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ASHTON, WILLIAM S.

DETERMINATION OF FISH PASSAGE DISCHARGE FOR DESIGN OF
HYDRAULIC STRUCTURES ON LITTLE TONSINA RIVER, ALASKA

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DETERMINATION OF FISH PASSAGE DISCHARGE FOR
DESIGN OF HYDRAULIC STRUCTURES ON
LITTLE TONSINA RIVER, ALASKA

A

THESIS

Presented to the Faculty of the University of Alaska

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

By

William S. Ashton B.S.

Fairbanks, Alaska

May 1983

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DETERMINATION OF FISH PASSAGE DISCHARGE FOR

DESIGN OF HYDRAULIC STRUCTURES ON

LITTLE TONSINA RIVER, ALASKA

RECOMMENDED:

Chairman, Advisory Committee

Department Head

APPROVED:

for Vice Chancellor for Research and Advanced Study

Date May 6, 1983

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ABSTRACT

The flow regime of the Little Tonsina River, Alaska, was analyzed to determine the peak and low flows during periods of fish migration. Seven methods of predicting the Critical Migration Discharge for use in designing hydraulic structures for fish passage were evaluated. These methods were evaluated to determine which method provided the most accurate prediction of streamflow during periods of fish migration. Three periods of analysis were considered: spring, April 1 to June 30; summer, July 1 to August 31; and fall, September 1 to October 31. For the Little Tonsina River the spring period 12-hour duration discharge with a 2-year return period and the fall period 7-day, 5-year return period low-flow were considered critical for the design of culverts for fish passage. The Critical Migration Discharge determined using floods predicted by regional regression equations overestimated the spring and fall design discharges by 51% and 8%, respectively.

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GLOSSARY

Actual discharge- refers to the streamflow of the Little Tonsina River recorded by the U.S. Geological Survey.

Breakup- high flows during the spring when river ice is broken up and carried downstream.

Critical Migration Delay- the maximum time period a fish, or group of fish, can be delayed without causing harm.

Critical Migration Discharge- the maximum discharge at which fish are able to migrate through a culvert.

Design fish- the slowest swimming fish species and/or age class of fish within a stream.

Mean annual flood- the arithmetic mean of all the annual maximum discharges. It is approximately equal to the 2-year return period flood read from the lognormal frequency curve of annual peak flows.

1-day flood- the highest mean daily discharge within a specified period with a 2-year return period.

Predicted discharge- refers to flood values determined from regional regression equations using basin and climatic characteristics of the Little Tonsina River.

Q_B- the discharge on the rainfall event hydrograph where a line extended from the recession existing prior to the rainfall event intersects at a point under the peak of the hydrograph, see Fig. 6.

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Q_I- the instantaneous peak discharge, see Fig. 6 and 7.

Q_2- the discharge represented on a rainfall or snowmelt event hydrograph with a duration of 2 hours, see Fig. 6 and 7.

Q_6- the discharge represented on a rainfall or snowmelt event hydrograph with a duration of 6 hours, see Fig. 6 and 7.

Q_{12}- the discharge represented on a rainfall or snowmelt event hydrograph with a duration of 12 hours, see Fig. 6 and 7.

Q_{24}- the discharge represented on a rainfall event hydrograph with a duration of 24 hours, see Fig. 6.

Q_{48}- the discharge represented on a rainfall event hydrograph with a duration of 48 hours, see Fig. 6.

7-day low-flow- the mean of the lowest seven consecutive mean daily discharges within a specified period.

3-day delay discharge- the discharge represented on a rainfall event hydrograph with a duration of 3 days, with a 2-year return period. For a more detailed definition see quote from Dryden and Stein (1975) on page 7.

3-day flood- the mean of the highest three consecutive mean daily discharges within a specified period with a 2-year return period.

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ACKNOWLEDGEMENTS

I wish to express my appreciation to my major professor, Dr. R.F. Carlson, and my committee members, Prof. J. Burdick and Dr. J.D. LaPerriere for their helpful suggestions throughout the preparation of my thesis.

Appreciation and recognition is expressed to the U.S. Geological Survey and the Alaska Department of Fish and Game for furnishing the field data. My sincere appreciation to the people who reviewed my earlier drafts and gave helpful suggestions, and to Ginnie Ferrell for drafting the figures and for preparing slides for my thesis defense.

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CHAPTER 1 INTRODUCTION

1.1 Description of Problem

Four criteria must be considered for effective and practical design of hydraulic structures, primarily highway 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. This three-dimensional representation provides a more detailed description of the flow regime than the peak annual discharge.

Development of arctic oil and gas resources in the United States and Canada provided an impetus to study the effects of highway culverts on fish passage (Dryden and Jessop, 1974; MacPhee and

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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 culverts blocking fall out-migration (Elliott, 1982). Delay of spawnable fish 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

The objective of this study was to compare representative fish passage culvert design methods to determine which method provides the most accurate estimate of the discharge during periods of fish migration.

1.3 Method of Approach

I selected seven methods of estimating the fish passage discharge for comparison. To determine the ability of each method to estimate the fish passage discharge they were compared using the recorded flood values from a selected stream and flood values predicted by regional regression equations. To provide enough data

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for a useful comparison, the selected stream should have a minimum of 5 years of continuously recorded U.S. Geological Survey (USGS) streamflow records, have an available report of fisheries information, be in interior Alaska and be of a size requiring a culvert for any highway crossing. The Little Tonsina River was selected after examining available USGS streamflow records and Alaska Department of Fish and Game (ADF&G) fisheries surveys (Fig. 1). Actual streamflow values used in the comparison of selected methods were from USGS water stage charts and published mean daily flow values. Predicted values were from regional regression equations. Equations from Lamke (1979) were used for predicting the mean annual flood and the 10-year flood. Equations from Ashton and Carlson (1983) were used for predicting the 1 and 3-day spring, summer and fall period floods with a 2-year return period. Abundance, location and movement data on the fisheries of the Little Tonsina River were from ADF&G reports. For fisheries data not available in the ADF&G report, literature values were used.

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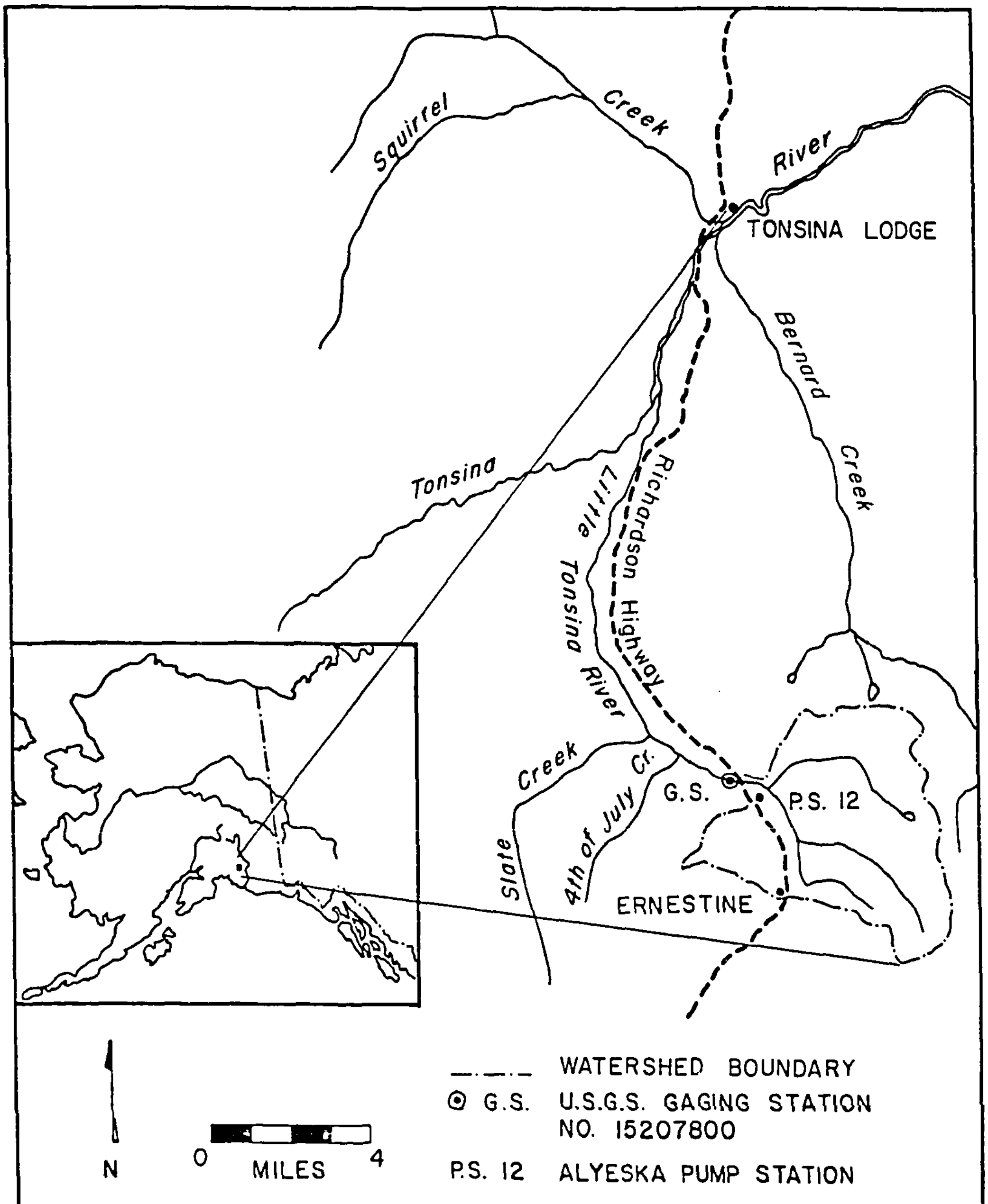

Fig. 1. Little Tonsina River, Alaska. Gage location was lat. 61° 28' 49", long. 145° 09' 05", in the NW 1/4 sec. 36, T. 4S., R. 1E., on the right bank 50 ft dowstream from Richardson Highway crossing, and 15.4 mi south of Tonsina.

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CHAPTER 2 LITERATURE REVIEW

2.1 Fish Passage Culvert Design Methods

Culverts are typically placed on ungaged watersheds with drainage areas less than 50 mi^2. Flood prediction methods used in the design of culverts include:

1. empirical formulas such as the rational method,
2. unit hydrograph techniques,
3. computer models such as HEC-1,
4. use of existing streamflow data.

Fleming and Franz (1971) present a thorough review of these methods. Culverts are designed to pass the instantaneous maximum discharge for a specified return period, where the selected return period depends on the design life of the structure. The design return period varies from 10 years for minor culvert structures (U.S. Forest Service, 1979) to 50 years for two lane highways (Anon., n.d.).

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

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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. I propose that this definition be expanded 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. The slowest swimming fish in a given stream is termed the "design fish" (Watts, 1974). 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 spring breakup (high flows due to river ice breaking up). For years with small summer rainfall events, the peak annual discharge occurs during spring breakup.

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 Oregon streams, Gebhards

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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 they add that "the distance to spawning beds must be considered." The closer to the spawning site the smaller 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, but this is unlikely.

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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

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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 7-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 Design Fish

Arctic grayling are the primary design fish in interior Alaska (SPCO, 1982) and migrate during spring breakup. Two studies of Arctic grayling on Poplar Grove Creek, a bog-fed stream near Glenallen, Alaska, measured grayling swimming speeds through culverts and fish ladders (MacPhee and Watts, 1976; Tack and Fisher, 1977). These studies provide data on the time of year and time of day when grayling migrate upstream and downstream, the time interval juveniles and yearlings lag behind adults in their upstream migration, and the timing of the peak breakup discharge as it relates to peak migration.

Tack (1980), in a summary of Arctic grayling migration patterns, identifies the water source of a stream as an important factor in determining how grayling use a stream. Tack generally describes four basic stream types and their uses by grayling. Glacier-fed streams are used for overwintering or as migratory routes to other

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streams. Spring-fed systems are used for feeding streams, but not for spawning or overwintering. Bog-fed streams are primarily used for spawning and feeding, but not overwintering. And rapid runoff streams are used for spawning and feeding, and lower reaches of the stream are used for overwintering. Migrations among these stream systems is complex; for further discussion see Tack (1980) and Armstrong (1982).

During three of the combined four years of study on Poplar Grove Creek, the spring breakup discharge peak preceeded the adult grayling migration peak by six days or more. The maximum is nine days. In all four years, the peak juvenile migration is within four days of the peak adult migration. In two of four years, the peak yearling migration is within four days of the peak adult migration. The lag is 10 and 13 days in the other two years. The spawning run lasts approximately 10 days (MacPhee and Watts, 1976).

2.3 Design Methods Selected For Comparison

Methods to determine the design discharge for fish passage are classified into four groups: using a percentage of the floods at a selected return period; use the mean annual flood; designing for low flows; and, selecting a discharge with a duration of 1 to 7 days, depending on the return period. Annual peaks and annual low-flows are used in the following design methods unless specified

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otherwise. For ungaged watersheds, Dane (1978) recommends using a Critical Migration Discharge of 30% of the mean annual flood. Watts (1974) recommends 60% of the 10-year return period flood for adults and 20% of the 10-year return period flood for juveniles. Dryden and Stein recommend the 3-day delay discharge at the mean annual flood and the 7-day delay discharge at the 50-year return period flood. Ashton and Carlson (1983) provide a method for predicting high flows with durations of 1, 3, 7, and 15 days for three periods of the year. The periods are defined as: spring, April 1 to June 30; summer, July 1 to August 31; and fall, September 1 to November 30. Of the methods reviewed, seven (Gebhards and Fisher, 1972; Watts, 1974; Dryden and Stein, 1975; Katopodis, 1977; Dane,1978; USFS, 1979; and Ashton and Carlson, 1983) provide a means to predict the fish passage discharge (Table 1).

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TABLE 1. Summary of Critical Migration Discharge prediction methods.

Author	Critical Migration Discharge
Gebhards and Fisher, 1972	Use the annual peak flow that will not cause a delay longer than 48 hours.
Watts, 1974	60% of 10-year return period flood for adult fish and 20% of 10-year return period flood for juvenile fish.
Dryden and Stein, 1975	Use the 3-day delay discharge at the mean annual flood and 7-day delay discharge at the 50 year return period flood.
Katopodis, 1977	Use the mean annual flood.
Dane, 1978	Use 30% of mean annual flood.
U.S. Forest Service, 1979	Use the 7-day low-flow with a 5-year return period.
Ashton and Carlson, 1983	Do not recommend what duration period to use, but do provide a method for predicting high flows with durations of 1, 3, 7 and 15 days for three periods of the year.

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CHAPTER 3 STUDY AREA

3.1 Hydrology

The Little Tonsina River is a tributary to the Tonsina River, within the Copper River basin (hydrologic unit number 19050003). The climate is predominately interior with occasional maritime influences. Snowmelt dominates the input to runoff processes with rain causing peak discharges during the summer and fall. Groundwater inflow provides fall and winter base flows. Snowmelt and river ice breakup occur between late April and late June. Water levels rise rapidly during this period as a function of snowmelt. The rate of snowmelt is affected by the ambient air temperature, solar radiation, percent cloud cover, and rain-on-snow events (Gray and Male, 1981). Snowmelt at higher elevations, inflow from groundwater and lake storage provide the baseflow from late June to late August. The magnitude of the baseflow depends on the preceeding winter's snowfall and the factors affecting snowmelt. Peak runoff from early September to late October is due to rainfall events with slight, if any, influence by snowmelt. Baseflow during the fall is from lake storage, groundwater inflow and residual snowmelt. The river typically freezes over in late October or early November. The river is frozen over from November to mid-April to late April. Flows during this period are probably from groundwater inflow.

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3.2 Fisheries

Prior to and during construction of the trans-Alaskan oil pipeline (1974-1976), ADF&G studied the fishery resources of the Little Tonsina River and its tributaries from the confluence with the Tonsina River to Pump Station 12. Fisheries data, like hydrologic data, tend to be very site specific. Wherever possible, fisheries data are used from the study of the Little Tonsina River. Values from the literature are used when no field data are available. The Little Tonsina River supports seasonally or year-round populations of coho salmon (Oncorhynchus kisutch), king salmon (Oncorhynchus tshawytscha), Dolly Varden (Salvelinus malma), Arctic grayling (Thymallus arcticus), round whitefish (Prosopium cylindraceum), and sculpin (family Cottidae) (Anon., 1977).

Coho appear to spawn from September 1 to November 7 (Anon., 1977). The most upstream coho spawning site is just below the gaging station (Fig. 2). Juvenile coho have been observed upstream of the gaging station (Anon., 1977). The specific timing and nature of the coho spawning run on the Little Tonsina River have not been described. Most of juvenile coho out-migrate as age 0 and age I fish (Anon., 1977). King salmon spawning areas (Fig. 2) and areas of observed movements are approximately 3 mi downstream of the stream gage, and so are outside of the study area.

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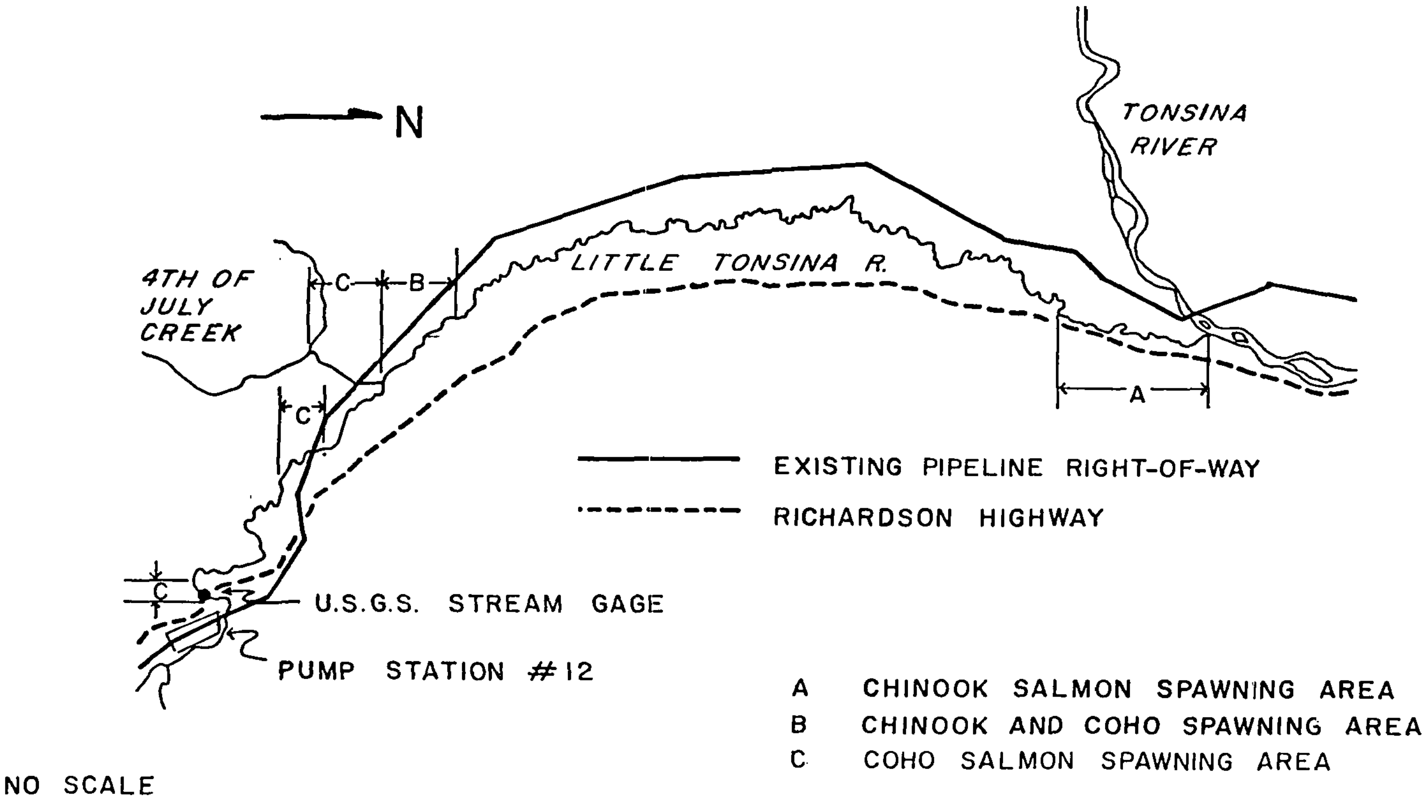

Fig. 2. Spawning areas within the Little Tonsina basin. Location shown of the trans-Alaska oil pipeline and Alyeska Pump Station 12 (After Anon., 1977).

Dolly Varden are present throughout the Little Tonsina River from May to November and spawn "sometime in the fall" (Anon., 1977). According to Morrow (1980), spawning takes place from late August to the end of November, with most activity during September and October. Spawning areas are not defined, however, ADF&G observed Dolly Varden spawn in the same general area as coho (Anon., 1977).

Arctic grayling were observed upstream of the gage, where there is suitable habitat, but no spawning was observed (Anon., 1977). The spawning migration of Arctic grayling occurs during spring breakup and is related to the rise in water temperature to 1°C in rapid runoff rivers. Spawning is associated with a water temperature of 4°C (Armstrong, 1982).

3.3 Basin Characteristics

The geology of the Little Tonsina watershed is primarily Valdez schist with some metavolcanics and metagreywacke. The watershed is near the southern limit of permafrost. The extent of permafrost in this area is affected by minor differences in aspect and vegetation (Kreig and Reger, 1983). Table 2 lists basin and climatic characteristics of the Little Tonsina River. The hydraulic geometry of a stream channel is a measure of the stream width, mean depth and mean velocity at different discharges. Figures 3 to 5 show the channel hydraulic geometry 80 feet downstream from the

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TABLE 2. Basin and climatic characteristics for the Little Tonsina River, Alaska.

Basin Characteristics[a]		Climate Characteristics[b]	
Drainage Area	22.7 mi^2	Mean Annual Temperature	27°F
Area of Forest	51%	Mean Minimum January Temp.	0°F
Area of Glaciers	1%	Mean Annual Precipitation	17 in
Area of Lakes	1%	Precipitation Intensity[c] 24 hour 2 year rainfall	2.5 in
Main-Channel Slope	449 ft/mi	Mean Annual Snowfall	50 in
Stream Length	5.7 mi		
Mean Basin Elevation	3,320 ft		

a. Characteristics, unless otherwise noted, are from USGS Quadrangles Valdez B-3, B-4, C-3, C-4 using methods described in National Handbook of Recommended Methods for Water-Data Acquisition, Chapter 7 (USGS, 1978b).
b. Values, unless otherwise noted, are from Hartman and Johnson (1978).
c. From U.S. Weather Bureau Technical Paper 47.

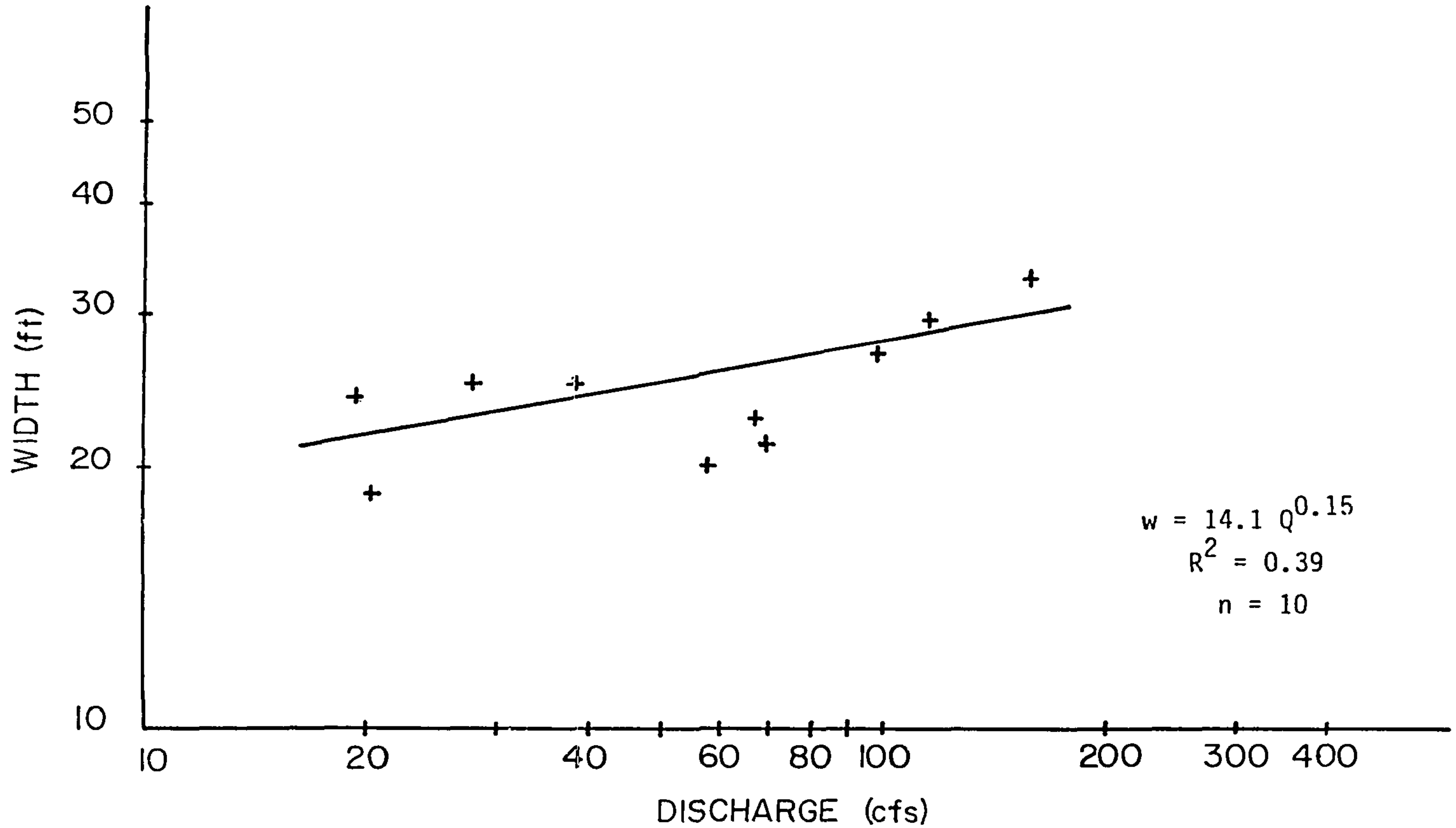

Fig. 3. Discharge vs width. Hydraulic geometry of the Little Tonsina River at 80 ft downstream from the Richardson Highway crossing. Q = discharge and w = channel width.

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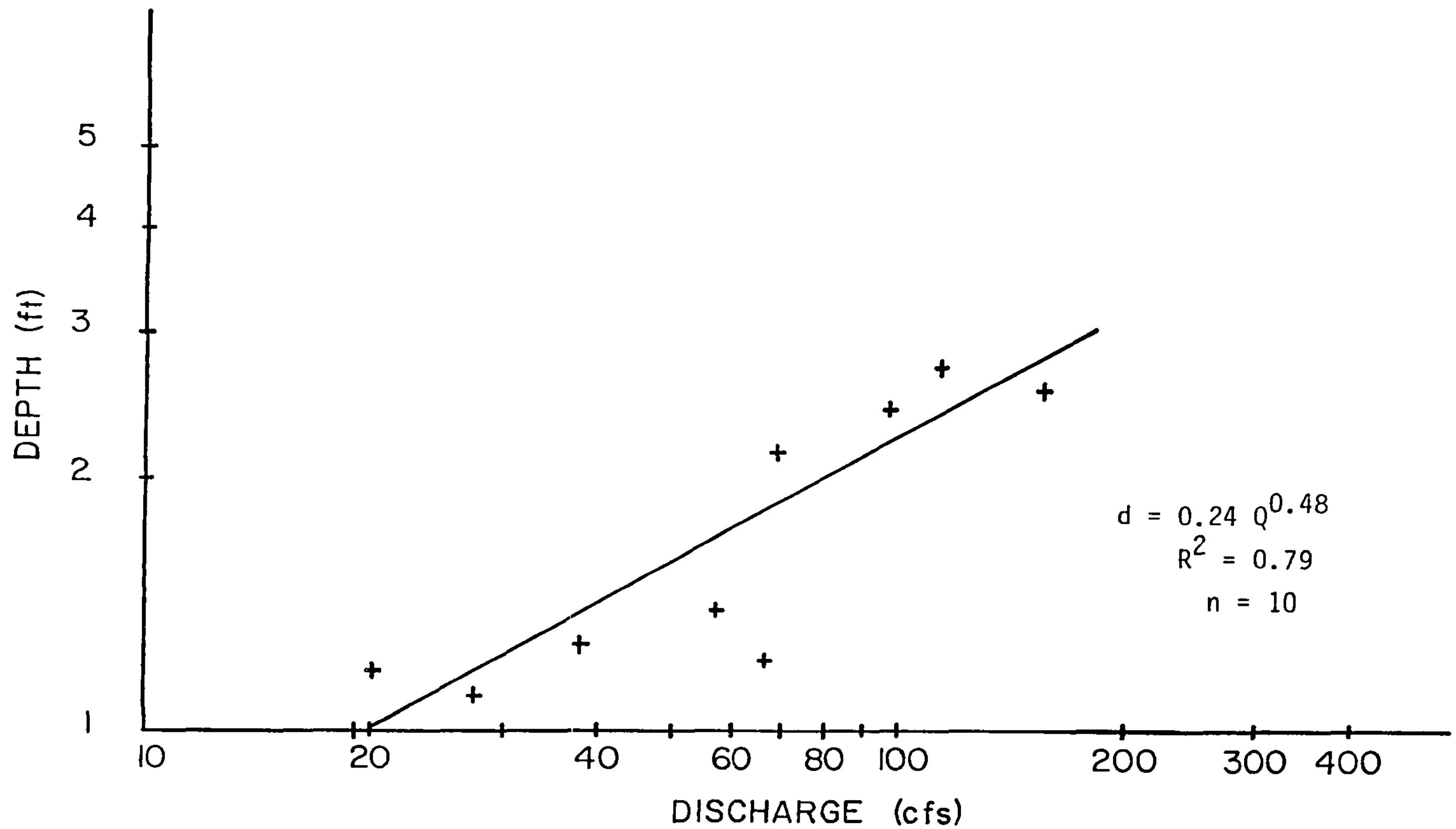

Fig. 4. Discharge vs depth. Hydraulic geometry of the Little Tonsina River at 80 ft downstream from the Richardson Highway crossing. Q = discharge and d = depth.

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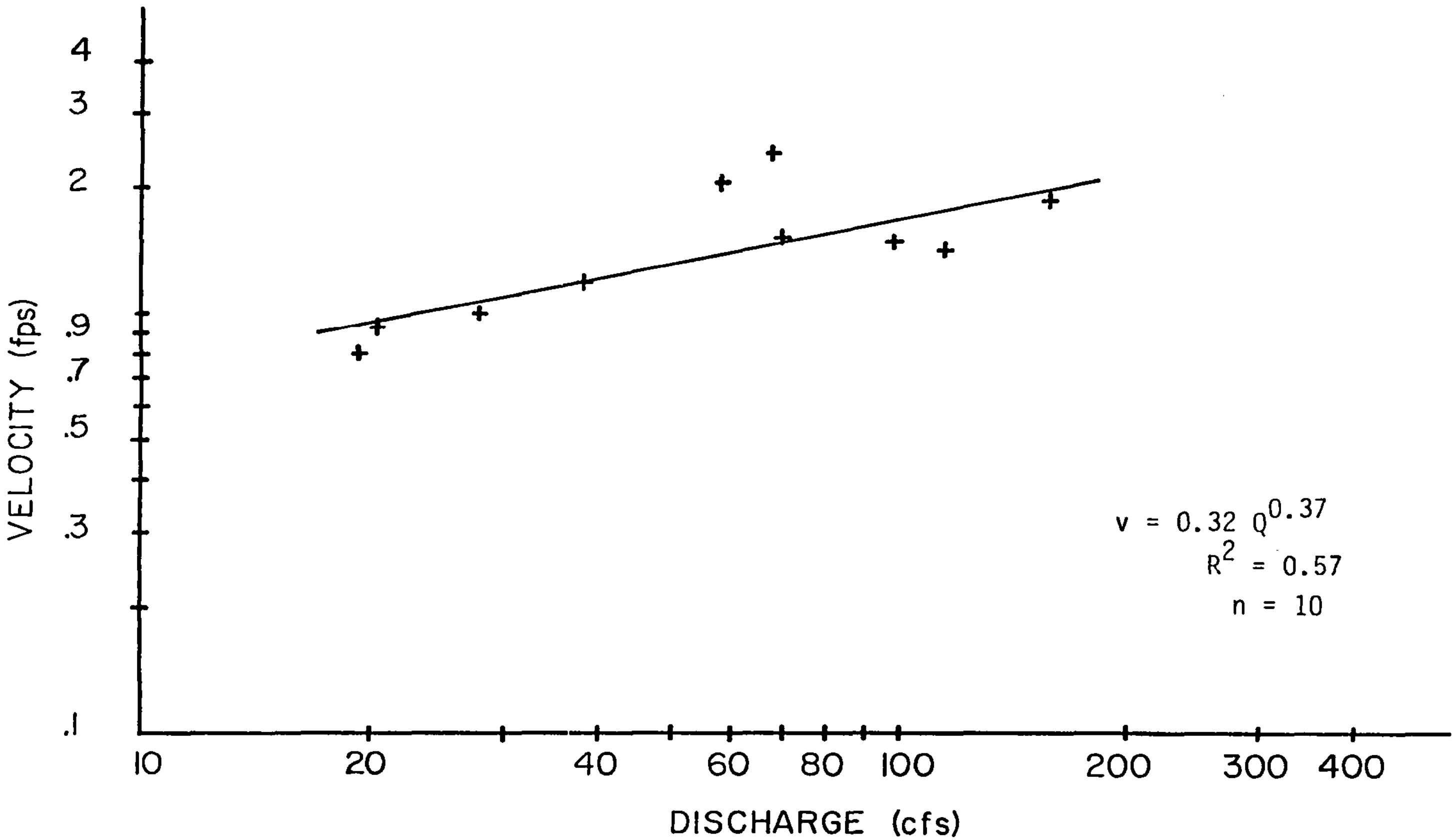

Fig. 5. Discharge vs velocity. Hydraulic geometry of the Little Tonsina River at 80 ft downstream from the Richardson Highway crossing. Q = discharge and v = velocity.

Richardson Highway crossing, which is 30 feet downstream of the stream gage. Table 3 compares exponents from the hydraulic geometry equations listed in Fig. 3 to 5 with literaure values.

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TABLE 3. Comparison of exponents in at-a-station equations of hydraulic geometry for selected rivers.

River[a]	Exponents		
	Width b	Depth f	Velocity m
Little Tonsina River, Ak.	0.15	0.48	0.37
Average of 11 sites in the upper Green River basin, Wy.	0.16	0.38	0.44
Average for a large number of basins	0.50	0.40	0.10

a. Exponents for rivers other than the Little Tonsina are from Dunne and Leopold (1978).

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CHAPTER 4 METHODS AND MATERIALS

Snowmelt, rainfall, and rain-on-snow peak flow events were visually selected from USGS water stage records. Dates and amounts of rain and snow were extracted from National Oceanic and Atmospheric Administration Climatological Data Records. The climate stations used were Ernestine for 1973, 1975, and 1976 and Tonsina Lodge for 1974, 1977, and 1978 (Fig. 1). For streamflow analysis, the calendar year was divided into three periods: spring, April 1 to June 30; summer, July 1 to August 31; and fall, September 1 to October 31. The largest event within each period was selected for further analysis. An event was included within the period in which its peak occured. During the spring period, peak flows were seperated into snowmelt peaks and rain-on-snow peaks. Snowmelt events were defined as having no precipitation for two days prior to the peak. For each rainfall event, the base flow was determined using hydrograph separation techniques (Linsey et al., 1949). No baseflow estimates were made for snowmelt events. For each event selected, gage heights were read from USGS water stage charts for the instantaneous peak and flows with durations of 2, 6, 12, 24 and 48 hours (Fig. 6 and 7). The discharge at a specific duration was determined by reading the gage height at the point where, parallel to the time axis, the maximum gage height was read for the duration of interest (Dryden and Stein, 1975; Fig. 6 and 7). Gage heights

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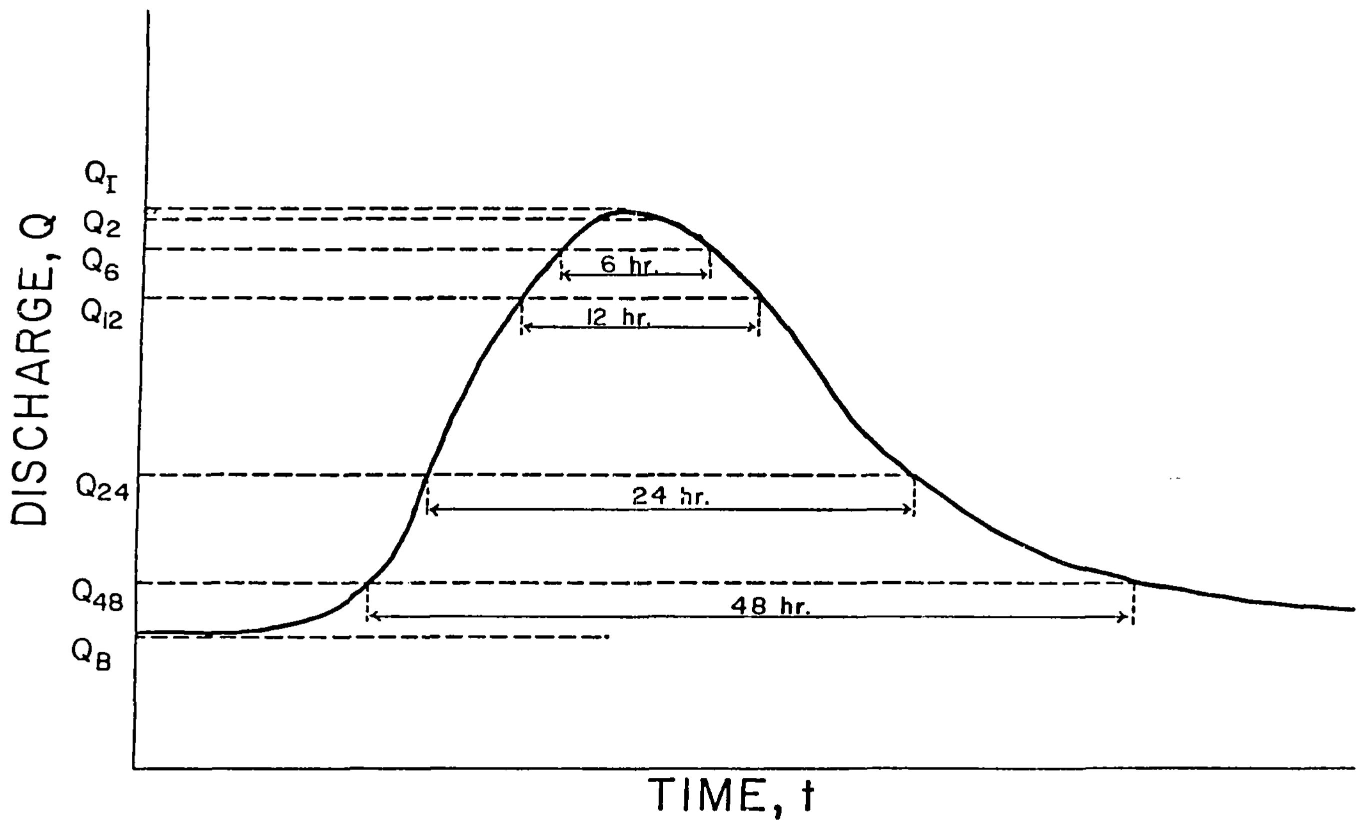

Fig. 6. Definition of selected duration discharges for rainfall hydrograph.

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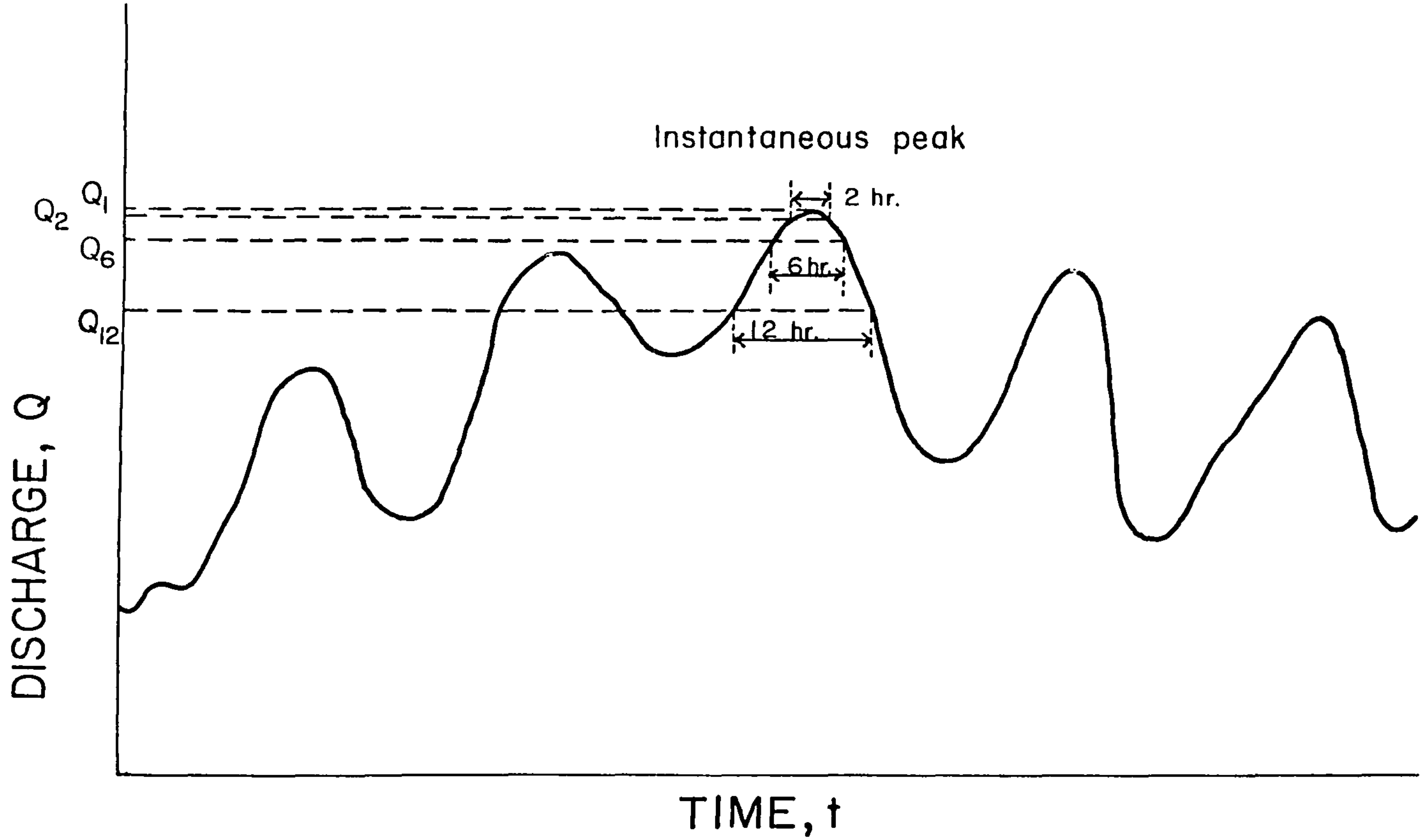

Fig. 7. Definition of selected duration discharges for snowmelt hydrograph.

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were converted to discharge values using the station rating curve and shift values supplied by the USGS.

Frequency curves for the high and low flows were computed using the lognormal disribution with the Blom plotting position (Cunnane, 1978). Floods with recurrence intervals up to 10 years were computed. One and 3-day floods were computed from USGS mean daily values (USGS, 1974, 1975, 1976, 1977, and 1978a). Flood frequency values for the 1 and 3-day floods were computed using methods described by Ashton and Carlson (1983), with the exception of the fall dates when October 31 was used instead of November 30. Low-flows for each period were computed for durations of 3, 7, 14, and 30 days using USGS mean daily flows.

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CHAPTER 5 RESULTS

The gage was operational September 1, 1972, to September 30, 1978. The float for the water stage recorder was removed or frozen in during the winter months. Typically, the gage was cleared of ice by May 6 and was frozen in by November 3 (Table 4). The baseflow of the annual hydrograph fluctuated from year to year depending on the previous winter's snowfall (Fig. 8 and 9). Calendar year 1972 has data for only part of the year, and therefore was not shown. October through December 1978 was estimated from precipitation records. The peak on November 11, 1976, is outside the fall period so it was not included in the analysis.

The Q_2 was equal to the Q_I, and the Q_6 was 94% to 99% of the Q_I. The Q_2 and Q_6 were deleted from further analysis because they were not significantly different from the Q_I. No period had more than two 72-hour duration flows during the six years of record. During the spring period, there were four peak snowmelt events and two peak rain-on-snow events. The slopes of the frequency curves are different for these types of events and may influence a frequency analysis (Kite, 1977). The number of events was too small to compare the slopes of the frequency curves for snowmelt and rain-on-snow events. Due to a short period of record, however, methods of treating mixed populations were not applicable

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TABLE 4. Ice-free and freeze-up dates and spring water temperatures for Little Tonsina River, Alaska.

Calendar year	Date gage cleared of ice	Date daily water temperature reached			Date gage frozen-in	Spring period peak flow
		maximum of 1°C	maximum of 4°C	minimum of 4°C		
1972	-	-	-	-	Nov. 4	-
1973	April 30	May 5	May 13	May 23	Oct. 11	June 19
1974	May 13	April 11	May 15	May 27	Oct. 21	May 31
1975	April 29	April 29	May 15	May 21	Nov. 1	May 12
1976	May 6	May 6	May 20	May 26	Dec. 1	June 3
1977	April 25	April 20	May 13	May 25	Nov. 9	May 29
1978	May 23	April 1	May 10	May 20	-	June 12
Average date	May 6	April 22	May 14	May 24	Nov. 3	June 2

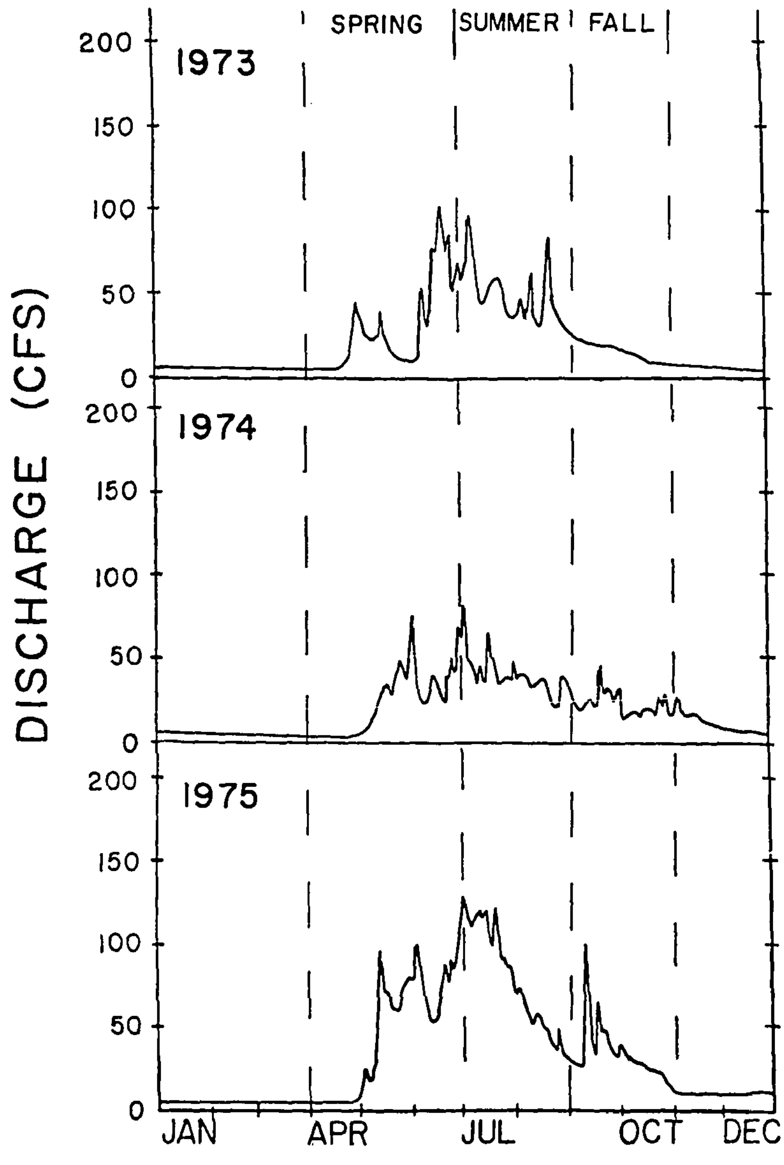

Fig. 8. Annual streamflow hydrograph, calendar years 1973, 1974 and 1975. The dates of each period are: spring, April 1 to June 30; summer, July 1 to August 31; and fall, September 1 to October 31 (data from USGS, 1974, 1975 and 1976).

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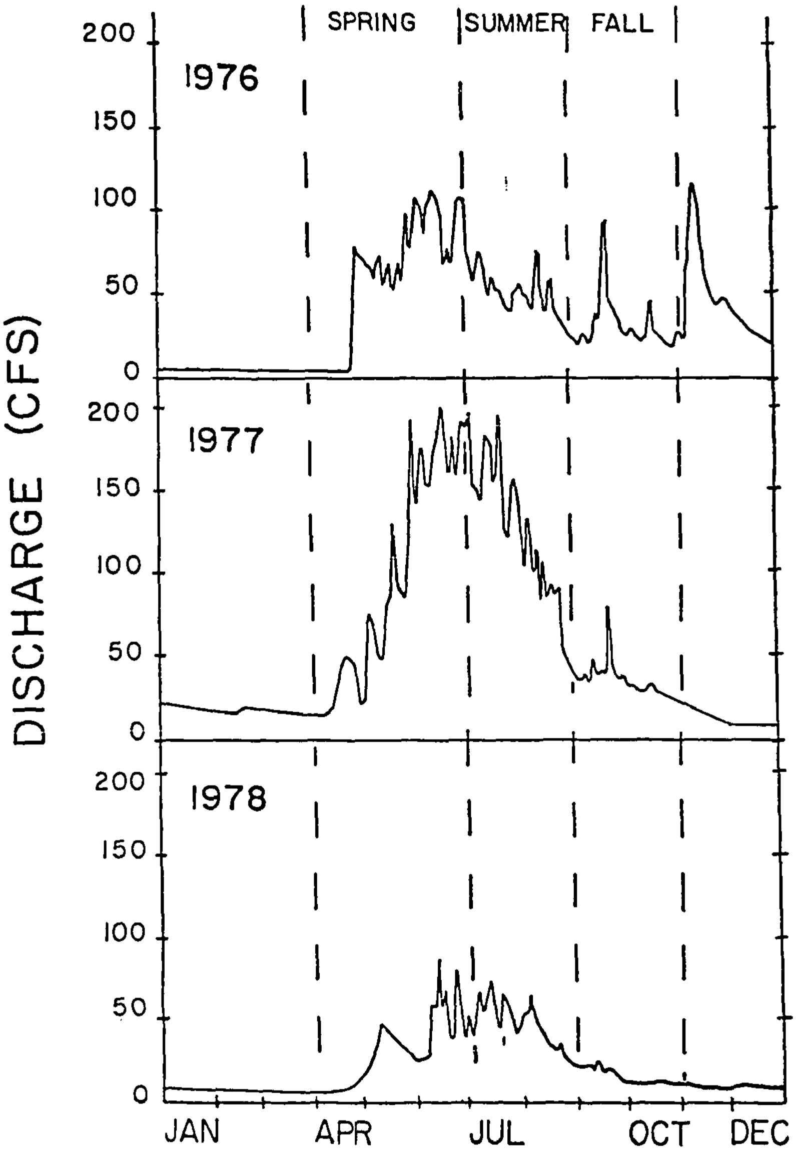

Fig. 9. Annual streamflow hydrograph, calendar years 1976, 1977 and 1978. The dates of each period are: spring, April 1 to June 30; summer, July 1 to August 31; and fall, September 1 to October 31 (data from USGS, 1976, 1977 and 1978a).

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(USGS, 1982). The spring period is treated as one population. The extent and elevation of the snowpack during the summer period was unknown, so I assumed all summer events were rainfall events. Figures 10 to 12 present the results of the flood frequency analysis. The 1 and 3-day floods are plotted with the Q_{24} and Q_{48} flood values. The mean annual flood is plotted to show the relationship of it to the flood values presented by this paper. Figures 13 to 15 present the results of the low-flow frequency analysis.

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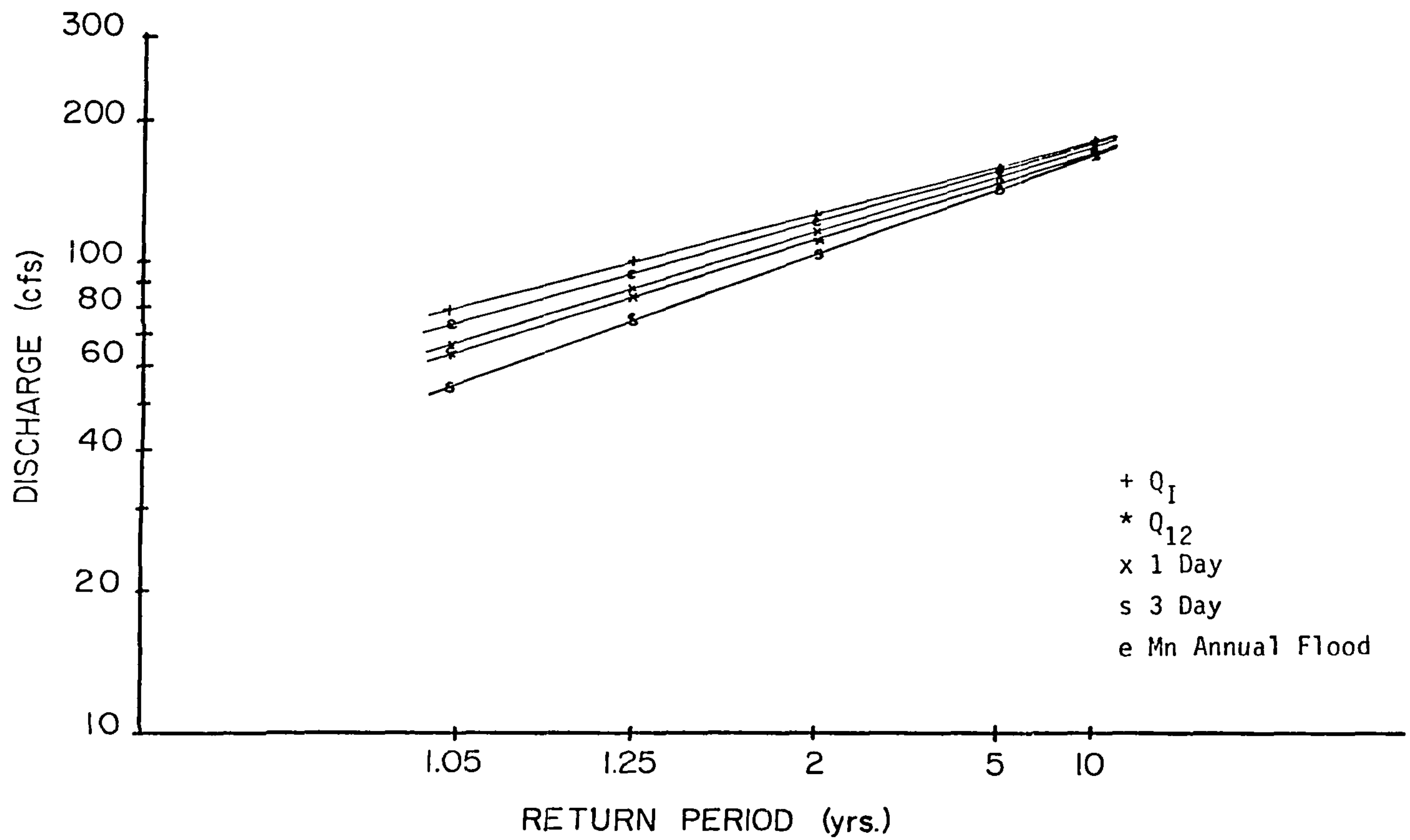

Fig. 10. Spring period flood-frequency curves. Spring period is April 1 to June 30. See list of terms for definitions of selected discharges.

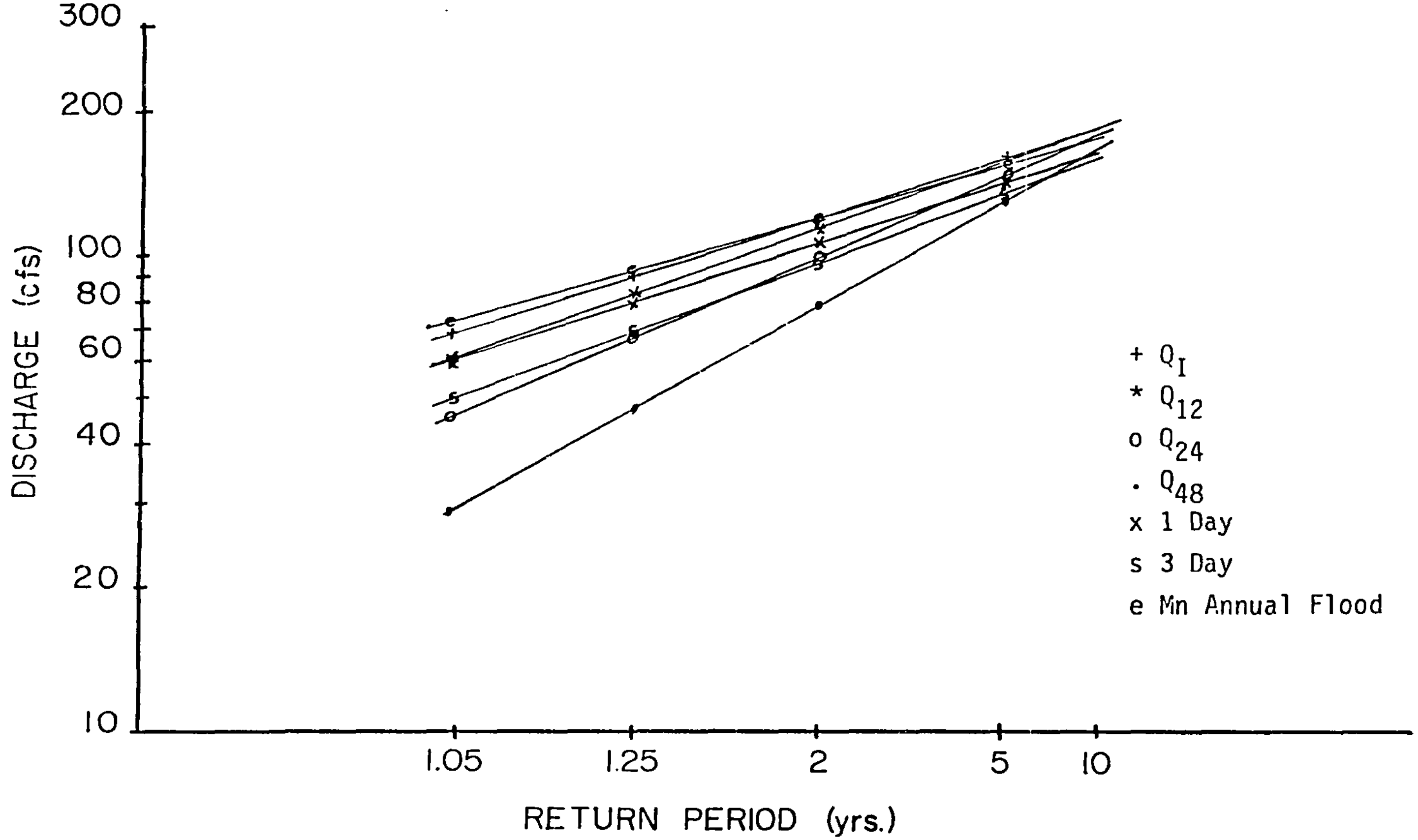

Fig. 11. Summer period flood-frequency curves. Summer period is July 1 to August 31. See list of terms for definitions of selected discharges.

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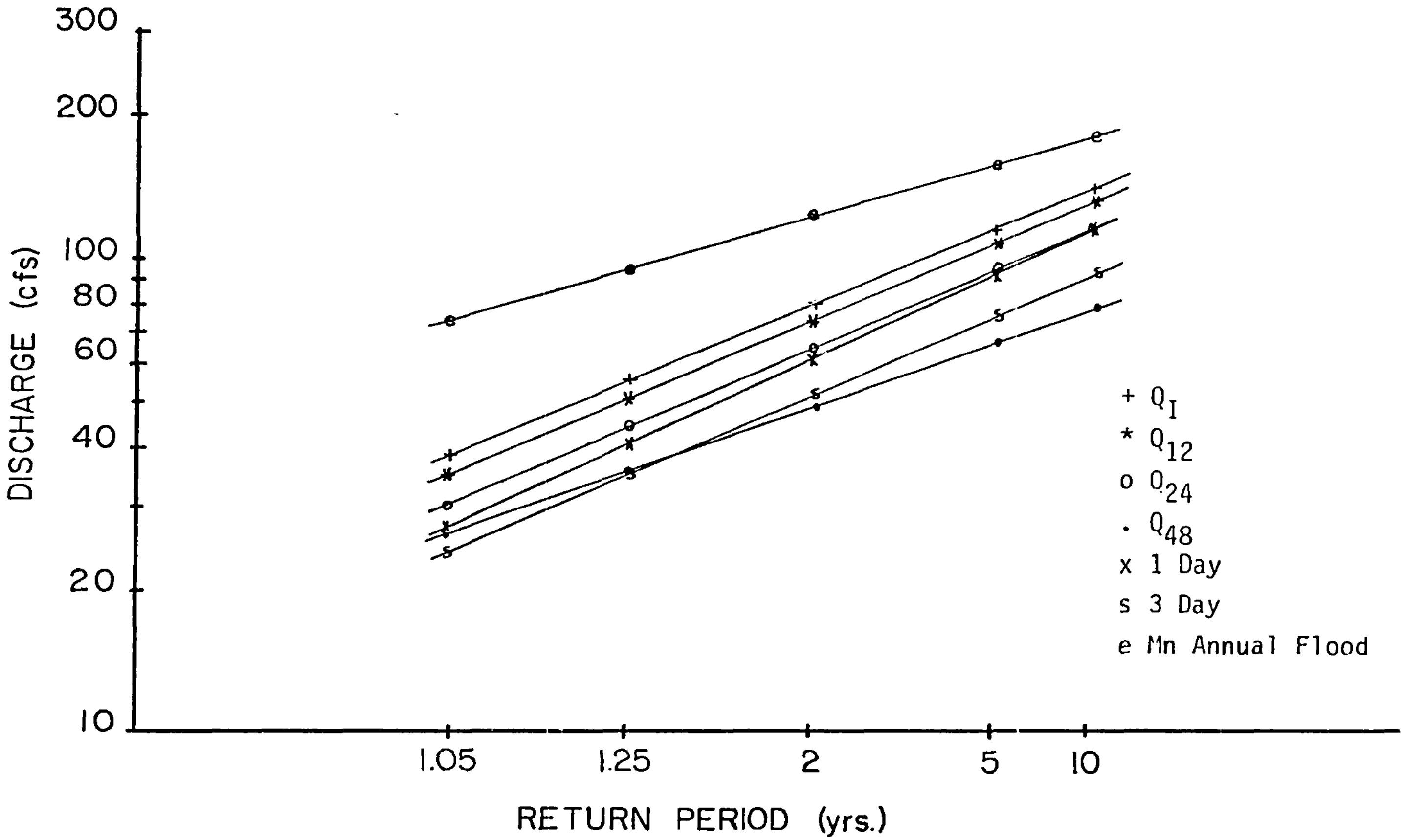

Fig. 12. Fall period flood-frequency curves. Fall period is September 1 to October 31. See list of terms for definitions of selected discharges.

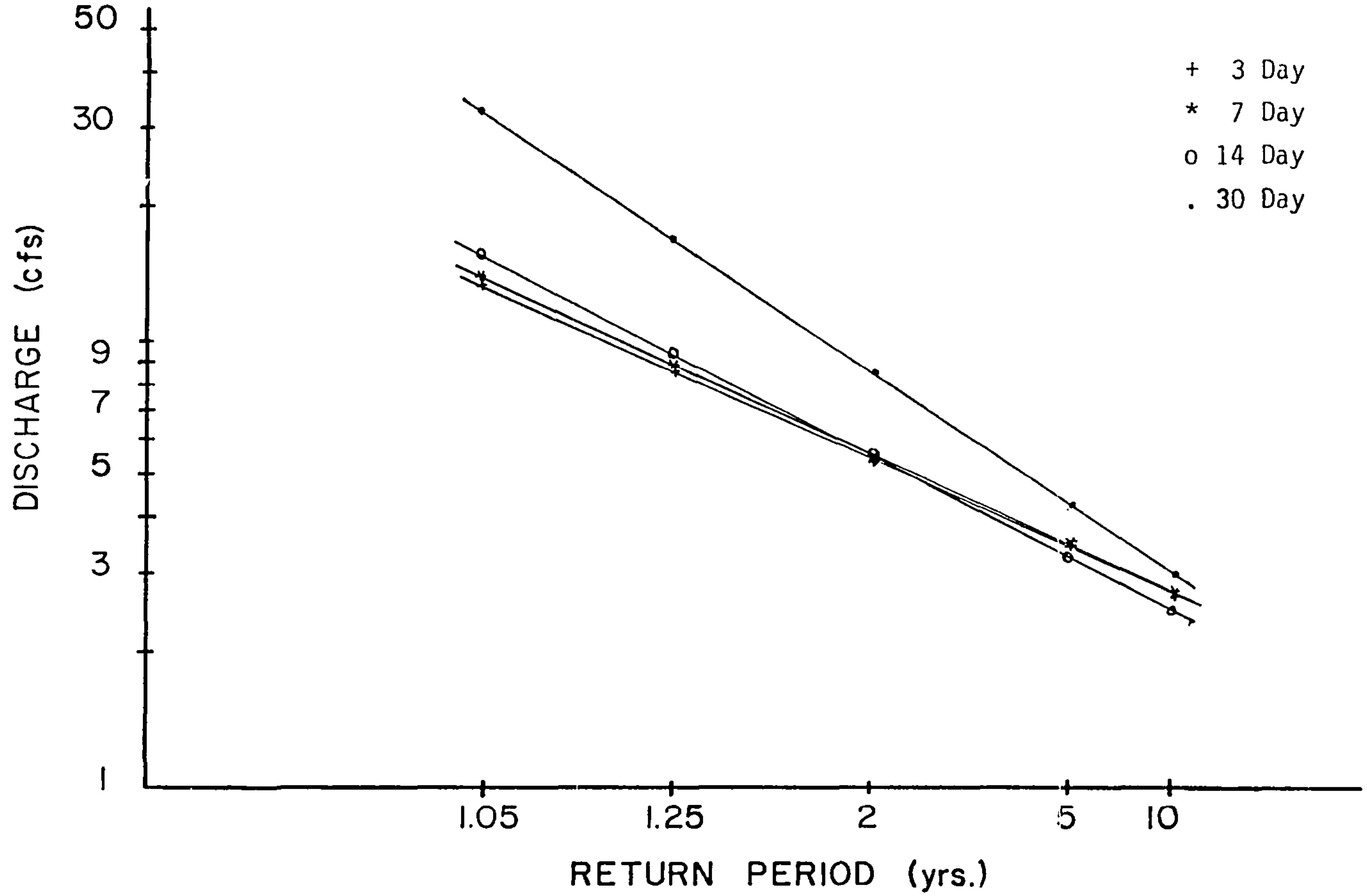

Fig. 13. Spring period low-flow freqeuncy curves. Spring period is April 1 to June 30.

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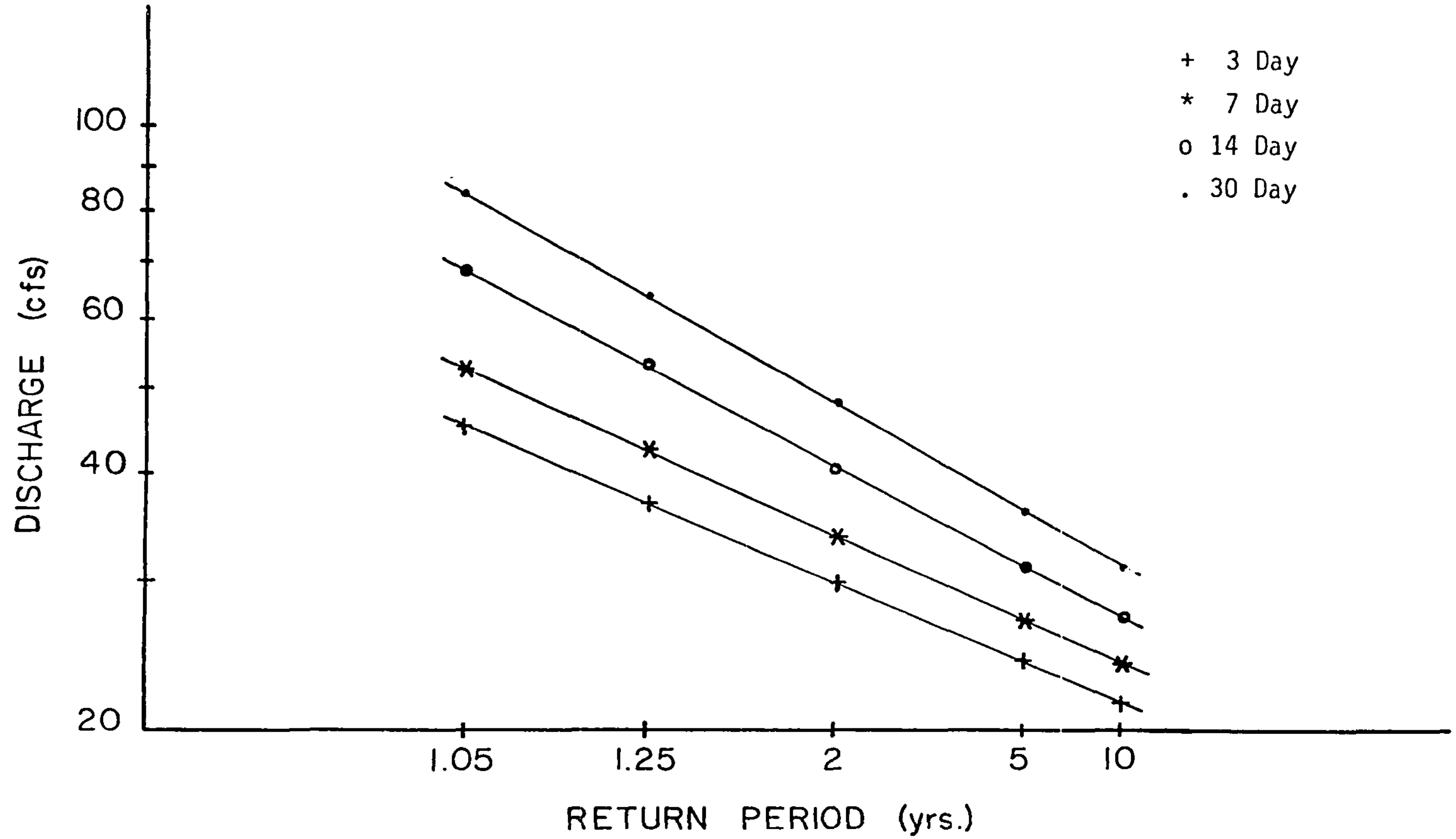

Fig. 14. Summer period low-flow frequency curves. Summer period is July 1 to August 31.

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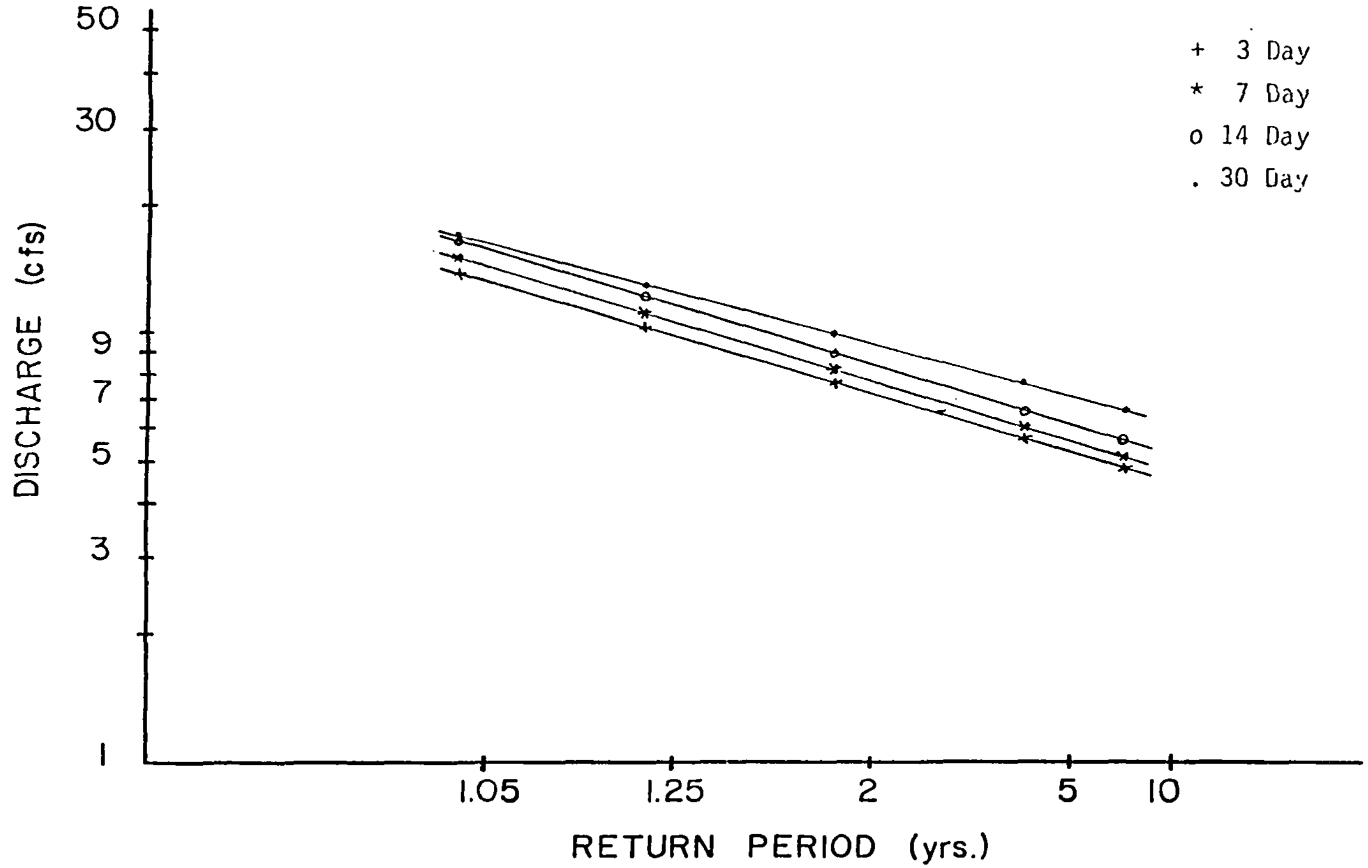

Fig. 15. Fall period low-flow frequency curves. Fall period is September 1 to October 31.

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CHAPTER 6 DISCUSSION

6.1 Flow Regime During Fish Migration Periods

Spring grayling migration is the period of the year, for the Little Tonsina River, when peak flows and peak fish migration are most likely to coincide. Studies show that most grayling move upstream between 1400 and 2100 hours, with the peak numbers moving between 1700 to 1800 hours (MacPhee and Watts, 1976; Tack and Fisher, 1977). These studies did not report the timing of diurnal peak flows. During snowmelt on the Little Tonsina River, diurnal peak flows occurred between 2100 and 2400 hours, with subsequent lows between 0900 and 1200 hours for 5 of 8 diurnal cycles. For the remaining 3 events, peaks occurred between 0600 and 0900 hours, with subsequent lows between 1800 and 1900 hours. During 2 years of record there is more than one episode of strong diurnal variation in discharge. In one year there was no episode of strong diurnal variation.

Several species of fish are reported to respond to the flow regime of a stream (Armstrong, 1965; Hartman et al., 1982). The major migration peaks of Dolly Varden in southeast Alaska occur in conjunction with a rise in water level (Armstrong, 1965). Although the cause of increased grayling movements remains unknown, the

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relative occurrences of peak fish movements and diurnal peak flows are important.

I believe, based on available data, the 12-hour duration discharge (Q_{12}) is a reasonable spring Critical Migration Discharge. For years when the peak discharge and peak grayling migration occur on the same day, the peak of the grayling run will probably pass prior to the start of the 12-hour duration discharge. Any grayling not passing prior to the peak will probably be delayed 12 to 18 hours until the next diurnal grayling movement starts upstream. The spring breakup peak of Poplar Grove Creek preceeded the adult peak migration by an average of 6 days. For the Little Tonsina River, snowmelt peaks and rain-on-snow peaks occurred primarily in late May and June, and did not have a consistent date of occurrence.

I found no experimental evidence or field studies to suggest grayling migrate at the Q_I even though they do migrate during breakup. Reed (1964) observed them migrating through channels cut in the ice by surface runoff water. On the Little Tonsina River, the streamflow peak for the spring period was after the peak flow due to the ice going out. During spring snowmelt, the rise in water temperature to 1°C appears to be associated with grayling migration, and water temperatures of 4°C are associated with grayling spawning (Armstrong, 1982). Data on grayling movement in Poplar Grove Creek and temperature data from the Little Tonsina

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River (Table 4) indicate that grayling probably move in the Little Tonsina River prior to the spring period peak flow. Therefore use of Q_{12} as the Critical Migration Discharge is a conservative assumption. Low-flows during the spring period occur before river ice breakup and are not a critical time for fish passage.

During the summer period, coho fry migrate downstream (Anon., 1977), and adult grayling may migrate downstream to feeding areas (Armstrong, 1982). No other fish were observed in the study area during this period (Anon., 1977). On a coastal stream in British Columbia out-migration of coho fry shows a strong positive response to peak flows (Hartman et al., 1982). During the fall period coho and Dolly Varden migrate to spawning areas over two to four weeks (Anon., 1977), and grayling adults, juveniles and young-of-the-year migrate downstream to overwintering areas (Armstrong, 1982).

Alaska Department of Fish and Game draft regulations for culvert design recommend considering

> the velocity of the water when the fish are present, the time of year at which these velocities occur..., the species of fish present and their upstream swimming capabilities, and the size and/or age class of the fish requiring passage.

Arctic grayling are in the class of slowest swimming adult fish, and passage of juvenile grayling is important (Tack and Fisher, 1977), therefore, spring is the critical design period. The draft regulations specify that the mean water velocity in the culvert

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during the mean annual flood be less than or equal to the allowable culvert water velocity based on the design fish and culvert length. These regulations require consideration of the flow during the time fish are present and specify fish passage at the mean annual flood. They do not, however, state whether the design flood (in this case the mean annual flood) can be reduced by a percentage if it can be shown that peak fish movement and peak discharge are likely to occur at different times.

6.2 Comparison of Methods for Predicting Critical Migration Discharge

Representative methods for determining the Critical Migration Discharge were compared to select the method which provides reasonable estimates of peak and low flows during periods of fish migration (Table 5). The methods were compared using actual streamflow data from the Little Tonsina River, and flood values predicted by regional regression equations. By comparing the methods using streamflow from the Little Tonsina River I determined which method provides the "best" estimate of the Q_{12}. I selected the best method based on actual flows, because predicted flows change as more data are incorporated into regional regression equations.

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TABLE 5. Comparison of Critical Migration Discharge prediction methods.

Method	Critical Migration Discharge[a] (cfs)					
	Spring		Summer		Fall	
	Actual[b]	Predicted[c]	Actual[b]	Predicted[c]	Actual[b]	Predicted[c]
This paper						
Q_I	122	-	120	-	78	-
Q_{12}	108	-	113	-	73	-
Q_{24}	-	-	100	-	64	-
Q_{48}	-	-	80	-	49	-
Q_B	-	-	65	-	28	-
Gebhards and Fisher, 1972	-	-	80	-	49	-
Watts, 1974						
Adults	107	206	107	206	107	206
Juveniles	36	41	36	41	36	41
Katopodis, 1977	121	163	121	163	121	163
Dane, 1978	36	49	36	49	36	49
U.S. Forest Service, 1979	3.4	-	27	-	13	-
Ashton and Carlson, 1983						
1-Day	113	280	108	107	60	70
3-Day	103	248	98	94	51	59

a. For an explanation of the methods, see Table 1. The discharges used by this paper are defined in Fig. 6 and 7.
b. The Critical Migration Discharge was determined using streamflow data from the Little Tonsina R.
c. The Critical Migration Discharge was determined using floods predicted by regional regression equations.

For the spring period (using actual flows), Watts (for adult fish) and Ashton and Carlson provide the closest estimate of the Q_{12}. The mean annual flood overestimates the Q_{12} by 12%. I used Dryden and Stein's method of determining the duration discharge for durations of 2, 6, 12, 24 and 48-hours. The 72-hour, or 3-day, delay discharge was not included in the analysis because there were insufficient events to analyze. The 72-hour, or 3-day, delay discharge can be approximated by the baseflow during the summer and fall periods. Because of this problem, Dryden and Stein's method was dropped from further consideration. Ashton and Carlson's method (based on actual streamflow) provided the best estimate of the Critical Migration Discharge for each period.

Design for low-flows is important for fall out-migration to overwintering areas, and summer and fall spawning migrations (Metsker, 1970; USFS, 1979; Elliott, 1982). The low-flows critical for fish passage in the Little Tonsina River are during the fall period. I did not find any fisheries study that identified a critical delay or frequency of occurrence for design low-flows. Only one method proposes a specific duration and return period for a design low-flow (USFS, 1979). It is the 7-day duration, 5-year return period low-flow.

To be effective, a method for estimating the Critical Migration Discharge must be applicable to ungaged streams. In Alaska floods

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on ungaged streams are typically predicted using regional regression equations. These equations are typically developed using annual instantaneous peak discharges. The Q_{12} is a measure of the discharge at a time other than the annual peak, therefore, its values are typically not available for ungaged streams. The method that estimates the discharge closest to the Q_{12} using floods predicted from regional regression equations is the most suitable for design purposes.

Using predicted floods, all of the methods overestimate the spring period Critical Migration Discharge. For the Little Tonsina River the predicted mean annual flood provides the closest approximation of the Critical Migration Discharge. For low-flows using predicted floods, Watts (for juvenile fish) provides the closest estimate.

6.3 Conclusions

Based on actual streamflow, Ashton and Carlson's method provides the best estimate of the Critical Migration Discharge during the spring period. To predict the high flow for ungaged basins compute the spring 1-day flood using regression equations from Ashton and Carlson (1983), and compare with the mean annual flood computed using the regression equations developed by Lamke (1979). The smaller of the two is used. This is recommended because Ashton and

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Carlson state their predicted spring 1-day floods can be higher for some streams than the mean annual flood predicted by Lamke.

No regional regression equations for low-flows in Alaska have been developed. To provide a means of estimating the 7-day, 5-year low-flow, use 20% of Ashton and Carlson's fall period 1-day flood. Comparing predicted flood and low-flow discharges (computed using the recommendations given above) to actual streamflow, the Critical Migration Discharge is overestimated in the spring period by, 51% and the fall period low-flow is overestimated by 8%.

In the design of culverts for fish passage the design discharge at high and low flows, are two of many design factors. Additonal considerations include: excessive culvert length; ice blocking the culvert in the spring; improper placement of the culvert in the stream channel; and most importantly, field changes in the design which do not consider fish passage. The design of culverts for fish passage is a interdisciplinary problem including engineering, hydraulic, economic and fishery considerations. These must be balanced to provide the most efficient culvert design.

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