7 is seven days, 14 is fourteen days, and 30 is thirty days; and q is the return period, 1.25, 2, 5, 10 and 20 years.

Dependent Variable Q(m,n,q)	Regression Constant $a \times 10^{-2}$	Regression Coefficients				Percent Standard Error	
		b	d	e	f	+	-
Q(s, 3, 1.25)	1.12	0.617	1.426	-	-	30	23
Q(s, 3, 2)	1.06	0.567	1.414	-	-	25	20
Q(s, 3, 5)	1.21	0.504	1.364	-	-	23	19
Q(s, 3, 10)	1.44	0.528	1.175	-	0.232	20	17
Q(s, 3, 20)	1.71	0.494	1.133	-	0.223	20	17
Q(s, 7, 1.25)	0.986	0.627	1.458	-	-	30	23
Q(s, 7, 2)	1.08	0.558	1.424	-	-	26	21
Q(s, 7, 5)	1.31	0.487	1.366	-	-	23	19
Q(s, 7, 10)	1.47	0.452	1.331	-	-	23	19
Q(s, 7, 20)	1.66	0.422	1.295	-	-	22	18
Q(s, 14, 1.25)	0.880	0.640	1.493	-	-	31	24
Q(s, 14, 2)	1.01	0.565	1.449	-	-	26	21
Q(s, 14, 5)	1.25	0.489	1.388	-	-	23	19
Q(s, 14, 10)	1.44	0.451	1.347	-	-	23	19
Q(s, 14, 20)	1.66	0.422	1.306	-	-	23	19
Q(s, 30, 1.25)	1.33	0.625	1.174	0.333	-	28	22
Q(s, 30, 2)	0.955	0.562	1.298	0.232	-	26	21
Q(s, 30, 5)	1.38	0.493	1.406	-	-	26	21
Q(s, 30, 10)	1.65	0.456	1.352	-	-	25	20
Q(s, 30, 20)	1.88	0.431	1.306	-	-	25	20

TABLE A11. Regression constants and coefficients for predicting summer period low flows for selected durations and return periods. The subscripts m, n and q in Q(m,n,q) are: m is the period of the year where su is summer; n is the flow duration in consecutive days, where 3 is three days, 7 is seven days, 14 is fourteen days, and 30 is thirty days; and q is the return period, 1.25, 2, 5, 10 and 20 years. See note below.

Dependent Variable Q(m,n,q)	Regression Constant $a \times 10^{-2}$	Regression Coefficients		Percent Standard Error	
		b	c	+	-
Q(su, 3, 1.25)	4.51	0.739	1.312	22	18
Q(su, 3, 2)	3.40	0.732	1.306	26	21
Q(su, 3, 5)	2.71	0.719	1.294	30	23
Q(su, 3, 10)	2.51	0.706	1.283	31	24
Q(su, 3, 20)	2.36	0.697	1.274	33	25
Q(su, 7, 1.25)	4.53	0.748	1.320	23	19
Q(su, 7, 2)	3.43	0.740	1.314	26	21
Q(su, 7, 5)	2.72	0.729	1.302	30	23
Q(su, 7, 10)	2.52	0.716	1.292	32	24
Q(su, 7, 20)	2.36	0.707	1.282	33	25
Q(su, 14, 1.25)	4.75	0.764	1.322	24	19
Q(su, 14, 2)	3.57	0.763	1.311	26	21
Q(su, 14, 5)	2.83	0.754	1.295	30	23
Q(su, 14, 10)	2.58	0.746	1.284	31	24
Q(su, 14, 20)	2.41	0.737	1.273	33	25
Q(su, 30, 1.25)	5.90	0.803	1.273	23	19
Q(su, 30, 2)	4.09	0.807	1.280	25	20
Q(su, 30, 5)	3.28	0.791	1.269	29	22
Q(su, 30, 10)	2.82	0.787	1.269	30	23
Q(su, 30, 20)	2.62	0.778	1.260	31	24

Note: When using the equations from this table for streams in the Anchorage bowl (the area between Rabbit Creek on the south and Peters Creek on the north), multiply result by 1.4 to get the summer low flows. When using the equations from this table for streams in the Yukon River drainage, multiply result by 0.6 to get the summer low flows.

TABLE A12. Regression constants and coefficients for predicting fall period low flows for selected durations and return periods. The subscripts m, n and q in Q(m,n,q) are: m is the period of the year where f is fall; n is the flow duration in consecutive days, where 3 is three days, 7 is seven days, 14 is fourteen days, and 30 is thirty days; and q is the return period, 1.25, 2, 5, 10 and 20 years.

Dependent Variable Q(m,n,q)	Regression Constant $a \times 10^{-2}$	Regression Coefficients b	Regression Coefficients d	Percent Standard Error +	Percent Standard Error -
Q(f, 3, 1.25)	0.810	0.662	1.660	28	22
Q(f, 3, 2)	0.853	0.635	1.589	25	20
Q(f, 3, 5)	0.966	0.600	1.509	24	19
Q(f, 3, 10)	1.11	0.572	1.456	23	19
Q(f, 3, 20)	1.19	0.556	1.420	23	19
Q(f, 7, 1.25)	0.748	0.661	1.696	27	21
Q(f, 7, 2)	0.820	0.632	1.616	25	20
Q(f, 7, 5)	0.962	0.594	1.528	23	19
Q(f, 7, 10)	1.06	0.575	1.478	23	19
Q(f, 7, 20)	1.18	0.557	1.433	23	19
Q(f, 14, 1.25)	0.675	0.657	1.749	28	22
Q(f, 14, 2)	0.747	0.634	1.660	25	20
Q(f, 14, 5)	0.889	0.599	1.565	24	19
Q(f, 14, 10)	0.987	0.580	1.513	23	19
Q(f, 14, 20)	1.10	0.559	1.469	23	19
Q(f, 30, 1.25)	0.582	0.642	1.855	29	22
Q(f, 30, 2)	0.647	0.633	1.747	26	21
Q(f, 30, 5)	0.781	0.608	1.633	24	19
Q(f, 30, 10)	0.886	0.590	1.572	23	19
Q(f, 30, 20)	0.992	0.577	1.518	23	19

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